Service Discovery and Invocation for Mobile Ad Hoc Networked Appliances

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***Abstract* -- In this paper, we present a protocol for service discovery and invocation for the mobile ad hoc appliance network. To achieve lightweight service discovery and deal with appliance mobility, the bootstrapping mechanism in the push model and the query/reply mechanism in the pull model are invoked based on the on-demand multicast routing protocol. The service invocation is scalable to different appliances because multi-level mobile objects for multi-level services are used. This approach realizes small service footprint and flexible service employment considering the capability heterogeneity in the appliance network.**

I. INTRODUCTION

A. Mobile Ad Hoc Appliance Network

Technologies of wireless communication make wireless personal area networks available for home networks. Moreover, appliances integrated with miniaturized digital systems are becoming network-supported. Home networks in the near future will become mobile ad hoc in terms of network structure. In this paper, a home network is called a mobile ad hoc appliance network because it generally has two parts: an infrastructure-less mobile-appliance network, which includes mobile devices and sensors, and an infrastructured network, which connects with the PSTN (Public Switch Telephone Network) and the Internet. Fig. 1 shows the generic architecture of the mobile ad hoc appliance network.

The infrastructure-less mobile-appliance network is a dynamically reconfigurable wireless network with no fixed infrastructure due to the nomadism and mobility of the mobile appliances. It is therefore a mobile ad hoc network (MANET) [1]. Moreover, communication routes between the mobile appliances are often multihop because of their limited radio propagation range. All the networked appliances are assumed to support IP (Internet Protocol) stack.

B. Network Characteristics

Heterogeneity is the most important characteristic of the mobile ad hoc appliance network. In studying service discovery and invocation in such a network, two aspects of heterogeneity must be addressed.

One is the appliance resource heterogeneity. Different appliances, which have diverse processing powers, memory amounts, display-panel sizes, and power supplies, provide or utilize different services. For example, mobile appliances are likely to be constrained by low processing power and the memory capability.

The other heterogeneity is the communication link. Specifically, wireless links in the network generally have low and volatile bandwidth and large transmission

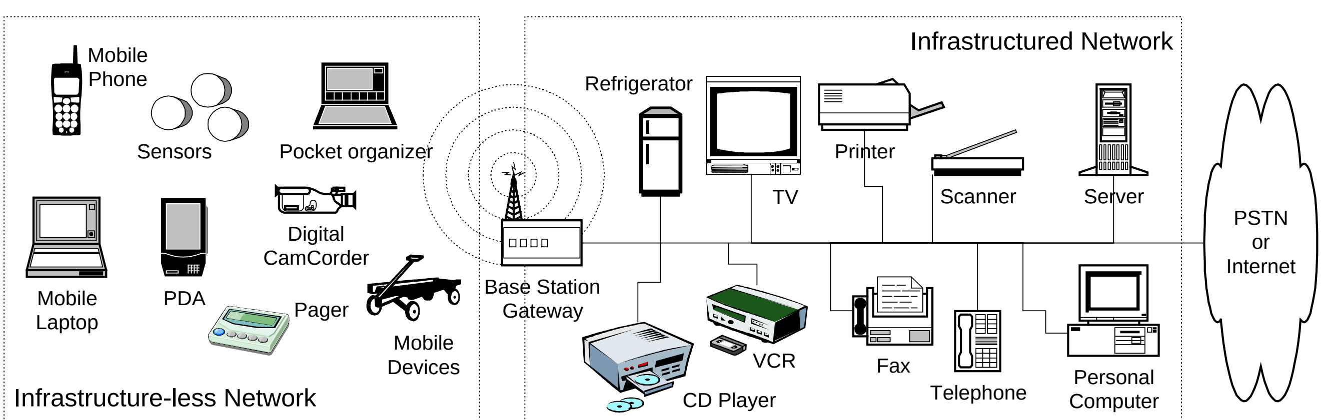

Figure 1: Generic architecture of a mobile ad hoc appliance network

latency. Because of dynamic channel sharing and fading, the available bandwidth of a wireless link changes frequently and abruptly, and it may be affected by cell handoff and blackout.

Generally the base station is the articulation point in the mobile ad hoc appliance network. It also functions as a gateway to bridge heterogeneities in the network. For example, it may cache the data and states of a client-server session when there are poor-quality wireless connections.

C. Objectives

Service discovery and invocation is an important issue in the implementation of a mobile ad hoc appliance network. It is challenging because of the above-mentioned network characteristics, such as the heterogeneities of the appliances and communication links, the mobility in the network, and so on.

We present a protocol for lightweight service discovery and scalable service invocation for mobile ad hoc networked appliances in this paper. Section II presents the protocol based on the on-demand multicast routing protocol. Section III discusses the protocol performance and related work. Section IV concludes the paper with a discussion of future work.

II. Service Discovery and Invocation

Service discovery and invocation address how appliances discover what types of services exist in the network, and how those appliances employ the discovered existing services.

Multicast is used for service discovery and invocation in the mobile ad hoc appliance network because of (*i*) the broadcast nature of wireless communication environment, (*ii*) the infrastructure-less feature of the mobile-appliance network, and (*iii*) the one-to-many character of service provision and consumption. Since multicast protocols are not as well established and supported in infrastructure-less networking environment as in infrastructured networks, we study multicast protocols for mobile ad hoc networks first.

A. Multicast for Mobile Ad Hoc Networks

Several multicast protocols have been proposed to support multicast in mobile ad hoc networks. A performance comparison study of ad hoc wireless multicast protocols in a realistic common simulation environment is reported in [2]. It provides quantitative performance analysis of five protocols with different characteristics: adhoc multicast routing (AMRoute) [3], on-demand multicast routing protocol (ODMRP) [4], ad hoc multicast routing protocol utilizing increasing id-numbers (AMRIS) [5], core-assisted mesh protocol (CAMP) [6], and flooding. Table 1 summarizes its main results.

Based on these results, in this paper, ODMRP is used for service discovery in the mobile ad hoc appliance network. Because service discovery schemes using traditional multicast protocols are commonplace in the infrastructured networks, we focus on the service discovery scheme using ODMRP in the mobile ad hoc network and its integration with the traditional scheme.

Table 1: Comparison of multicast protocol for MANET

Protocol Summary	**Quantitative Analysis Results**
AMRoute Tree configuration Not loop-free Dependent on unicast Periodic messaging Control packet flood	• Performs well under no mobility • Suffers from loops and inefficient trees even for low mobility
AMRIS Tree configuration Loop-free Not depend on unicast Periodic messaging Control packet flood	• Effective in a light traffic scenario with no mobility • Performance susceptible to traffic load and mobility
CAMP Mesh configuration Loop-free Dependent on unicast Periodic messaging No control packet flood	• Better performance when compared to tree protocols • With mobility, excessive control overhead causes congestion and collisions that degrade performance
Flood Mesh configuration Loop-free Not depend on unicast No periodic messaging No control packet flood	• Very effective and efficient in most simulation scenarios • Not scalable to large mobile ad hoc networks
ODMRP Mesh configuration Loop-free Not depend on unicast Periodic messaging Control packet flood	Very effective and efficient in most simulation scenarios.

B. Service Discovery

Based on the multicast protocol, both the push and pull models are used in service discovery for service mobility and network-resource saving. One approach is the bootstrapping mechanism in the push model. The other is the query/reply mechanism in the pull model.

1) Bootstrapping Mechanism in the Push Model

Every appliance that provides a service, which is called a server, multicasts an advertisement to the mobile ad hoc appliance network. Each server and its possible consumers make a multicast group. The advertisement includes the service name, the server's unicast address/port pair, and the protocol type that a client appliance should use to request the service. Table 2 illustrates the advertisement format. Table 3 shows the combination of an ODMRP *join query* packet header with the service advertisement.

Table 2: Format of service advertisement

1 byte	1 byte	1 byte	1byte
Type	Option Field	Time to Live	Service Port
Server Address (in unicast form)			
Service Name (ID)			
Protocol Type		Reserved	
Optional Fields			

Type:	0x01 as service advertisement.
Option Field:	0, no optional information 1, optional fields at the end
Time to Live:	Geographical scope the service covers in terms of the number of hops
Service Port:	The port number of the service point
Server Address:	The unicast IP address of the server
Service Name:	The index or the name of the service
Protocol Type:	The protocol type that the server and clients use
Reserved:	0, ignored on reception
Optional Fields:	Service description for multi-level services

Table 3: Format of revised ODMRP *Join Query* packet header

1 byte	1 byte	1 byte	1byte
Type	Reserved	Time to Live	Hop Count
Multicast Group IP Address for the Service			
Other Fields in ODMRP Join Query Packet Header			
Service Advertisement			

Reserved: Specifying whether a service advertisement is attached. Multicast Group IP Address for the Service: The IP address of the multicast group that consists the server and its possible consumers.

Table 4: Format of ODMRP *Join Reply* packet as a service awareness reply

1 byte 1 byte 1 byte 1byte

Type	Count	R	F	Reserved
Multicast Group IP Address for the Service				
Other Fields in ODMRP Join Reply Packet				
Sender IP Address (in unicast form)				
Other Fields in ODMRP Join Reply Packet				

Reserved: Specifying whether a packet is a service awareness reply. Multicast Group IP Address for the Service: The IP address of the multicast group that consists the server and its possible consumers.

Any appliance interested in this service stores the advertisement in its local service registry, and sends a service awareness reply, if it is appropriate. A *join reply* packet is used without any attachment because it already provides sufficient information as a service awareness reply. Table 4 highlights the necessary fields in the *join reply* packet as a service awareness reply.

Once some clients send back service awareness replies, the server sends its updated service advertisements by piggyback in ODMRP *join query* packets. Otherwise it will wait for explicit queries from clients and reply back in the pull model, which is illustrated in the following section.

As the articulating point of the mobile ad hoc appliance network, the base station gateway translates service advertisements between multicast domains in infrastructure-less and infrastructured networks. Moreover, it supports the query/reply mechanism, i.e., replying to a service query of whether or not it has the service advertisement in its local service registry. Note that the base station may not have overall information of all existing services in the mobile ad hoc appliance network because the geographical coverage of a service can be controlled by the field of *Time to Live* in the service advertisement.

2) Query/Reply Mechanism in the Pull Model

We assume that services have well-known service names, such as "printing" or "address book", and corresponding unique service IDs.

Once an appliance needs a service, it first gets the service ID and then sends a query to a well-known multicast address, which corresponds to the service query multicast group, asking about the existence of the service. The service query multicast group consists of servers and devices that support the service query/reply mechanism, such as the base station gateway.

The format of the service query message is the same as that of the service advertisement, which is illustrated in Table 2. However, the content is different: (*i*) the *Type* field is set to 0x02 as service query, (ii) the *Option* field is 0, and (*iii*) the *Service Name* is the service ID of the queried service. Since it is also piggybacked in an ODMRP join query packet, correspondingly, the *Reserved* field in Table 3 specifies whether a service query is attached. Moreover the *Multicast Group IP Address* field is set to the well-known multicast address for service queries.

The format of the reply message for a service query is also the same as that of the service advertisement illustrated in Table 2. When an appliance receives a service query, if it supports the service query/reply mechanism, it waits for a random time to check whether there is already a reply message with latest information that has been issued by a device. If affirmative, it ignores the service query message. Otherwise, it fills in the blank fields such as *Time to Live*, *Server Address*, *Service Port*, *Protocol Type*, and/or the *Option Field(s)*, if such information is available locally, and sends the reply message. The server always replies to the service query message with the updated service information.

C. Service Invocation

Based on the discovered service information such as the server address/port pair, the protocol type to communicate between the server and clients, and the multicast route setup by ODMRP, a connection may be established between the server and client appliances. Then the successfulness of the service depends on the flexibility of its service invocation. In this paper, the concept of multi-level mobile objects for multi-level services is introduced to realize the flexibility of service employment.

1) Mobile Object

In our service invocation scheme, mobile objects are used to achieve lightweight service invocation because the original service object, such as a printer driver or a camcorder real-player, resides on the server appliance and may be invoked remotely or migrated to the client appliance by request.

A mobile object is defined as an object communicating between two applications. The object is not required to be autonomous. It normally does not have its own threads and is not capable of moving itself autonomously between processes. Moreover, no semantic information is exchanged regarding the capabilities of mobile objects with the exception of their interfaces. This makes them flexible for implementation. Mobile objects incorporate both code, which may be loaded using a *ClassLoader*, and state, which may be externalized, e.g. by using Java object serialization. Both are required elements to represent a mobile object.

2) Multi-level Mobile Objects

The uniqueness of our scheme is the use of multi-level mobile objects for multi-level service invocations. It is useful if a server appliance offers multiple versions of a service in an ascending order of complexity. A client appliance could then be served the most powerful version of the service that it understood.

III. DISCUSSIONS

A. Protocol Performance

The service discovery protocol is lightweight because it is based on ODMRP, and its service discovery information is piggybacked in the routing control packets. Therefore the implementation workload and resource consumption is lightweight once the mobile appliances support multicast routing functionality in the mobile ad hoc appliance network.

Moreover this implementation avoids excessive traffic overhead of periodic advertisement since only updated service advertisements are distributed and the service query/reply mechanism in the pull model is used. Furthermore the pull model deals with mobility in the network because the advertised and registered service can be obsolete after a certain period of time due to the mobility of either the server or client appliances.

The service invocations are scalable to different appliances because multi-level mobile objects for different services can be used. Note that even without unicast support in the mobile ad hoc network, services still can be invoked by multicasting the mobile objects via the ODMRP mesh routes established in the service discovery phase. In this case, service security becomes more complicated because all members of the service multicast group get a copy of the mobile object.

B. Related Work

There have been a number of research efforts on the service discovery and invocation in recent years. For example, both Bluetooth [7] and IrDA [8] offer their proprietary service discovery protocols as parts of their protocol stacks. Jini [9] network technology and UPnP

(Universal Plug and Play) are promoted by industrial companies such as Sun Microsystems, Inc. and Microsoft Corporation. SLP (Service Location Protocol) [10] provides a scalable framework for the discovery and selection of network services to serve enterprise networks with shared services. However, as mentioned in [11], they are not suitable for working in the mobile ad hoc networking environment.

In [11], a two-stage resource discovery protocol for mobile ad hoc networks is proposed. However, details such as packet format for service discovery are not provided.

Our research is distinguished from the previous work in three aspects. First, the push and pull models are used in service discovery, based on the on-demand multicast routing protocol for appliance mobility and network-resource saving, in mobile ad hoc appliance networks. Second, mobile objects are used for service invocation to achieve service mobility and small service-footprint. Third, the concept of multi-level mobile objects for multi-level services is introduced to realize flexibility of service employment, considering the capability heterogeneity existing in the appliance network.

IV. Conclusions and Future Work

Home networks in the near future will become mobile ad hoc appliance networks because of the development of wireless technology and miniaturization of digital systems. Heterogeneity in such networks makes the implementation of service discovery and invocation a challenging problem.

In this paper, we presented a protocol for service discovery and invocation for the mobile ad hoc appliance network. To achieve lightweight service discovery, the bootstrapping mechanism in the push model and the query/reply mechanism in the pull model are designed based on the on-demand multicast routing protocol. The service invocation is scalable to different appliances because multi-level mobile objects for different services can be used.

Our future work includes: (*i*) extending the existing implementation [12] of service discovery and invocation in infrastructured heterogeneous networks to mobile ad hoc appliance networks, and (*ii*) quantitatively studying the performance of the presented protocol.

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References

[1] S. Corson and J. Macker, “Mobile ad hoc networking (MANET): routing protocol performance issues and evaluation considerations,” *RFC (Request for Comments) 2501*, January 1999.

[2] S. Lee, W. Su, J. Hsu, M. Gerla, and R. Bagrodia, “A performance comparison study of ad hoc wireless multicast protocols,” *Proc. IEEE Infocom’2000*, pp. 565-574, Tel-Aviv, Israel, March 2000.

[3] E. Bommaiah, M. Liu, A. McAuley, and R. Talpade, “AMRoute: ad-hoc multicast routing protocol,” *Internet Draft*, work in progress, August 1998.

[4] S. Lee, M. Gerla, and C. Toh, “On-demand multicast routing protocol (ODMRP) for ad hoc networks,” *Internet Draft*, work in progress, June 1999.

[5] C. Wu, Y. Tay, and C. Toh, “Ad hoc multicast routing protocol utilizing increasing id-numbers (AMRIS) functional specification,” *Internet Draft*, work in progress, November 1998.

[6] J. Garcia-Luna-Aceves and E. Madruga, “The core-assisted mesh protocol,” *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, pp. 13801394, August 1999.

[7] The Official Bluetooth SIG (Special Interest Group) Website, http://www.bluetooth.com/

[8] IrDA Specifications, http://www.irda.org/standards/specifications.asp

[9] Jini Network Technology, http://www.sun.com/jini/

[10] J. Veizades, E. Guttman, C. Perkins, and S. Kaplan, “Service location protocol,” *RFC (Request for Comments) 2165*, June 1997.

[11] D. Tang, C. Chang, K. Tanaka, and M. Baker, “Resource discovery in ad hoc networks,” *Technical Report CSL-TR-98-769*, Stanford University, August 1998.

[12] L. Cheng and I. Marsic, “Hybrid cluster computing with mobile objects,” *Proc. of Fourth International Conference on High-Performance Computing in the Asia-Pacific Region*, pp. 909-914, Beijing, China, May 2000.