

Project ID/Title: RIGS 16-357-0521 / Strategic Profiling and Analytic Modelling of Node Misbehaviour in Adhoc Networks via Game Theory

Project Sponsor: Ministry of Higher Education Malaysia (Kementerian Pendidikan Tinggi) under Research Initiative Grant Scheme

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Abstract

Ubiquitous Computing and Internet of Things (IOT) are extremely popular in recent age and therefore imparting high level security mechanism is highly indispensable for such advanced technical systems. However, the security problems in Mobile Adhoc Networks (MANETs) are a constant topic of interest and have been drawing attention of research community from the past decade, where massive study has already been witnessed for addressing the security affairs. One of the precarious problems encountered in MANET is that of identifying the malicious nodes. This is because nodes in MANET are equally influential to take accountability during transmission. Coordination among nodes during communication and working without control of any central manager truly ensembles them to be applied in IoT. However, the identification and later mitigation of malicious nodes becomes an immensely difficult task especially when Selfish/Erroneous nodes exist along with normal Collaborative nodes in the Regular camp. The presence of selfish nodes is potentially harmful as similar behaviour can be imitated by malicious nodes which are the point of concern of many security aspects. While reviewing some techniques on the security system in MANET, it was found that game theory had a prime contribution in the past few years due to potential accuracy in its probabilistic approach and computational efficiency. Therefore, this study accentuates the use of game theory and probability theory considering selfish nodes in the regular node camp while modelling the Regular versus Malicious node game and thereby enhancing the prior mathematical schema of strategical decision making to accommodate for the same. The proposed study performs statistical analysis and presents a mathematical model to mimic the multi-stage game between regular and malicious node using Game Theory. Furthermore, it does not use any complex cryptographic protocols that tend to increase network overhead. The framework tries to effectively represent the various unpredictable actions of node cooperation, node declination, node attacks as well as node reporting that can model the strategic profiling of various mobile nodes. Understanding the patterns and then deploying the algorithms in security products can reduce intrusion to a greater extent.

Key words

Internet of Things (IoT), Routing Security, Game Theory, MANET, Malicious attacker nodes

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1. Introduction

In the modern era of networking and communication system, mobile adhoc network has increasingly attracted many researchers for its potential benefits in the line of infra-structure free communication system. A mobile adhoc network (MANET) consists of various independent wireless devices that can move at any direction. Each node is considered as a router and hence MANET is completely infrastructure-free networking system. MANET system can be considered as advanced version of wireless networking hence; it is also shrouded by all the issues that any wireless networking system may possess. Within a MANET, the entire communication system between the mobile nodes takes place in wireless environment thus extremely susceptible to vulnerabilities that are applicable in any wireless networking system. Mobile nodes are treated as routers so there doesn't exist any infrastructure, further they can move in any direction at any unpredictable time thereby mapping the topology of a MANET as of dynamic type [1]. The significance of the transmission happens in MANET system due to existing neighbouring nodes that play a pivotal role in forwarding data packets. Usually, the mobile nodes that come in transmission range of each other are termed as neighbour nodes [2]. When the mobile nodes are required to forward data packets to any of the non-neighbouring nodes, the MANET system takes the aid of series of multiple hops where the intermediate nodes behave as routers in it [3].

One of the biggest networking issues in MANET is that its transmission range as well as sensing range highly differs as the network consists of numerous. types of wireless nodes with various IEEE standards connected with each other. For this reason, the transmission boundaries are hard to be seen or defined. This is the gateway for entries of all the security breaches that may possibly occur in MANET as the wireless communication channel is highly unguarded from any types of external signals in less reliable wireless medium [2]. Moreover, as the nodes arbitrarily move hence, it often results in either portioned nodes or link breakage on the cost of communication channel established. Such issues not only give rise to QoS issues like bandwidth issues, energy issues, routing issues, but also such issues easily welcome all types of possible attacks on the MANET system. The security of the MANET system is shrouded with various security loopholes e.g. absence of infrastructure, resource limitation, restricted physical security, and more importantly the dynamic topology. It has already been seen in the

prior work [4-6] that cryptographic techniques are frequently considered and prioritized in majority of the security approaches in MANET. In sturdy association with mathematical theories, cryptographic techniques are quite challenging to design without enough researches and excavating the security analysis of MANET [5]. One of the easiest ways to find feasible solutions for accomplishing security in MANET is to explore the prior research work that claims cryptographic techniques as a solution for security. The prime aim of adopting such a step will be to accomplish a better security solution that is computationally efficient and can guarantee scalability, network performance, storage etc. As the schema of object-oriented programming can be preferably discussed using software engineering design patterns [5], similarly, cryptography is adopted very frequently in majority of the prior research to discuss secure framework that can address network breaches in MANET. Majority of the work illustrating cryptography as a solution was seen to address various attacks and mitigation techniques [7] and secure routing protocols in MANET [8]. However, it is quite challenging to decide whether cryptographic techniques should be encouraged much in next generation of research work in securing MANET system. The prime reason behind this is higher computational complexity associated with advanced cryptographic techniques.

Unfortunately, the presence of such vulnerable features of MANET permits intruders to perform malicious activity in the network where the feasibility of detection of the intruder is extremely less due to decentralization format of the network topology in MANET [9]. The cost of such attacks and intrusion has to be paid by the genuine mobile nodes where their communication system is sabotaged very badly affecting the final application performance, loss of data, eavesdropping, and massive intrusion. Further from review of literature, it can be established that solutions based on routing protocols are abundantly higher even as a part of security based techniques used in MANET, however, it should be clearly understood that purely emphasizing on the routing based approach can overlook the malicious behaviour in large scale MANET applications as various factors like node behaviour, dynamics of strategies adopted on different types of nodes are quite complex to be solved when routing approach is mechanized [10]. Although there are many ranges of issues that has been discovered in the past few decades in the area of MANET e.g. Power issues [11,12] routing issues [13], QoS issues [14], but the issues pertaining to security are still unsolved [9,10]. While there is massive volume of research work that can be witnessed from some of the major publishers, but still one

efficient system ensuring proper and failproof security is yet to be seen and standardized for future security protocols.

1.1. Problem Statement

The uncertain scenario of selection by routing protocols for communication system in MANET gives rise to one of the peak security issue i.e. authenticating genuine or malicious nodes. This is due to the absence of integrated digital certificate-based node verification system between two mobile nodes in MANET. The presence of such malicious node is potentially harmful to any MANET application and has widespread damage of the computing resources connected in MANET. There are almost multiple numbers of attacks that have been recorded almost every layer i.e. transport, application, network, data link or MAC, and physical [15]. This basically states that MANET is more vulnerable to different types of attacks that disrupt the trust and reputation system existing among the mobile nodes. The cost of attack scenario is much worst, when the network is considered for larger dimension such as IOT environment.

While performing the preliminary study of the proposed system, it was known that large amount of previous study has emphasized on usage of cryptographic protocols to secure MANET, where implementation becomes a big question mark and challenges time and space complexity of those sophisticated algorithms [5]. Majority of the work done till date is focused on Intrusion Detection System (IDS) or more focused on detection of malicious node, however, the proposed study does not attempt to create any IDS or try to identify malicious because one or the other way, the attackers are smart enough to bypass the designed security [16].

The proposed study attempts to design a mathematical model that captures the actual pattern of malicious activities in MANET based on probability theory as well as considering presence of erroneous / selfish nodes among the regular nodes. The scenario is considered in this way to address the loopholes of security in large scale MANET considering multi-stage game theory. Understanding the pattern and then deploying the algorithms in security products will reduce the intrusion or malicious behavior to a greater extent. Evaluating the pattern can give an empirical finding about the feasibility of various events (good or malicious activities) of a mobile node that can actually exhibit lots of hidden traits of the strategies adopted by mobile nodes (that may be regular or malicious). Therefore, providing solution as mitigation

techniques can be designed precisely based on actual analysis of the behavior of the malicious nodes in MANET.

2. Background

MANET in the IoT perspective can be designated as a group of smart machines capable of communicating self-sufficiently even in absence of any centrally governing infrastructure and this network is progressively prominent in transmission of future smart peripheral procedures in Internet of Things. Research is going on by MANET work group for systematizing secure routing conventions for such type of IoT empowered MANETS. At the present, MANET based Routing protocols have their own margins; therefore, designing advanced routing protocols is very much indispensable for securing MANETS since the Mobile MANET Smart devices have to concurrently operate as intermediary nodes for forwarding, routers, data sources and endpoints. Maintaining Quality of service for IoT applications is a challenging task as well. Moreover, the interest of the research community in security games has consistently increased during the last years since they provide a quantitative framework for modeling the interactions between malicious users and defense systems. The previous record of studies concerned with the mitigation of misbehavior problem of nodes in MANET environment has been tabulated in Table 1. Although such techniques are quite successful in formulating tactics for managing selfish nodes in the environment of MANET, however, some couldn't successfully accomplish the ultimate effective routing policies and maximize QoS throughput. Further, this section also discusses about the literature which specifically employs Game Theory as a tool while securing MANETS.

Table 1. Summary of the findings

AUTHOR	CONTRIBUTION	RESULT OBTAINED	LIMITATIONS
(Wang and Wu) [17]	Proposed Global punishment based repeated-game model to stimulate node cooperation.	-Proposed model enhances node forwarding probability	-Focusing on the node forwarding process rather than malicious behavior detection or analysis.

			-Not applicable for Sybil attack, newcomer attack, collusion attacks.
(Suganya and Priya) [18]	Presented a new replication allocation technique	-Reduced routing misbehavior in delay tolerant network.	-Effect of false positives is not considered. -Existence of Malicious Nodes not considered.
(Sengathir and Manoharan) [19]	Developed a security add-on for Multicast Adhoc On Demand Distance Vector protocol	-Effective in detecting misbehaving node.	-No line drawn between Selfish and Malicious Nodes. -Malicious Nodes Modeled as fragile. -Not applicable to other routing protocols.
(Rath and Panigrahi) [20]	Presented major security related issues due to cooperation of MANET and IoT	-Encouraged the need for development of more secured, challenging and intelligent routing protocols at the intersection of MANETs and Internet of Things.	
(Wang et al.) [21]	Proposed Mean Field Game Theoretic Approach for Security Enhancements in	-Significantly improves the lifetime of MANET and reduces the	-Scenario of multiple attackers and multiple defenders not taken into account

	Mobile Ad hoc Networks	compromising probability -Enables an individual node in MANET to make distributed security defense decisions	
(Kumar et al.) [22]	Designed a novel mechanism to detect misbehavior by a 2-hop acknowledgement.	-Increase in Packet delivery ratio with the add-on for the DSR routing Scheme. -System works pretty good even in presence of comparable No. of misbehaving nodes.	-Focused on the problem of detecting misbehaving links instead of misbehaving nodes. -Result fetched on a single Routing Protocol i.e. DSR -Effective with consideration of dense MANET environment otherwise will cause network partitioning.
(Rachedi et al.) [23]	Applied Reverse game theory on cluster model to simulate cooperation.	-Prolonged cluster lifetime. -Increased number of clusters and reduction in cluster's size.	-Validation with respect to security is not done. -Malicious behavior is not discussed
(Li et al.) [24]	Proposes a game theoretic framework to analyze the strategy profiles for	-Formulated PBE strategy outperforms both pure and mixed strategies.	-Does not consider the selfish nodes in the regular node camp.

	regular and malicious nodes.		-Collusion between Malicious nodes not considered.
(Hamdi and Abie) [25]	Proposes a game-based model for adaptive security in the IoT, with an emphasis on e-Health applications	-Extends the lifetime of the smart things by 47% compared to existing models. -Strikes a balance between security-effectiveness and energy-efficiency	-Simulated on limited threat scenarios only

3. Objectives

The prime aim of the proposed study is to perform a statistical analysis and thereby design a mathematical model that illustrates the tussling among regular and malicious nodes under diverse vulnerable security condition taking into account the disagreement in node cooperation by the selfish / erroneous nodes within the regular camp. The specific objectives are following:

1. To conduct a critical review into various sets of the prior research works done in the area of security system in mobile adhoc network that pertains to the misbehavior problems of the mobile nodes to discuss the prominence of open issues in the same.
2. To design a strategic decision making mathematical model using game theory taking into account the tactics adopted by regular node, selfish node, and malicious node and thereby design the game specification.
3. To formulate the assessment parameters that results either in attack or in deporting mechanism to other clusters in order to study the decision level of the mobile nodes and perform extracting the information related to the condition of decision model for regular nodes to report and update the MANET and attacker node to deport from the attacked cluster.

4. To assess the complexity of node misbehavior by simulating the disagreement in node cooperation due to selfishness along with malicious node attacks in multiple levels of game and formulate the condition of belief system when the nodes chooses to cooperate, or decline, or initiate attack in the considered environment of MANET.
5. To conduct a comparative performance analysis, considering the prior work with the proposed system with respect to evaluation of Detected False positives and the Utility of Regular and Malicious Node

4. Methodology

The process flow diagram for the proposed system is given in Figure 1. The past research works in this domain [19] have failed to take into account the feasibility that diverse threat frequencies may be chosen by an intruder towards diverse adversaries, but the proposed study takes into consideration more sophisticated and smart malicious nodes thus causing the competition between malicious and regular nodes to be more realistic. The framework proposed has classified the malicious/regular nodes by making use of a multi-phase strategy i.e. virtual competition for finding the optimal scheme of malicious and regular nodes to compute general decision-making process. The regular node is assisted by the neighbouring surveillance strategy for receiving feedback from the adjacent neighbouring nodes at that time and also computing the adequacy and trust of proof towards conflicting nodes based on the number of attacks on routing and the identified cooperation. A threshold schema is incorporated in the proposed system for choosing the rating of nodes in the logical region as malicious or not. If the node is not rated as malicious, then regular node opts to provide probability support based on the level of trust. Other than this, malicious nodes estimate the risk to get caught in their present locations; therefore, they follow their protocol for deciding whether or not they should decamp to some other logical region. The malicious node decides to attack if the node does not decamp to some other region. The most significant issue in such a decision process is to work out deciding rules for regular as well as malicious nodes consequent with the event profiles given away by the probability of cooperation by regular nodes or probability of attack by the malicious node. Moreover, the system identifies the events and best possible decision protocols by analysing the mobile adhoc network when the framework desiring to attain Perfect Bayesian Equilibrium is deployed. The proposed system

incorporates a multi-collusion-based attacker model in which attacker nodes cooperate with each other in order to conduct attacks.

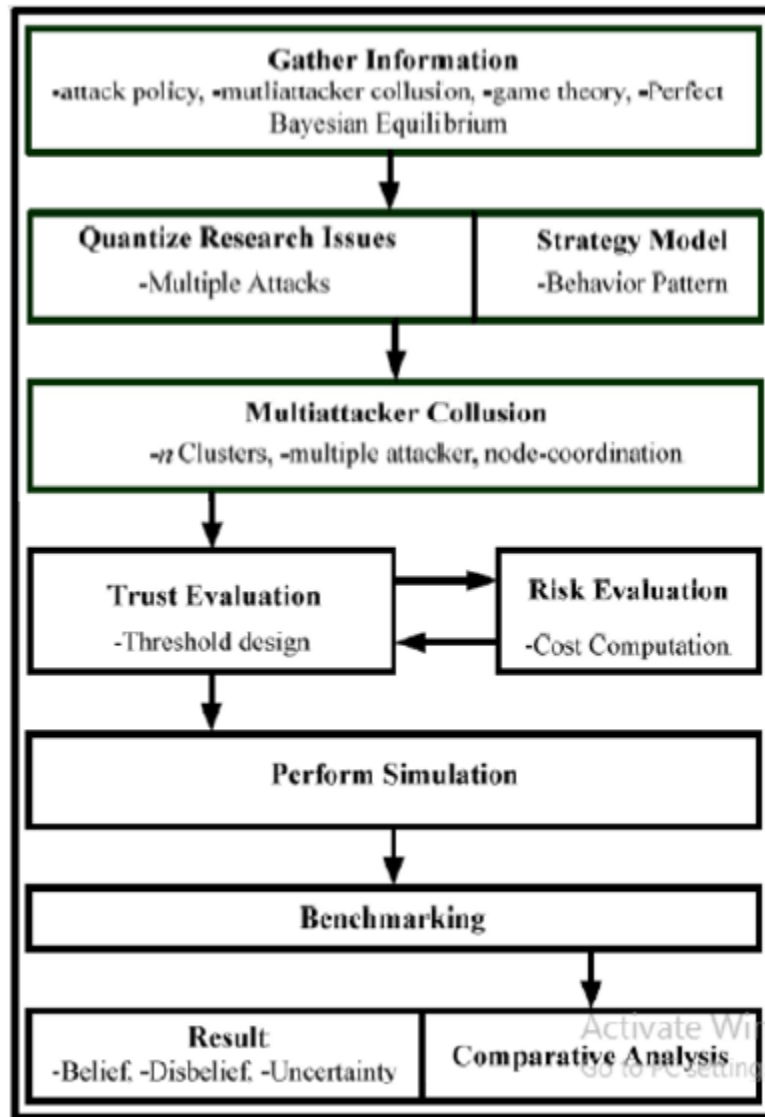


Figure 1. Process Flow of the Research

The simulation is being carried out for four different combinations, thus giving rise to four scenarios as described below:

Scenario-1: This scenario considers the prior decision-making model in completely collaborative environment.

Scenario-2: This scenario considers proposed decision-making model in completely collaborative environment.

Scenario-3: This scenario considers prior decision-making model in partially collaborative environment.

Scenario-4: This scenario considers proposed decision-making model in partially collaborative environment.

Completely collaborative environment means all nodes within the regular nodes are always collaborative; selfishness is never exhibited by regular nodes (SF for all regular nodes = 0). Partially collaborative environment portrays a situation wherein regular nodes may choose to behave selfishly at some point of time in the game i.e. (SF for all regular nodes $\neq 0$).

5. Findings

The results accomplished in this study are the outcome of the collective evaluation of i) Pure Strategy, ii) Mixed Strategy, and iii) PBE strategy. The evaluation is performed under a controlled research environment where every simulation parameter has played a significant role in furnishing the results from various scenarios however the simulation parameters were kept constant for all of the four scenarios for the purpose of comparison. Hence, the accomplished results can be further debated as below:

5.1. Utility of Regular Nodes

It has already been ascertained that the PBE strategy outperforms other strategies in all the four scenarios considered, hence will be formed as the basis of all the result analysis. Figures 2 and 3 depict the utility comparison of regular nodes for the proposed and prior model in completely collaborative and partially collaborative MANET environments respectively. The results fetched in figures 2 and 3 clearly point out to an important fact that there is a radical decrease in the overall network utility (modelled as regular node utility here) when selfish nodes exist among them. Average decline in regular node utility due to selfishness accounts to 24% (approximately). This means the selfishness when exhibited by nodes is in particular one of the core reasons for communication degradation in MANET.

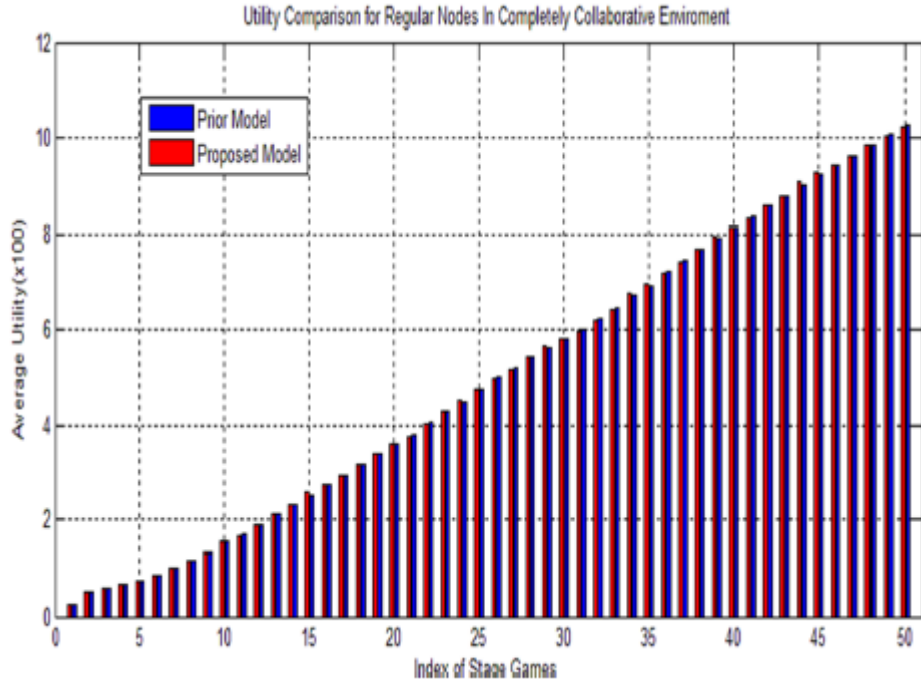


Figure 2. Regular Nodes Utility Comparison with Proposed and Prior Model in Completely Collaborative Environment

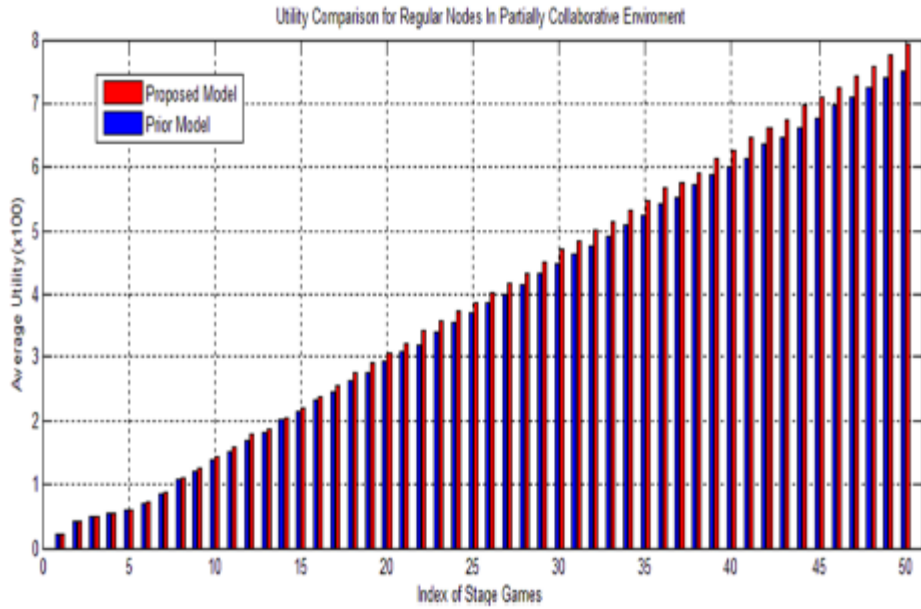


Figure 3. Regular Nodes Utility Comparison with Proposed and Prior Model in Partially Collaborative Environment

5.2. Utility of Malicious Nodes

PBE strategy is formed as the basis for analysing the utility of malicious nodes. Figures 4 and 5 depict the utility comparison of malicious nodes for the proposed and prior model in completely collaborative and partially collaborative MANET environments respectively. It can be clearly established from figures 4 and 5 that the average utility score of malicious nodes is almost the same with the prior and the proposed decision model in both MANET environments.

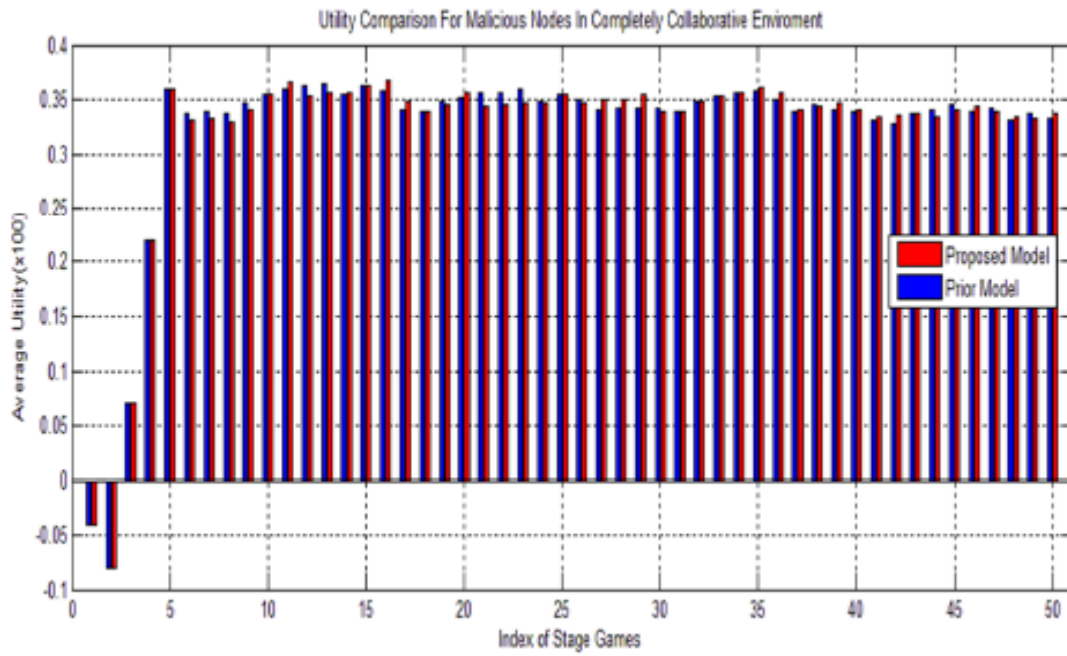


Figure 4. Malicious Nodes Utility Comparison with Proposed and Prior Model in Completely Collaborative Environment

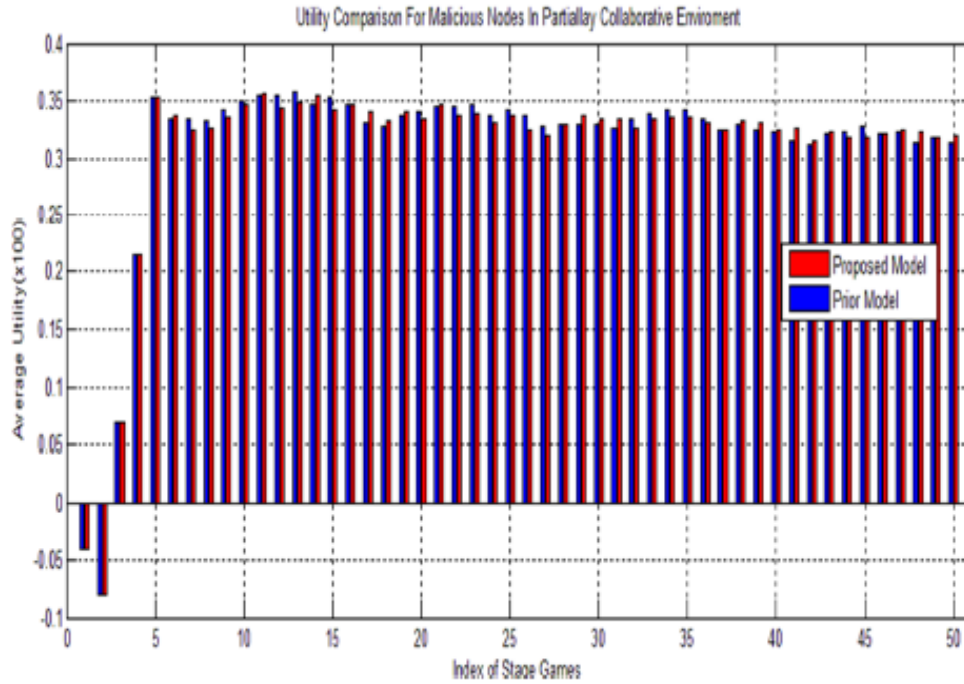


Figure 5. Malicious Nodes Utility Comparison with Proposed and Prior Model in Partially Collaborative Environment

5.3. Detected False Positives

When the proposed and prior models were checked for false positives in completely collaborative environment, none was recorded. Figure 6 presents the false reporting done by regular nodes against other regular nodes. The nodes which were wrongly reported as malicious were all selfish nodes only with the proposed model, but that has not been the case with the prior model, even collaborative regular nodes have been alleged as malicious. Occurrence of false positives started early with the prior model in the sixth stage of the game, however with the proposed model the first false positive was detected after the twelfth stage only. Some occurrences of false positives were found in identical triplets with the prior model, however no such occurrence was observed with the current one.

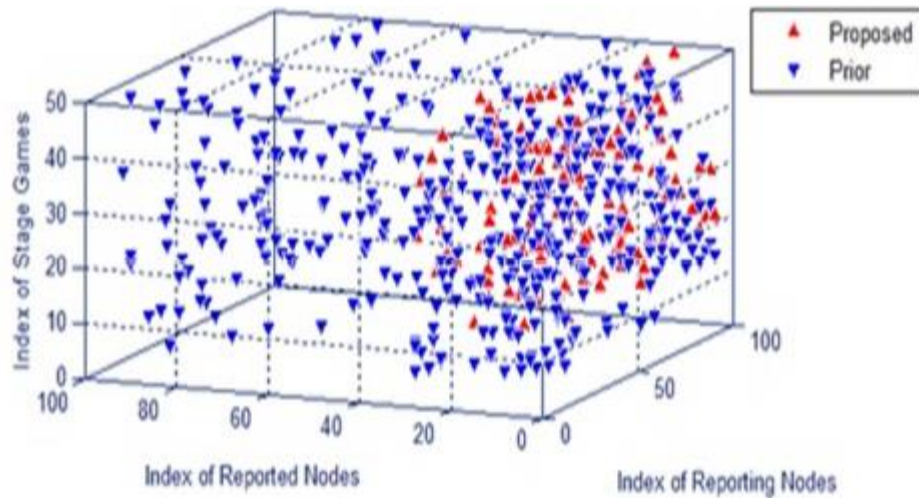


Figure 6. Detected False Positives with Prior and Proposed Model in Partially Collaborative Environment

6. Conclusion

The framework presented in this study has been conceived as virtual competition that is mapped with expected strategies so that it can be used for updating by regular node and attacking by malicious node employing Perfect Bayesian Equilibrium. The simulation results have shown improved accuracy for capturing malicious nodes, with respect to their behavior at all stages and their strategy for decamping to some other logical region. The proposed study has been able to identify some computationally challenging task related to the security of MANETs by employing game theory for the analysis of behavioral patterns of different kinds of nodes in a MANET. The proposed system is able to demonstrate the motivation behind the behavior adopted by the nodes taking into account malicious as well as regular nodes. The efficiency of the framework proposed can be owed to the employment of Perfect Bayesian Equilibrium in order to understand the impact of several empirical parameters (such as payoff, belief, cooperation/attack, uncertainty, etc.) that are evaluated during the simulation process. It is understood that the results obtained can further lead to research works in this domain for effectively addressing the modelling of malicious node activities in MANETs.

7. Output

1. A comprehensive evaluation of various sets of prior research works done in the area of security system in mobile adhoc network that pertain to the misbehavior problems of the mobile nodes and latter deducing open issues from the same
2. Formulation of a Bayesian game framework to study the strategy of collaborative, selfish/erroneous and malicious nodes in MANETs.
3. Proposition of decision rules for regular nodes to report and malicious nodes to depot, which comply with the sequential rationality requirement.
4. Comparison of Equilibrium strategy profiles for different types of nodes to reveal the hidden connection between a mobile nodes best response and cost and gain of each individual strategy.
5. Patent on the novel framework that illustrate the rationale behind the node's adopted behaviour considering regular, selfish, erroneous and malicious nodes within the MANET environment; thus, validating itself as a feasible non-cryptographic solution for securing deployed adhoc networks.

8. Future Plan of the Research

Currently, the proposed system doesn't consider the detection or identification of a specific malicious nodes present in the simulation environment; Nevertheless, it extracts cumulative and quantified empirical results of the malicious behaviour. However, combining the proposed model with an existing credit-based approach can lead to the formation of a non-cryptographic Intrusion Detection System which would solve major security hurdles in continual deployment of IOT.

In future, further pattern of behaviours based on machine learning process can be evolved for mitigating effect of malicious node by distinguishing nodes as collaborative, selfish and malicious with the MANET system. In order to have real time adoption, many possible game scenarios should be developed, and the pattern-based machine learning mechanism should be adopted to mitigate the effect of malicious node effect in real time scenario.

9. References

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