Abstract

A mobile agent is a software program with so high mobility that it is difficult to transmit and receive messages accurately. At present, the location management of mobile agent consists of tracking phase and message delivery phase, both of which dutifully create or incur plenty of update messages and interaction messages separately in order to guarantee the effectiveness of mobile agent location management scheme. However, the transmission of messages not only affects the overall performance of mobile agent location management scheme, but also causes the network overhead. Therefore, this paper proposes a ratio-based update scheme that can minimize the overall transmission cost of produced messages. A number of simulation experiments are conducted to evaluate the proposed scheme. And, as a consequence, the simulation results reveal that this scheme is general, adaptable, and possessed of higher granularity in the network latency; moreover, the results also indicate that this scheme is better than previous schemes in optimizing the caused overall performance overhead.

Keywords: Mobile Agent, Location Management, Agent Communication, Network Latency.

1. Introduction

A mobile agent can move among hosts on the network to complete tasks assigned by a user or an application. Its features of mobility and autonomy bring several advantages, such as bandwidth savings, limited latency, higher degree of robustness, and etc, on account of which the mobile agent has been successfully extended in many distributed systems and applications, for example information retrieval, network management, electronic commerce, etc.

Mobility and autonomy make mobile agent especially flexible, and therefore becomes a promising technology in distributed system. With these features, however, messages are difficult to be accurately transmitted to a mobile agent. Many significant services in a mobile agent system, nevertheless, have to be accomplished through interacting the messages exchanged between mobile agents, such as mobile agent communication [1, 2], fault tolerance [3], and mobile agent control [4]. Therefore, an economical location management that can also effectively transmit interaction messages among mobile agents is rather substantial and essential for a mobile agent system. For transmitting interaction messages to a mobile agent accurately, the location management scheme is forced to operate in two phases; one is the tracking phase, which keeps track of location information of mobile agents continuously, and the other is the message delivery phase, in which the interaction messages are forwarded to a mobile agent along the location information. Update message and forwarding pointer are the most widely adopted methods for tracking phase. Update message is sent by a mobile agent to refresh its location information that is maintained in a Location Management Server (LMS). Forwarding pointer is a location reference left by a mobile agent at current location to indicate its next destination before it starts moving. Therefore, the maintained location information must be able to connect consecutively for providing interactive messages a channel leading to the next immediate mobile agent. This channel starts at a responsible LMS for a mobile agent, may include several intermediate hosts, and ends at the current location of the mobile agent. The duration of time that an interactive message travels through a channel is the message delivery phase.

The overall performance is the most interesting issue upon developing a mobile agent location management scheme, where each mobile agent gives and brings plenty of messages (update messages and interactive messages) as executing assigned tasks on a network. Transmitting these messages not only affects the overall performance of the location management scheme, but also increases the load of
the network. Hence, it is imperative to create and send messages under more effective management. The submitted performance optimization scheme in this study will prove to minimizing the overall transmission cost of produced messages.

Increasing the frequency of updates of a mobile agent surely decreases the transmission cost of interaction messages, while the overall transmission cost could be increased due to the growth of the number of update messages. Facing such a conflict, the focus of most of existing studies emphasizes on balancing the trade-off between the transmission costs of update messages and interaction messages to optimize the overall performance. This study further discover that the updating location information of a mobile agent, as the ratio between the costs of transmitting update message and interactive message reaches a threshold, can optimize the overall transmission cost of produced messages more effectively. Therefore, this paper proposes a ratio based scheme which is established on this update criterion and enacts a number of simulation experiments to evaluate and compare the scheme with other well-known schemes, and the results exhibit that the overall transmission cost of messages in our scheme is lower than those previous, and that this scheme is more general and adaptive to various network latencies.

The rest of this paper is organized as follows: Section 2 introduces related works and analyzes the key issue of designing a mobile agent location management scheme. Section 3 presents the proposed intelligent update algorithm. Evaluation results are indicated in Section 4. Conclusions are given in Section 5.

2. Related work

With features of mobility and autonomy, a mobile agent’s itinerary can be shifted dynamically according to the network status and the requirements of application. Baumann [5] identified two types of mobile agent location management schemes, the Preordained Path and the Autonomous Migration, according to the migration behavior of mobile agents. In the Preordained Path scheme, a mobile agent migrates between hosts only based on a predefined itinerary, and can not move arbitrarily as a mobile code. A mobile agent in such a scheme can be easily located by using binary search [6] or probability estimation [7]. To harness more of the mobile agent’s features of mobility and autonomy, the focus of recent researches has been set on the type of Autonomous Migration in which the itinerary of a mobile agent can be determined dynamically.

Both the earlier mobile agent location management schemes, the Home-proxy scheme (HP) and the Forwarding-proxy scheme (FP), are characterized to facilitated implementation, and, thus, adopt home-based LMS architecture. The HP scheme uses only update messages to track the location of a mobile agent; once the mobile agent changes its location, it sends an update message to refresh the location information maintained in the LMS. In this way, a channel always consists of the LMS and a mobile agent’s current location only, which, thus, keeps the transmission cost of interaction messages extremely low at any moment. However, the overall performance is not as good as expected due to the excessive usage of update messages. On the other hand, the FP scheme, differing from the HP scheme in utilizing only forwarding pointers in tracking phase, which produces no messages, instead causes no additional performance overhead in tracking phase. However, in the FP scheme the length of a channel gets longer and longer with the increasing number of a mobile agent’s movements and interaction messages must route through a long distance to reach a mobile agent, which consequently damages the overall performance seriously when mobile agents interact frequently. This is referred to as the lengthy channel problem in mobile agent location management. Mobile agent platforms such as MOA [8], Grasshopper [9], Aglet [10], and SPRINGS [21] use HP scheme, while platforms such as Mole [11] and Voyager [12] adopt FP scheme.

Another popular choice in developing mobile agent location management scheme is Hierarchical LMS architecture; it can distribute the risk of system, the network failures, and the load of location management uniformly to a group of LMSs which have been organized as a balanced tree structure. This architecture generally divides hosts in a mobile agent system into groups according to their geographic locations. In each group one or more LMSs is deployed to administrate the statuses of mobile agents currently in the group. In such a location management scheme, a mobile agent’s channel starts at the root LMS, following the non-terminal LMSs, and finally ends at the leaf LMS. The current resident host of a mobile agent is administrated by the leaf LMS. At present, many schemes have been
developed based on the hierarchical LMS architecture, for example, the domain gateway server scheme [13], the hierarchical AgentTracer scheme [4], the Search-by-Path-Chase [14], and the hierarchy shadows scheme [3].

Hierarchical LMS architecture manages mobile agents' location information with locality, while the risks and load are shared among LMSs, therefore, it is excellent in both scalability and reliability. However, this architecture is globally constructed and each LMS is a dedicated and stationary server, and, therefore, many additional costs are difficult to estimate, for example, of installation, management, and maintenance of the LMSs, and of selecting a best network position for each LMS. In [15], a hierarchical dynamic monitoring mechanism was proposed. Nevertheless, this paper employs mobile monitoring agents to replace the traditional dedicated and stationary LMSs. Additionally, the mobile agent location management scheme in global networks, as developed by Patel et al. [22], and the distributed location databases, as developed by Pitoura et al. [23], are hierarchy-based location management architectures. Although problems of the hierarchical LMS architecture can be avoided this way, managing such a mobile monitoring agent mechanism could still be a torment.

Home-based LMS architecture is simpler for constructing a universal mobile agent management environment. But, both HP and FP schemes are too simple for optimizing the overall performance. The HP scheme produces too many update messages, while the FP scheme costs much higher to transmit interaction messages due to lengthy channels. For balancing the costs between the transmission of update messages and interaction messages to optimize the overall performance, a movement-based scheme, called the dU scheme, has been proposed in [16], and a time-based scheme has been described in [17]. In the dU scheme, a mobile agent updates its location information after d migrations between hosts, while in the time-based scheme, after an interval of time $\tau$ has elapsed, a mobile agent updates its location information to its LMS. Both of the two schemes use different criteria to decide the adequate update timing, and their evaluation also proved the overall performance can be largely improved by this way.

Both the dU scheme and the time-based scheme have been proved, at the right timing, to improve the performance of mobile agent location management schemes. Because the higher the transmission cost of update messages is, the lower the transmission cost of interaction messages will be, and vice versa, therefore, there should exist a specific ratio between the transmission costs of update messages and interaction messages as the best update timing mechanism. Based on this idea, this paper proposed a ratio based update scheme and tried to locate this exact ratio for mobile agent location management schemes.

3. The ratio-based update scheme

Hop counts between each pair of hosts on a network can be regarded as network latency metric according to the requirement of an application. Different network latency metric represents different requirements of costs [19]; for example, hop counts reflect network resources consumed and RTTs indicates response times. This paper assumes that each host in a mobile agent system can detect the transmission costs between itself and other hosts in the system periodically by using network tools, such as traceroute or ping.

Suppose that the states of the hosts that provide important services for mobile agents are stable, i.e. with seldom failures or crashes, the exploration and maintenance of transmission costs information would be economy. In the implementation of this paper, such transmission costs are kept track on a membership table by each host, called the membership costs.

3.1. Tracking phase

In the ratio-based update scheme which is based on the home based LMS architecture, a mobile agent send out an update message at the best update timing to minimize the overall transmission cost of produced messages in a mobile agent system. To be more precise, a mobile agent updates its location information as the ratio between its current update cost and message delivery cost is below a threshold r. Threshold r is defined as follows as the message delivery cost is proportional to the length of a channel.
Minimizing Message Delivery Cost in Mobile Agent Location Management
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\[ r = \frac{\text{update cost}}{\text{length of channel}} \]

where length of channel is regarded to as the delivery cost of interaction messages. Figure 1 illustrates how the relation of \( r \) is established. In this figure, mobile agent MA migrates from \( H_{i+k} \) to \( H_{i+k+1} \). As MA is at \( H_{i+k} \), the transmission cost of interaction messages is represented by the length of the current channel. After MA arrives at \( H_{i+k+1} \), the transmission cost of interaction messages become the length of the current channel plus the length of the current migrations just made. Thus, the computation of \( r \) is to divide the update cost on current host \((H_{i+k+1})\) by the length of current channel plus current migration of MA.

![Figure 1](image)

As described, before the next update of location information, a channel gets longer and longer with the increasing number of mobile agent’s migrations. In the definition, the value of \( r \) inverses to the length of a channel and, therefore, the value of \( r \) gets smaller and smaller as the mobile agent keeps migrating on the network.

For continuously calculating the value of \( r \), a mobile agent has to carry the length of its current channel and update it during its life span. When a mobile agent arrives at a new host, it asks the host for the update cost and the cost of current migration for computing the value of \( r \). If the value of \( r \) is smaller than a default threshold value, the mobile agent updates its location information. In addition, the mobile agent leaves a forwarding pointer which indicates to the next destination before it departs from the current host. In the update case, the channel of mobile agent would be renewed as LMS points to the current host, while in the forwarding pointer case, the current channel would be updated to a new channel which is obviously the current channel plus the current migration. The optimal threshold value of \( r \) will be obtained by simulation experiments described in later sections.

3.2. Message Delivery phase

Interaction messages are handled in the message delivery phase, which are sent among mobile agents along channels. To reach a mobile agent accurately, an interaction message have a field containing the identification of the receiver agent to enable the hosts on a channel to forward it in the correct direction. On receiving an interaction message, a host on a channel extracts the identification of the receiver agent from the field, queries the location table for the next destination of the channel and, then, sends the interaction message there. Conversely, if the receiver agent has no records in the location table, the host returns a failure message to the LMS. Accordingly, the hosts on the channel repeat the forwarding process until the interaction message reaches the current location of the receiver agent.

Fields of an interaction message vary in different applications that require mobile agents to communicate, coordinate, or negotiate with each other for completing different tasks. Under such circumstances, interaction messages must include the name of the sender agent for the
receiver agent to reply to the message. Obviously, a reply message sent by a receiver agent is another interaction message and, therefore, is delivered in the same way. A sender agent that remains stationary and requests to initiate a session that interacts directly can also add the address of the host, where it currently stays, in the interaction message for a direct delivery to the host.

Reliable message delivery is vital for mobile agent location management. Communication failure is of major concerns in this issue. As an interaction message reaches the mobile agent’s current location and the mobile agent has left, communication failure occurs. The mailbox approach [2, 20] is often adopted to resolve a communication failure. For delivering the interaction message reliably, the proposed ratio-based update scheme assigns each mobile agent a mailbox at creation time. For delivering the interaction message reliably, the proposed ratio-based update scheme assigns each mobile agent a mailbox at creation time. As a mobile agent’s home host receives an interaction message for it, the following procedure is conducted:

1. The received message is assigned a serial number based on the incoming sequence;
2. A copy of the message is stored in the mobile agent’s mailbox; and
3. The message is forwarded to the next host on the mobile agent’s channel.

A mobile agent always includes in the update message the serial number of the message that it last received and, then, sends it to the home host. The home host that receives the update message not only refreshes the location information of the mobile agent in the location table, but also checks the mobile agent’s mailbox to see if the mobile agent has missed any messages. The home host then pushes the lost messages to the mobile agent directly.

4. Simulation Experiments and Evaluation

The ratio-based scheme proposed in this paper is evaluated by both computing the transmission cost of total messages produced and conducting simulation experiments. This section first introduces the way of calculating the overall transmission cost of messages by formulation, and then shows the evaluation results obtained by experiments.

This paper constructed a simulation environment to conduct experiments precisely. The network topology of the environment used in this paper is established by using the nem [18] network topology generator that can create a network map resembling a real network. In the simulated network, distance between a pair of hosts on the network map is measured by using the hop counts and over 10,000 routers is created with the longest distance between hosts controlled in 22 hops. This experiment is conducted for numerous rounds for a mobile agent, and the mobile agent’s each itinerary contains 100 randomly selected hosts. Furthermore, for the best assessment, each experiment also compares the performance of the ratio-based scheme with that of the two famous schemes, the HP and the dU.

4.1. Formulation and Computation of Network Overhead

Messages created in the period of the tracking phase are the update messages and in the delivery phase are the interaction messages. Total cost of the update messages is denoted as $C_T$ and formulated as follows:

$$C_T = N_U \times C_U$$

where $N_U$ represents the total number of update messages and $C_U$ represents the average cost of each update message, i.e. the total cost is the sum of the transmission cost of each update message.

On the other hand, depending on applications, interaction messages may differ in the size and in the content. While for conveniently formulating the total cost $C_M$, interaction messages are assumed to be identical, and thus equation is as follows:
where $N_I$ represents the total number of interaction messages and $L_C$ represents the average length of a channel.

The total transmission cost of produced messages, denoted as $C_{total}$, is then computed by summing $C_T$ and $C_M$, and is formulated as follows:

$$C_{total} = C_T + C_M$$

As described in the previous sections, performance of a mobile agent location management scheme is greatly affected by the messages produced in the scheme. Computing the total transmission cost of all messages created for managing location information and communications of mobile agents, therefore, has become a main criterion in evaluating a location management scheme. The computation process is suitable not only for the ratio-based scheme, but also for other existing home based LMS architecture schemes. In the following section, the performance of the ratio-based scheme is evaluated according to the computation process.

### 4.2. Optimal Threshold

In the ratio-based scheme, there exists an optimal $r$ value to yield optimal overall performance. A simulation experiment is conducted to find out the best value of $r$ for the ratio-based scheme. The result of this experiment shows that the best value of $r$ varies under different interaction rates. A mobile agent may receive messages at any moment during the course of its itinerary. The interaction rate represents the average number of message received per host in an itinerary. It reflects the probability of how many messages that a mobile agent will receive during the course of an itinerary. Take an itinerary that has 100 hosts for example; if a mobile agent receives 10 messages throughout its itinerary, the interaction rate is 10% in average, while in the case of receiving 100 messages, the average interaction rate is 100%. It is possible that the interaction rate is larger than 100%, as long as a mobile agent receives more than one message in the average on every host. Figure 2 shows the experiment result of the best value of $r$ under various interaction rates.

![Figure 2. The best value of $r$](image)

As can be seen from Figure 2, the value of $r$ gets bigger and approaches 0.92 with the increase of interaction rate from 0% to 1000%. The result forms a basis of selecting a best value of $r$ with different interaction rate. Moreover, when the value of $r$ becomes very small, e.g. almost zero, the ratio-based scheme functions just the same as the FP scheme does. On the
contrary, as the value of r approaches the other extreme value 0.92, the ratio-based scheme performs like the HP scheme.

4.3. Number of Updates

The most complicated work in the mobile agent location management is the overall performance evaluation that equals to the computation of transmission cost of all produced messages. Most of these messages are update messages and interaction messages. As aforementioned, the way for optimizing the overall performance is to balance the trade-off between the costs of transmitting these two kinds of messages. Experiments have been conducted in this paper to compare the performance of HP scheme, dU scheme, and ratio-based scheme in the aspects of transmission cost of update messages, interaction messages, and all produced messages respectively.

The experiment result for comparing the transmission costs of update message appears in figure 3 first, which displays the average number of updates of HP scheme, dU scheme, and ratio-based scheme with interaction rate stretching from 0% to 1000%. Simulation experiments conducted for the three schemes uses the same network topology and latency metric; the comparison of average number of update messages that a mobile agent produced is sufficient to reveal the average costs of updates in the schemes. Furthermore, comparing the number of update messages better displays the capability of controlling the quantity of produced update messages for the three schemes. As shown in figure 3, when the interaction rate is between 80% and 100% the dU scheme performs better than the ratio-based scheme, which concludes that the ratio-based scheme can control and even reduce the cost of updates more effectively.

4.4. Length of Channel

This section reviews a conducted experiment for calculating the average length of a channel that each interaction message experiences. Figure 4 displays the results. When the interaction rate is high, the length of a channel has more impact than the number of updates on the overall performance. An interaction message can seriously damages the performance of a mobile agent location management scheme due to the lengthy channel problem, not to mention the enormous number of interaction messages if mobile agents interact frequently.

In figure 4, the three lines come close to each other from about 10 hops as interaction rate greater than 300%. In fact, the actual values of HP and dU scheme are both 9.908 hops and that of ratio-based scheme is 9.76 hops. The average length between any pair of hosts in the
constructed simulation environment is exactly 9.908 hops. The results imply that the three schemes in the experiment basically are all suitable for applications of high interaction rate; nevertheless, the ratio-based scheme retains the length of channel more effectively.

![Figure 4](image1.png)

**Figure 4.** The average length of a channel

### 4.5. Total Transmission Cost

The experiment result of computing the total transmission cost of produced messages ($C_{total}$) for HP scheme, dU scheme, and ratio based scheme is shown in figure 5, which displays the average total costs with the increase of interaction rate. As can be seen from the figure, the HP scheme is worse than both the dU and the ratio-based schemes as interaction rate is low. The reason is that the update mechanism of HP scheme is monotonous and creates exceeding update messages. On the other hand, the dU and the ratio-based schemes update location information more flexible than the HP scheme and, therefore, they perform well in all interaction rates. The ratio-based scheme always performs better than the dU scheme irrelevant to interaction rates and this is because it controls the update timing more accurate than the dU scheme. This is the reason behind the superiority of ratio-based scheme to the other two schemes in both figure 3 and 4.

![Figure 5](image2.png)

**Figure 5.** Comparison of overall performance overhead
4.6. Error Scope of r

In accordance with the variation of interaction rate to assign the best value of \( r \) is not easy, because the creation of an interaction message is actually difficult to predict. Instead of proposing a solution for this issue, this paper proposed the usage of an \textit{Error Scope} of \( r \) within which the performance of the ratio-based scheme is guaranteed to be better than those of the HP and the dU schemes for a same interaction rate. An experiment is conducted to examine such an \textit{error scope} of \( r \) corresponding to different interaction rates and Figure 6 shows the result of the experiment.

![Figure 6. The Error Scope of r](image)

Three curves are drawn in figure 6, where the upper curve represents the upper bound, the lower curve represents the lower bound, and the curve in between represents the best value of \( r \). The curve of the best value of \( r \) is the same as the one shown in figure 2 except where the vertical scale set to 1 only. At any interaction rate, select a value of \( r \) between the upper curve and the lower curve would perform better than the other two schemes, e.g. at the interaction rate 100%, the ratio-based scheme could be better than HP scheme and dU scheme in the aspect of performance by setting the value of \( r \) between upper bound 1.5 and lower bound 0.34. For this example, the corresponding overall performances are 1958, 1952, and 1744 hops respectively when \( r \) is at upper bound, at lower bound, and at the best value 0.54, while the overall performance of the dU and the HP schemes are both 1981 hops, because dU is the same as HP when interaction rate is greater than 100%.

As shown in figure 6, because the error scope of \( r \) extends to a wide range so that the ratio-based scheme can still achieve satisfactory performance without having to modify the value of \( r \) constantly with the variant of interaction rates. This proves that the proposed ratio-based scheme is more flexible than other peer schemes.

5. Conclusion

Observations from surveying the existing studies in the home-based location management models discovered that to optimize the overall performance of such a scheme, location information of mobile agents must be updated at the right time, at which there exists a specific ratio between the update cost and the message delivery cost. This paper thus proposed a ratio-based update scheme for optimizing the overall performance of mobile agent location management schemes. Simulation results confirm that the overall performance of the ratio-based scheme is better than the other two well-known schemes, the dU and the HP schemes.

Location management of a mobile agent is rather essential for a mobile agent system, in which many significant services are accomplished among interactions, for example, task
communications and coordination, fault tolerance, control of mobile agents, and etc. And, the proposed ratio-based scheme, with its promising performance, can be applied to these topics without any doubts.

6. References