

Identifying Open Problems in Random Walk based Service Discovery in Mobile Ad hoc Networks

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Abstract:¹ Service discovery in mobile ad hoc networks (MANETs) is a challenging issue. The nodes in a MANETs offer spontaneous and variable connectivity. Also the proximity of a given service as well as the kind and the number of services vary unpredictably with time. Traditional directory based architectural solutions can hardly cope with such a dynamic environment while a directory-less approach has to resort to network-wide searches. Some solutions integrate a Service Discovery Protocol (SDP) with the routing protocol. These can improve performance but still there is need for network wide searches which is a source of inefficiency. There has been lot of work on the problem of service discovery by leveraging on the random walk based search in wired peer-to-peer networks. These works present interesting results that can be useful for MANETs and can be good candidates for SDP, as these methods require fewer resources as compared to SDPs using some sort of flooding. In this paper we have tried to identify some of the open problems in service discovery in MANETs that use random walk.

1 Introduction

A service is defined as a software that can perform specific function/functions on the behalf of users and applications over the network [AKS05]. Gibbins and Hall [GH01] define service discovery as the process of discovering location of software entities/agents that can provide access to network resources such as devices, data and services.

The number of storage and computing devices are increasing. Some of the devices provide lot of resources/services but are fixed and some are small, mobile and scarce in resources. The mobile devices can also provide services that may be of interest to other mobile devices. So there is always a need for having a mechanism that can discover and utilize services provided by other devices. The service discovery techniques are used for this

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purpose. Most of the existing service discovery protocols not only include algorithms for finding the location of a particular service but also algorithms for service announcement, service selection and dealing with mobility. Service Description is also an important aspect of a service discovery protocol. Proper descriptions facilitate the searching of a service. Usually these aspects are an intrinsic part of a service discovery protocol. As far as our present work is concerned we shall restrict to that aspect of service discovery that is concerned with finding the location of a particular service in mobile ad hoc networks.

Most of the protocols use flooding as a basic mechanism for searching a particular service. In some protocols advertisements are flooded to all of the nodes in the networks and in some query is flooded. Most of the protocols use hybrid of both methods. This wastes a lot of bandwidth of the network, making it very difficult for using such protocols for MANETs in which the bandwidth is already a scarce resource. The use of random walk as a mean of searching for an item is a well-established technique in wired unstructured Peer-to-Peer (P2P) networks [Ra02]. These random walk based method however use very little network resources and do not disturb whole of the network during the service discovery process. Such methods are very attractive for MANETs. The topology of a mobile ad hoc network is however structurally different from wired P2P network. The suitability of random walks, thus have to be studied carefully. In the following sections we shall identify some open problems regarding the service discovery in MANETs using random walk method. These open problems are identified as we go through this paper. The rest of the paper is organized as follows. In section 2 we shall describe some of the important work done in service discovery in wired networks and wireless ad hoc networks. In section 3 we shall explain the motivation for using random walk for service discovery. In section 4 we shall introduce hint as a bias and then based on hint we shall present a generic random walk based mechanism for service discovery. Our understanding is that most of the service discovery protocols that use random walk in mobile ad hoc networks use or will use this basic algorithm. The algorithm presented use hint for biasing the random walk. In section 5 we give an example that calculates hint and then uses random walk for service discovery. In section 6 we discuss some of the issues that are open for further investigation and finally in section 7 we give conclusion.

2 Existing Work in Service Discovery

There has been quite a good amount of work in service discovery regarding the wired networks but the problem has not been addressed very successfully in MANETS.

2.1 Service Discovery in Wired Networks

In wired networks four types of architectures have emerged.

2.1.1 Directory-based Architecture

In this architecture some nodes with better computation and memory resources are selected as Directory Agents (DAs) that keep a repository of all the service information in the network in a directory. These DAs advertise themselves to other nodes. Service provider nodes register with these DAs. Clients contact these DAs to get the location of service providers. Examples include Jini [Su99] by Sun Microsystems, Universal Description, Discovery and Integration (UDDI) [Oa95] by OASIS Consortium and Salutation [Sa99] by IBM. This approach is suitable for infrastructure-based networks or when changing topology is not an issue (as in 1-hop wireless networks) but not suitable for MANETS where the topology of the system keeps on changing due to the mobility of nodes.

2.1.2 Directory-less Architecture

In this architecture there is no service coordinator. Clients contact service provider directly by flooding the service query. This results in a high overhead produced due to flooding. The flooding of the query message consumes lot of bandwidth, computational and battery resources, which are already scarce in MANETS thus making this architecture unsuitable for MANETS. Examples of this architecture include Service Location Protocol (SLP) [Pe99] by IETF and Universal Plug and Play (UPnP) [Mi99] by Microsoft Corporation.

2.1.3 Hybrid Architecture

This architecture is hybrid of directory-based and directory-less architectures. In this architecture servers may either register their services with DAs (if they are available) or wait for the client service query. Client may send a service query to DAs (if they are available) or directly to service providers using flooding. This architecture is again not suitable for MANETs for the reasons method in the previous two architectures.

2.1.4 Integrating Service Discovery with Route Discovery

Service discovery can be integrated with the route discovery function of on-demand or hybrid routing protocols, as both exploit network-wide broadcasting. Such a cross-layer design principle can improve the performance but there is still need to resort to network wide searches. For example the protocol by Polyzos and Ververidis [PV05].

2.2 Service Discovery in MANETS

Some of the important service discovery protocols proposed for MANETS are following. Kozat and Tassiulas proposed a distributed service discovery architecture for MANET, which relies on a virtual backbone for locating and registering available services within a dynamic network topology [TK04]. The architecture consists of two independent parts:

backbone management (BBM) phase and distributed service discovery (DSD) phase. A similar approach has been proposed recently by Sailhan and Issarny [BBL05] for implementing a scalable directory service for MANET. The architecture is based on homogeneous and dynamic deployment of cooperating directories among the network arranged in a virtual network. Despite the goal of the architecture as achieving scalability, the paper presents performance results only for a few nodes (90 nodes). Another protocol is Konark [Ve03] that is designed specifically for the discovery and delivery of services in multi-hop ad hoc networks. It supports both push and pull modes, with a cache in all devices and uses multicast to advertise and discover services. Allia [Ra02] by Ratsimor, Chakraborty et. al. also follows a decentralized directory-less approach in which the nodes, which are geographically close form groups called alliances. Klein and Konig-Ries et. al. propose a protocol called Service Rings [KKO03b] that form an overlay structure by grouping of nodes that are physically close and offer similar services. Each service ring has a designated service access point (SAP) through which the nodes within the ring can be accessed as it has all the information about the services offered within the ring. These SAPs are also connected with SAPs of other service rings thus forming a hierarchical structure. The directory information is kept in chosen edges that are dynamically selected. Another protocol that forms overlay network is Lanes [KKO03a] by Klein, Konig-Ries et. al. It is inspired by Content Addressable Network (CAN) protocol, which is used for service discovery in wired peer-to-peer networks. Some nodes are grouped together to form an overlay network forming lanes of nodes. Each group is called a lane. Nodes in the same lane have the same directory replicated in each node cache. There are different lanes in a network that are loosely coupled with each other. A field theoretical approach to service discovery has been proposed by Lender et al. [MLP05]. A service is modeled by a (positive) point charge, and service request packets are seen as (negative) test charges that are attracted by the service instances. They map the physical model to a mobile ad hoc network in a way where each network element calculates a potential value and routes service requests towards the neighbor with the highest potential and hence towards a service instance.

3 Motivation for Using Random Walk and Biased Random Walk

Given a graph and a starting point, we select a neighbor of it at random and move to this neighbor. We then select a neighbor of this point at random and move to it and so on. The random sequence of points selected this way is a random walk on the graph. The interested reader is referred to [Lo93] in which the theory of random walks on a graph has been explained in detail. In this approach the node, which is interested in a particular service sends a query message. This query message plays the role of the walker that randomly moves on the graph formed by MANET and eventually approaches the service. The advantage of this approach is that there is no flooding that wastes lot of scarce bandwidth resource in MANET. Also there is no broadcast storm problem that results in collision of packets. In random walk on the graph [Lo93] the neighbor is selected randomly, but a biased selection can also be made. There is an interesting result in this

regard. Let us consider a simple case of $N+1$ nodes arranged in one-dimensional form as shown in Figure 1.

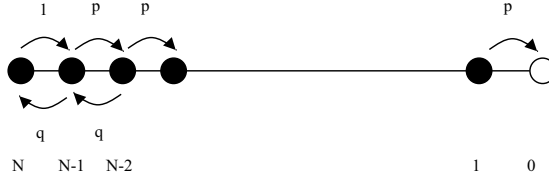


Figure 1: Random Walk on $N+1$ points

Suppose a node i wants to search a service present in node s . For this purpose, to forward a query message there are always two options available; one is sending the query message towards the service provider node s and second is sending the query message away from it. Let the probability p of forwarding the query message to the neighbor node that is near to service provider node s be 0.5. Then the probability q of selecting a node away from the node s is also 0.5. Thus the selection of node for forwarding the query packet is completely unbiased. In this case the mean hitting time is N^2 where the hitting time is the expected number of steps or hops in a random walk before a node s on the rightmost side of Figure 1 is visited for the first time, starting from the leftmost node in Figure 1 [Lo93] [GG87]. Let us take another case in which if each node selects a neighbor node towards the service provider node with probability $p = 1$, that is, the selection is biased, then there are exactly N hops. Thus biasing the selection process from 0.5 to 1 reduces the number of hops from N^2 to N , a query message takes to reach the required service. Although this result is just for a particular case of having the nodes present in a linear fashion and the search-initiating node being the left most but even then this is quite interesting. From this we can anticipate that in a more general case biasing decreases the number of hops of a query message to reach a target. In a service discovery protocol if we can find some way to bias the selection of next neighbor towards the service provider, such that the probability is $0.5 < p < 1$, we can then considerably decrease the number of hops required for the discovery of service. The problem remains to find some metric that can be used to bias the next hop selection for service discovery packet. This metric will help in selection of nodes for forwarding the query message to nodes that can form a bridge to the service provider such that the query message reaches the service provider in a few number of hops. In the next section we shall describe a generic random walk based algorithm that uses such a metric.

4 A Generic Algorithm for Random Walk based Service Discovery

A Service Discovery Protocol (SDP) based on random walk can be biased. Let us call the biasing information as hint. Hint is calculated with respect to a service. It provides the proximity of a node i to a node s at time t . In other words it gives the information that the

node i has some time ago remained in contact with the service provider node s . Contacts can be of two types, direct or indirect. Direct contact means to be in the neighbor, that is, in the wireless range and indirect contact means nodes are not in wireless range of each other but can contact each other through some other node(s). No hint will be available in case node i has never been in the contact of node s . Hint can be calculated by any suitable method. One of the methods is to use Global Positioning System (GPS) information. Here we shall describe another method to calculate hint, which is given in section 5. This method makes use of node speeds.

Let us now describe a generic algorithm for service discovery that uses hint. This algorithm can be described to occur in two phases. In the first phase hints are calculated and distributed in the network. These hints are stored in the nodes. It is not necessary that every node may have enough information to calculate the hint. So in a mobile ad hoc network some nodes may have hints and some nodes may not have a hint. In the second phase, when a node wants to search for a particular service, it sends a query message to its neighbor nodes. A forwarding protocol that runs on each node forwards the query message according to a policy. The algorithm can be described as follows.

Hint creation and distribution phase

1. Node i , after every ΔT secs, when passing near a service provider exchange some specific information (that helps in calculating hint) and calculate hints with respect to the particular service.
2. The calculated hints are stored in the service table of the node i , which in addition to hints also store information about the service corresponding to the hint. For example the service table contains the description of the service, ID of the node having the service, etc. The previous values of hints are deleted from the service table after every ΔT secs.
3. A node while moving sends its stored hints to the newly encountered neighbors that have not been able to calculate hints due to lack of some specific information (example in next section).

Forwarding protocol

1. A node wishing to discover a service S generates a request message containing the description of S .
2. If there are some nodes that have hints regarding the requested service, then among these nodes, a node is selected probabilistically for the next hop.
3. If hints are not available then the selection of the next hop node is at random.

There are some points that need further clarification.

- In the hint creation and distribution phase the time interval ΔT secs is mentioned. This time interval needs not to be constant. It can vary with the mobility of nodes. For example ΔT can be small for node that are moving fast and it can be long for node moving slowly.
- There is a reference to some specific information. This specific information depends on the method of calculation of hint. This will be further explained in the next section by giving an example.
- In the forwarding protocol the node for next hop is selected probabilistically among nodes that have hints. In fact the hints do not always give the correct indication of proximity of the service provider. Small value of hint may or may not be close to the service provider as compared to another small value. This is because a node after calculating hint may go completely in a direction that make it away from the service provider as compared to other nodes. So we probabilistically select among the given choices and the probability of selection of a particular node depends on the confidence of the correctness of the value of hint.

5 An Example Implementing the Generic Algorithm

The most obvious method in determining the nearest node to the service provider is using the Euclidean distance. We can then have a Euclidean metric for biasing the selection process for the next node. But this metric requires GPS to determine the relative distances of the nodes from the service provider.

GPS is not always possible. Another interesting technique, based on finding the relative speed of different nodes with respect to the service provider can be used. Hint h_{is} [BBL05] is calculated and stored by node i for a service provider node s .

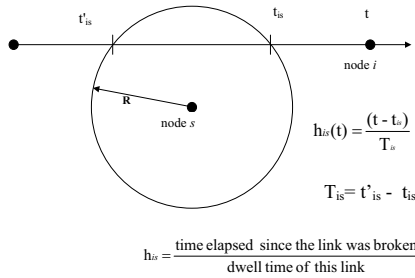


Figure 2: Calculation of hint using relative speeds

To calculate hint, node s sends an advertisement message after every ΔT secs containing the description of the service. This advertisement message is picked up by a mobile neighbor node i , which then updates its service table. The service table at node i , in addition

to other information also records the duration of the last wireless link established with s and time elapsed since the link with s was broken. The node i after every ΔT secs calculates hint and while moving sends the hint to the newly encountered neighbors. The nodes that have low values of hints are more probable to be near to the node s . For details see [BBL05].

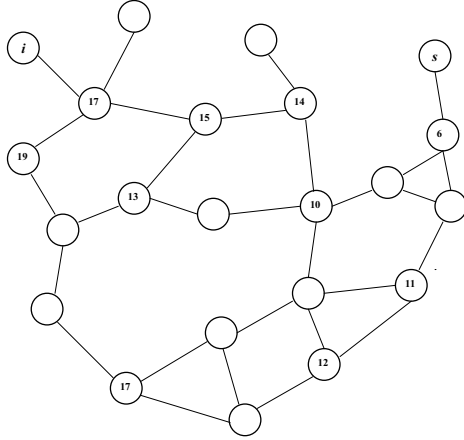


Figure 3: Mobile nodes with and without hints

Figure 3 shows the first phase of hint creation and distribution. The values shown in the node are the hints. Note that some nodes have hints and some nodes do not have hints.

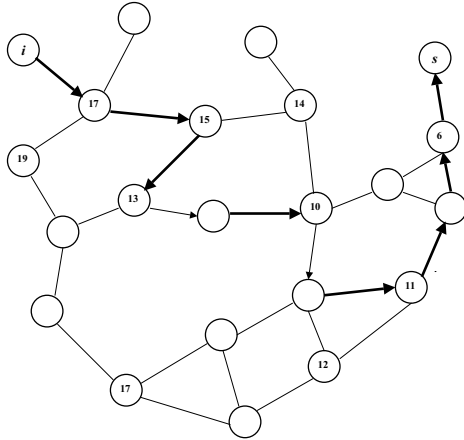


Figure 4: Biased random walk of query message

Figure 4 shows the forwarding protocol in action. The query messages starts from node i and following a random selection (shown as thin arrow) and probabilistic selection (shown as thick arrow) eventually reaches the node s .

6 Discussion

In the previous section we discussed an algorithm that is a “generic biased random walk based service discovery algorithm”. We call it generic, as most of the random walk based algorithms would have the same form except that the hint may be calculated in a different way. We see that there are many issues that still remain to be solved.

6.1 Flooding is not better than Random Walk.

One of the main issues is to show that flooding is not better than random walk or under what conditions flooding is better than random walk. It has been proved in [SGM04] that random walk is better than flooding under some specific conditions but these results are mainly for wired peer to peer networks. Such an effort is required for broadcast based wireless ad hoc networks.

6.2 Next hop selection

Selection of next hop node is based on a hint, if available. We gave an example of hint that is calculated using times. The problem still remains to find a better hint, which can guide the query message to the service provider in least number of hops or the shortest path available in network.

6.3 Termination criteria

In the presented generic algorithm no criteria has been defined for the termination of random walk search. The search can be terminated when the random walk first encounters the requested search or it may continue to search for other service providers till a specific TTL is reached. There could be other termination criteria. For example a search can be terminated if a node is visited a specific number of times, etc. One can investigate other termination criteria and their effect on the service discovery process.

6.4 Simultaneous random walks

Instead of one random walk, there can be many random walks simultaneously searching for a service. This can increase the probability of finding the service and decrease the searching time. An interesting investigation would be to investigate the number of simultaneous searches that can be made for efficient discovery of a service.

6.5 Loop formation

Since the next hop selection for a query message is probabilistic so there is no possibility of loop formations under the condition of mobility of nodes and probability of having incorrectness in the values of hints. But if the system becomes static and all of the nodes have hints that give correct information about the proximity of the service provider then there can be a possibility of loop formation and a query request can just keep on moving in a loop instead of moving in the whole network for the discovering the service. Conditions under which looping may occur and methods to avoid looping of the query message should be investigated.

6.6 Effect of mobility

An interesting investigation would be study the effect of mobility on service discovery using the biased random walk method presented here under different mobility scenarios.

6.7 Effect of different hints

The method of hint calculation also affects the discovery mechanism. Hints calculated in different way would affect the way random walk is progressed for service discovery. One can study properties of random walk under the effect of different hints.

6.8 Distributed selection

In the method presented the process of selecting a node is done in a centralized way. A node finds its neighbors and receive this information and then locally based on this information selects a particular node for the next hop. Another method can also be investigated in which a node forwards the query message to its all neighbors. All these neighbors may be running some protocol for selection and eventually one of the neighbors decides to forward the query message.

7 Conclusion

In this paper we tried to present some of the open problems in service discovery that use random walk in MANETs. We explained different concepts of random walk and service discovery and while explaining these, we identified some of the problem areas and problems that still need attention. We presented an algorithm that we called as a generic random walk based algorithm and then discussed different aspects of it and problems and issues

that need further investigation.

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