

Mobile Agent Paradigm in Computer Networks

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ABSTRACT :

Mobile agent technology has recently emerged as one of the most promising paradigms in computer networks and in the Internet. Mobile agent paradigm has a wide potential for use in programming languages design and implementation, decision support and expert systems, management, in fact almost anywhere where there is a need for adaptive entities, with high degree of flexibility and dynamism.

In the paper, we give an overview on the current state of affairs in the proliferation of the mobile agent paradigm in studying and modeling computer networks and point to few directions in the research that show a fairly large promise. The work posits our affirmative view of this novel field in computer networks and it evaluates its overall impact on the networks and the future of the Internet.

I. INTRODUCTION

The concept of agent comes from Artificial Intelligence and Distributed Artificial Intelligence where it is abstract of robot idea. Until now, there is no universal definition on what agent is. However, these definitions reached to the consensus based on main feature of agent that agent is pieces of code that can act autonomously on behalf of its owner and other entities. Mobile agent is agent with ability to freely migrate between locations across networks. Therefore, mobile agent is combination of two distinct concepts: mobility and agent. The main idea of mobility in mobile agent is move of self-contained program near to data source. This migration results significant reduction of traffic transmission over network.

Generally, mobile agent can be defined as a self-standing software segment, possibly written in a script language, and with a varying degree of autonomy. It can freely migrate across a network to perform tasks on behalf of many actors in the network system, such as other agents or moreover users.

There exist many different arguments about the advantage and disadvantage of mobile agent technology. However, the advantage of mobile agent over client-server model in applications of distributed system can not deny although the client-server model has been dominant in networks, including distributed systems for many years. Indeed, the basic functionality of client-server model relies on the necessary data transmission between a client and a server. Unfortunately, this sometimes leads to too much network traffic being generated even in the case of simple transactions. For instance, when the bandwidth is low then there is a possibility that network congestion will occur. Naturally, things might be improved in some situations, if one infuses a kind of equity between the client and the server, which leads to peer-to-peer approach.

Today, networks have been expanding almost anywhere. The complexity of networks also is increasing in terms of the functionalities, services and number of users than a couple of decades ago. It leads to huge challenges on network technology, particularly when vast amounts of data

must transport across the network with a high level of users' diversity demands on the provision of services, the quality of services, reliability and security.

To face with these challenges in the dynamic, open, distributed and heterogeneous network environments, mobile agent is now considered as suitable emerging technology for network applications due to its capacity on scalability, independence from hardware and software and only dependence on execution environment.

In the paper, we will examine highlight advantages of mobile agent paradigm in part two. An overview on the current state in the development of this paradigm will be represented in part three. Few directions in the research that show potential domains for applications using mobile agent and its overall impact on networks and the future of the Internet also are exposed in both parts three and four. This certainly includes, but is not limited to network and resource management, routing, congestion control, Quality of Service (QoS), fault tolerance, and security.

II. MOBILE AGENT PARADIGM

Despite some setbacks and yet unexplored territories, the research clearly indicates many advantages of mobile agent paradigm. The renowned IBM report lists them in seven categories [1]. Sundsted also showed in [2,3] three reasons to adopt mobile agent architecture. Here, we only want to emphasize outstanding advantages of mobile agent paradigm in communication networks.

Today, we are using communication model "client-server" with remote procedure call approach (RPC). In this model, usually, client and server are separate computers. They communicate each other over the network by sending and receiving messages that are either requests from clients or responses from server. The responses often contain a large volume of data that are the result for requests. In this approach, only with simple request e.g. to delete n files that are older than two months from server, client must send or receive $2(n+1)$ messages. It means that number of interactions over network is very large. Further RPC between clients and servers require ongoing communication. Hence, network bandwidth and connectivity will become a problem. Especially, it can become critical limitation in mobile computing networks, wireless networks or low-bandwidth networks where devices are often disconnected from network.

New alternative approach is Remote Programming (RP). RP allows a client to send a subprogram to a server. The subprogram executes on the server and sends the result back to the client. Mobile agents generalize RP to allow arbitrary code movement. In mobile agent paradigm, agents will migrate freely from this host to another host over the network and bring with it not only data but also segments of code or programs. These programs will be called to execute on hosts when agents visit. It results calls from client will become local rather than remote for procedures running in server. Therefore, number of traffic transporting over the network will reduce significantly.

The key difference between client-server paradigm and mobile agent is in mobile agent approach client talks server at the local place rather than over network. Mobility of mobile agent helps client machine can migrate to server by transporting codes from client to server. Client then can make the requests directly to server. By using mobile agent, clients and servers can exchange interactions each other without using network. It leads to the performance advantage of mobile agent. These advantages can be throughput, network bandwidth, availability, network utilization, completion time, convenience, latency, easy to implement, and cost.

In addition, connectivity between client and server needs only long enough in order to mobile agent with assigned duties can move to the server and later, comes back its home to return the

completed results to its owner. Computer does not need to be connected while agent implements its duties. It means that mobile agent does not require ongoing communication so it can solve the problems caused by low-bandwidth, unreliable network connections as well as it can overcome the limitations in RPC approach of client-server model as mentioned above. This is also one advantage of mobile agent that is exploited based on mobile agent's mobility when running asynchronous interactions.

In summary, mobile agent reduces significantly network traffic and communication delays due to no need to transfer amount of intermediate data over the network. Hence network bandwidth is used more effectively. Further, with autonomous character of agent, mobile agent can obtain greater degree of flexibility when it carries duties to execute at nodes that it visits. Mobile agent can decide by itself where it will go and what it will do. This is very useful, especially in distributed applications because developers do not need to define exactly all necessary requirements or role of client and server in design time.

Developing, testing and deploying distributed applications are easy by using mobile agent technology because they hide the communication channels but not the location of computation [4]. Detecting and handling network failure only need during mobile agents migrate. Therefore, unlike applications developed on client-server model, applications based on mobile agent paradigm can continue to carry out even when computer of agent owner is disconnected from network. Besides, application software does not need to preinstall but they can dynamically distribute over the network. Since limitation of client-server model and advantages of mobile agent in communication model, mobile agent give chances so that developers can approach to flexible peer-peer model where clients and servers communicate as peers and their roles can exchange depending on current requirements.

In addition, applications that use mobile agent will be more scalable because mobility of mobile agent results agent to move to suitable location in network. The ability of mobile agent that can well adapt to real-time modifications in heterogeneous environment also bring to advantages of mobile agent because heterogeneity is typical character of communication networks today.

III. CURRENT SITUATION OF MOBILE AGENT DEVELOPMENT

There are two main communities researching on agent called intelligent agent and multi agent system community and mobile agent community. The first one deals with less or more static agents that rely on co-operation, co-ordination and intelligence of agents. The second one concentrates the research on exploiting and applying mobility of agent to different application areas. There are two kind of mobility called strong mobility and weak mobility. With strong mobility, the entire agent state that consists of data state and execution state are transferred together with the code to the new location. When agent arrives to its new location, its state is automatically restored. While weak mobility migrate only data state. There are many common features between mobile agent migration and process migration. They are reduction of network traffic, load balancing, fault resilience, asynchronous interaction and data access locality. However, mobile agent does not have similar transparency requirements. It leads to the implementation of mobile agent systems and their applications are much simpler. Further, applications can be more easily modeled with mobile agent than with client-server model.

Recent years, mobile agents have been developed very fast and they attract many attentions of researchers in academia and industry. As natural consequence, a large number of mobile agent systems, both in academia and industry, were developed. Some of the best known are: Telescript, Aglet, Voyager, Concordia, Agent Tcl, TACOMA and MOA. In [5], authors give an overview of these systems.

Generally, each mobile agent system has private characters. For example, they can be either strong mobility or weak mobility. However common requirements of these systems on infrastructure are they need to provide the functions for the agents to migrate from one location to another, to communicate with each other and to interact with the hosts in network. Infrastructure must guarantee privacy and integrity for agents and the underlying computer system. Infrastructure also needs to have ability to prevent malicious agents attacking other agents or the computer systems, and vice versa agents need to be protected against a potential malicious system when visiting them.

Despite existing many mobile agent systems have been developed in academic environment well as industry but none of them has been successful in productizing agent system or widely deploying agent applications. There are potential capacities in mobile agent applications but only few have merged in practice. Until now, the mobile agent paradigm is none or very few indications for a “killer” application based on the mobile agent approach. Basically, while mobile agent systems can substantially improve occasionally the system performance, most of the applications can be implemented efficiently by using traditional techniques also. In addition, environment where mobile agent can be accepted and executed still is not ready in order to mobile agent applications can be exploited widely in the real world such as in computer networks or in the Internet of today.

There are many applications developed based on different mobile agent systems using programming language Java or script language such as Tcl. Problem is how applications that are developed on this mobile agent system can run and interact transparently with other systems. Different mobile agent systems have different characteristics but almost mobile agent systems allow an agent to freely migrate in heterogeneous networks. However, to use widely mobile agents, agent’s code must be contingent upon the portability of the code across different mobile agent mechanisms that require a huge standardization effort. OMG MASIF is considered as the first standard mobile agent system. Now, there are various standardization efforts for mobile agent systems from the organizations such as the Agent Society [6], FIPA [7], the Object Management Group [8] and GMD FOKUS and IBM Corp. [9].

One other important major issue need the concern is security due to the existence of many open and unresolved problems. For example, the infrastructure of mobile agent systems, in principle, lacks the ability to protect an agent from potentially malicious system when visited by agents. However, security is very hard to achieve for mobile agent system due to security technique is insufficient to support mobile agent. In protection of mobile agent systems, to protect agents from malicious hosts is a problem that is not yet solved. There are four proposed directions to solve this problem. Currently, all of them are not applied yet to applications in real world due to only ongoing works. The organizational approach eliminates problems by allowing only trustworthy institutions to run mobile agent systems. The trust/reputation approach allows agents to move only to trusted hosts or good reputation. The manipulation approach offers mechanisms to detect manipulation of agent data or the execution of code but without protection from read attacks. The black box protection approach generates black box code out of agent code based on code obfuscating techniques. Agents are protected for certain time interval. After expiration of this interval, agent and data become invalid.

IV. MOBILE AGENT APPLICATIONS

Applications of mobile agents mainly focus on exploring two goals: reduction of network traffic and asynchronous interaction. There exist applications using mobile agent paradigm on different areas. In this part we will describe some application of mobile agent in communication networks, particular in network management, e-commerce, resource management, routing and fault tolerant.

Mobile agent is convenient and effective paradigm for distributed applications, particularly for partially connected computing where devices are often disconnected from network, have low-bandwidth and unreliable connections and frequently change their address for each reconnection. One mobile agent system developed by Dartmouth College is Agent Tcl [10]. In this system, mobile agents can transparently migrate among mobile computers or between mobile computers and permanently connected computers. Hence, any mobile agent can carry out its pre-assigned duties on network hosts regardless of when mobile computer connect to the network.

One of applications based on Agent Tcl is to gather and retrieve information for its user. Retrieval information can be distributed collections of technical reports, medical records or mechanical drawings. This application is very useful, especially for networks with low bandwidth connection or networks where hosts are often disconnected to the network. In these networks, mobile agent can move to necessary information sources in Internet, access and filter them to obtain result data rather than transferring multiple requests and responses over the network. Since mobile agent is not affected by loss of connection, it can continue its tasks when computer is disconnected from network. When this computer is reconnected again, mobile agent can return with its result. It leads to applications can continue running even computer on the network is disconnected for long time.

Other application of Agent Tcl is workflow. In this application, mobile agent carries the description of multi-step task from host to host, interacting with each user in order to complete a part of task at this site [11].

In network management, mobile agents are used to implement duties of network management by delegation and to deliver tasks. Mobile agents gather the information from the network elements, execute the required computations, and transfer only the result information to the network manager. Mobile agents with different functions are created and can communicate each other to execute tasks of network management. For example, mobile agent can be used to decentralize network management activities. They can autonomously carry out some daily duties of network administrator such as install and upgrade software and periodically monitor the networks, e.g. mobile agent can bring the software to perform the installation onto different computers in the network. In addition, due to using mobile agent, the network management policies can change and adapt quickly to the changes of today dynamic network environment. Hence, mobile agents can support for the provision better the services and performance in network management.

Mobile agent can be used to distribute code to SNMP agent. At each managed device, mobile agent interact with SNMP agent and gather necessary information instead of management station frequently sends requests to SNMP agents and waits to receive responses from SNMP agents. Mobile agents with the code and data will migrate to managed entities and perform predefined management tasks along with pre-assigned travel. Using mobile agent can avoid the transportation of a large amount of data over the network, reduce bottleneck and network traffic across the network. Therefore, mobile agent approach helps network management to overcome technical limitations of centralized management using Simple Network Management Protocol (SNMP) such as scalability, reliability, performance degradation, and difficulties in delegation since networks are expanding and become more distributed [12]

Other application of mobile agent in network management is network monitoring. In this application, mobile agents will visit network nodes, interacts with network monitor at each network node to obtain local recent status information. In the same time, network monitor also will update its database with new status information that mobile agent bring from the rest of network. By this way, no extra messages are generated due to the cooperation of network monitors. Mobile agents can optimal locally the distribution of network status information in the situations where bandwidth is limited or network is congested. By using mobile agent, the

limitations caused by centralized network monitoring when monitored network is large or low-bandwidth can be eliminated [13].

In electronic commerce, mobile agents can roam on the Internet, search electronic catalogs to find the products with best prices that meet the customer's need, chose products and vendors, interact with billing, inventory, and shipping agents, arrange and negotiate the purchase on behalf of owner. Mobile agent can carry out these duties even while owner's computer is disconnected from network. When owner's computer is reconnected, all agents will return home with results so connectivity need only few seconds.

In resource management, mobile agents are used to provide flexible resource management. Service policies are implemented based on current requirements rather than policies that are embedded in the network elements. Mobile agents also are used to re-act to events behaviors in the network, modify dynamically route and redistribute resources.

In routing, mobile agent are used to discover and maintain routes in networks. Most of routing models proposed are based on the biological imitation of ants when they find the routes. In these models, mobile agents work as ants roaming the network to discover routes and update the routing tables in the various network components. Mobile agent seems to be very suitable in routing and has performed this duty effectively.

In fault tolerant and secure networks, mobile agent are used to check the state of the network due to their mobility. When mobile agent detects fault it can restart back from previous state due to the capacity of mobile agent in storing its execution state. Therefore mobile agents have been considered as means to promote fault tolerant and secure networks.

V. CONCLUSIONS

In this paper, we gave an overview on current situations of mobile agent paradigm, hence to present overall picture about what is mobile agent paradigm in computer network; how mobile agent technique has applied in computer network and its applications, especially in fields network management, resource management, routing, fault tolerant and security. In addition, we also pointed out some unresolved problems, the challenges as well as the directions of current researches. Applications using mobile agents technology in network communication showed that mobile agent can improve significantly network performance and are very useful for distributed applications. Ability of mobile agent paradigm also indicates that technical limitations of client-server model as well as user diversity requirements on service in dynamic, distributed open network environment can be solved rather easy. One thing might be that complex and global systems, such as networks are, require often a multi-paradigm approach, and mobile agent paradigm is certainly one of them. We also believe that mobile agent will become main paradigm for next generation of distribution system although now the availability of mobile agent environment still is one of obstacle so that technology of mobile agent can be deployed widely. However, we do not argue that mobile agent can solve any problem. Complex problems are rarely solved with single technique so they should be divided into sub-problems. Depending on the appropriateness of each sub-problem that it can be solved by either mobile agent paradigm or client-server paradigm, but frequently is a combination of both paradigms. In here, mobility of mobile agent often is used to reduce network traffic in the cases where there are series of client-server transactions

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