ASESDP : An Efficient Service Discovery Protocol in Pervasive Computing Environments

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Abstract— Service discovery is the technology of finding needed services in networks, and a key point in pervasive computing environments. This paper presents a novel service discovery protocol: ASESDP(AIP and SRR Enhanced Service Discovery Protocol). In ASESDP, tow schemes are proposed to enhance its performance: AIP(Advertisement Information Piggybacked) and SRR(Shortest Reply Route). In AIP, parts of advertisement information are piggybacked in the service reply packet, which makes the advertisement information propagating along the reply path, and spreads its transmission area. In SRR, in order to reduce the service response time, the shortest reply route is chosen to forward the service reply packet to the source node sending the service request. With the theoretical analysis and Glomosim simulation results, it is verified that ASESDP can reduce the number of service request packets, save the response time, and improve the efficiency of service discovery.

Index Terms—pervasive computing, MANET, service discovery, advertisement information.

I. INTRODUCTION

Pervasive computing environments are comprised of handheld, wearable, and embedded computers in addition to regular desktop clients and servers. These are inter-connected using some combinations of wireless ad-hoc networks and wireless infrastructure-based networks, such as WLANs[1]. In such dynamic environments, the cohort of computing elements dynamically changes with time, so they still are suffering from numerous limitations: inadequate processing capability, limited battery life, frequent line disconnection and so on. Lack of fixed infrastructure support is a natural phenomenon in such environments, which leads to the dependency on other devices for resources[2].

How to find these resources efficiently is a prerequisite for good utilization of shared resources in the network. Service discovery is the technology of finding needed services in networks, and an integral part of every system running in such environments, and hence it turns into a key point in pervasive computing environments.

At present, there have been considerable service discovery protocols in pervasive computing environments. Protocols like Jini[3], UPnP[4], UDDI[5] and Service Location Protocol[6] have been developed in wired networks. Konark[7], Lanes[8] and Service Rings[9] are used in wireless networks. In GSD[10], Allia[11], PCPGSD[12] and CNPGSDP[13], services presented on the nodes are classified into several groups, and these protocols find needed services in ad-hoc environments. All of these mentioned protocols have a common feature, that is, they propose some schemes in course of finding services to solve how to find useful resources efficiently and timely. They seldom consider, after finding matched services, which measure in course of replying the response can be used to improve the whole efficiency of service discovery.

Based on above problems, we present a novel service discovery protocol: ASESDP(AIP and SRR Enhanced Service Discovery Protocol). It inherits the virtues of group-based intelligent forwarding of service requests and peer-to-peer caching of service advertisements in GSD[10], and proposes two schemes: AIP (Advertisement Information Piggybacked) and SRR(Shortest Reply Route). In AIP, the service reply packet carries not only the reply information but also parts of advertisement information to widen the transmission area of the advertisement information. And in SRR, the shortest reply route is chosen to forward the service reply packet to the source node, which can save the response time. By this way, while the maximum hop number of service advertisement packet is limited, ASESDP can still find matched services efficiently, and decrease packet overhead.

The rest part of this paper is organized as follows. In Section 2, ASESDP is described in detail. Section 3 presents the theoretical analysis for ASESDP, which shows that ASESDP can reduce packet overhead greatly. In Section 4, comparative studies between ASESDP and three other service discovery protocols are performed

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through extensive simulations using GloMosim. Simulation results are shown, and in the end, a conclusion is given in Section 5.

II. ASESDP

ASESDP is a group-based distributed service discovery protocol for pervasive computing environments. It is based on the concepts of peer-to-peer caching of service advertisements and intelligent forwarding of service requests in light of service groups propagated with service advertisements in GSD. However ASESDP has some differences from GSD, it proposes AIP and SRR scheme to broaden the transmission area of advertisement information and reduce the response time.

2.1 Data structures in ASESDP

Because of the limited space, this paper only shows several structures more especial in ASESDP. The main data structures in ASESDP are shown in Fig.1. Modified or new fields are highlighted with bold italic.

2.1.1 Structure of service reply packet

The structure of service reply packet is shown in Fig.1(a). In ASESDP, parts of advertisement information of reply node are piggybacked in service reply packet. They are highlighted with bold italic, such as the *local group* field, the *life time* field, the *other group* field and its subfields. By this way, they can be propagated along the reply path and stored in SIC(Service Information Cache) of every node on the reply route.

The *packet type* field indicates the type of the message packet. The *server id* field identifies the producer of the packet. The *source id* field represents the node that generates the corresponding service request packet. The *receiver id* field denotes the current receiver of the packet, and is used to forward the packet to the source node. The *local service* field stores the descriptions of services provided by the server indicated by *server id.* The list of the service groups that the local services belong to is stored in the *local group* field. The *other group* field contains the id list of services provided by the server's d-hop adjacent nodes, the service groups that the services belong to, the list of the nodes and the total node number. The value of the *remain hop* field indicates the number of hops that the service reply packet can still travel. The life time of the advertisement information piggybacked by the service reply packet is stored in the *life time* field.

2.1.2 Structure of service request packet

When a node needs services that it does not have, it should first check its own SIC to decide whether there are any matched services. If no matches are found, the node should create a service request packet and forward the packet. The structure of service request packet in ASESDP is shown in Fig.1(b).

The *request id* field is used to identify different service request packets from one node. The *sender id* field indicates the current sender of the packet. The *request service* field stores the descriptions of the requested service. The *receiver count* field denotes the number of nodes that should process the forwarded packet sent by the current node, and the list of these receivers is stored in the *receiver list* field. The *hop count* field indicates the number of hops that the packet has traveled. Other fields of service request packet are the same as those of service reply packet.

2.1.3 Structure of SIC

In ASESDP, a node would update its SIC(Service Information Cache) whenever it receives a service advertisement packet or a service reply packet. While a node constructs a new service advertisement packet or a new service reply packet, SIC must be taken into account too. The structure of a SIC item is shown in Fig.1(c).

The *server id* field indicates the producer of service advertisement packet or service reply packet, namely the server node. The *packet id* field is used to distinguish different SIC entries of one node. The *sender id* field denotes the current sender of service advertisement packet or service reply packet. Other fields of the SIC item are the same as those of service reply packet.

2.1.4 Structure of RRT

In order to route a service reply packet to the source node, each node maintains a RRT(Reverse Route table) to store information of the corresponding service request packet and its path. At the time of forwarding a service request packet, the node should add or update its RRT entry. The structure of a RRT entry is shown in Fig.1(d).

The *predecessor id* field indicates the node from which the corresponding service request packet is forwarded, that is to say, it denotes just the next hop node that the service reply packet will be transmitted to. The *hop count* field stores the number of hops that the corresponding service request packet has traveled. Other fields of RRT are the same as those of service request packet.

2.2 New schemes in ASESDP

2.2.1 Advertisement Information Piggybacked AIP) scheme

In most service discovery protocols, a node advertises its service information to its neighbors by means of service advertisement packets. In this way, when the maximum hop of service advertisement packet is larger, in theory, matched services can be found efficiently and quickly. But in fact, it often results in great packet redundancy, enormous bandwidth use and waste of the limited resources. On the contrary, when the maximum hop of packet is less, the spread of service information will be restricted, and so the efficiency of service discovery will drop largely.

packet type	server id	receiver id	source id	local service	***local group***	***other group***	remain hop	***life time***

node number	***group id***	***info id***	***node id***	· · · · · ·	***node id***

(a) Structure of a service reply packet

packet type	source id	request id	sender id	request service	receiver count	receiver list	***hop count***

(b) Structure of a service request packet

packet id	server id	sender id	local service	local group	other group	Life time

node number	group id	info id	node id	· · · · · ·	node id

(c) Structure of a SIC item

source id	request id	predecessor id	***hop count***

(d) Structure of a RRT item

Fig.1 Parts of structures in ASESDP

ASESDP introduces the AIP(Advertisement Information Piggybacked) scheme to solve the above problems. In AIP, parts of advertisement information of server node are carried in its service reply packet. With the transmission of service reply packet, the advertisement information is spread along the reply path as well as, and cached in SIC of every node on the path just like what the service advertisement packet does. By the AIP scheme, many service advertisement packets can be saved. Even the maximum hop number of service advertisement packet is limited, ASESDP can still achieve efficient service discovery.

2.2.2 Shortest Reply Route SRR scheme

Generally, while receiving a service request packet, a node will first check its RRT to decide whether the packet is duplicated. The duplicated service request packet will be discarded. When the packet is not duplicated and its maximum hop number does not exceed the limit, the node will forward the packet if it does not have matched services in SIC, and update its RRT on the basis of the packet.

However in ASESDP, when a node receives a duplicated service request packet, it does not discard the packet, but compares the hop count of the packet with that of the corresponding entry in its RRT, and choices the packet owning the less hop count to store in RRT. So a service reply packet traveling along the node indicated by the *predecessor id* field in RRT will always have the shortest route. This scheme is named as Shortest Reply Route (SRR). By this way, the shortest route can be chosen to forward the reply packet to the source node, which saves the response time.

2.3 Operations of ASESDP

2.3.1 Service request packet forwarding

In ASESDP, instead of simple discarding a duplicated service request packet, a node choices the packet having the shortest route to store in RRT. If the node has no matched services, it would forward the packet. Otherwise, the node would construct a service reply packet and send it. The pseudo code of forwarding a service request packet in ASESDP is as follows:

Algorithm: Forwarding Service Request Packet
Input: *Req:* received service request packet;
Definitions:
Self-id: The identity of the current node;
MaxReqHop: The maximum hop number of service request packet;
Output: *Req*(updated service request packet) or *Reply*(generated service reply packet);
Begin :

```
if  (FindItemInRRT(Req)= =true) then
{ // The service request packet is duplicated.
    if  (Req.hopcount < RRT.hopcount) then
    {//The hop number of service request packet
     // is less, so RRT is updated.
        RRT. predecessorid = Req.senderid;
        RRT.hopcount = Req.hopcount;
    }
    else
    {
        DiscardPacket(Req) ;
    }
}
else
{
    InsertIntoRRT(Req);
    if  (NoMatched(Req)= = true) then
    { //The current node has no matched service.
```

```
            Req.hopcount ++;
            If (Req.hopcount <= MaxReqHop) then
            {//The hop count does not reach the
             //limit.
                  Req.senderid = Self-id;
                  ForwardingPacket(Req);
             }
             else
             {
                DiscardPacket(Req);
             }
        }
        else
        {//Create a service reply packet and send it.
                GeneratePacket(Reply);
                UnicastPacket(Reply);
        }
}
End.
```

2.3.2 Service reply packet forwarding

When a node receives a service reply packet, it should first judge whether it is just the receiver of the packet. If not, it would update its SIC in terms of the advertisement information piggybacked in the packet, and discard the packet. Otherwise, it would update its SIC and forward the packet. The pseudo code of forwarding a service reply packet in ASESDP is as follows:

```
Algorithm: Forwarding Service Reply Packet
Input: Reply: received service reply packet;
Definitions:
        Self-id: The identity of the current node;
Output: Reply: updated service reply packet;
Begin:
Reply.remainhop--;
if (Reply.remainhop>0) then
{
        if (Reply.receiver-id= = Self-id) then
        {// The current node is just the receiver,
         //updates its SIC and forwards the packet.
            Updated(SIC);
            ForwardingPacket(Reply);
         }
         else
         {
            Updated(SIC);
            DiscardPacket(Reply);
          }
}
else
{
        if (Reply.source-id= =Self-id) then
        { // The current node is just the source node,
          //updates its SIC and accesses the packet.
            Updated(SIC);
            Access(Reply);
         }
         DiscardPacket(Reply);
 }
 End.
```

III. Theoretical analysis

3.1 Information Node Ratio (INR)

Let n denote the total number of nodes in the network. By the limited hop traveling of service advertisement packet sent by one server node, k nodes update their SIC in terms of the packet. That is, k nodes contain the correlative service information of the server node in their SIC. And the information can be used to discover matched service quickly. So by this time, if any node in the network sends a service request packet to look for the same service as that in the service advertisement packet, generally, the ratio(named Information Node Ratio(INR)) of the number of nodes that can provide the correlative service information to the total number of nodes is:

$$P_{USUAL} = \frac{k}{n} \tag{1}$$

Let s denote the average number of service reply packets that the sender node receives after a service request packet is sent, and r indicates the average number of hops that each service reply packet travels. Then in ASESDP, by using AIP scheme, after one SDP session, $s \times r$ nodes update their SIC in terms of the advertisement information piggybacked in service reply packets. In other words, after one SDP session, in the network, $s \times r$ nodes are increased to provide the relevant information to find the matched services. Let i denote the number of times that a service has been requested in life time of cache. So by this time, if any node requests the same service in the network, the INR is:

$$P_{ASESDP} = \frac{(k + s \times r \times i)}{n} \tag{2}$$

Because s, r and i are all equal or greater than 0, according to Eqs.(1) and (2), it is obvious that ASESDP enhances INR, and so it can improve the efficiency of service discovery.

3.2 Packet overhead

In one service advertisement interval, packet transmissions include three parts: service advertisement packets, service request packets, and service reply packets[12]. That is,

$$P_{total} = f \times P_{adv} + c \times (P_{req} + P_{reply}) \tag{3}$$

Where f is the frequency of service advertisement packet generation; $Padv$ is the total number of service advertisement packets sent in one service broadcast interval; c is the number of SDP sessions in one service broadcast interval; $Preq$ is the number of service request packets in one SDP session; and $Preply$ is the number of service reply packets in one SDP session.

In ASESDP, the increased INR denotes that more nodes store the correlative service information, which can help to discover the requested service quickly. Therefore so long as the matched services exist, a service request packet can find the services by few hops forwarding. Because the hop number is directly proportional to *Preq* in Eq.(3), and hence *Preq* is reduced.

Preply in Eq.(3) can be calculated as:

$$P_{reply} = d \times l \tag{4}$$

where d is the average number of repliers in one SDP session; l is the average number of hops between the sources and the corresponding repliers in one SDP session. In ASESDP, the SRR scheme can cause l to decrease directly, which makes *Preply* reduce.

In summary, because the value of *Padv* in Eq. (3) is same, the reduction in *Preq* and *Preply* causes the value of *Ptotal* in ASESDP to reduce.

IV. Simulation studies

4.1 Definition of performance metrics

Definition 1 Request packet number : It denotes the average number of service request packets transmitted in one SDP session.

Definition 2 Reply request ratio : It is the ratio of the number of service reply packets to the number of service request packets in one SDP session. It reflects the overhead of successful service discovery.

Definition 3 Succeeded SDP ratio : It is the average ratio of the number of sessions in which at least one service reply packet is received by the request node to the total number of sessions. It indicates the protocol efficiency.

Definition 4 Average first response time: It is the interval of the average time between the arrival of the first service reply packet and the generation of the corresponding service request packet. It measures the promptness of service discovery protocols. It is indirectly affected by the distance between the requester and the corresponding first replier.

4.2 Simulation settings

To perform comparative simulation analysis, four service discovery protocols are implemented in GloMosim: the flooding service discovery protocol (denoted as BASIC), GSD, PCPGSD and ASESDP. The Distributed Coordination Function (DCF) of IEEE 802.11 is used as the underlying MAC protocol. The Random Waypoint Model(RWM) is used as the mobility model. In this model, a node selects a random destination point and then moves towards the destination with a speed V selected randomly. After reaching the destination, it will keep static for a random period P. Then the node will randomly select a new destination and move to it with a new speed. The node will repeat the process continuously. In our experiments, $P = 0$, $V = 0$.

4.3 Simulation results

The simulation scenarios are created with 100 nodes randomly distributed in the scenario area, and among them, 50 nodes are selected randomly as servers at the beginning of each simulation to produce the services. In each simulation, 50 service discovery sessions will be set up at random time by randomly selected nodes. The basic parameters used in all following experiments are listed in Table 1.

Table 1. Basic parameters used in simulations

Parameter	Value
Scenario area	1000×1000m
Node number	100
Server node number	50
Simulation time	1000s
Service advertisement interval	20s
Valid time of SIC item	21s
Wireless bandwidth	1Mbps
Session number in each simulation	50

4.3.1 The effects of the maximum hop of service advertisement packets

To study the effects of the maximum hop of service advertisement packets, we perform 4 simulation sets that simulate four service discovery protocols, respectively. In these simulations, the maximum hop of service request packets is set to 3, the number of service groups is 2, and the number of services in each service group is 7. Each set includes 5 parts, in which the maximum hop of service advertisement packets is fixed to 1, 2, 3, 4 and 5. Each simulation includes 50 sessions. The experiment results are showed in Fig.2.

Fig.2(a) shows the effects of the maximum hop of service advertisement packets on the request packet number. In ASESDP, because the service advertisement information is spread more widely with the service reply packet, the service request packets sent in one session can find the matched services after fewer forwarding hops. So ASESDP has less request packet number than other three protocols.

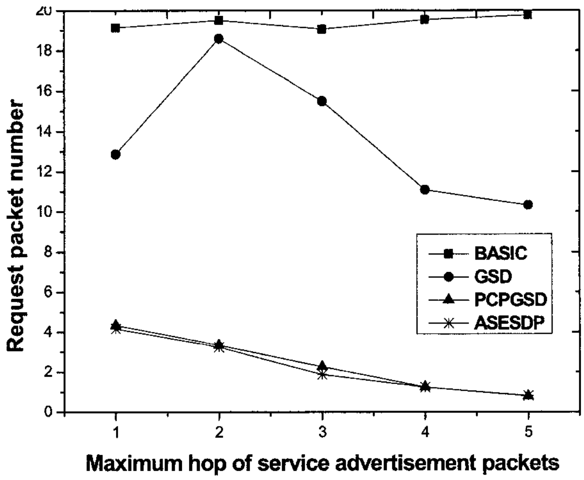
Fig.2(b) shows the effects of the maximum hop of service advertisement packets on the reply request ratio. ASESDP has the highest reply request ratio comparing with other three protocols. This indicates that ASESDP can receive more service reply packets under equal number of service request packets, and therefore its cost is least.

Fig.2(c) shows the effects of the maximum hop of service advertisement packets on the succeeded SDP ratio. The more the maximum hop of service advertisement packets is, the more widely the packet would be spread. So except for BASIC, the succeeded SDP ratio of other service discovery protocols increases as the maximum hop of service advertisement packets increases. ASESDP has the highest succeeded SDP ratio. Especially when the maximum hop of service advertisement packets is 1, the metric of ASESDP is about 1.08 times of PCPGSD, 1.1 times of GSD, and

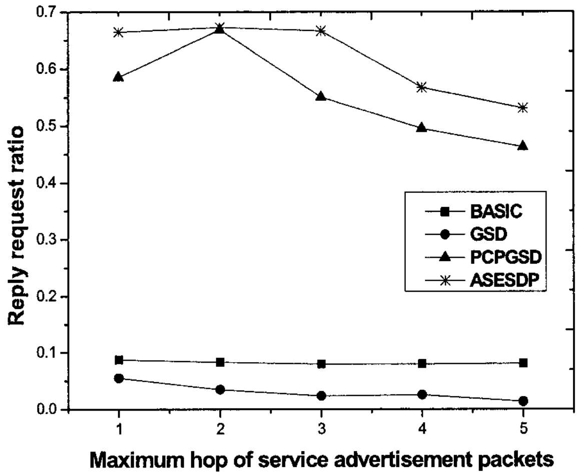
2.38 times of BASIC.

Fig.2(d) shows the effects of the maximum hop of service advertisement packets on the average first response time. Because ASESDP choices the shortest reply route to transmit service reply packets, it has the fastest response speed in all four service discovery protocols. The larger the maximum hop of service advertisement packets is, the more widely the packet would be spread. So the advantage of ASESDP on average first response time becomes less remarkable when the maximum hop of service advertisement packets is larger.

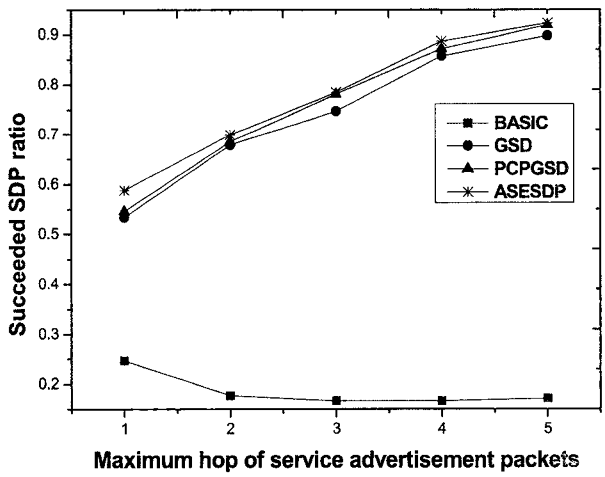
The experiment results reflect that the performances of ASESDP are superior to those of BASIC、GSD and PCPGSD while the maximum hop of service advertisement packets changes.



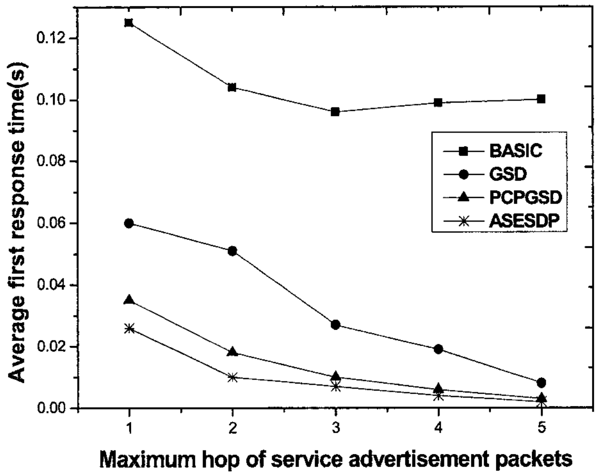
(a) Advertisement maximum hop vs. request packet number



(b) Advertisement maximum hop vs. reply request ratio



(c) Advertisement maximum hop vs. succeeded SDP ratio



(d) Advertisement maximum hop vs. first response time

Fig.2 Influence of the maximum hop of service advertisement packets

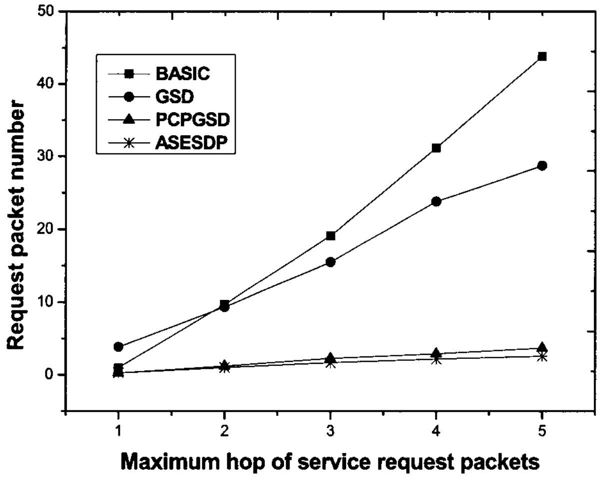
4.3.2 The effects of the maximum hop of service request packets

To study the effects of the maximum hop of service request packets, we perform 4 simulation sets that simulate four service discovery protocols, respectively. In these simulations, the maximum hop of service advertisement packets is set to 3, the number of service groups is 2, and the number of services in each service group is 7. Each set includes 5 parts, in which the maximum hop of service request packets is fixed to 1, 2, 3, 4 and 5. Each simulation includes 50 sessions. The experiment results are showed in Fig.3.

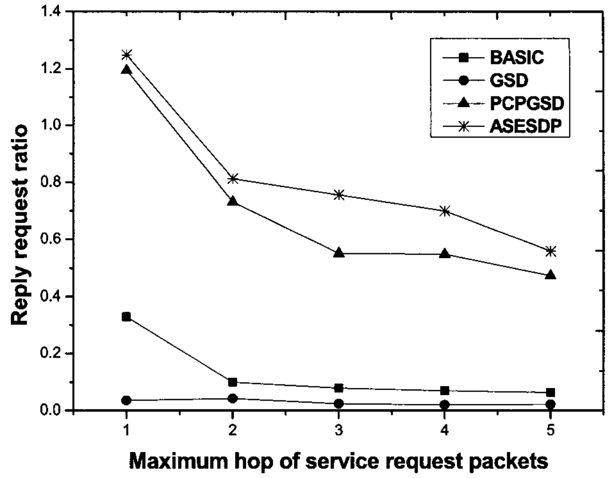
Fig.3(a) shows the effects of the maximum hop of service request packets on the request packet number. For each protocol, the request packet number increases as the maximum hop of service request packets increases from 1 to 5. However, in PCPGSD and ASESDP, the slope is much less than that in BASIC and GSD. ASESDP has the lowest request packet number among the four service discovery protocols. And with the maximum hop of service request packets increasing, the advantage of ASESDP is greater.

Fig.3(b) shows the effects of the maximum hop of service request packets on the reply request ratio. ASESDP has the highest reply request ratio comparing with all the other protocols. In terms of the definition of reply request ratio, this indicates that ASESDP receives more service reply packets under equal number of service request packets, and therefore its cost is least.

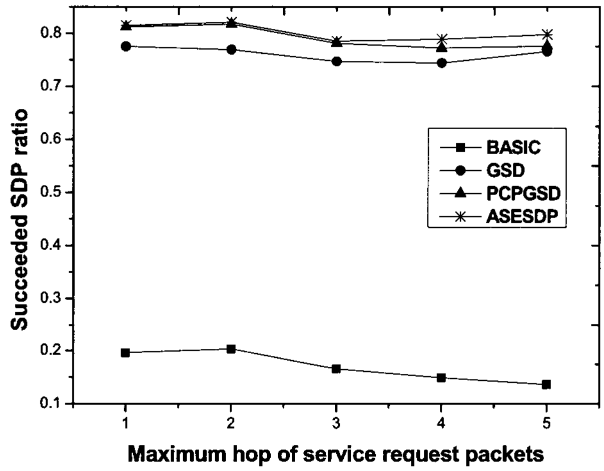
Fig.3(c) shows the effects of the maximum hop of service request packets on the succeeded SDP ratio. ASESDP has the highest succeeded SDP ratio. Especially when the maximum hop of service request packets is 5, the metric of ASESDP is about 1.03 times of PCPGSD, 1.04 times of GSD, and 5.87 times of BASIC.



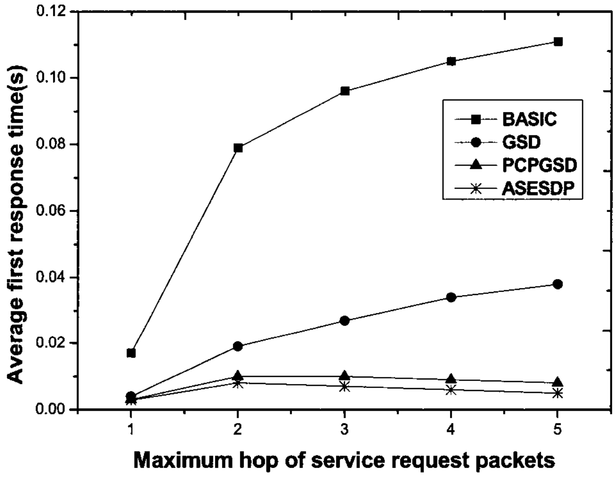
(a) Request maximum hop vs. request packet number



(b) Request maximum hop vs. reply request ratio



(c) Request maximum hop vs. succeeded SDP ratio



(d) Request maximum hop vs. average first response time

Fig.3 Influence of the maximum hop of service request packets

Fig.3(d) shows the effects of the maximum hop of service request packets on the average first response time. Even though ASESDP has the highest succeeded SDP ratio, it is still the most prompt protocol under different maximum hops of service request packets. It is due to that the SRR scheme forwards service reply packets more quickly, and hence saves the response time.

The experiment results reflect that the performances of ASESDP exceed those of BASIC、GSD and PCPGSD under different maximum hops of service request packets.

IV. CONCLUSIONS

In this paper, a novel service discovery protocol ASESDP is introduced. ASESDP is a group-based service discovery protocol, it carries parts of advertisement information of server node in the service reply packet to widen the transmission area of advertisement information. Because more nodes store the correlative service information of server node, and the shortest reply route is chosen to forward the service reply packet, the more quick reply can be received after the node sends a service request packet. By this way, ASESDP can reduce the number of service request packets, save the response time, and improve the efficiency of service discovery.

Mathematical analysis and simulation results both show that ASESDP is super over BASIC, GSD and PCPGSD in terms of service response time, packet overhead and service discovery efficiency. Therefore, it is certain that ASESDP is an efficient, prompt service discovery protocol for pervasive computing environments.

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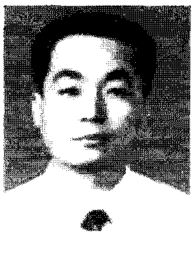

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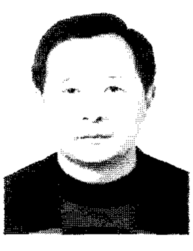

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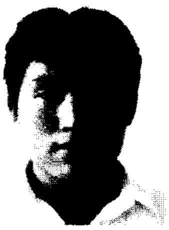

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