Mobile Agents for Routing, Topology Discovery, and Automatic Network Reconfiguration in Ad-Hoc Networks

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ABSTRACT

Wireless networks and the usage of mobile devices are becoming popular in recent days, especially in creating ad-hoc networks. There is thus scope for developing mobile systems, where devices take an active part of creating a network infrastructure, and can actually be used to route data between networks. This research proposes to assess different models of the usage of static and mobile agents to determine the best route through ad-hoc networks. The determination of this route is a complex one, and requires research into the best metrics to identify the best path, such as memory capacity, network performance, processing capabilities, cost, and so on. One model is to use a mixture of mobile and static agents to gather relevant information. These agents could perform important tests, which could be used to generate the best route through a network. This research looks at different models for the deployment of these agents, which balance the usage of static and mobile agents. These are appraised in the terms of performance, reconfigurability, and easy of installation.

Keywords: mobile agents, stationary agents, wireless networks, ad-hoc networks, routing protocols, topology discovery, automatic network reconfiguration

1 Introduction

In the last few years, the widespread use of wireless communications has begun. The technology has existed for more than 20 years and has been commercially available for more than 10 years [1]. Currently, there is an increasing interest in wireless communications from both an academic and industrial perspective. The main feature that makes wireless networking so important is the ability to enable mobility. At present, many people carry numerous portable devices, such as laptops, mobile phones, PDAs, and MP3 players, for their professional and private lives [2]. The great benefit of wireless networks is concentrated in the ability of users to communicate, cooperate, and access Internet services in an anytime and anywhere fashion.

Wireless networks can be grouped into two categories: infrastructured networks; and infrastructured-less networks [3]. The first type is a network with fixed and wired gateways. The gateways for these networks are known as access points. A mobile unit within these networks connects to, and communicates with, the nearest access point that is within its communication radius. The second type is commonly known as wireless ad-hoc networks and consists of a collection of geographically distributed nodes that communicate with one another over a wireless medium without the need of fixed routers [4]. Thus, each node could be used as a mobile router, equipped with a wireless transmitter/receiver, which is free to move around in an arbitrary fashion [5]. Initially the motivation for ad-hoc networks was based on military applications. While military applications still dominate a great part of research in this field, the recent rapid development of mobile communications brought about a number of commercial applications of ad-hoc networks. Such examples as described in [6] include disaster relief, conferencing, sensor networks, personal area networks, and embedded computing applications.

Another important area of research is the mobile agent paradigm that has been proposed as a promising solution for distributed computing over open and heterogeneous networks [7].

A mobile agent can be defined as a software program that can suspend its execution on a host computer, transfer itself to another agent-enabled host on the network, and resume its execution on the new host [8]. The key features of mobile agents that distinguish them from traditional distributed programming are: mobility; network awareness; communication; intelligence; reactivity; autonomous; goal-oriented; temporally continuous; learning; flexible; and character [9, 10]. Mobile agent technology has been proposed for a number of applications such as Internet-wide collaborative systems [11], network management [12], monitoring systems [13], information retrieval [14], intrusion detection systems [15], and e-commerce [16]. A new potential application of mobile agents is in mobile computing environments, and, especially, in wireless networks. Mobile agents are ideal for such environments because of their ability to support asynchronous communication and flexible query processing. This is because user tasks can be delegated to mobile agents, when a mobile client is disconnected [17]. Also, as shown in [18], in certain cases, mobile agents can reduce network traffic compared to the traditional client-server approaches and maintain load balancing, thus increase performance of network nodes especially in wireless ad-hoc networks. In this paper we

propose a novel application of mobile agents and ad-hoc networks in terms of routing, topology discovery, and automatic network reconfiguration, with a focus on performance and security.

In this paper, Section 2 presents a background to mobile agents and ad-hoc networks. Section 3 presents applications of mobile agents in ad-hoc routing. The highlight is on similar research in this field and to properly define the research idea and possible benefits. Section 4 defines a generic model in terms of network bandwidth, power limitation of mobile devices, problems of TCP over wireless networks, environment, and security. Section 5 defines planned experiments that will be used in order to prove or disprove our hypothesis, and Section 6 summarizes the paper.

2. Background

The mobile agent concept is not new, and has been proposed to overcome certain limitations of traditionally designed distributed systems, especially client/server systems, and provide better flexibility by adding mobility of code, artificial intelligence, and improve data and network management possibilities [19]. According to the definition given in [8], a mobile agent is a program that can migrate from host to host in a network of heterogeneous computer systems and fulfill a task specified by its owner. Thus, a mobile agent is an autonomous entity that has the ability to communicate with other agents and host systems. A mobile agent consists of its code and state, which carries with it during the self-initiated migration.

Mobile agent systems provide an environment in which mobile agents can exist. This environment is called agent server, which hides the vendor specific aspects of its host platform and offers standardized services to an agent that is docking on to such a server. Services include access to local resources and applications, communication with other agents via message passing, migration, basic security services, creation and termination of agents. The infrastructure is set agent servers that run on top of platforms (nodes) within a possibly heterogeneous network (Figure 1). The platform that an agent originates is called home platform and is assumed as a trusted environment for that agent.

Some well-known mobile agent systems are: MOLE [20], Telescript [21], Aglets Workbench [22], ffMAIN [23], and D'Agents [24]. Despite the fact that these systems were built to serve the same purpose, they have many differences in terms of terminology, concepts, and architecture. Some of these systems were developed in academic environments and others were developed by the industry. Nevertheless, some of these systems have already disappeared (such as Telescript, Kafta, or Odyssey), others will disappear, while others should emerge in a near future [25].

The research on mobile agents has forked from intelligent agents in 1996 [10]. An intelligent agent and a mobile agent share common characteristics, with basic difference that the former is restricted to a particular environment, whereas the later can roam a network of heterogeneous computer systems by initiating a migration on its own. Research on this topic is mainly concentrated on: security, interoperability (FIPA and MASIF standards), and mobility.

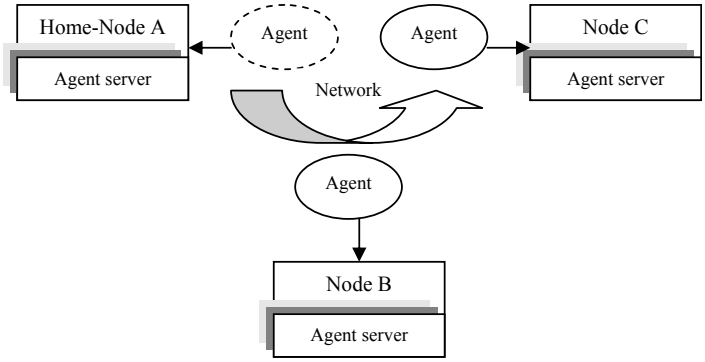

Figure 1: Mobile agent system

2.2 Wireless ad-hoc networks

An ad-hoc network is a multi-hop wireless network in which mobile hosts (MHs) communicate without the support of a wired backbone, HA/FA or BS for routing messages and location management [26]. Multi-hop communication between two mobile nodes within an ad-hoc network takes place when these nodes are not in direct radio range, with other nodes acting as routers [27]. Thus, an ad-hoc network has no fixed infrastructure where each mobile host can act as a router and moves in an arbitrary manner. Such networks have been proposed as the networking solution for those situations where the network set-up time is a major constraint and/or a networking infrastructure is either not available or not desirable [28]. An example of such a network is illustrated in the Figure 2.

In an ad-hoc network, the most important function is routing. However, routing can be considered as a challenging issue. The first reason is that routers in such a network are mobile, since mobile hosts perform the routing process. The second reason is that routing requires processing power that mobile hosts running on batteries may not be able to provide. Furthermore, due to the nature of mobility, a route that can be consider as good now, may break or not be optimal some time later. Therefore, a lot of research in the field of ad-hoc networks has been concentrated on how to design and implement efficient routing protocols.

Applications of ad-hoc networking can be found in our everyday lives where some of them can be considered as vital. Maybe the most important one is in military or rescue operations. Another application is people in meetings that want to share information quickly. Furthermore, the vision of ad-hoc networking includes scenarios where people carry devices that can

network on an ad-hoc basis. For example in an airport scenario, a user's devices can both interconnect with one another and connect to local information points – for example, to retrieve updates on flight departures, gate changes, and so on [2]. Nevertheless, in order to reach that level certain obstacles must be solved.

2.3 Routing protocols in ad-hoc networks

One of the most important research areas within wireless communication is low-power design [29]. Up to now, power conversation has typically been considered at the physical level. However, most of the energy savings at the physical level have already been achieved. Therefore, the key to energy conversation in wireless communications lies within the higher levels of the wireless protocol. As a result, the issue of routing is a crucial component of the solution to the problem of providing high-quality communication in mobile wireless networks. Ramanathan [30] presents a review of routing techniques in mobile communication networks that are already available as well as open research issues.

Various routing schemes have been proposed for ad-hoc networks [31]. Two common ones are:

- **Location-Aided Routing** (LAR). LAR [32] uses location information obtained from the Global Position System (GPS) [33] to limit the propagation region of Route Requests.
- **Distance Routing Effect Algorithm for Mobility** (DREAM). DREAM is different from LAR in that it performs routing table updates periodically. The routing table or location table contains the coordinates for every destination in the network. Location information exchange is done on a periodic basis.

Both of these schemes make use of location information of mobile nodes to improve routing protocol performance.

2.4 TCP and UDP over a Wireless LAN

TCP is a reliable transport protocol tuned to perform well in traditional networks, where congestion is the primary cause of packet loss [34]. However, in the case of wireless networks where host are mobile, significant losses may incur due to bit-errors and hand-off. Such an environment violates basic assumptions made by TCP, resulting to delegated end-to-end performance. A good deal of research has been carried out in order to improve TCP/IP performance over wireless networks. Key areas include improvements on end-to-end reliable transport performance and low latency handoff with negligible data loss. A case study that investigates problems with TCP and UDP performance over wireless networks can be found in [35]. Also, the authors propose a set of improvements and discuss the effectiveness of their scheme.

3. Application of Mobile Agent Paradigm in Ad-Hoc Routing

Mobile agents have the ability to support asynchronous communication and flexible query processing. Therefore, the mobile user can assign a task to a mobile agent and when the agent feels that there is communication availability it will roam the network and fulfill the task delegated by its user. In this way, a mobile node requires less communication connectivity than it would need following traditional client/server approaches. Another equally important reason for mobile agents in wireless networks is that they can reduce network traffic. As discussed earlier, mobile nodes running on battery power do not have enough power to run complex routing protocols necessary in ad-hoc networks. An alternative is to use mobile agents to perform routing operations and thus reduce complexity and network traffic. Therefore, saving important battery life of mobile computers.

The research proposes to access different models of the usage of static and mobile agents to determine the best route through ad-hoc networks. The idea is based on the fact that in each mobile node there will be a static agent that will run on the background monitoring available resources such as **connection availability**, **processing power**, **memory capacity**, **cost**, and so on. In addition to static agents, mobile agents will be independently roaming the ad-hoc network gathering information from static agents. Then they will use the information gathered to perform necessary calculations in order to determine the best path for routing network traffic.

Based on this scenario we will use two simplified examples in order to demonstrate our idea. Consider the case illustrated in Figure 2 where A, B, and C are mobile nodes and belong to wireless networks WN_A, WN_B, and WN_C respectively. Suppose that WN_A intercepts (•) with WN_B and that WN_B intercepts (•) with WN_C. Therefore, A can see B as a neighbourhood node and vice-versa, and B can see C as a neighbourhood node and vice-versa. However, A cannot see C and vice-versa because they are not in range, and cannot see any other node that belongs to a network that does not intercept with its own. Our intention is to use a mixture of static and mobile agents to discover network topology in any ad-hoc network and thus create a location map that will be self-organized as mobile terminals move. The updates will be performed in a periodic basis. An important research question arising at this point is the following. Can we define and implement a model that will perform the functions described above in an effective and efficient way?

An extension to the above example is presented here and illustrated in Figure 3. Consider the case where A, B, C, D, and E are mobile nodes and belong to wireless networks WN_A, WN_B, WN_C, WN_D, WN_E, and WN_F respectively. Suppose that WN_A•WN_B, WN_B•WN_C, WN_A•

WN_D, WN_D•WN_E, WN_E•WN_F, and WN_E•WN_F. In case that mobile node B wants to communicate with mobile node E, it can chose to pass network traffic through node A or node C since WN_B that the mobile node B belongs to; intercepts with WN_A and WN_C. A decision should be based on various parameters such as the available processing power of mobile node C and D, memory capacity, and so on. Unfortunately, without a certain countermeasure node B would decide to pass network traffic to a randomly selected adjacent node. This can decrease scalability, availability, and performance. Can a mixture of static and mobile agents be used to determine the best route to ad-hoc networks? Can this model increase performance and reconfigurability by eliminating the probability of errors?

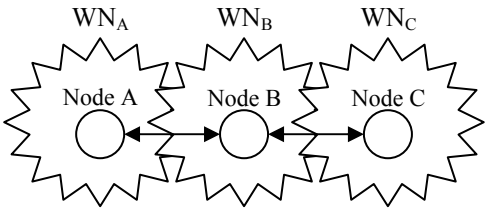

Figure 2: Discovering Network Neighbourhood

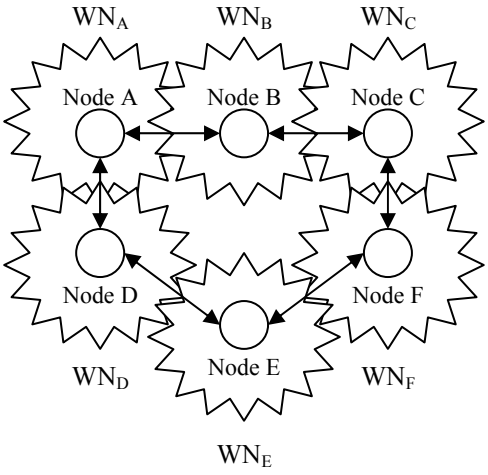

Figure 3: Passing network traffic to adjacent WNs

In wireless networks, due to inherent mobility of nodes, problems may arise when a mobile node decides to move from a wireless network to another. Based on our simplified example in Figure 3, consider the cased where node F which belongs to WN_F and is reachable from node C and E; decides to move close to node A. In the new situation node F will only be reachable through node A. However, node C and E will not know it. Can we use mobile agents to broadcast the updated information concerning the geographical location of each mobile node, and then call them back after they successfully completed their task?

In summary, our research is concerned on accessing different models of the usage of static and mobile agents to determine the best route through ad-hoc networks. Static agents that are resident on mobile hosts can perform important tests, such as memory capacity, network performance, processing capabilities, cost, and so on. Mobile agents can use this information to determine the best route at a given time and thus periodically inform mobile nodes, which is the best path to pass network traffic.

3.3 Similar research involved in this field

The idea of using mobile agents for routing purposes in dynamic ad-hoc networks has been explored in MIT Media Lab [36] a few years earlier. Chpudhury et al. [37] followed the same direction by proposing a distributed mechanism for topology discovery in ad-hoc wireless networks using mobile agents. In their work they try to overcome certain limitations observed in MIT's research. Another very similar research by Marwaha et al. [38] proposes a combination of an on-demand routing protocol called Ad-Hoc On-Demand Distance Vector (AODV) with a distributed topology discovery mechanism using ant-like mobile agents. Their results show that their scheme achieves reduced end-to-end delay compared to conventional ant-based and AODV routing protocols.

Lui et al. [27] presents a unified framework for resource discovery and QoS-aware provider selection in ad-hoc networks by the use of self-organized discovery agents. Simulation results show that their framework improves the QoS delivered to the clients, while cost and response time are kept at a low level. Wang [26] and Suh [39] conduct similar research which utilizes an agent-enabled multicast routing protocol in wireless mobile networks. Their results show that the agent-enabled scheme achieves improved performance over traditional routing protocols. Hadjiefthymiades et al. [40] present a proxy-based architecture that manages to accelerate Web browsing in wireless Customer Premises Networks (CPN). The implementation of this architecture is based on mobile agent technology. Although there are many other interesting proposals in mobile agents and wireless routing, we cannot present them here. For a more extensive research on this topic, the reader can refer in [41–45].

3.4 Possible benefits and outcomes from this research

The main aim of this research is to design and implement a novel routing scheme based on mobile agent technology in wireless ad-hoc networks that will provide the following benefits. Maximize network **performance**, **scalability**, **provide end-to-end reliable communications** and **reduce possible delays**, and **minimize losses** that may incur due to bit-errors and handoffs.

Another very important issue that must be carefully taken into consideration is security. Without the appropriate countermeasures, mobile nodes may run

malicious agents instead of routing agents. Security issues will be closely examined throughout the design and implementation of this research. Therefore, the proposed scheme aims to balance between performance and security.

4. Model Definition

In this section we propose a generic model based on our research proposal. At this stage the model does not include great detail. Our intention here is to demonstrate our research proposal rather than present a complete framework. Greater detail as well as results from experiments will be made available in a later stage of this research.

Each mobile node will run an agent server that provides the basic functionality for static and mobile agents, such as migration, communication, and security. Possibly, the agent server will be written in Java language due to its object-orientation nature, object serialization and remote method invocation techniques, and enhanced security [46]. Static agents will be resident on mobile hosts and will be continuously running. These agents will be mainly responsible for the following operations: maintain a routing table; decide the best path to route network traffic based on information found on the routing table; and monitoring system's resources in terms of memory capacity, processing capabilities, network performance, cost, and so on. On the other hand, mobile agents will be responsible for the following operations: collect information generated from static agents; update routing tables on mobile hosts; and discovering new routes. They must also inform static agents; and other mobile agents for changes in the network.

Static agents will maintain routing tables continuously, decide the best path dynamically, and monitor system's resources periodically. Mobile agents will collect information from static agents periodically, update routing tables periodically, and communicate with static agents and other mobile agents when necessary. Figure 5 illustrates the model with four mobile hosts, four static agents, and two mobile agents.

5. Experiments

The most suitable research method for this project is experimental research. The field of ad-hoc networks and mobile agents is new, rapidly developing, and not always well understood. Through experimental research, we can gain important knowledge in such a new field. We are planning to run a set of experiments in order to prove our hypothesis: Mobile agent technology can be used for routing, topology discovery, and automatic network reconfiguration in ad-hoc networks with purpose to improve performance, scalability, provide end-to-end reliable communications and reduce possible delays, and minimize losses that may incur due to bit-errors and handoffs.

At the moment, research is continuing on an efficient mobile agent system suitable for ad-hoc networks. Such a system shall use efficient migration strategies, incorporate security, and be light-weight. All of these factors are equally important. The mobile agent system is intended to be used on wireless devices with low processing capabilities and thus it should be as light weighted as possible in order to avoid processing overhead. It should use efficient migration strategies, since this will help in further reducing network traffic. In addition, it should make use of security features to avoid attacks initiated from mobile agents to mobile hosts and vice-versa, from mobile agents to mobile

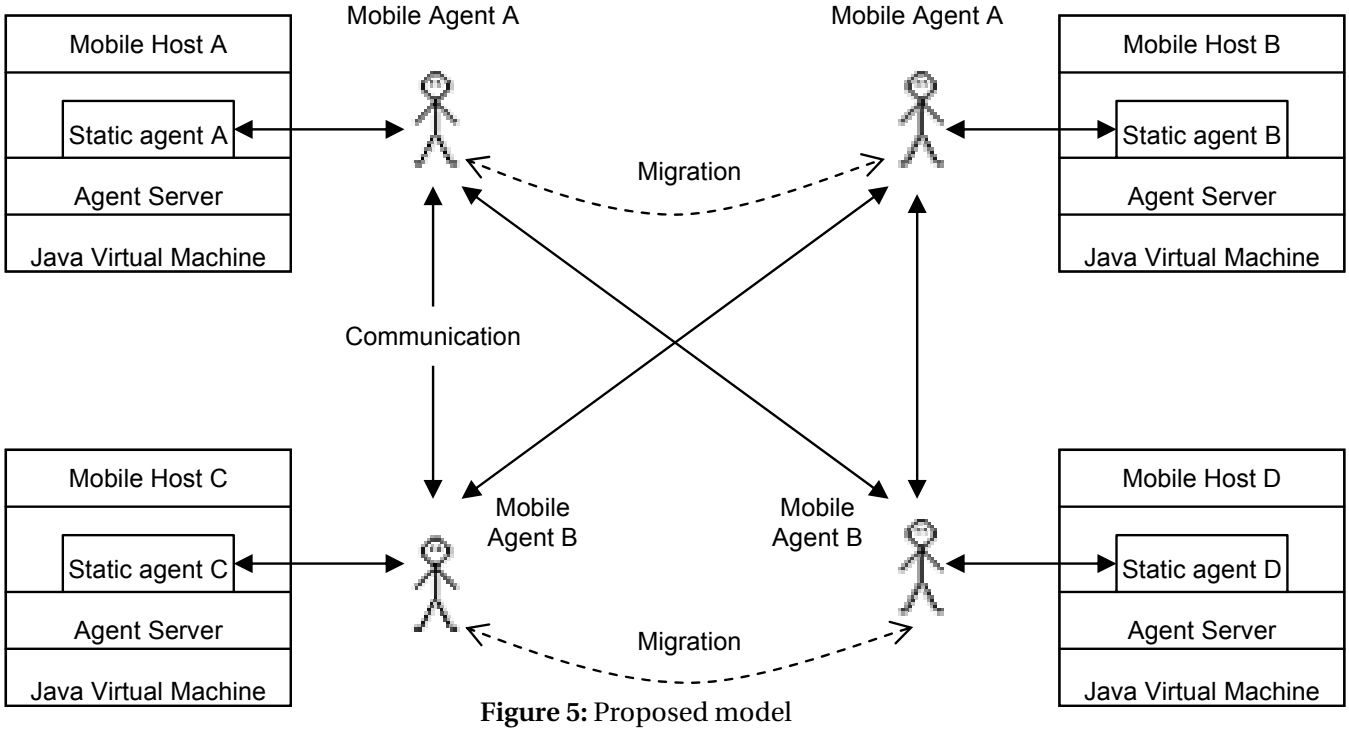

Figure 5: Proposed model

agents, and from other entities to mobile agents. In case we conclude that mobile agent systems in existence are not appropriate for this research we will have to look at the possibility of implementing a new suitable mobile agent system.

Further experiments are continuing on top of the mobile agent system and run simulation experiments. Results from these experiments will be compared with existing schemes in terms of performance, scalability, end-to-end reliability, and error handling.

6. Conclusions

In this paper we have proposed a research topic in the field of mobile agents and wireless ad-hoc networks, which is the focus of our research for the next three years. The main objective is to use mobile agent technology for routing, topology discovery, and automatic network reconfiguration in ad-hoc networks with purpose to improve over traditional schemes in terms of performance, scalability, end-to-end reliability, and error handling. We provided the necessary background to help readers to understand our research proposal. Then we presented our research proposal and outlined similar research taking place in this field. We have also defined a generic model that provides an initial model. This model will be refined, from the results if planned experiments that will be conducted in order to prove our hypothesis. Finally, we believe that there is great potential for this research and that it will form the basis for future research and implementation.

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