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A Survey on Reliability Estimation Techniques for Mobile Agent based Systems

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Abstract

Mobile Agent based Systems (MAS) is one of the fastest growing and emerging areas for application development in recent past. A mobile agent is a computer program that acts autonomously on behalf of a user or application moving in the heterogeneous communication environment. To ensure fault and failure free operation of mobile agent based commercial applications, reliability issues need to be addressed. In this paper, we present a complete survey of various techniques for estimation of reliability of MAS on the basis of factors that affect it. The survey concludes that reliability estimation techniques of MAS developed so far are based on aggregation of certain combinations of attributes in a specific environment. But, due to complex and dynamic nature of MAS, there is a great potential of further research in the area of their reliability assessment.

Keywords

Mobile Agents, MAS, MANET, Reliability, Monte-Carlo Simulation.

1. Introduction

A basic requirement in the development of MAS is to enhance reliability of mobile agent based applications particularly used in open environments such as the Internet. Major work done on reliability of MAS mainly focuses on the identification of various factors such as computing environment, status of the communication links, security of the mobile agents against malicious hosts, security of the hosts themselves, movement pattern of the mobile agents, inter mobile agent communication & various H/W components etc.

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A variety of approaches such as defining the overall reliability assessment process through a hierarchical structure consisting of reliability factors, reliability attributes, & reliability metrics at different levels of hierarchy and aggregating them starting with the bottom most level and gradually proceeding to the top most level have been used for the assessment and allocation of reliability of MAS.

Reliability models developed so far have mainly aggregated certain combinations of attributes that do not present the real picture. For example, one of the models calculates reliability of MAS by taking the long term average of mean number of mobile agents in the system that successfully completed their tours with respect to status of communication network. Another model considers a trust-enhanced security environment to calculate the overall reliability of system. It gives us a direction that overall reliability of MAS should not be assessed on the basis of a few attributes/parameters only. But, a complete list of attributes must first be exhaustively identified and then overall reliability of system must be assessed using an appropriate approach. Thus, there is enough scope to revisit various reliability models which have been developed for the assessment/allocation of reliability to MAS.

2. Survey Methodology

To study and analyze the previous work, exhaustive literature survey has been conducted. In this survey work, we identified 474 research papers related to different characteristics and issues pertaining to the reliability of each component individually as well as the whole MAS. The survey has been performed through following two steps.

STEP 1:
Out of the total 474 identified research papers, we shortlisted & examined 81 research papers that addressed different issues/factors affecting the reliability of MAS. Reliability issues were categorized according to three different components of MAS i.e. mobile agent, mobile agent Platform and communication channel as shown in figure 1.

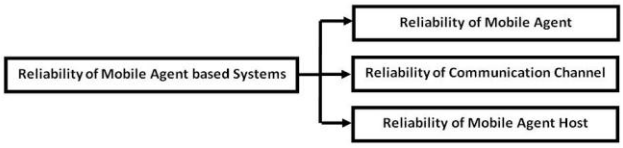

Figure 1: Distribution of Reliability of MAS

A complete description has been provided in the section 3.

STEP 2:
After identifying various factors responsible for reliability of MAS, eight reliability estimation models proposed so far have been discussed in details in the section 4.

3. Previous Work on Reliability Issues of Mas

Major work done so far in the context of reliability of the MAS mainly focuses on the identification of various factors that affect reliability of different components as stated above. Reliability (continuity of correct service) of MAS can be aggregated as a mean of reliability of all its components i.e. mobile agents, mobile agent host system (Node) and communication channel.

Issues related to MAS reliability can be further classified among three major categories.

A) Reliability Issues of Mobile Agent

The reliable execution of a mobile agent is a very critical design issue in developing MAS. Reliability of mobile agents depend on various factors such as mobile agent fault tolerance, degree of heterogeneity among the mobile agents, inter agent communication methods, mobile agent security, agent mobility model / migration pattern & priority level of agent [1] etc. The work done to address various factors on which reliability of mobile agent depends can be further classified into following categories.

i) Security of Mobile Agent

One of the major concern towards the reliability of mobile agent is its security/protection from various types of threats like authentication & authorization of the user [2], malware threats, communication of private information [3], denial of service attack, logic bomb or event-triggered attacks, compound attacks [4], security threats from malicious hosts [3,5,6] and malicious logic [7].

Various mobile agent code and data protection techniques like SandBox model, code signing, firewalling [AR10]8, contractual agreements, computing with encrypted functions, co-operating agents [6], SecMiLiA [9], trust management architecture- mobile trust [10], host authentication with designated hosts [11], security mechanisms using reference states [12] etc.

ii) Fault Tolerance capability of Mobile Agent

Reliability and fault-tolerance are the fundamental issues for development of robust MAS [13]. Aim of fault tolerance is to provide reliable execution of agents even in case of failures that may occur due to various errors that generate during system crashes, communication exceptions, security violations or migration request failure [14]. The use of mobile agent is critical and requires reliability of MAS in case of mobile agent's failures that may lead to bad response time and hence the loss of availability of the system [15]. Various fault-tolerance techniques have been proposed which can increase the robustness and reliability of mobile agent as well as MAS. Different fault-tolerance techniques for the agents such as failure detection, atomic migration protocol, explicit check pointing and restart, reconfigurable itinerary, failure recovery, software rejuvenation and on-the-fly upgrading are available in the literature [16].

A dynamic stage construction model with effective node selection method to ensure reliability and efficiency simultaneously is also available [13].
Besides the security problems through intended attacks, it is very crucial to understand that a mobile agent may simply get lost due to errors of the network or the hosts. [17]. An evaluation of the performance of the fault-tolerant schemes for the mobile agent environment has been performed that focuses on the checkpointing schemes and deals with the cooperating agents. The FANTOMAS (Fault-Tolerant approach for Mobile Agents) design offers a user transparent fault tolerance that can be activated on request, according to the needs of the task. A solution has been proposed for effective agent deployment using dynamic agent domains [18].

An approach to introduce fault tolerance in MAS through integration of checkpointing with antecedence graph approach significantly improves the reliability & performance of collaborating group of agents [14].
Another issue that may occur due to the autonomous behavior of mobile agents is that there is no natural instance to monitor the progress of an agent's

execution. Mobile agents may be blocked or lost due to node crashes or network partitioning even if other nodes are available that could continue processing. A protocol has been described that produces exactly-once semantics of agent execution and additionally reduces the blocking probability of agents by introducing observer nodes for monitoring the progress of agents [19].

iii) Mobile Agent Communication Techniques

Mobility feature of mobile agents makes it more complex for agents to communicate with each other and its environment in a reliable manner. Also, it is more difficult to trace other coordinating mobile agents. To address the issue of reliable communication & coordination among the agents and task of agent tracking, significant work has been done in the form of designing various communication protocols [20, 21, 22, 23, 24, 25, 26, 27 ,28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43], mobile agent messaging models [44, 45, 46, 47] and agent tracking mechanisms [48, 49, 50, 51, 52, 53, 54, 55].

iv) Migration Pattern of Mobile Agent

Various agent migration protocols offer a reliable and flexible way for migration of agents across the network, and provide a level of adaptability as well as security for a wide range of mobile agent based applications. In [56], the design and implementation of IMAGO migration protocol has been discussed that offers mobile agents to have relatively more reliability, security and adaptability. In [57] a reliable and secure connection migration mechanism for mobile agents has been presented that provides exactly-once delivery for all transmitted data during agent migration.

To demonstrate the reduced communication cost, a frequently claimed benefit of mobile agent technology, an approach [46] has been presented that can substantially reduce communication cost along with reliability of mobile agents in many scenarios by choosing an appropriate agent migration protocol.

v) Learning / Control Capability of Mobile Agent

Ability to train or control any mobile agent dynamically in its runtime makes it more reliable and productive in MAS. Several learning algorithms to train agents have been implemented and their performance impact was compared [58] in an extended environment. A pattern based design for agents having learning capability has been proposed in [59] with which the degree of intelligence increases along with the diversity of knowledge and capability of the agent. In addition, three efficient control mechanism for mobile agents [60, 61, 62] have been described which control and support productive agents working together for a common goal.

vi) Other Factors

Mobile agent control mechanism [60, 61, 62, 63], mobile agent chaining mechanism i.e. dynamic determination and updating of itinerary mobile agents [50, 64], flocking of mobile agents [65, 66] etc. are a few other factors that can improve the performance and reliability of mobile agents.

B) Reliability Issues of Mobile Agent Platform

Mobile Agent Platform can be thought of as the system that provides the execution environment for mobile agents. In order to implement services based on mobile agents, a software platform (e.g., Aglets, Voyager, Grasshopper, Tryllian, JADE, Tracy, and SPRINGS. etc.) [67, 68, 69] is required to provide agents a number of basic services, such as the ability to communicate among them and move to other computers. Mobile agents are created and controlled by the owner node. Mobile agents are designed for special purpose that is completed by the roaming of these agents over the network. Various mobile agent platforms have been tested [67] in wireless environments, under a variety of conditions and scenarios. Some of the issues related to the reliability of mobile agent platform are agent-node communication, security of agent platform against vulnerable agent [70, 71], types of device used (fixed desktop PC or various mobile devices) representing variable processing power, fault-tolerance capability of platform etc.

C) Reliability Issues of Communication Channel

Beauty of the mobile agent concept that makes it so popular is its capability to work on different type of communication networks i.e. computer networks, distributed systems or MANET. Major factors that affect the reliability of communication channel are link connectivity, channel bandwidth, fault tolerance of network, security concerns of the channel etc.

After evaluating the individual reliability issues, some other issues considering the MAS as a complete system have also their impact on its reliability. A number of attributes like node mobility, network size, number of mobile agents, number of multiple agent

groups, time variant relative node positions, degree of heterogeneity among the mobile agents, multipath propagation, background noise level, channel bandwidth, communication link failure etc. have also been identified.

4. Reliability Estimation Models for MAS

Reliability estimation of MAS is a complicated problem for which only little attention has been paid. Major work done in this area is related to calculate task route reliability of MAS. Various reliability estimation methods that are available focus on calculation of reliability of MAS on the basis of network conditions. Algorithms are available that are concerned with some of the important factors such as agent/node fault tolerance, mobility pattern, network size, link type, simulation time, environmental factors, priority level of agents, delay tolerance etc. which can affect reliability of the system.

Eight exiting reliability estimation models have been grouped in three categories according to the method used for reliability estimation and working environment of MAS. Out of eight reliability estimation techniques, two techniques given by Mosaab Daoud and Qusay H. Mahmoud are discussed in part A and B. Rest of the six techniques proposed by Chandreyee Chowdhury and Sarmistha Neogy are presented in part C.

A) Reliability Estimation Algorithm(s) for MAS

Some of the initial work done to calculate the reliability of MAS was presented by Mosaab Daoud and Qusay H. Mahmoud. They mainly introduced two algorithms to calculate task route reliability of the MAS based on the conditions of underlying computer network and a random walk generator algorithm that was designed to address the issue to find out best strategy to simulate agent's tour or walk [72, 73, 74].

The reliability of MAS is defined as the probability of fault free operation of MAS during a period of time. It was observed that the reliability of MAS depend on the reliability of computer communication network. To proceed further, we now mathematically define the reliability of MAS as:

$$R_S = P_r \text{ (MAS is operational } | \text{ X, Z)} \qquad (1)$$

Here X and Z represent the random state vector of the communication links and nodes respectively. In these algorithms, the reliability of MAS has been estimated by taking the long term average of mean number of mobile agents in the system that have successfully completed their walks (tours) with respect to the status of computer communication network. Monte Carlo technique has been used to estimate the required reliability. In the first Algorithm (R_MAS1), only reliability of communication links has been considered to calculate the overall reliability of MAS (R_S). In the next algorithm (R_MAS2) it was extended to include node reliability in the scenario.

Results obtained from R_MAS1 show that the reliability of MAS vary between 0.727 to 0.737 despite the changing number of agents when p_i =0.9 for all i and q_r =1 for all r. In the case of R_MAS2, when reliability of nodes was also considered as a factor, the reliability of MAS dropped down to 0.482 (when k=1); i.e. the reliability of MAS decreased by 34%. By varying the random paths obtained from random walk generator algorithm, it was clearly observed that the route used by an agent play a key role in estimating the reliability of MAS.

B) Fuzzy Approach to Reliability Estimation of MAS

In continuation to their previous work, Mosaab Daoud and Qusay H. Mahmoud suggested a fuzzy approach to solve the problem of lack of information about the failure rates of processors and communication links that makes it hard to estimate the required reliability using the conventional approach. The reliability of MAS was explored under the assumption of uncertainty regarding the system's environment (network) [75]. It was observed that the reliability of MAS is fully affected by the failures of processors and communications links used during the agent's mission to perform the required task within a specific time limit. Since a fuzzy number represents uncertainty in a numeric value, the failure rates used to estimate reliability of MAS were taken as fuzzy numbers. It was also observed that symmetric failure rates produce symmetric fuzzy reliability and the curve of de-fuzzified system reliability coincides with the curve of fuzzy most promising reliability. In addition, there was some indication that the number of mobile agents (k) in the network somehow does not play a significant role in the overall system reliability due to the static nature of the model. Also, due to the concept of restricted random walk

suggested earlier, the usage of each link/node in generating the random walks is uniformly distributed.

C) Reliability Estimation of MAS in MANET

We are now in the world of wireless generation of communication networks that is robust, affordable, easy to connect and always available. Mobile adhoc network (MANET) is a self-configuring network of mobile devices connected in wireless medium. The growth of laptops and smart phones has made MANET a popular research topic since the mid-1990s. Significant work has been done to evaluate protocols and their abilities, assuming varying degrees of mobility within a bounded space, usually with all nodes within a few hops of each other.

Mobile agents can be used in applications for wireless network to save bandwidth and time. Though mobile agents have been used recently in various applications of MANET, reliability analysis of such applications is not much discovered. Due to motion and location independence the reliability of MANET becomes a factor that may affect the performance, strategy and availability of MAS. Thus the work of reliability estimation of mobile agents for MANET is the first of its kind. Certain reliability issues that should be addressed before the mobile agents can be used for a broad range of commercial applications in MANET.

To identify and analyze different factors that can affect the reliability of MAS in MANET, six reliability estimation models have been proposed by Chandreyee Chowdhury and Sarmistha Neogy. These reliability estimation models identify the impact of different factors that affects the overall reliability of MAS in MANET. Various reliability estimation techniques proposed by Chandreyee Chowdhury and Sarmistha Neogy are discussed below.

1) A scalable approach to estimate the reliability of a MAS for MANET

An introductory work has been done on estimating reliability of independent mobile agents roaming around in MANET [76]. It was assumed that the agents can select their route dynamically and the MAS consist of a number of independent mobile agents operating simultaneously. Node and link failure due to mobility or other factors was predicted according to NHPP. An algorithm was proposed for estimating the task route reliability of MAS which are based on the conditions of the underlying wireless network. The reliability of MAS considering different failures of the underlying network was estimated.

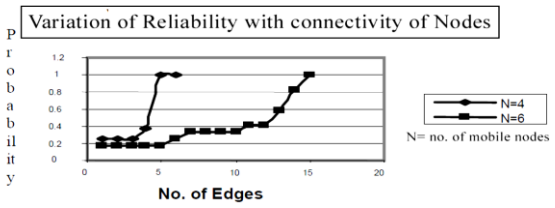

Figure 2:Relaibility Variation with connectivity of the nodes

If an agent can successfully visit M nodes out of the N desired nodes successfully then it accomplished M/N portion of its task. Thus the reliability of agent may be taken as M/N. A randomized agent planning strategy was proposed where an agent selects a destination randomly and the routes are also updated dynamically as agents roam the network in order to reflect node mobility.

Task route reliability $\lambda_i(t)$ and individual software reliability $r_i(t)$ of mobile agent i is aggregated to calculate average reliability of all agents as per equation (2).

$$\lambda(t) = \frac{1}{k} \sum_{i=1}^{k} \lambda_i\ (t)\ r_i \qquad (2)$$

Significant results obtained from the algorithm can be summarized as below.
If the mobility of network is higher, then the reliability of the system will be lesser. If the number of agents is small, then a small variation in their numbers can affect the reliability of MAS greatly but with larger number of agents, a small variation in number of agents does not harm much in the overall reliability calculation of the system. Reliability of MAS not only depends on the network size but also on the connectivity of the links and hence on the average link failure rate as can be seen in figure 2.

2) Estimation of the reliability of MAS for MANET with addition of Quality of Service (QoS) requirement in terms of link capacity

In continuation to the their previous work, reliability of MAS was estimated with Quality of Service (QoS) requirement in terms of link capacity to be satisfied by mobile agent that is assumed to move through a

path in MANET [77]. MAS was assumed to have independent groups of agents.

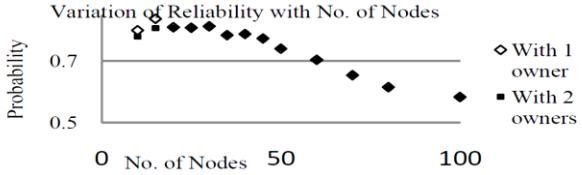

Figure 3: Variation of reliability with number of nodes

Results obtained from the simulation of MAS implementing the reliability estimation algorithm can be summarized as below.

- **i.** Reliability of the agents is highly dependent on the relative node positions which change with time.
- **ii.** Reliability drops as the MANET gets bigger.
- **iii.** Number of nodes (Figure 3), the degree of heterogeneity among the mobile agents, demanded capacity requirement of the mobile agents and transient environmental factors have an important role in the reliability prediction of MAS for MANET applications.

3) Reliability estimation of delay tolerant QoS Mobile Agent System in MANET

In addition to previous work, maximum delay was considered as another QoS requirement. Different agent groups in the system finish an independent task. Each agent group has its own QoS requirements in terms of maximum delay. It is observed that different parameters of MANET like decentralized control, time varying channels and node's mobility affects the reliability of MAS [78]. The reliability estimation has also shown that even with large number of heterogeneous agent groups with differing demands of QoS (demanded minimum capacity or maximum delay), the MAS gradually reaches a steady state.

4) Reliability estimation of MAS in MANET with Dynamic Topological and Environmental Conditions

As already seen, the reliability of MAS depends heavily on the conditions of MANET, like area covered by a node, size of MANET and node mobility. A reliability estimation model of MAS for MANET [79] was presented in terms of initial node positions and their respective speeds.

According to the presented scenario, when all MANET nodes have the same difference in speed and the overall MANET nodes are slower than normal, the nodes will remain dense ensuring higher reliability. On the other hand, for a given mean, higher the standard deviation, lesser will be the MAS reliability. This shows that when all the nodes move with comparable speed (lower standard deviation), overall reliability improves. But when some nodes lag behind the others, reliability of MAS would get hampered as the MANET breaks into a number of clusters. In general, it is observed that for a faster MANET, MAS is found to be appreciably reliable only if all the nodes move with comparable speeds. It is also observed that if the heterogeneity among mobile agents increases, even for a fixed size of MAS, reliability improves and slowly reaches a stable state. In the model, every model agent is provided with a preferred priority list of migration sites by their owner. Longer the priority list more choices will be available for the agent to choose its next destination. But still, the probability of successful migration of agent remains highly dependent on the position and connectivity of the next destination.

5) Reliability estimation of delay tolerant QoS Mobile Agent System in MANET

It is suggested that if the agents are intelligent enough to share information and learn about the underlying MANET conditions dynamically then we can make MAS on MANET more reliable. A protocol has been introduced [80] to estimate reliability of learning based agents. The results achieved have shown that learning of agents about MANET boosts the performance and improved reliability in MANET. Here also, MAS is assumed to be consisting of a number of different groups of agents where each group completes an independent task.

If a mobile agent is not able to move to a node at a particular time then it will leave that information (regarding the unavailability of a particular node or the node may be selfish) with the present node along with a timestamp. Thus other agents (from same or different groups) may read that information, update their own data and change migration policy accordingly, if necessary. Reinforcement learning technique is applied to gather connectivity information about the underlying MANET from the other agents' reported information. A blackboard

model of multi agent communication is implemented to enable such kind of knowledge sharing. Blackboard model can be considered as a window to share data, through which various mobile agents can indirectly communicate with each other by successfully reading and writing publicly available network information. The mobile agents predict their next move according to the available knowledge.

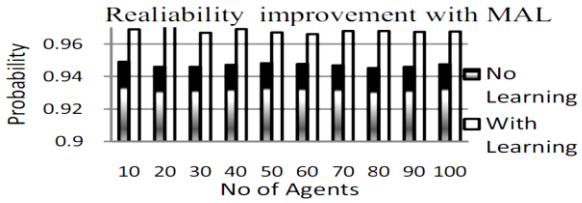

Figure 4: Improvement in Reliablity by using MultiAgent Learning Technique

Results obtained from the simulation clearly show (Figure 4) that learning of roaming agents improves MAS performance as new agents may waste no time or effort in migrating to an unreachable/selfish node rather they will try to traverse the connected portion of the MANET first. A metric Owners' View of Agent Reliability (OVAR) was introduced to reflect learning of the nodes. This metric calculates agent reliability w.r.t. its owners' view of the network.
The reliability of the MAS is calculated from average reliability of all agent groups taken over a certain time period for 'q' simulations despite the uncertainties of MANET. Results obtained from the simulation of MAS show that intelligent agents perform more reliably as they learn about dynamicity of MANET and update their migration pattern accordingly. Also it is found that when OVAR is included in reliability calculation, it produces better measure of reliability than the tradition calculation. Importantly, it was also found that if we use learned agents to face the challenges of MANET dynamics, MAS performs particularly better even in noisy environment.

6) Reliability of MAS in QoS Mobile Network

A reliability estimation algorithm for calculating the task route reliability of MAS [81] that is based on the conditions of the QoS mobile network was discussed. Mobile hosts in mobile network access useful information through wireless data communication affecting both availability and reliability of the services provided. A mobile host working as an owner creates an agent group having similar QoS requirements. Here, MAS consist of G groups of agents where each group finishes an independent task (involving different nodes) having a specific delay limit and different migration pattern (QoS parameter). Here M agents from G (<=N Mobile) groups start their travel from G owner nodes. Each owner shares the list of nodes that are highly beneficial for the assigned task among its (M/G) agents. Normal distribution was used to generate priority list of nodes for the agents where the mean of the distribution was the same for each group. The number of higher priority nodes to be visited is decided by standard deviation (X). Agents from a group exhibit more resemblance in migration pattern when X is small. Mobile agent reliability is analyzed with increasing task load on the agents by increasing X. But as X upturns further, the difference between high and low priorities reduces. Task of agent becomes tougher that results as a fall in agent's reliability. The effect of delay tolerance on mobile agent performance is analyzed. Results show that as delay limit for agents increase the agents can tolerate transient faults at wireless links more efficiently. Results obtained from the simulation carried out show that MAS performs best when half of the total nodes required to visit are assigned higher priorities over others.

5. Conclusion and Future Work

In this survey paper, first we inspect different issues / factors that affect the reliability of MAS. Reliability issues of MAS are categorized and identified according to its three basic components i.e. mobile agent, mobile agent platform and communication channel. Then, we discuss eight existing reliability estimation models to study the contribution of each identified factor towards reliability of MAS and aggregation method used to calculate overall reliability of MAS. From the literature survey presented here it can be clearly observed that while estimating reliability of MAS in different communication environments many significant factors like security issues, fault tolerance capability, agent communication method, agent mobility, learning ability of agents, flocking mechanism, agent tracking etc. are still unexplored. Thus, the list of factors and attributes identified in the survey work can be refined and augmented to include certain more unaddressed factors and attributes. Also, appropriate methodology may be selected for aggregation of individual reliability issues of all such components. Existing models for reliability assessment / allocation while designing MAS can be enhanced and/or new models may be developed by including the

contribution of each factor and attribute in dynamic computing environment.

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