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Design and Evaluation of a Hierarchical Service Management Method using Bloom Filters for Large MANETs

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ABSTRACT

We propose a hierarchical service management method using Bloom filters for large MANETs. In this paper, a MANET is comprised of logical grid hierarchy, and each mobile node within the lowest service region multicasts the Attenuated Bloom Filter (ABF) for services itself to other nodes within the region. To advertise and discovery a service efficiently, the server node of the lowest server region sends the Summary Bloom Filter (SBF) for the ABFs to the server node of upper server region. Each upper server has the set of SBFs for lower vicinity service regions. The traffic load of the proposed method is evaluated by an analytical model, and is compared with that of two alternative advertisement solutions: complete advertisement and no advertisement. As a result, we identify that the traffic load of the proposed method is much lower than that of two alternative advertisement solutions.

Key words: Service Advertisement, Service Discovery, Bloom Filters, MANETs.

1. INTRODUCTION

Ad hoc networks enable spontaneous connectivity among wireless devices, without requiring any particular infrastructure. In addition to, ad hoc routing protocol increase connectivity by offering multi-hop communication, while supporting a continuously changing topology, leading to the automatic configuration of infrastructure-less Mobile Ad hoc NETworks (MANETs). However, effective exploitation of networked services those best match the application's requirements, still taking into account the MANET's dynamics. Some discovery protocols for MANETs have been proposed over the last of couple of years but they induce significant traffic overhead, and thus primarily suited for small-scale MANETs with few nodes [1].

A service is an entity that can be used by a person, a software program, or another service. It may be a computation, storage, a communication channel to another user, a software filter, a hardware device, or another user. Service advertisement and discovery is an important component for ad hoc communication and collaboration in ubiquitous computing environments since it enables to provide services to peers and to be aware of and use the available services from peers [2].

MANETs pose a number of challenges for service discovery. First of all, not all nodes may be able to reach one another directly, so provisions must be made to allow for the discovery of services located multiple hops away. Secondly, it is highly desirable to minimize the generated network traffic, because nodes will often operate on limited battery power and on a shared medium with limited capacity. Thirdly, nodes may have limited memory and processing power available. This imposes limitations on the amount of information nodes can be required to maintain, and the amount of processing they may be required to perform. Fourthly, the mobility of nodes causes reachability and availability to change; a service discovery protocol

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for MANETs must deal with this effectively [3].

We propose a hierarchical service management method using Bloom filters for large MANETs. In this paper, a MANET is comprised of logical grid hierarchy, and each mobile node within the lowest service region multicasts the Attenuated Bloom Filter (ABF) for services itself to other nodes within the region. To advertise and discover a service efficiently, the server node of the lowest server region sends the Summary Bloom Filter (SBF) for the ABFs to the server node of upper server region. Each upper server has the set of SBFs for lower vicinity service regions. The performance of the proposed method is evaluated by an analytical model, and is compared with that of two alternative advertisement solutions. The rest of the paper is organized as follows. Section 2 gives a brief description of related works for service advertisement in MANETs. Section 3 provides an overview of Bloom filters and attenuated Bloom filters. Section 4 illustrates the proposed hierarchical service management method using Bloom filters. The performance of the proposed method is evaluated through an analytical model in Section 5. Finally, Section 6 concludes the paper and describes our future works.

2. RELATED WORKS

The topic of service advertisement and discovery has been extensively researched in technologies such as Jini and the service location protocol [2]. The Jini technology infrastructure and programming model are built to enable services to be offered and found in networking environment. These services take advantage of Jini technology to announce their presence to other services and users, to discover each other, and to make calls to each other. A pair of these protocols, discovery/join, fulfills the service advertisement functionality. It occurs when a device is plugged in. The discovery protocol is used when a service looks for a lookup server with which to register. The join protocol is used when a service has located a lookup server and wishes to join it. The lookup protocol is used when a client or user needs to locate and invoke a service described by its interface type and possibly, other attributes. Figure 1 outlines the discovery/join/lookup processes in Jini. The discovery/join is the process of adding a service to a Jini system. A service provider, e.g., a device or software, is the originator of a service. First, the service provider locates a lookup server by multicasting a request on the local network for any lookup server to identity itself. Then, a service object for the service is loaded into the lookup server that contains a Java programming language interface for the service including the methods that users and any other descriptive attributes. The service is now ready to be looked up and used.

Service Location Protocol (SLP) establishes a framework for service discovery using three types of agents that operate on behalf of network-based software: (1) Service Agents (SA) advertise the location and attributes on behalf of services, (2) Directory Agents (DA) aggregate service information, and (3) User Agents (UA) perform service discovery on behalf of client software. Figure 2 illustrates active and passive methods for service discovery in SLP. In active discovery, UAs and SAs multicast SLP requests to the networks. In passive discovery, DAs multicast advertisement for their services and continue to do this periodically in case any UAs or SAs have failed to receive the initial advertisement. SLP has two modes of operation: (1) when a DA is present, it collects all

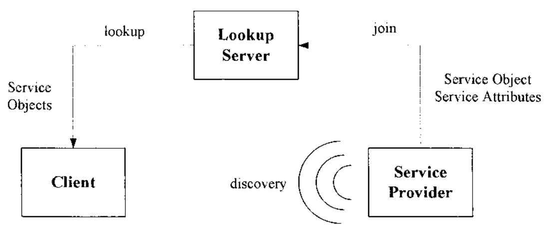

Fig. 1. Jini Processes of discovery/join/lookup.

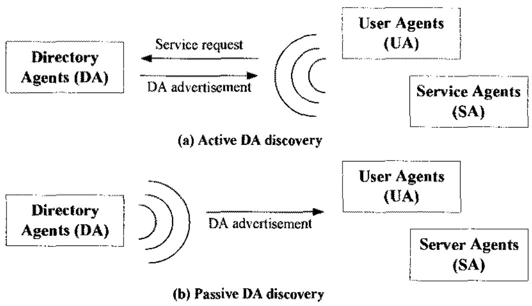

Fig. 2. Methods of service discovery in SLP.

service information advertised by SAs, and UAs unicast their requests to the DA, and (2) in the absence of a DA, UAs repeatedly multicast the same requests they would have unicast to a DA. SAs listen for these multicast requests and unicast response to the UAs if it has advertised the requested service.

In [3,4], a service discovery protocol for local ad-hoc networks based on the use of attenuated Bloom filters has proposed. Every node has an attenuated Bloom filter for each of its neighbors. There are so many attenuated Bloom filters as there are neighbor. When a query arrives at a node, the node will check its attenuated Bloom filters to find an outgoing link that is a likely direction where the requested service can be found. The number of layers per attenuated Bloom filter is same for all nodes in the network. The first level of the attenuated Bloom filter contains only services that one hop away. The second filter contains services that are two hops away and so on. This can be used to give an advantage to services that are nearer in the overlay network. The larger the distance from a node, the more services will be contained in the corresponding attenuated Bloom filter. This means a larger chance of false positives. The Bloom filter can be seen as a way to summarize availability services. The attenuated Bloom filter of depth d can discover services that are located up to d hops away.

Attenuated Bloom filters are used in [5] for context discovery. There, an analysis is done on the false positive chance and the size and depth of Bloom filters.

3. BLOOM FILTERS

A Bloom filter is a simple space-efficient randomized data structure for representing a set of in order to support membership queries. A Bloom filter for representing a set $S=\{x_1, x_2, \cdots, x_n\}$ of n elements is described by an array of m bits, initially all set to 0. A Bloom filter uses k independent hash functions $h_1, \cdots, h_k$ with range $\{1, \cdots, m\}$. For each element, the bits $h_i(x)$ are set to 1 for $1 \leq i \leq k$. A location can be set to 1 multiple times, but only the first change has an effect. To check if an item y is in S, we check whether all $h_i(y)$ are set to 1. If not, then clearly y is not a member of S. If all $h_i(x)$ are set to 1, we assume that y is in S, although we are wrong some probability. Hence, a Bloom filter may yield a *false positive,* where it suggests that an element x is in S even though it is not. Figure 3 provides an example. For many applications, false positives may be acceptable as long as their probability is sufficient small. To avoid trivialities we will silently assume from now on that $kn < m$ [6].

Attenuated Bloom filters (ABFs) are extensions to bloom filters. An attenuated Bloom filter of depth d is an array of d regular Bloom filters of the same length w. A level is assigned to each regular bloom filter in the array, level 1 is assigned to the first Bloom filter and level 2 is assigned to the second

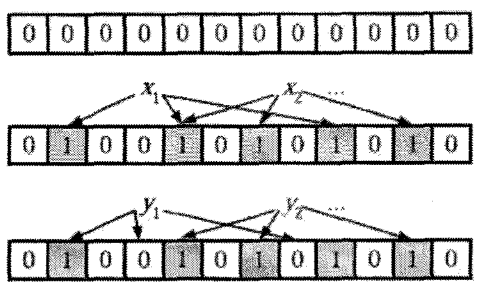

Fig. 3. An example of a Bloom filter.

Bloom filter. The higher levels are considered attenuated with respect to the lower levels. Each node stores an attenuated Bloom filter for each neighbor. The i-th Bloom filter in an attenuated Bloom filter (depth: d; $i \leq d$) for a neighbor B at a node A summaries the set of documents that will probably be found through B on all node i-hops away from A [7].

4. HIERARCHICAL SERVICE MANAGEMENT METHOD

4.1 System Model

In this paper, we assume that each node is aware of the geographical positions of itself through GPS functionality. Like the model of SLALoM [8], given a square region of area A, the topology is divided G logical unit regions (referred to as order-4 regions). In the 4-level logical grid hierarchy such as Figure 4, each node is aware of the size of the topography as well as the size of an order-4 region. It then combines K^2 order-4 regions to form order-3 regions, combines $4K^2$ order-4 regions to form order-2 regions, and so on.

Each node selects a server region in each order-3 region via a function F_1 that maps roughly the same number of nodes to each order-4 region in an order-3 region and selects a server region

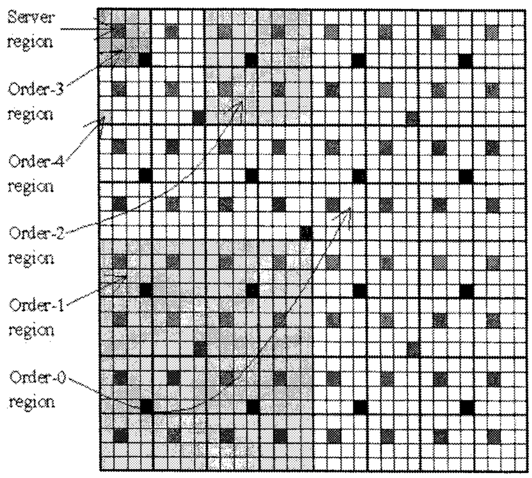

Fig. 4. Logical grid hierarchy for a MANET.

in each order-2 region via a function F_2 that maps roughly the same number of nodes to each order-3 region in an order-2 region, and so on. Any node within every server region is selected randomly as a service server.

Formally, the logical grid hierarchy can be represent as follows. Let the region of the minimum level in a logical grid hierarchy be order-m region. There are $O(A/K^2)$ order-$(m-1)$ server regions and $O(A/4K^2)$ order-$(m-2)$ server regions in A, respectively. For nodes u and v, there are the order-$(m-1)$ server region of u within at the most and the order-$(m-2)$ server region of u within at the most $2\sqrt{2}K$ from the position of v, respectively.

4.2 Service Aggregation

In the proposed hierarchical service management method, the mobile node multicasts an advertisement message to all nodes within order-3 region that is the lowest service region in our logical grid hierarchy for exchanging service information.

The service information is represented by an ABF. An ABF consists of multiple layers of Bloom filters, where the first layer contains a Bloom filter representing services available at sending node, the second layer consists of service available one hop away from the sending node, and so on, up to a configured number of hops away. This number of hops is called the depth. The depth of the ABF is 4. So, a mobile node can discovery the located services 3 hops away from itself.

Figure 5 shows how information from incoming ABFs is aggregated and represented in an outgoing ABF. The bottom node receives ABFs from the left and right nodes. It then sends out an ABF containing a layer corresponding to its own services (top low), one layer that is the bitwise OR of the first layer received from the left node and the first layer from the right node (middle row), and one layer containing the bitwise OR of the second layer received from the left and right nodes (bottom row), and so on. The fourth layers

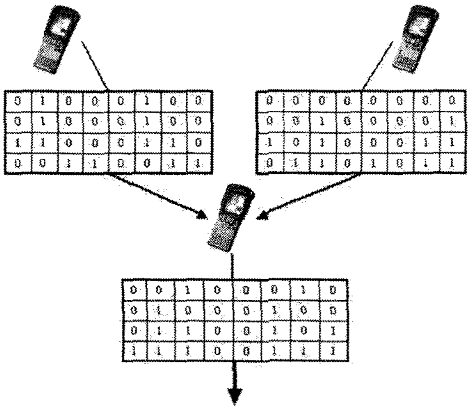

Fig. 5. Aggregation of service information.

received from the left and right nodes are not represented in the ABF sent out the from the bottom node, because they represent services too many hops away.

4.3 Service Advertisement

Since ABF only encodes information about service up to a maximum number of 3 hops away within order-3 region. Figure 6 shows the distribution of a particular service in a network with a regular grid structure.

In this example, the depth is 2. The node in the center sends out the announcement containing information about a service it offers. This information is received from the sending node's neighbors.

The service server of order-3 region that is the lowest region in the logical grid hierarchy builds a Summary Bloom filter (SBF) for the gathering service information from its own region. The SBF is formed by the row bitwise OR from the ABF

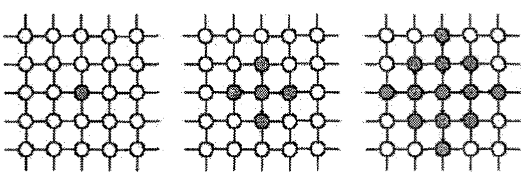

Fig. 6. Distribution of service information in a network with a regular grid structure.

ABF	0	0	1	0	0	0	1	0
	0	1	0	0	0	1	0	0
	0	1	1	0	0	1	0	1
	1	1	1	0	0	1	1	1
	↓	↓	↓	↓	↓	↓	↓	↓
SBF	1	1	1	0	0	1	1	1

Fig. 7. An example of an SBF formation.

of its own region. Figure 7 shows the process of the SBF formation. The server sends the SBF to the service server of order-2 region.

The service server of the order-2 region receives four SBFs from the service servers of the lowest neighbor order-3 regions. The server stores the received SBF information with the logical address of order-3 region server, respectively. Also, the server builds an SBF from received four SBFs by row bitwise OR, and send the SBF to order-2 service server, and above process is repeated until order-0 region.

4.4 Service Discovery

Bloom filters encode only availability information. Also, they do not encode that information precisely, but with a small probability of false positives. To discover services with certainty and to discover the address at which these services can be contacted, nodes send query messages. This is the only time queries are sent. Beside the name of the requested service, queries carry a query id used to avoid loops, a time-to-live (TTL) limiting the distribution of the query to depth hops, and the address of the node the query originated service.

Figure 8 shows the distribution of queries in the worst case. If a mobile node does not has the information about requesting service, the mobile node send the query message to the server of the order-2 region that belongs in its own. To discover the service from the four lower order-3 regions, the server of order-2 region receiving the query message searches for the requesting service from

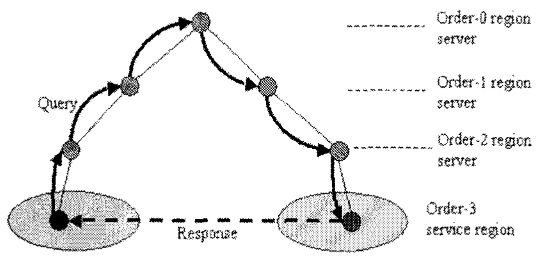

Fig. 8. Sending of a query.

it's own SBF. The above process is repeated until discovering the service or order-0 region server.

If a region server discovers the requesting service, the region server sends the query message to the lower region server providing requesting service. The above process is repeated until the node providing the requesting service receives the query message. Accordingly, the node providing the service that receives the query message last sends a response message to the query originated node.

5. PERFORMANCE EVALUATION

In our performance analysis for service management methods, we evaluate the total costs of transmissions in bits per node on the basis of the used performance modeling in [5]. General notation used for performance analysis is listed in the Table 1. Further notation is introduced below.

The total costs are the sum of advertisement cost (*adcost*) and discovery cost (*dicost*).

$$Cost_{our} = adcost + dicost. \tag{1}$$

We assume that advertisements are broadcasted periodically at a constant rate. Therefore the advertisement cost can be defined as:

$$adcost = \mu \times (r \times adpack_{ABF} + k \times adpack_{SBF}), \tag{2}$$

where μ is the advertisement rate, r is the number of nodes in the lowest region, k is the sum of the hops between neighboring layer servers, $adpack_{ABF}$ is the advertisement packet size of ABF, and $adpack_{SBF}$ is the advertisement packet size of SBF.

The service discovery cost is defined by equation (3).

$$dicost = \lambda \times (2 \times (l + k) \times qpack), \tag{3}$$

where λ is query rate, l is the hops from a node of the lowest region to the server of upper region, and $qpack$ is the query packet size. We have to specify the size of the packets for advertising and querying. We assume that the proposed hierarchical service management protocol is running on top of UDP. For both advertisements and queries, besides the header of the Bloom filters protocol advertisement (AD) and query (Q) messages, the header of the UDP, IP, and MAC layer will be attached. The $adpack_{ABF}$ and the $adpack_{SBF}$ are defined as follow:

$$adpack_{ABF} = header_{MAC} + header_{IP} + header_{UDP} + header_{AD} + w \times d, \tag{4}$$

$$adpack_{SBF} = header_{MAC} + header_{IP} + header_{UDP} + header_{AD} + w \times h, \tag{5}$$

where w is the width of the filter, d is the depth of the filter, and h is the order of the lowest region. The query packet size is defined as follows:

Table 1. Notation for performance analysis.

General		Bloom Filter	
Notation	Description	Notation	Description
n	Number of services per node	w	the width of the filter
μ	advertisement rate	d	the depth of the filter
λ	query rate		
s	the size of service information		

$$qpack=header_{MAC}+header_{IP}+header_{UDP}+header_{Q}+w\times h. \quad (6)$$

To evaluate the performance of the hierarchical service management, we compare it with two alternative discovery solutions: complete advertisement and no advertisement.

Complete advertisement floods all network nodes within x hops with a complete description of all service information. Nodes have the complete map of the network, which indicates how nodes can send queries directly to the destination. It is proactive protocol. The cost of complete advertisement is evaluated by equation (7).

$$Cost_{compl\_ad}=\mu\times Totalnumofnodes_{x-1}\times(header_{MAC}+header_{IP}+header_{UDP}+header_{AD}+n\times s). \quad (7)$$

In the no advertisement case, nodes do not advertise service information. When a query comes, nodes forward it to all the neighbors. It is a reactive protocol. The cost of no advertisement is evaluated by equation (8).

$$Cost_{no\_ad}=\lambda\times(Totalnumofnodes_{x}-1)\times(header_{MAC}+header_{IP}+header_{UDP}+header_{Q}+s), \quad (8)$$

where n is the number of services per node and s is the size of service information.

Table 2 shows the parameter and values for analytical performance evaluation.

Table 2. Parameters and value for analytical evaluation.

Parameters		Values
w		128 bits
d		4
n		3
λ		0.1
μ		0.1
s		32 bits
The sizes of headers	MAC	160 bits
	IP	320 bits
	UDP	64 bits
	AD	32 bits
	Q	192 bits

Figure 9 shows the performance of service management methods over the number of grids. The performance of service management methods is evaluated by above analytical model. Accordingly, the traffic load of the proposed method is evaluated by equation (1), and it is compared with that of two alternative advertisement solutions: complete advertisement and no advertisement. As a result, we know that the traffic load of the proposed method is much lower than that of two alternative advertisement solutions. As the size of MANETs is larger, the performance of our method is better. Therefore, we know that the proposed method is suitable for large MANETs.

The performance of service management methods depends on the rates at which advertisement are sent and queries are generated. Accordingly, the performance of service management methods is also evaluated by equation (9).

$$Total\ Cost=adcost+(\lambda/\mu)\times dicost, \quad (9)$$

where λ/μ is Query-to-Advertisement Ratio (QAR). QAR measures the volume of queries against the frequency of service advertisement, it is analogous to the Call-to-Mobility Ratio (CMR) used in cellular networks. Figure 10 shows the performance of service management methods over QARs when the number of grids is 1,024. Complete advertisement method doesn't need a query message because that all network nodes has all service

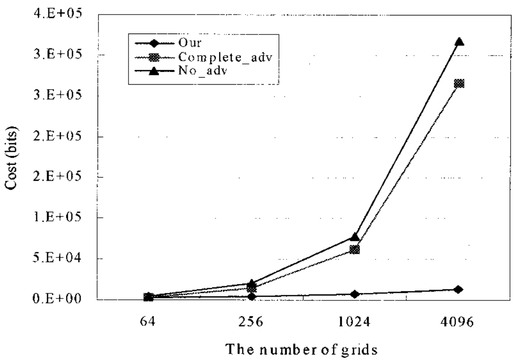

Fig. 9. The performance of service management methods over the number of grids.

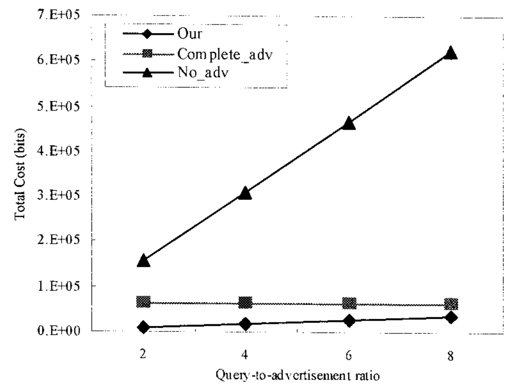

Fig. 10. The performance of service management methods over query-to-advertisement ratios.

information. Consequently, complete advertisement has constant performance regardless of QARs. While the traffic load of our and no advertisement methods increases when QAR increases because that these methods need a query message when a node locates a service. But the proposed method uses Bloom filters on the on the strength of logical grid hierarchy so that the traffic overhead due to query messages is slightly increased. Therefore, we identify that the performance of our method is better than that of two alternative advertisement methods regardless of QARs from Figure 10.

6. CONCLUSION

We propose a hierarchical service management method using Bloom filters for large MANETs. In this paper, a MANET is comprised of logical grid hierarchy, and each mobile node within the lowest service region multicasts the Attenuated Bloom Filter (ABF) for services itself to other nodes within the region. To advertise and discovery a service efficiently, the server node of the lowest server region sends the Summary Bloom Filter (SBF) for the ABFs to the server node of upper server region. Each upper server has the set of SBFs for lower vicinity service regions. Each upper server has the set of SBFs for lower vicinity service regions. The performance of the proposed hierarchical service management method is evaluated by traffic load. The traffic load of the proposed method is evaluated by an analytical model, and it is compared with that of two alternative advertisement solutions: complete advertisement and no advertisement. As a result, we know that the traffic load of the proposed method is much lower than that of two alternative advertisement solutions. In addition, the performance of our method is better than that of two alternative advertisement methods regardless of QARs, as the size of MANETs is larger, the performance of our method is better. Accordingly, we identify that the proposed method is suitable for large MANETs.

Future works include the performance evaluation for our algorithm through a simulation, the design of a dynamic service advertisement model with different filter depth according to service types and the design of an adaptive hybrid service management method considering filter depths.

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