Survey of Service Discovery Protocols and Benefits of Combining Service and Route Discovery

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Summary
Service discovery is an emerging field in the area of ubiquitous computing. There are various techniques and protocols particularly tailored to specific sets of objectives. This paper analyses the current state of the art and presents taxonomy of service discovery protocols. It demonstrates also the benefits of combining the service discovery with route discovery in MANETs.

Key words:
MANETs, Service Discovery Protocols, Routing Layer Support.

1. Introduction

A service can be any tangible or intangible thing that can be useful for someone. For example when a laborer works for building a house, he is giving his services for which he is paid. Similarly a teacher teaches to his students providing them knowledge that is useful for students. This act of teaching is a service provided by a teacher to his students. In our context of mobile ad hoc networks any facility provided by a device that can be useful for any other device is a service.
A service in this context could be a software service like providing an implementation of some algorithm (for example, converting one audio file format to another) on a device so that when some device needs this service, it can contact that device and use it. A service can also be a hardware service like a printer that can be used by a mobile device to print a file. To get benefit from these services a device must be able to locate them in the network and also have the ability to invoke these services [1]. Here comes the role of service discovery protocols.
In fixed and wired networks service discovery protocols simplify the interaction among users, devices and services [22]. Service discovery protocols allow devices to automatically discover network services thus making the task of net-work administration and configuration easy.

In wireless mobile ad hoc networks devices are free to move. The characteristic limitation of a mobile device is that it has to be small in size and weight. Such devices inherently have few and limited number of resources as compared to fixed devices. So it becomes important to utilize the resources and services available in other devices to accomplish the tasks that cannot be done alone. For example a mobile device without a printing support will require a printer to fulfil the printing task. Thus forming ad hoc network between mobile devices and getting benefit of resources available in a network require knowledge of services available by other devices and how to interact with these services. The service discovery protocols aim at these aspects. More specifically the service discovery protocols not only provide mechanisms for locating a particular service but also mechanisms to advertise a service, invoke a service, select a service if there are more than one services of the same type available and to describe a particular service so as to make its searching easy.

There is a lot of research going in the field of service discovery. Basically there are three types of networks as far as the research in service discovery is concerned. First are the wired networks, second are single hop wireless networks and third are the wireless multihop mobile ad hoc networks. The service discovery protocols suggested for one type of network are not suitable for another type of network because each network is based on different assumptions, the most important being the mobility and rate of joining and leaving of devices from the network. In the first type devices do not move at all and there is no join/leave at all or the join and leaves are few and far between. In the second type the network formed is ad hoc with very restricted mobility and having low rate of join/leave. There are one or more nodes that are fixed. But in the third type of network the devices are assumed to have unrestricted mobility and these can join or leave the system at any rate. There may be no fixed node. Due to these assumptions the problem of service discovery is very challenging in the third type of networks.

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In wired networks many service discovery protocols have being suggested, some of which have gained the status of industry standard. For example Jini[14] by Sun, Universal Plug and Play (UPnP) [8]by Microsoft, Salutation[5] by IBM and Service Location Protocol (SLP) [7] by IETF. Mainly the service discovery protocols for wired networks fall into one of the three categories. Some are directory-based, like Jini that has a centralized place to store information about the services. Some are directory-less like UPnP that has a peer-to-peer (P2P) architecture and the service information is stored on each device. The third category is the hybrid of the above two. For example SLP can work in both modes, that is with or with out a directory depending on the situation.

In single hop ad hoc networks there are also some mature protocols available. For example Bluetooth SDP[19] and DEAPSpace [15]. Bluetooth's SDP is an industry standard. These protocols may follow P2P architecture like DEAPSpace or a client-service approach like Bluetooth SDP.

In multihop Mobile Ad hoc Networks (MANETs) a lot of research is going on but still it has not been mature enough to be used by industry. The main reason for this lack of mature research, in spite of lot efforts by the research community is because of the challenging issues due to the unrestricted mobility of devices. A lot of work has been done in the field of routing in MANETs. One can take advantage of this work for studying the service discovery problem. But essentially the service discovery problem is different from the routing problem. In routing we know the ID of a node, which is unique and data is only sent to that particular device, whereas in service discovery there is a service, which may not be unique and its multiple copies can reside on different devices. The task is to find that service, which best fits some given criteria. A service discovery protocol (SDP) may use an underlying routing protocol to invoke and get a reply from a particular service residing on a particular device.

There are some SDPs that integrate the functionality of routing and service discovery. Thus service discovery and routing although are quite related to each other but specifically have distinct characteristics. One can take advantage of the research work going in one field for the benefit of other. There are some good surveys of the service discovery protocols that also include SDPs for MANETs. For example the surveys done by Cho and Lee[4], Zhu and Mutka [21] and Marin-Perianu, Hartel and Scholten [16]. These surveys survey the service discovery protocols for all of the three types of networks and none of the survey go deep into surveying service discovery protocols for only mobile ad hoc networks. In this paper we have concentrated on SDPs for MANETs only.

The remainder of this paper is organized as follows: In section 2 service discovery protocols are reviewed and some scenarios of service discovery in MANETs are presented. Then, Section 3 presents the motivation of combining Service and Route discovery. The paper concludes with our contributions and outlook to future work.

2. Related Work

Nodes in an ad hoc network need access to servers such as web servers, mail servers, name servers, print servers and tftp servers. We cannot statically configure nodes with a list of servers. This is because the node which needs the service (client) and the node providing the service (provider) may move, fail, shut down or run out of battery power. Node movement may even cause a node to get partitioned from the rest of the network. Also, a provider may decide to terminate its service at any time.

One approach for service discovery in wired networks is for a set of nodes (directory agents) to store information about providers. Clients then query the directory agents to discover providers. A static and hierarchical structure of directory agents can be maintained as in Domain Name Service (DNS). However, such a structure would not be suitable for an ad hoc network which is dynamic in nature. Service discovery protocols are needed which take into account the dynamic topology of an ad hoc network. A fully distributed protocol would be more robust for such a network.

2.1 Scenarios for service discovery in MANETs

There are many applications scenarios for service discovery in MANETs:

- In MANETs, some of the connected hosts might have, in addition to the ad hoc network interface, an external connection to the Internet. Such nodes may announce this ability as a service to the participating ad hoc nodes. Using service discovery, members of the MANET are then able to use such a gateway service.
- In an electronic parking system, a service is defined differently. In such a scenario, implemented as a sensor network, each parking slot is equipped with a sensor. Whenever the slot is not occupied, the sensor announces a parking

service and a guidance system is able to route the car to the parking slot.

- Using their wireless hand-held device or notebook, participants in collaborative applications or distributed gaming environments need to discover application or game servers before participating in a session.

2.2 Overview of Service Discovery Protocols in MANETs

GSD: Novel Group-based Service Discovery Protocol for MANET

GSD is a group-based distributed service discovery protocol for mobile ad hoc networks [3]. It is based on the concept of peer-to-peer caching of service advertisements and group-based intelligent forwarding of service requests to reduce the broadcast storm problem. It does not require a service to register to a lookup server.

For service description the semantic capabilities offered by the DARPA Agent Markup Language (DAML) are used to effectively describe services and resources present in the network. This language supports ontologies to achieve flexibility in service matching and is therefore well suited for the heterogeneity of services in mobile ad hoc networks. The services present on the nodes are classified into hierarchical groups. Each node advertises its services to its neighbors within a defined number of hops. An advertisement also includes a list of the several service groups that the sender node has seen in its vicinity. This group information is used to intelligently selectively forward a service request to other nodes in the network where there are chances of service availability. Thus, the semantic features present in DAML is used to reduce network flooding. In other words, by maintaining the local advertisement, a node has information about all the services present in his vicinity, as well as information about available service groups that may can be reached through a particularly node in his vicinity. Thus, instead of broadcasting a request, a node selectively forwards the request to those nodes that have seen the same group of services in its vicinity.

Allia: Alliance-based Service Discovery for MANET

Allia is a peer-to-peer caching based and policy driven service discovery frame-work to facilitate service discovery in mobile ad-hoc networks [18]. The approach adapts structured compound formation of agent communities to the mobile environment and achieves high degree of flexibility in adapting itself to the changes of the ad-hoc environment. The framework takes into consideration device capabilities and limitations, as well as user and application preferences regarding usage of the devices. This gives the users of mobile applications the ability to control the ways in which their own resources are utilized.

The main goal of the platform formation is to provide an agent better access to services in the vicinity. An agent actively forms its own alliance and passively joins other alliances in an environment. An alliance helps in service discovery and the alliance formation does not have the overhead of explicit leader election. An alliance of a particular node is a set of nodes whose local service information is cached by this node. Thus, a node explicitly knows the member nodes in its alliance. However, a node is not aware of the alliance where it is a member of. Whenever a node leaves a certain vicinity, and enters a new vicinity, it constructs its own alliance by listening to advertisements. It also becomes a member of other alliances by advertising its local services. Therefore a node do not need to register or deregister with the alliances when it changes its location. Policies can be used to reflect device capability as well as to restrict platform functionality to take user, application and network preferences into consideration.

Policies can specify caching, advertisement and forwarding preferences. Policies can also be used for security restrictions like access rights and credential verification. When an agent needs to discover a certain service, it first looks at its local platform to check whether that service is available. On failure, it checks the members of its alliance to discover the service. If the service is still unavailable, the source platform tries to broadcast or multicast, depending on his local policy, the request to other alliances in its vicinity. To take care of network resources policy-based multicasting can be used, where the node multicasts the request to other nodes in its vicinity where there are greater chances of obtaining the service. By passive caching of advertisements rather than actively pulling of service descriptions from neighboring nodes, network changes can be detected. Also advertisement collisions are not as frequent as in pull-based paradigm, where, in respond to a particular request, the advertisements from different nodes can collide with each other at the receiver.

Lanes: Lightweight Overlay for Service Discovery in MANET

Lanes are application layer overlays to discover services offered in a mobile ad hoc network [12]. They offer a fault-tolerant and efficient structure, which can be used for semantics-based service discovery. Admittedly, a concrete service description is not addressed in the paper and the approach is service description independent.

Lanes are based on the Content Addressable Network (CAN), a scalable indexing system for large-scale decentralized storage applications on the Internet. A Distributed Hash Table (DHT) is used to associate hash values (keys) with some kind of content in a distributed and decentralized way. Participants in the DHT each only store a small section of the contents of the hashtable and thus provide scalability.

The basic concept of Lanes is a two-dimensional overlay structure, called lanes, which is similar to, but less strict than the one used in the CAN. One dimension of this overlay propagates service advertisements, the other one distributes service requests. A proactive operation is used within one lane (allowing to use unicasts to well-known predecessors and successors) and a reactive operation is used between the lanes (leading to anycasts to reach an arbitrary node in neighboring lanes). Thus, a node has only to maintain the information of its lane. Within a lane, there is a strict relationship of predecessors and successors and also the lanes are arranged in a well defined order. Nodes in the same lane share the same anycast addresses and can be treated equally form the outside. A large lane that consists of too many nodes, can be divided into two neighboring lanes and short lanes can be combined to one new lane. As the nodes are well arranged in a lane, only one periodic ping message Lanes tries to be a good compromise between weakly structured approaches, which are easily adapted to network characteristics but typically scale poorly, and highly structured approaches with optimal adaptability to user profiles at the cost of highly inefficient maintenance in dynamic network topologies.

DSDP: Distributed Service Discovery Protocol

DSDP is a distributed service discovery architecture which relies on a virtual backbone for locating and registering available services within a dynamic network topology [13]. The proposal consists of the formation of a virtual backbone, as well as distribution of service registrations, requests, and replies. The dynamic virtual backbone is formed from a subset of the network nodes, such that each node in the network is either a part of the backbone or one hop away from at least one of the backbone nodes. The nodes in the virtual backbone act as service brokers and form a mesh structure that is interconnected by virtual links. Each non backbone node is associated with at least one service broker in the backbone.

Services have to be registered to at least one service broker in the backbone. When a node requests a service, it sends a request messages to its service broker, wherefrom the messages is forwarded further in the backbone, which has the distributed knowledge of all available services in the network. Broadcasting of such messages would inefficiently waste network resources which is crucial in shared wireless mediums. Therefore in DSDP the backbone together with a source based multicast tree algorithm helps to make the service discovery and registration algorithm more scalable and efficient. For each node requesting or registering services a multicast tree on the backbone is established, whereby every backbone node has to maintain a forwarding list for these trees. Reverse paths in these subtrees are used for reply messages.

Konark: Service Discovery and Delivery Protocol for MANET

Konark is a service discovery and delivery protocol designed specifically for mobile ad hoc networks and targeted towards device independent services[10]. Konark assumes an IP level connectivity among devices in the network. To describe a wide range of services, Konark defines an XML-based description language, based on WSDL, that allows services to be described in a tree-based human and software understandable form. A basic tree structure is given to simplify interoperability between services. Service advertising and discovery can be done at any level of the tree, thus enables service matching at different stages of abstraction, from generic (such as "entertainment") to very specific at the leaf of the tree (such as "Tetris"). The service advertisements contain name and URL of the service, as well as a time-to-live (TTL) information to help self-healing of the systems. The client peers can cache this service information to use it later so that they do not have to locate the services again. If no service information is cached for a desired service, a distributed pull method is used to retrieve the service location. To simplify the framework, widely accepted Internet standards are used. IP multicast is utilised to locate peers and to communicate service information and each node hosts a micro HTTP server that can handle service delivery, which is based on SOAP.

Secure Service Discovery Protocol for MANET

A dynamic service discovery infrastructure for small or medium size mobile ad hoc networks [2]. The Protocol allow finding, locating and evaluating services in vicinity required by client and fit for high dynamic environment without directory agent or central registry. The protocol is reactive, therefore based on pull model with no service advertisements, and each node have to maintain a small size cache to keep the present valid service descriptions and behave as a delegate of the service to response service request. The service framework is described rather sketchy in [2]. But also a method to provide best quality of service is outlined.

DEAPspace: Transient Ad hoc Networking of Pervasive Devices

The DEAPspace project develop a framework for small portable computing devices that enable them to communicate via a wireless network and share hardware resources and software services [11]. DEAPspace is target for short range networks. It supports the development of ad hoc proximity-based collective distributed applications, thus it addresses peer-to-peer networking instead of the client-server model. The main components of this framework are the discovery algorithm and the service description model. The discovery algorithm is proactive. By regularly single-hop broadcast messages, a device share its full world view with the proximate devices view. These messages can be restrained if the world view of a device correspond with the view of its neighbours. Each service is defined primarily by an input format, an output format, a name and an address. The name offers some consistent human-readable information to allow the user to discriminate between similar services. The format descriptions are hierarchical unique object identifiers (OIDs), based around the MIME types, to allow service queries to be specified to whatever precision is appropriate.

GCLP: Geography-based Content Location Protocol

GCLP is a protocol for efficient content location in location-aware ad hoc networks [20]. The Protocol makes use of location information to lower proactive traffic, minimizing query cost and achieve scalability. GCLP assumes that all devices in the network know their own location. It makes use of this information to periodically advertise content to nodes along several geographical directions. Nodes that attempt to locate content need only contact one of these nodes to become aware of the presence of the desired content. A node can advertise its services by sending periodically update messages that follow a predefined trajectory through the network. This significantly decreases the amount of proactive traffic as it is limited to nodes along the trajectories. Nodes along these trajectories cache the information received from the update messages.

A client that want to locate a service on the network, sends out a query message that similarly propagates along predefined trajectories. In dense networks, these trajectories should intersect at least at one node, which will then reply the query. After receiving a reply, the client may establish a direct connection with the service using the underlying routing protocol.

3. Motivation for combining service and route discovery

Service discovery protocols for MANETs are studied in detail in the previous section. In all these protocols, service discovery results in a client discovering the address of the node which provides the desired service. In some protocols, more detailed information about the service may also be obtained by the client, such as service attributes and an access mechanism. However, a route to the provider has to be obtained separately as part of a route discovery process. This means that for a client to get a mapping from a service type to the address of a provider and then to obtain a route to the provider, two separate processes are required. in this section we will explain the effects of combining these two processes, so as to obtain the IP address of a provider and a route to it at the same time.

In an ad hoc network, each message consumes significant network bandwidth as well as computation and battery power at each node along its path. Service discovery itself requires the exchange of a large number of messages[17]. The subsequent discovery of a route to the service by the underlying routing protocol would require another exchange of messages. However, by integrating service and route discovery we are able to discover a service provider and a route to it using the same set of messages. Hence, an integrated approach will significantly reduce the bandwidth consumed and the overall latency in discovering a service and a route to the service.

The drawbacks of strict layering in the design of network protocols have been pointed out by Cooper in[6] and a soft layering approach has been proposed where information is exchanged between the layers. Also, in[9], Goldsmith and Wicker point out that energy constrained ad hoc networks can benefit greatly from cross-layering. This is because due to energy constraints in such networks, the control message transmission in the network and the overhead of processing these messages at each node must be minimized. Thus, we see that in an ad hoc network, communication between the layers of the network protocol stack or integration of the functionality of two or more layers is sometimes implemented, if doing this makes it possible to significantly improve the performance of such a network.

Traditionally, service discovery is considered an application layer function. However, doing service discovery at the network layer in order to reduce the communication and processing overhead. Such a deviation from the strictly defined functionality of each layer is reasonable in the case of an ad hoc network. In the next subsection we are going to choose five from the above protocols to analyse their limitations in term of energy consumption.

3.1 Limitations of SDPs

One aspect of the discovery approach which we consider significant and we pay particular attention to it is energy consumption. the majority of the protocols described above are designed without considering the power constraints typical in wireless networks. They make an extensive use of multicast or broadcast transmissions which are power hungry in wireless networks.

Allia is an agent based service discovery protocol, centered on peer-to-peer caching of service information. Every node in the network periodically broadcasts service advertisements. Nodes with similar types of services form alliances by caching each other's services. So, when a node receives a service request, which it cannot fulfil (doesn't have an appropriate service), it checks whether it has cached information about other nodes (allies) that offer similar services. In case such information is indeed cached, this node sends back the appropriate reply. If there is no cached information, then, depending on its policy, the node either broadcasts this request to the other nodes in its vicinity or forwards it to the members of its alliance. When a node caches service information sent by another node, then this node automatically becomes a member of the caching node's alliance. Allia uses Unique Universal Identifiers (UUIDs) for services, which should be a-priori known to all nodes. However, Allia is entirely agent based and hence it is too demanding in terms of computational power and resources in general. It also does not address energy consumption, and no related measurements or metrics are provided.

The other approach is the Group-based Service Discovery Protocol (GSD). GSD is also based in peer-to-peer caching of service advertisements and selective forwarding of service requests. GSD generates fewer messages compared to a simple broadcasting scheme, since service requests are not broadcast but instead forwarded only to those nodes that have already cached information about similar services. However, GSD uses DAML-based service descriptions in the advertisement messages (instead of simple UUIDs) and performs semantic matching, thus increasing energy consumption.

Similarly to GSD, Konark is a distributed service discovery protocol based on peer-to-peer caching of service information. In Konark, every node maintains a service registry, where it stores information about its own services and also about services that other nodes provide. This registry is actually a tree-structure with a number of levels that represent service classi¯cation. Upon receiving a service advertisement, a node updates its registry by classifying that service under the appropriate leaf of its tree. Service advertisements are in an XML-like language (similar to WSDL but smaller), hence allowing semantic matching, leading to increased energy consumption, but more precise resolutions. Konark uses multicasting for service requests and unicasting for service replies; hence it is more efficient than simple broadcasting schemes in terms of messaging overhead.

DEAPspace employs a periodic broadcast scheme for service advertisements. Each node sends the full list of services that it is aware of in its one-hop vicinity. Hence DEAPspace is targeted to smaller networks than Konark. In DEAPspace each node listens to its neighbors' broadcasts. In case the node doesn't find its own services in these messages, it schedules a broadcast sooner than usual, informing all the others about its presence and the services it can provide. In contrast to the aforementioned approaches, DEAPspace deals with the problem of energy consumption explicitly, by forcing weak nodes to go into idle mode during pauses between (the periodic) broadcasts.

SANDMAN, like DEAPSpace, is another service discovery protocol that implements power savings. This is done by grouping nodes with similar mobility patterns into clusters; in each cluster, one of the nodes (called clusterhead) stays awake permanently and answers discovery requests. The rest of the nodes periodically wake up to provide the actual services and also inform the clusterhead about their presence and services. The clusterheads are re-elected periodically to avoid draining a single node's battery. Simulation results show energy savings up to 40% of service requests. Increasing the size of a cluster can attain even higher savings. However, this results in a dramatic increase of the average interaction latency due to the fact that a requesting node has to wait the sleeping node to wake up in order to interact with its services. It is clear from the above discussion that only the latter two approaches take into account energy consumption and provide related metrics and comparisons.

3.2 Routing Layer Supported Service Discovery

Our motivation for adding routing layer support for service discovery stems from the fact that any service discovery protocol implemented above the routing layer will always require the existence of some kind of routing protocol for its own use. Hence, two message-producing processes must coexist: the first one communicates service information among service providers and service requestors; the second one communicates routing information among them. As a result, a node is forced to perform multiple times the battery-draining operation of receiving and transmitting (control) packets.

4. Conclusion and futue work

The vision of pervasive computing and/or ambient intelligence requires enabling ubiquitous computing and networking so that mobile users can seamlessly get access to digital services anywhere, anytime. MANETs are one enabler of such a vision, providing networking capabilities to mobile devices without requiring any infrastructure. However, the specifics for MANETs such as potentially highly dynamic topology and networking of heterogeneous wireless nodes whose energy needs to be saved for enhanced autonomy, require special care in handling of distributed service provisioning. In particular, the discovery of services must allow accessing services of the overall MANET for increased availability, while limiting ressource consumption in the network. MANETs are extremely dynamic due to the mobility of their comprising nodes, the wireless chanel's adverse conditions and the energy limitations of small devices. The great majority of service discovery protocols developed for MANETs deal with the above issues at the application layer.

In this paper we have reviewed a number of existing service discovery infrastructures and we have argued that by implementing service discovery at the routing layer instead of the application layer, the resulting communication and battery consumption overheads are significantly reduced.

Our current work focuses on evaluating and enhancing some approaches of providing routing layer support for service discovery. In the future work we plan to implement the beneficial impact of Bloom Filter technique on integrated approaches performance as sufficient technique that summarizes services available in the network and embedding them into routing packets.

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