A Simple Resource Advertisement and Discovery Protocol for Large and Dense MANETs *

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Abstract **With remarkable advances in wireless technologies, applications of mobile ad hoc networks will be in widespread use in the near future. Thus, the geographical network environments may become large and dense. In such network environments, a large number of resource discovery queries may be generated when specific resources or services are needed. In this paper, we propose a simple resource advertisement and discovery (SRAD) protocol for applications in mobile ad hoc networks. The SRAD protocol self-organizes a proximity network and works in a fully distributed architecture without centralized control and management. The simulation results show that the SRAD protocol can achieve the same level of performance as in the broadcast-based protocols while generating fewer transmitted messages in large and dense mobile ad hoc networks.**

Index Terms—service discovery, MANET, resource discovery, large and dense, protocol, SRAD

I. Introduction

With recent advances in wireless technologies as well as the availability of pervasive computing devices such as personal digital assistants (PDAs), smart phones and even electric watches, wireless communications and networking are experiencing a renaissance, and applications of mobile ad hoc networks (MANETs) may be in widespread use thus the network environment becomes large and dense. Mobile users may request the desired services, resources or information anytime and anywhere, hence, the provision of resource advertisement and discovery mechanism for large and dense MANETs becomes necessary [1].

Resource discovery allows client nodes to look for remote resources or services and carry out transactions with other nodes. General ad hoc routing protocols, however, are not suitable for resource or service discovery because the destination address of the resource is usually unknown when needed.

A large and dense network environment implies a large-scale network with high density of mobile node population. Here, "large-scale" is relative to the radio coverage of mobile nodes. If the network diameter, i.e., the ratio of network topology area to a mobile node's radio coverage area, is larger than 8, the network is said to be *large* [2]. On the other hand, the density of mobile node population is defined as the ratio of the total radio coverage area of all mobile nodes to the geographical network area, that is, $N\pi r^2/A$, where N is the number of mobile nodes, r is the radius of the coverage area of a mobile node, and A is the geographical area of the network [3]. In this paper, we define a dense network environment as the density of mobile node population being 8π, namely, a mobile node has an average of $(8\pi - 1)$ neighboring nodes in its radio coverage.

A resource discovery protocol provides client applications for discovering the existence of services provided by server applications. Generally, a service can also be defined as hardware such as printer. In this paper, we consider that a *resource* could vary from information-orient services such as weather reports or provision of location information, data-oriented services such as music downloading, or commerce-based services such as ticket subscribing, or public services such as printers and cameras.

Mobile nodes can look for their desired resources using broadcast simply by flooding. However, this will result in some serious problems such as the wastage of bandwidth, and a large amount of power consumption in mobile nodes. Hence, the design of an efficient resource discovery protocol must tradeoff the performance measures such as *hit rate* and the cost, e.g., *the number of transmitted messages*. Here we define *hit rate* as the ratio of the number of successful attempts on the desired resource information to the total number of queries.

We propose in this paper a simple resource advertisement and discovery (SRAD) protocol for applications in large and dense MANETs. The architecture of the SRAD protocol is fully distributed, without centralized control and management. In addition, a resource description and management scheme is devised to share loads among mobile nodes.

II. Related Work

There already exist considerable efforts on service discovery standardized by different industrial consortiums and organizations. Protocols such as Sun's Jini [4], Service Location Protocol (SLP) of IETF [5], Salutation and Salutation-lite from the Salutation Consortium [6], Universal Plug and Play (UPnP) from the UPnP Forum [7], and Service Discovery Protocol (SDP) for personal area connectivity of Bluetooth [8], have been proposed to facilitate applications to discover services available on stable networked devices. These protocols are primarily centralized or semi-centralized in their

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architectures, furthermore, an implicit assumption is that the underlying network is reliable for communications. These higher layer protocols are thus not suitable for MANETs.

In the research field of peer-to-peer (P2P) computing, many fully distributed systems, algorithms and protocols have been proposed. The *Gnutella* protocol is simple, efficient and fault-tolerant but it uses flooding that causes high network traffic. The *Freenet* system is a distributed information storage system that can pool unused disk space across thousands of desktop computers to create a collaborative virtual file system, however, it is usually used to find files shared by anonymous authors. Other protocols like *CAN*, *Chord*, *Pastry*, *Tapestry*, and *Tornado*, have their structured P2P architectures that can guarantee reliability, availability, and access quality [9, 10, 11]. However, they are based on the construction of a *distributed hash table* which requires management overhead as performance penalty.

A resource discovery and service location system named Intentional Naming System (INS) [12] integrates name resolution and message delivery to offer application-layer anycast and multicast. But it requires that some devices or computers in a network can potentially act as name resolvers to form an application-level overlay network and route client requests to the appropriate services.

A novel content location protocol called GCLP for MANETs can be found in [13]. The GCLP makes use of physical location information to lower proactive traffic while reducing query cost. In GCLP, advertisement and discovery messages are sent in four fixed opposite geographical directions, however, in this way, it may not work well in an ad hoc network environment where nodes are not uniformly deployed in a geographical area.

III. THE SRAD PROTOCOL

If a resource discovery protocol heavily relies on network-wide broadcast, mobile nodes will experience considerable power consumption. Besides, resource discovery mechanism must be designed properly so that users can discover the resource efficiently while the cost is minimized. In this paper, we assume that mobile nodes reside in a two-dimensional plane and have the capability of location awareness that their location information can be obtained precisely. By using the location information, the performance of the networking protocol can be improved.

3.1. Concepts of SRAD protocol design

Mobile nodes are assumed to be peers that they have symmetric roles. Individual peers voluntarily contribute resources to the network. Rather than being divided into clients and servers, a node may act as both a client and a server. For convenience, a mobile node providing service or resource information is called a *server*, and a node interested in certain resource provided by a server is called a *client*. A server periodically advertises its information by disseminating the advertisement messages within a certain resource area. Nodes that lie in the resource area will cache the resource information of the server. When being queried, the node that has the cache of the resource information will send a reply to the client node, and after the client node receives the reply, the resource discovery operation is completed.

3.2. Resource description and management scheme

In the application layer, the location information of a restaurant, for example, can be described using a *resource descriptor* in this form: < *information-orient. location. restaurant* >. Then, the resource descriptor is encoded as a 128-bit *resource key* using the MD5 algorithm. In this way, a resource descriptor can be encoded as a unique number called *resource key*.

In order to share loads among mobile nodes, the SRAD protocol is devised to let server nodes advertise their resource information along one of the twenty line trajectories uniformly distributed on a plane. Hence, the resource key will then be used to determine a direction (or angle) for information dissemination using a hashing function. To do so, the ***modulo-k*** scheme is chosen as the hashing function. In this paper, we let *k* be 20 to divide 180 degrees into 20 parts. Then, using the tangent function, we can easily get a slope of a line trajectory. Here we call it the *main slope* (S_m).

3.3 Resource advertisement and discovery

As shown in Figure 1, the resource advertisement is performed on the basis of the line trajectory with *main slope* and a tolerance that forms a *resource area*. Mobile nodes that lie within the resource area must cache the resource information. Resource discovery is performed on the basis of another perpendicular line trajectory that forms a *discovery area*. Note that the *disseminating range* is a tolerance of an angle to allow the resource information to be disseminated. The *discovery range* is a tolerance of an angle to allow the resource information to be discovered. If a node in both resource area and discovery area has the resource information, or a node coming from the resource area just moves to the discovery area holds the resource information, it must send a reply to the client node.

3.3.1 Line-based (LB) SRAD protocol

A. Resource advertisement

The server node advertises its resource information using an advertisement (ADV) packet every $T_{interval}$ seconds. $T_{interval}$ depends on the speed of the mobile node, in a highly dynamic situation, it is desirable to have a small $T_{interval}$. The ADV packet contains the following fields:

< Packet type, Source ID, Server's Coordinate, Sequence Number, Resource Key, Hop Count, Lifetime, Main Slope >

The Hop Count field is used as hop count limitation that confines the distance an ADV can travel. The Source ID and Sequence Number fields are used to distinguish duplicate advertisements. The Lifetime field in ADV packet defines the lifetime of the resource information to be cached. High mobility server nodes in a MANET will set a small lifetime for this resource entry. This cached resource entry would be deleted once its lifetime expires. Each entry in the cache contains the following fields:

< Server ID, Resource Key, Server's Coordinate, Previous ID, Sequence Number, Lifetime >

When a node receives an ADV packet with new sequence number, it calculates whether itself lies in the resource area or not. If true, the resource information is recorded in the cache for a specified lifetime. Then, the node decrements the value of the Hop Count field in the ADV packet by one, and broadcasts it again if the value of Hop Count is larger than zero; otherwise, the ADV packet is discarded. Because an ADV packet keeps the server's coordinate and the main slope of a line trajectory, a node can determine whether itself is located in the resource area by some calculations.

This advertisement process will be carried out until the value of Hop Count field in the ADV packet reaches zero. In this way, the ADV packet is broadcasted within a confined resource area roughly along a line trajectory to avoid flooding the network.

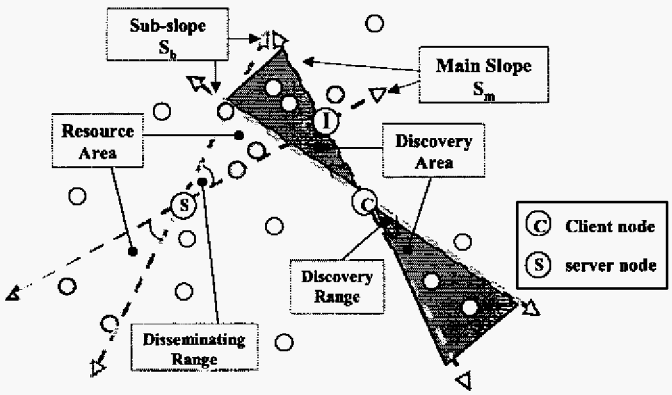

Figure 1. Resource area and discovery area.

B. Resource Discovery

When a client wants to find a resource or service, it first checks if it has cached the resource information that has not expired. If false, it calculates the resource key using the encoding process as described in section 3.2. Thus, the client can obtain the same resource key as what server obtains. Using that resource key, the client node can calculate the main slope of a line trajectory to disseminate a resource request (RREQ) packet for resource discovery.

The client firstly generates a RREQ packet and initiates the resource discovery process. Note that for resource discovery, the RREQ packet is disseminated along a line trajectory perpendicular to the line trajectory used in the resource advertisement process. The nodes that lie in both the resource area and discovery area can send a resource reply (RREP) packet to the client node using unicast to complete the resource discovery process. Moreover, if a node coming from the resource area just moves to the discovery area, it will also send a RREP packet to the client node. The RREP packet consists of the following fields:

< Packet type, Sequence Number, Server's ID, Server's Coordinate, Resource Key, Hop Count, Coordinate of the Reply Node, Main Slope, Lifetime >

When a node receives a RREQ packet, it first checks whether the RREQ packet is a duplicated one. If true, the RREQ packet is discarded. Otherwise, if it has cached the resource information, it then sends back a RREP packet directly to complete the resource discovery process, or else it then determines whether or not itself lies in the discovery area using geometry calculations. If the node lies in the discovery area and does not have the desired resource information, then, the node decrements the value of the Hop Count field in the RREQ packet by one, and broadcasts it again if the value of Hop Count is larger than zero; otherwise, the RREQ packet is discarded. A resource discovery process fails if the client node does not receive the RREP packet within T_{RTT}, the maximum tolerable round trip time. T_{RTT} is set according to the average number of hops the RREQ packet is expected to travel. If resource discovery processes fail frequently, T_{RTT} and the value of the Hop Count field in the RREQ packets can be set larger.

3.3.2 Enhanced line-based (ELB) SRAD protocol

It is possible that a server is located at the geographical border of the network and no neighboring node lies on the discovery trajectory or resource area. Besides, because the geometric coverage area near the server is small, some nodes may be close to the server but could not recognize the resources of the server. Hence, the enhanced line-based (ELB) SRAD protocol is proposed. The ELB protocol uses two main slopes that form two line trajectories perpendicular to each other to disseminate the ADV and RREQ packets.

In the ELB protocol, the resource discovery process is the same as that of the LB protocol based on one selected main slope. But if the first resource discovery process fails, the client node will try to send another RREQ packet using the other main slope.

3.3.3 Cross-line-based (CLB) SRAD protocol

To increase *hit rate* and consider that mobile nodes may not be uniformly distributed in the network, the cross-line-based (CLB) SRAD protocol is proposed. In the CLB protocol, the resource advertisement process is the same as that of the ELB protocol based on two main slopes. But the former discovers resource based on two main slopes at the same time. The performance penalty of the CLB protocol is that the transmitted message overhead is more than that of the ELB protocol since it discovers resource along two line trajectories.

IV. Simulation Study

For comparisons, an on-demand (OD) resource discovery protocol modified from the AODV routing protocol to support resource discovery is implemented in simulations.

The performance metrics to be observed include:

- *Number of transmitted messages*: the total number of broadcast messages in the network.
- *Average hit rate*: the ratio of the total number of successful resource discoveries to the total number of queries.
- *Average hop-count*: the number of hop-counts between the client nodes and the reply node that is located at the discovery area.

Besides, how moving speed of mobile nodes affects the performance of the SRAD protocol will also be discussed.

4.1 Simulation metrics

Each mobile node has a communication range of 100 meters. Nodes are uniformly distributed and confined to a region of 500m x 500m and 1000m x 1000m, respectively, in simulations.

Every node randomly selects a destination point and a speed in an interval of [0, V_{max}] km/hr after a pause time *P* seconds. When the mobile node reaches the destination, the same process is repeated. In the simulation, the pause time is set to be 100 seconds and the value of V_{max} varies from 7.2 km/hr to 57.6 km/hr.

The simulation parameters are summarized in Table I. The disseminating range and discovery range are tolerances of angle in degrees to allow the resource information to be disseminated and discovered as shown in Figure 1.

TABLE I. Simulation Parameters

Environment / Parameters	Highly dense	Large and dense
Simulation region	500m x 500m	1000m x 1000m
Total number of nodes	100 to 500	1000
Speed of node (km/hr)	7.2 to 57.6	7.2 to 57.6
Radio coverage (meter)	100	100
Number of server nodes	1	1
Disseminating range	18^0	18^0
Discovery range	18^0 and 36^0	18^0
Number of client nodes	30	30
$T_{interval}$ (second)	50	50
T_{RTT} (msec)	100	100
Hop Count	3	6

4.2 Simulation results

A. Comparison of LB, ELB and CLB protocols in hit rate

In the simulation results, we find that the more nodes in the network, the higher the average hit rate. The larger the discovery range in degrees, the higher the average hit rate. The LB protocol has lower average hit rate than the ELB and CLB protocols in a relatively sparse network because it discovers resource information only along a line trajectory. In a highly dense network, these protocols all have high average hit rate approaching 100%, because there are so many redundant nodes caching the resource information.

B. Comparisons of LB, ELB, CLB and OD protocols

Figure 2 gives the results with 18^0 discovery range in a region of 500m x 500m. Figure 2(a) shows that the OD protocol introduces much more overhead than the other three protocols as the number of nodes increases, because it discovers resource information simply by flooding. The LB, ELB and CLB protocols just advertise and discover resource information along confined trajectories, thus they produce much fewer transmitted messages.

Figure 2(b) shows that the ELB protocol introduces fewer overheads than the CLB and LB protocols. The CLB protocol uses two discovery trajectories, so it produces more overhead than the ELB protocol does. Note that although the ELB and CLB protocols use two advertisement trajectories, they produce fewer messages in the network. This is because more client nodes may have cached the advertised resource information prior to sending the query messages. Figure 2(c) indicates that the OD protocol can achieve the highest hit rate. The hit rate for LB, ELB and CLB protocols improves when the density of mobile node population increases. Figure 2(d) shows that the average hop counts needed to obtain the resource information. That is, the three SRAD protocols can find resource information efficiently and quickly compared to the OD protocol.

To improve the hit rate of the LB protocol in sparse network environments, the discovery range of a client node can be enlarged to 36^0. In a region of 500m x 500m, we find in the simulations that using 36^0 discovery range in low density network environments makes the hit rate efficiently improved from 78%, 86% and 86% to 92%, 96% and 96%, respectively for the LB, ELB and CLB protocols. Moreover, either in low or highly dense environment, the three SRAD protocols can achieve good hit rate. That is, in the network that has high density of mobile node population, the three SRAD protocols have the same hit rate of over 99% as high as that of the OD protocol.

Although using 36^0 discover range doubles the number of transmitted messages in using 18^0 discover range, the LB, ELB and CLB protocols have fewer overheads than that of the OD protocol. Besides, the LB, ELB and CLB protocols need fewer hop counts to get resource information compared to the OD protocol.

C. The effect of the speed of mobile nodes

In the simulation results, we find that the moving speed of mobile nodes does not significantly affect the hit rate either in highly dense or in large and dense network environments. This is because the discovery time, i.e., the latency in discovering the desired resource, is so short that only few mobile nodes that have cached the resource information can leave the discovery area within that period of time.

D. A comprehensive comparison

Table II shows the comparison of various metrics in terms of average total number of transmitted messages, average number of advertisement and discovery messages, average hit rate, and average hop count for OD and the three SRAD protocols for large and dense network environment. The result shows that about 52,258 transmitted messages are generated using the OD protocol. Nevertheless, using the LB protocol guarantees a hit rate of 89.6% and its overhead is only 6.5% of that of the OD protocol. Because in ELB and CLB protocols, more nodes may have cached the advertised resource information and can send a reply directly to the source of query in the discovery process, these two protocols generate fewer messages in the network than the LB protocol does. Hence, using the ELB and CLB protocols guarantees a hit rate of 98.3% and their overhead are respectively 4.4% and 5.5% of that of the OD protocol.

TABLE II. Comparison of various performance metrics with 1000 nodes

Protocol / Metrics	LB	ELB	CLB	OD
Total no. of messages	3391.3	2314.6	2866.4	52258.6
Average no. of advertisement messages	487	1034.3	1056.9	0
Average no. of discovery messages	2904.3	1280.3	1809.5	52258.6
Hit rate	0.896	0.983	0.983	1
Average hop count	2.473	1.457	1.346	5.431

V. CONCLUSIONS

In this paper, we propose the SRAD protocol for resource advertisement and discovery in large and dense MANETs. The SRAD protocol self-organizes a *proximity network* and works in a fully distributed architecture without centralized control and management. It assures the client nodes that if more than one server nodes advertise resource information described by the same resource descriptor, the most proximate server will first be discovered. Besides, the SRAD protocol can quickly locate the desired resource within a few hop counts in a limited discovery time, even in a network of dynamic topology. It also guarantees a very high hit rate as compared to that of the on-demand protocol that simply uses flooding. Moreover, the SRAD protocols can work well in either sparse or highly dense wireless networks.

The simulation results show that the SRAD protocol can achieve the same level of performance as in the broadcast-based on-demand protocol, while generating fewer transmitted messages in large and dense mobile ad hoc networks. Furthermore, the SRAD protocol has three variations considering the redundancy of line trajectories for resource advertisement and discovery. The ELB and CLB protocols can guarantee a higher hit rate and generate fewer messages than the LB protocol, however, the LB protocol needs fewer nodes to cache the advertised resource information than the ELB and CLB protocols. If an ad hoc network consists of limited-memory nodes, the LB protocol may be preferable.

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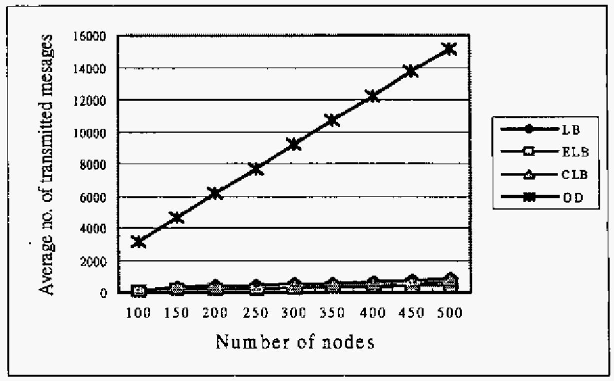

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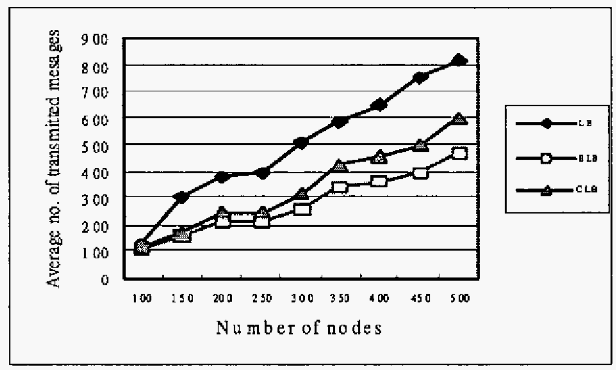

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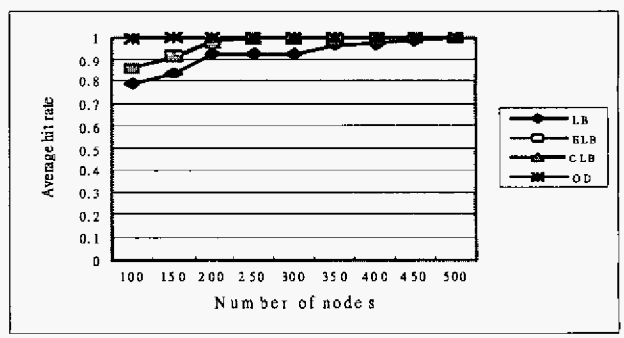

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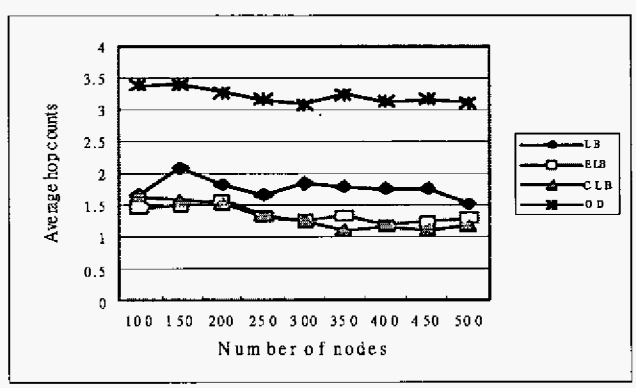

(d)

Figure 2. Comparisons of various metrics using 18^0 discovery range.