



A Hierarchical Model for Reliability Estimation of Mobile Agent based Systems

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Abstract: Mobile Agent based Systems (MAS) is one of the emerging areas for application development in recent past. To ensure fault and failure free operation of MAS based commercial applications, reliability issues need to be addressed. This research paper describes a hierarchical model for reliability estimation of Mobile Agent based Systems. Different factors and their attributes affecting reliability of MAS have been listed and aggregated as per developed model. The model relates MAS reliability factor such as security to reliability attributes such as confidentiality, availability, integrity of agents. The quantitative assessment of reliability factors has been done based on analysis of the data collected from literature survey. The relationship from reliability factors to reliability attributes has been determined in accordance with their impact and significance. Various reliability factors have been used to develop an equation by empirically formulating the reliability of MAS. Main aim of our hierarchical model for reliability estimation of Mobile Agent based Systems is to develop a proper formulation for the estimation of reliability in terms of the reliability factors.

Keywords: Mobile Agents; MAS; MANET; Reliability; Reliability Model; Reliability Factors and Attributes; Reliability Estimation; Reliability indicator

I. Introduction

Reliability is still a vague and multifaceted concept, which means different things to different people. The way we measure reliability depends on the viewpoint we take. The direct assessment of reliability is very difficult. Therefore, in order to better quantify reliability, researchers have developed indirect models that attempt to measure reliability by using a set of reliability factors and their attributes.

With increasing use of MAS based commercial applications, demand of highly reliable MAS continues to intensify. MAS must ensure consistent and fault free operation every time they are used.

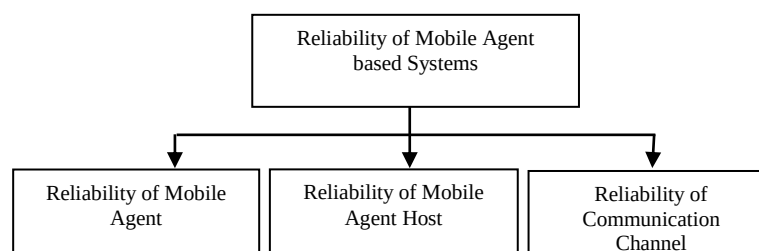
Various MAS reliability estimation models have been developed to quantify likelihood of MAS failure. Most of these models are based on MAS failure observations made during test or operation. However, in certain cases, it will be impossible to observe an adequate number of failures. Reliability models 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.

Our Hierarchical Model for Reliability Estimation of Mobile Agent based Systems defines the overall reliability assessment process through a hierarchical structure consisting of reliability factors, reliability attributes and 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.

II. Model Development

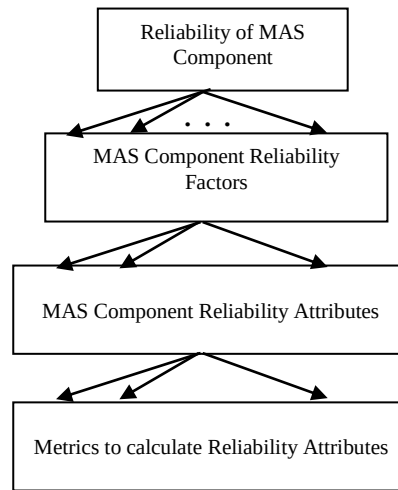
Reliability of MAS is categorized according to three different components of MAS i.e. mobile agent, mobile agent host and communication channel as shown in figure 1.

Figure 1 Distribution of Reliability of MAS



Methodology of proposed model is based on a hierarchical model for assessment of quality of object oriented design based software [1]. A general schematic for the assessment of MAS reliability of each component has been shown in the Fig. 2.

Figure 2 Schematic Hierarchical Structure for Reliability Estimation of MAS



A. Identification of MAS Component's Reliability Factors

On the basis of our literature survey [2], factors affecting reliability of MAS are refined and augmented to include certain more unaddressed factors like Security of Mobile Agent, Design & Programming of Mobile Agent, Fault-tolerance of Mobile Agent, Quality of Mobile Agent, Control Mechanism of Mobile Agent, Security of mobile agent platform, Fault-tolerance capability of mobile agent platform, Security issues of the channel and Fault-tolerance capability of communication channel.

Final optimal set of factors and related attributes to calculate each MAS component's reliability is finalized on the basis of their impact towards defining MAS reliability and their broad competence to include all aspects of MAS reliability. Security [3]-[7], fault tolerance [8]-[12], quality of mobile agent [13], control mechanism [14]-[16], dynamic topological and environmental conditions [17] and link capacity [18] were taken separately as the initial set of factors in the model. This set of factors was then further individually reviewed to see if they really contribute towards the MAS reliability.

Since the factor 'Design and Programming of Agent', and 'Inter Dependency of Agents' will be responsible for Mobile Agent Quality directly, the two factors are merged to include 'Quality of Mobile Agent', in the final set. After individual review of initial set of factors, the final set of reliability factors which has been considered in the model development is: security, fault tolerance (for all three components of MAS), quality of mobile agent, control mechanism, (for Mobile Agent), dynamic topological and environmental conditions and link connectivity (for Communication Channel).

This set of factors although extensive enough to identify desired characteristics of reliable Mobile Agent based Systems but it is not limited, and can always be changed to denote different goals and objectives. The table I, II and III give a brief definition of these factors for each component of MAS to be used in the model development.

Table I. Reliability Factors of Mobile Agents

Sr. No.	Reliability Factor	Description
1.	Security	The primary obstacle to adopt mobile agent systems
2.	Fault Tolerance	Refers to those attributes and techniques which insure that lesser number of faults and can be able to recover from faults.
3.	Quality of Mobile Agent	Refers to the ability of agent's design and code to achieve the desired functionality and behaviour
4.	Control Mechanism	Refers to locating agents, detection of orphan agents and termination of agents

Table II. Reliability Factors of Mobile Agent Platform

Sr. No.	Reliability Factor	Description
1.	Security	Refers to perform the security process for visiting mobile agents on Mobile Agent Platform
2.	Fault Tolerance	Reflects the timely detection of critical agent platform and thus prevent platform failures

Table III. Reliability Factors of Communication Channel

Sr. No.	Reliability Factor	Description
1.	Security	Refers to Securing Communications Over Insecure Channels
2.	Fault Tolerance	Reflects the timely detection & recovery of link or network failure
3.	Dynamic Topological and Environmental Conditions	Refers to the impact of lively topological and Environmental Conditions changes
4.	Link Capacity	Reflects the management of communication link capacities of the network so that Communication resource costs are minimized under Quality-of-Service constraints.

B. Identification of MAS Component's Reliability Attributes

Various attributes of the factors impacting MAS reliability discussed above are the tangible concepts that can be directly assessed by examining the relationships and functionality of the MAS components. Various attributes of individual factors affecting reliability of MAS have been frequently used in the literature [2] for assessment of MAS reliability. All shortlisted attributes of each factor used in this paper have been mentioned in table IV.

In order to develop a basis for relating reliability attributes to reliability factors, a wide study of publications and books [17]-[35] was done. The table IV shows the influence of each of the attribute on the reliability factor. An up arrow symbol ($\blacktriangle$) indicates that the related reliability attribute has positive influence on the reliability factor and the down arrow symbol ($\blacktriangledown$) indicates that the related reliability attribute has a negative influence on the reliability factor.

Table IV. Reliability Attributes of MAS

MAS Component	Reliability Factors	Reliability Attributes	Influence On MAS Reliability
Mobile Agent	Security	Confidentiality	$\blacktriangle$
		Availability	$\blacktriangle$
		Non-repudiation	$\blacktriangle$
		Authentication of origin	$\blacktriangle$
		Integrity of Agents	$\blacktriangle$
	Fault Tolerance	Agent Fault Recovery	$\blacktriangle$
	Quality of Mobile Agent	Mobile Agent Code Quality	$\blacktriangle$
	Control Mechanism	Agent Tracking	$\blacktriangle$
		Termination of useless / orphan agents	$\blacktriangle$
Mobile Agent Platform	Security	Confidentiality	$\blacktriangle$
		Integrity	$\blacktriangle$
		Availability	$\blacktriangle$
		Non-repudiation	$\blacktriangle$
	Fault Tolerance	Platform Fault Recovery	$\blacktriangle$
Comm. Channel	Security	Confidentiality	$\blacktriangle$
		Integrity	$\blacktriangle$
		Availability	$\blacktriangle$
		Non-repudiation	$\blacktriangle$
	Fault Tolerance	Channel Fault Recovery	$\blacktriangle$
	Dynamic Topological and Environmental Conditions	Channel Noise Level	$\blacktriangledown$
	Link Connectivity	Node Density	$\blacktriangle$
		Channel Bandwidth	$\blacktriangle$

C. Identification of Metrics to calculate Reliability Attributes

Each of the reliability attribute identified in the table 4 and used in this paper represents a characteristic of the factor affecting reliability of MAS that is very well defined to be quantitatively assessed by using one or more well-defined metrics. A complete overview of various metrics [34, 35, 36, 37, 38] revealed that there are several metrics that can be modified and used in the assessment of some reliability attributes but there are some attributes for which no such metrics could be found. As a result, a few new metrics have been defined and used in development of the proposed model. The complete set of metrics used in development of the proposed model is described in table V.

Table V. Reliability Metrics Descriptions

Sr. No.	Metrics	Metrics Description	Reliability Attribute Measured
To calculate Mobile Agent's Reliability Attributes			
1.	Confidentiality Impact (CC)	It measures the impact on confidentiality of a successfully exploited vulnerability.	Confidentiality
2.	Availability Impact (AC)	It measures the impact on availability of a successfully exploited vulnerability.	Availability
3.	Non-repudiation Impact (NRC)	It measures the impact on Non-repudiation of a successfully exploited vulnerability.	Non-repudiation
4.	Authentication (Au)	It measures the number of times an attacker must authenticate to a target in order to exploit a vulnerability.	Authentication of origin
5.	Integrity Impact (IC)	It measures the impact on integrity of a successfully exploited vulnerability.	Integrity of Agents
6.	Tolerated Fault Count (TFC)	It measures Number of faults tolerated per unit time.	Agent Fault Recovery
7.	Defect Density (FPC)	Defect Density calculates the ratio of defects against the code size. (Number of Defects/size).	Mobile Agent Code Quality
8.	Tracked Agent Ratio (TAR)	It represents ratio of total number of agents tracked to number of Agent in the system.	Agent Tracking
9.	Termination Ratio (TR)	It refers to the ratio of terminated useless agents with detected useless agents.	Termination of useless / orphan agents
To calculate Mobile Agent Platform's Reliability Attributes			
10.	Confidentiality Impact (CC)	It measures the impact on confidentiality of a successfully exploited vulnerability.	Confidentiality
11.	Integrity Impact (IC)	It measures the impact on integrity of a successfully exploited vulnerability.	Integrity
12.	Availability Impact (AC)	It measures the impact on availability of a successfully exploited vulnerability.	Availability
13.	Non-repudiation Impact (NRC)	It measures the impact on Non-repudiation of a successfully exploited vulnerability.	Non-repudiation
14.	Tolerated Fault Count (TFC)	It measures Number of faults tolerated per unit time.	Platform Fault Recovery
To calculate Communication Channel's Reliability Attributes			
15.	Confidentiality Impact (CC)	It measures the impact on confidentiality of a successfully exploited vulnerability.	Confidentiality
16.	Integrity Impact (IC)	It measures the impact on integrity of a successfully exploited vulnerability.	Integrity
17.	Availability Impact (AC)	It measures the impact on availability of a successfully exploited vulnerability.	Availability
18.	Non-repudiation Impact (NRC)	It measures the impact on Non-repudiation of a successfully exploited vulnerability.	Non-repudiation
19.	Tolerated Fault Count (TFC)	It measures Number of faults tolerated per unit time.	Channel Fault Recovery
20.	Noise Level (NL)	The ratio of the channel noise at any point in a transmission system to an arbitrary level chosen as a reference.	Channel Noise Level
21.	Node Density (ND)	Node Density is the number of nodes that can interfere with the channel in the area of a link.	Node Density
22.	Achievable bandwidth (AB)	Achievable bandwidth is the maximum amount of data per time unit that a link or path can provide.	Channel Bandwidth

D. Formulation for the Reliability Factors

Relationship between various reliability factors and reliability attributes has been shown in the table IV. For preparation of formulation for reliability factor in terms of the related attribute, the relative significance of attribute that influence a reliability factor has to be weighted proportionally so that the computed values of all reliability factors have the similar range. A range of 0 to +1 or -1 is selected for the computed values of the reliability factors. The weighted values of reliability attribute influences on the reliability factor should be proportionally adjusted so as to ensure that the sum of weighted values of all reliability attribute influences on a

reliability factor added to +1 or –1, the selected range for the computed values of reliability factor. Although other methods such as pair wise comparison and expert opinion aggregation etc. for weighting the influences of reliability attribute on reliability factor exist, the method discussed above has been considered because it is simple and straightforward to apply.

Because actual metric values of different ranges are combined in the computation of the reliability factor indices, the metric values have to be also normalized. The normalization can usually be done with respect to the highest metrics value in different scenarios of the MAS in the concerned framework. These normalized values of the reliability attribute metrics are to be then used for computation of the reliability factor values as per the formulation shown in table VI.

Table VI. Formulation for the Reliability Factors of MAS

Mobile Agent Reliability's Factor Computation	
Factors	Formulation for Index Computation
Security	$0.15 * \text{Confidentiality} + 0.15 * \text{Availability} + 0.25 * \text{Non-repudiation} + 0.25 * \text{Authentication of origin} + 0.20 * \text{Integrity of Agents}$
Fault Tolerance	$1.0 * \text{Agent Fault Recovery}$
Quality of Mobile Agent	$1.0 * \text{Mobile Agent Code Quality}$
Control Mechanism	$0.60 * \text{Agent Tracking} + 0.40 * \text{Termination of useless / orphan agents}$
Mobile Agent Platform Reliability's Factor Computation	
Security	$0.25 * \text{Confidentiality} + 0.25 * \text{Integrity} + 0.25 * \text{Availability} + 0.25 * \text{Non-repudiation}$
Fault Tolerance	$1.0 * \text{Platform Fault Recovery}$
Communication Channel Reliability's Factor Computation	
Security	$0.25 * \text{Confidentiality} + 0.25 * \text{Integrity} + 0.25 * \text{Availability} + 0.25 * \text{Non-repudiation}$
Fault Tolerance	$1.0 * \text{Channel Fault Recovery}$
Dynamic Topological and Environmental Conditions	$- 1.0 * \text{Channel Noise Level}$
Link Connectivity	$+0.50 * \text{Node Density} + 0.50 * \text{Channel Bandwidth}$

III. Formulation of MAS Reliability

Formulation of the MAS reliability in terms of the MAS reliability factor values will be based on the relative influence of these factors on the MAS reliability. This influence can be determined by either aggregating the opinion taken from some specified number of experts or from data available in the books and publications. The formulation proposed in this paper is based on analysis of the data collected from different books, publications and books [17]-[35].

The equation for calculating MAS reliability from the design MAS factor values is given in table VII.

Table VII. MAS Reliability Calculation

Reliability of Mobile Agent	$0.25 * \text{Security} + 0.20 * \text{Fault Tolerance} + 0.35 * \text{Quality of Mobile Agent} + 0.25 * \text{Control Mechanism}$
Reliability of Mobile Platform	$0.40 * \text{Security} + 0.60 * \text{Fault Tolerance}$
Reliability of Communication Channel	$0.25 * \text{Security} + 0.20 * \text{Fault Tolerance} + 0.15 * \text{Dynamic Topological and Environmental Conditions} + 0.40 * \text{Link Connectivity}$
Reliability of Mobile Agent	$0.40 * \text{Reliability of Mobile Agent} + 0.30 * \text{Reliability of Mobile Platform} + 0.30 * \text{Reliability of Communication Channel}$

IV. Conclusions and Future Work

The main goal of this research is to develop a proper formulation for the assessment of MAS reliability in terms of the MAS reliability factors. To accomplish this objective twenty two metrics which can be considered as useful reliability parameters of the MAS have been identified. These metrics were then related to calculate reliability attributes, which in turn were related to the reliability factors of MAS.

To conclude, the MAS reliability factors were used to properly develop a formulation for the assessment of MAS reliability. Formulation of the MAS reliability equation, reliability factor equations or establishing the relationship between reliability factors and reliability attributes are all established on the information attained from the books and publications.

This study is only the initial stage of a long-term study in predicting MAS reliability. Future research comprises identification of the MAS Reliability Prediction Systems (MRPS) of all top-ranked measures at different components of MAS. Possible tasks that allow quantification of reliability from MRPSs need to be explored and a study of outcomes so obtained can be done against the outcomes achieved from the present study. Also, verification of the outcomes obtained from this study need to be done by exhaustively accumulating values of various reliability metrics.

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