

# Design of Adaptive and Reliable Mobile Agent Communication Protocols

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## Abstract

*This paper presents a mailbox-based scheme for designing flexible and adaptive message delivery protocols in mobile agent (MA) systems. The scheme associates each mobile agent with a mailbox while allowing the decoupling between them, i.e., a mobile agent can migrate to a new site without bringing its mailbox. By separating the concerns of locating the mailbox of a mobile agent and delivering a message to the agent, we obtain a large space of protocol design with flexibility. Using a three-dimensional model based on the scheme, we have developed a taxonomy of MA communication protocols, which not only covers, as special cases, several known MA message delivery protocols, but also allows for the design of new ones well suited for various application requirements. We describe such an efficient and adaptive protocol derived from the model. The protocol guarantees reliable delivery of messages to mobile agents. We analyze the design trade-offs and performance of the protocol, using an analytic model as well as extensive simulation experiments.*

## 1. Introduction

In various situations, mobile agents need to communicate with each other. Remote inter-agent communication is thus a fundamental facility in mobile agent systems. Although process communication has been a cliché in distributed systems research, agent mobility raises a number of new challenges in designing message delivery mechanisms for effective and efficient communications between mobile agents.

- *Location transparency*: allow a mobile agent to send messages to other agents without knowing where they currently reside.

- *Reliability*: no matter how frequently the target agent migrates, messages can be routed to it in a bounded number of hops.
- *Efficiency*: achieve a balance of the trade-off between the costs of agent migration and message delivery.
- *Asynchrony*: keep the asynchrony of both migration and execution, so that little or no offset of the merits of mobile agent technology will be introduced.
- *Adaptability*: make the protocol adaptive to the requirements of different applications.

In this paper, we present a generic framework for designing MA message delivery protocols that satisfy the above requirements. The framework uses a flexible and adaptive mailbox-based scheme, which associate each mobile agent with a mailbox while allowing the decoupling between them. This flexible approach allows us to design a variety of algorithms which can be made adaptive to specific application requirements by evaluating the trade-offs between various design considerations. The generic framework not only covers, as particular cases, several known protocols, but also allows for the design of new ones that are suited for various application requirements. We describe such an efficient and adaptive protocol derived from the model. The protocol, called ARP (**A**daptive and **R**eliable **P**rotocol), guarantees reliable delivery of messages to mobile agents and satisfies other requirements described above.

## 2. Our Work

The design of a MA message delivery protocol mainly needs to address two issues: (1) tracking the location of the target mobile agent, and (2) delivering the message to the agent. Many mobile agent/object tracking

schemes have been proposed in the last several years in different contexts. The major schemes include central server, forwarding pointers, broadcast, hierarchical location directory, and group communications. The generic framework proposed in this paper is based on the concept of *mailbox* associated with a mobile agent. Its flexibility and adaptability comes from the decoupling between a mobile agent and its mailbox, allowing for the separation of the above two different concerns.

A mailbox, which is a message buffer used to store incoming messages destined to an agent, can be detached from its owner agent in the sense that the mailbox can reside at a location different from the current location of the owner agent. The communication between agents is divided into two steps: the *transmission* of a message from the sender to the receiver's mailbox and the *delivery* of the message from the mailbox to its owner agent. If an agent wants to send a message to another agent, it simply sends the message to the receiver's mailbox. Later the receiver receives the message from its mailbox using either pull or push. Notice that, for a frequently migrating agent, its mailbox can migrate at a much lower frequency.

Choices can be made in three aspects of designing a protocol that best suits the specific requirement of an application. The three aspects are *mailbox-to-agent message delivery*, *mailbox migration*, and *synchronization of message-forwarding with object-migration*. In the first dimension, we can have the choices of using either a *PUSH* or a *PULL* mode. In the second dimension, we can have *No Migration*, *Full Migration* and *Jump Migration*. In the third dimension, synchronization is performed either for coordinating the message forwarding by the host and the migration of the destination mailbox (*SHM*), or for coordinating the message forwarding from an agent's mailbox and the migration of the agent (*SMA*), or both (*FS*).

A taxonomy of MA communication protocols can be developed using this three-dimensional model. Mobile agent message delivery protocols can be described by combining parameters in these three dimensions. Most combinations have plausible applications. They not only cover the well known existing schemes, but also allow for the design of new ones that are suited for various application requirements.

Using the proposed framework, we have designed a reliable message delivery protocol, called ARP (*Adaptive and Reliable Protocol*). In ARP, the mailbox of an agent migrates from time to time, but not always with its owner agent. Both mailbox migration and message forwarding from all the hosts on the mailbox's migration path are synchronized. The agent periodically pulls messages from its mailbox.

The ARP protocol defines operation for two processes: *migrating* and *message-forwarding*. In the *migrating* process, if the agent decides to migrate with its mailbox, it will first de-register its current mailbox

address and, upon reaching the new destination host, register the new address with all the hosts on its migration path. In the message-forwarding process, messages are sent to the recipient at the address cached by the sender. If the recipient has been moved to another host, the messages will be forwarded to the current address.

The ARP protocol guarantees location transparency and reliability of message delivery between mobile agents. Asynchrony is improved because constraint on agent mobility and reliance on the agent home, as the location lookup server, is reduced. By separating the mailbox from its owner agent, the mailbox-based scheme also introduces great flexibility and adaptability. To demonstrate the adaptability and efficiency of the proposed ARP protocol, with the help of an analytical model as well as extensive simulation experiments, we analyzed the trade-offs between choosing design parameters, such as the time and frequency of mailbox migration. We also evaluated the performance of the protocol under different settings and compare it with other existing solutions. The results show that the proposed adaptive protocol can be designed to outperform existing protocols in terms of reducing the costs of both the migration and the message delivery operations.

Currently, we are working on a path compression algorithm for enhance the performance of the APR protocol, with the hope that, by removing redundant hosts from the migration path and by garbage collecting useless addresses maintained in the address cache, the migration cost can be greatly reduced.

Although the failures of hosts and channels are ignored in our discussion to concentrate on the problems caused by agent mobility, they do exist in the real world and the separation of the mailbox from the agent increases the protocol's vulnerability to these failures. Therefore, making the protocol more fault-tolerant is also under the scope of our future work.

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