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Collaborative Trust-based Secure Routing based Ad-hoc Routing Protocol

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ABSTRACT:
The current existing Authenticated Routing for Ad Hoc Networks (ARAN) secure routing protocol is capable of defending itself against most malicious nodes and their different attacks. However, ARAN is not capable of defending itself against any authenticated selfish node participating in the network. Therefore, the objective of my thesis is to make the Authenticated Routing for Ad Hoc Networks secure routing protocol capable of defending itself against authenticated selfish nodes participating in the mobile ad hoc network. The resulting new protocol is called Reputed-ARAN. This work is done by integrating a reputation-based scheme, to detect, punish and isolate selfish nodes, to currently existing ARAN protocol and then measuring the effectiveness of that integration.

1. INTRODUCTION

To understand routing principles in a MANET, it is a good idea to take a look at conventional routing algorithms such as distance vector, link state, flooding and source routing. This is because many of the routing protocols for a MANET have roots in traditional routing concept as underlying algorithm.[4]

1.1 Distance vector

The distance vector technique is based on that every node maintains a forwarding table with the best route to every node in a network. In a certain time interval the information is sent to every neighboring node in the network. These nodes then conduct a comparison between their own routing table and the received one. If the distance between any nodes in the received table is smaller compared to the one at hand, the node updates the routing table with the new value. If the value that is in the forwarding table is from the node that now is sending a new value, the node updates the forwarding table regardless of if the value is bigger than the existing one. This procedure is continuous so that each and every node has an updated forwarding table with the shortest path to all nodes in the network.

1.2 Flooding

With this technique every packet is sent to every node in the network and is broadcasted by the receiving nodes exactly once. Each node receiving the packet broadcasts it to every neighboring node, except the one it received it from. These, neighboring nodes, in term do the same and so on. To avoid retransmitting the same packet twice every packet is tagged with a source address and a sequence number which serve as a unique identifier. With these identifiers each node keeps track of which packets they have transmitted.
This approach has a very high consumption of network resources since every packet is sent to every possible node to ensure that the packet arrives to its destination. On the other hand it results in an extremely high delivery ratio [4].

1.3 Link state routing

Link state routing works almost like distance vector when it comes to the usage of a forwarding table. What differentiates them is how the table is updated. Link state generates its table so that every node keeps a map over the nodes in the network. From this map every node can use a shortest path algorithm to decide which way is the shortest to each destination and hence know what the next hop should be in the forwarding table. When there is a change in the network, for example a node connects or disconnects, a message is sent throughout the network to announce the change [1] .The message is called a link state advertisement (LSA) and is passed through the network by flooding. All nodes receive the message and update their maps accordingly. If this method is compared with the method used in distance vector, it makes link state routing more reliable, easier to detect errors and consume less bandwidth. This is because link state routing uses event-triggered updates instead of periodic updates as in distance vector [4].

2. LITERATURE REVIEW

Security in MANET is an essential component for basic network functionalities like packet forwarding and routing. Network operation can be easily jeopardized if security countermeasures are not embedded into basic network functions at the early stages of their design. In mobile ad hoc networks, network basic functions like packet forwarding, routing and network management are performed by all nodes instead of dedicated ones. In fact, the security problems specific to a mobile ad hoc network can be traced back to this very difference. Instead of using dedicated nodes for the execution of critical network functions, one has to find other ways to solve this because the nodes of a mobile ad hoc network cannot be trusted in this way [2].

There are basically two types of security threats to a routing protocol, external and internal attackers. An external attacker can be in the form of an adversary who injects erroneous information into the network and cause the routing to stop functioning properly [2]. The internal attacker is a node that has been compromised, which might feed other nodes with incorrect information. Fig. 3.1 illustrates the different attacks that can be made towards a network. [3,6].

2.1 Active and Passive Attacks

Security exposures of ad hoc routing protocols are due to two different types of attacks: active and passive attacks. In active attacks, the misbehaving node has to bear some energy costs in order to perform some harmful operation. In passive attacks, it is mainly about lack of cooperation with the purpose of energy saving. Nodes that perform active attacks with the aim of damaging other nodes by causing network outage are considered to be malicious while nodes that perform passive attacks with the aim of saving battery life for their own communications are considered to be selfish.

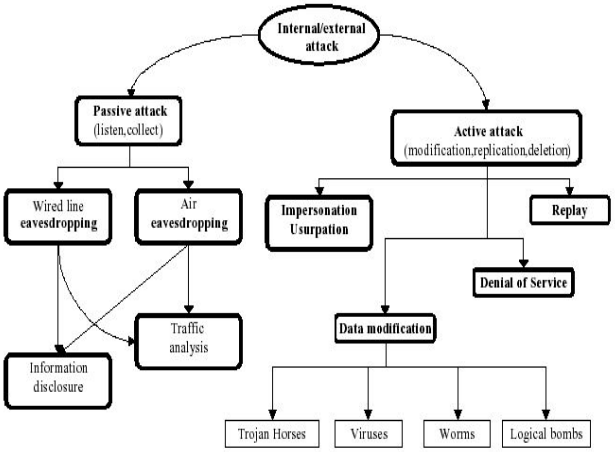

Fig.1: Different sorts of attacks

2.2 Malicious and Selfish Nodes in MANETs

Malicious nodes can disrupt the correct functioning of a routing protocol by modifying routing information, by fabricating false routing information and by impersonating other nodes. On the other side, selfish nodes can severely degrade network performances and eventually partition the network by simply not participating in the network operation.In existing ad hoc routing protocols, nodes are trusted in that they do not maliciously tamper with the content of protocol messages transferred among nodes. Malicious nodes can easily perpetrate integrity attacks by simply altering protocol fields in order to subvert traffic, deny communication to legitimate nodes (denial of service) and compromise the integrity of routing computations in general. As a result the attacker can cause network traffic to be dropped, redirected to a different destination or to take a longer route to the destination increasing communication delays. A special case of integrity attacks is spoofing whereby a malicious node impersonates a legitimate node due to the lack of authentication in the current ad hoc routing protocols. The main result of spoofing attacks is the misrepresentation of the network topology that possibly causes network loops or partitioning.

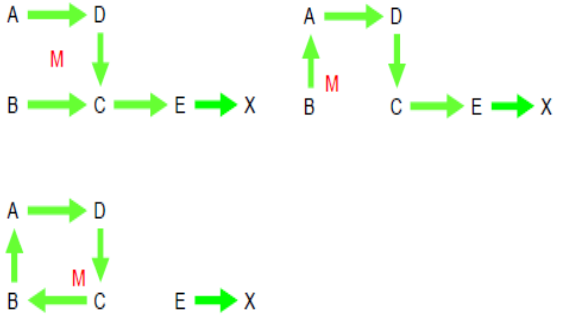

Fig. 2: Impersonation to create loops

In the above figure, a malicious attacker, M, can form a routing loop so that none of the four nodes can reach the destination. To start the attack, M changes its MAC address to match A's, moves closer to B and out of the range of A. It then sends an RREP to B that contains a hop count to X that is less than the one sent by C, for example zero. B therefore changes its route to the destination, X, to go through A. M then changes its MAC address to match B's, moves closer to C and out of range of B, and then sends to C an RREP with a hop count to X lower than what was advertised by E. C then routes to X through B. At this point a loop is formed and X is unreachable from the four nodes. Lack of integrity and authentication in routing protocols can further be exploited through "fabrication" referring to the generation of bogus routing messages. Fabrication attacks cannot be detected without strong authentication means and can cause severe problems ranging from denial of service to route subversion. A more subtle type of active attack is the creation of a tunnel (or wormhole) in the network between two colluding malicious nodes linked through a private connection bypassing the network. This exploit allows a node to short-circuit the normal flow of routing messages creating a virtual vertex cut in the network that is controlled by the two colluding attackers.

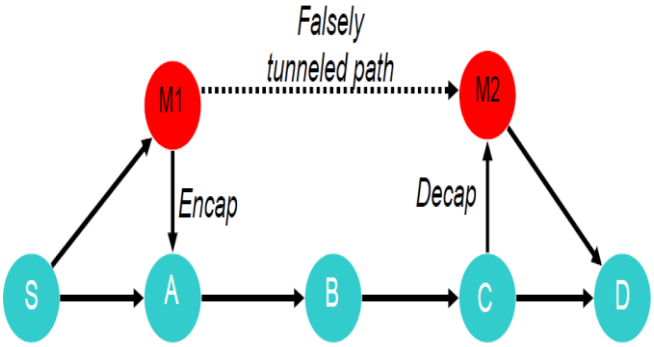

Fig. 3: Wormhole Attack

In the above figure, M1 and M2 are malicious nodes collaborating to misrepresent available path lengths by tunneling route request packets. Solid lines denote actual paths between nodes, the thin line denotes the tunnel, and the dotted line denotes the path that M1 and M2 falsely claim is between them. Let us say that node S wishes to form a route to D and initiates route discovery. When M1 receives a RDP from S, M1 encapsulates the RDP and tunnels it to M2 through an existing data route, in this case {M1->A->B->C->M2}. When M2 receives the encapsulated RDP, it forwards the RDP on to D as if it had only traveled {S->M1-

>M2->D}. Neither M1 nor M2 update the packet header to reflect that the RDP also traveled the path {A->B->C}. After route discovery, it appears to the destination that there are two routes from S of unequal length: {S->A->B->C->D} and {S- >M1->M2->D}. If M2 tunnels the RREP back to M1, S would falsely consider the path to D via M1 a better choice (in terms of path length) than the path to D via A.

Another exposure of current ad hoc routing protocols is due to node selfishness that results in lack of cooperation among ad hoc nodes. A selfish node that wants to save battery life, CPU cycles and bandwidth for its own communication can endanger the correct network operation by simply not participating in the routing protocol or by not forwarding packets and dropping them whether control or data packets. This type of attack is called the black-hole attack. Current Ad Hoc routing protocols do not address the selfishness problem and assumes that all nodes in the MANET will cooperate to provide the required network functionalities [2,4,5].

2.3 Routing Protocols' Security Requirements

To solve the security issue in an ad hoc network and make it secure we have to look at a number of requirements that have to be achieved. These requirements are: availability, confidentiality, integrity, authentication and non-repudiation [7].

The network must at all times be available to send and receive messages despite if it is under attack. An attack can be in the form of a denial of service or an employed jamming to interfere with the communication. Other possible threats to the availability are if an attacker disrupts the routing protocol or some other high-level service and disconnects the network. The node itself can also be the problem to availability. This is if the node is selfish and will not provide its services for the benefit of other nodes in order to save its own resources like, battery power. Confidentiality provides secrecy to sensitive material being sent over the network. This is especially important in a military scenario where strategic and tactical information is sent. If this information would fall into enemy hands it could have devastating ramifications. Integrity ensures that messages being sent over the network are not corrupted. Possible attacks that would compromise the integrity are malicious attacks on the network or benign failures in the form of radio signal failures. Authentication ensures the identity of the nodes in the network. If A is sending to B, A knows that it is B who is receiving the message. Also B knows that it is A who is sending the message. If the authentication is not working, it is possible for an outsider to masquerade a node and then be able to send and receive messages without anybody noticing it, thus gaining access to sensitive information. Non-repudiation makes it possible for a receiving node to identify another node as the origin of a message. The sender cannot deny having sent the message and are therefore responsible for its contents. It is particularly useful for detection of compromised nodes. However, because there are so many threats to protect from, there can not be a general solution to them all. Also different applications will have different security requirements to take into consideration. As a result of this diversity, many different approaches have been made which focus on different parts of the problems. In the coming section, a comparison of some of the existing secure mobile ad hoc routing protocols with respect to most of the fundamental performance parameters will be given [8].

3.PROPOSED REPUTATION BASED AUTHENTICATION SCHEME

Performance of Mobile Ad Hoc Networks is well known to suffer from free-riding, selfish nodes, as there is a natural incentive for nodes to only consume, but not contribute to the services of the system. In the following, the definition of selfish behavior and the newly designed reputation-based scheme, to be integrated with normal ARAN routing protocol ending up having Reputed-ARAN, are presented.

3.1 Problem Definition

Whereas most of the attacks performed by malicious nodes can be detected and defended against by the use of the secure routing ARAN protocol, as was explained earlier, there remain the attacks that an authenticated selfish node can perform.

There are two attacks that an authenticated selfish node can perform that the current ARAN protocol cannot defend against. To illustrate these two possible attacks that a selfish node can use to save its resources in a MANET communication that allows the categorization of attacks that lead an attacker to reach a specific goal is used. In the below table, the attack tree that cannot be detected by current ARAN protocol is shown:

Attack tree: Save own resources
OR 1. Do not participate in routing
1. Do not relay routing data
OR 1. Do not relay route requests
2. Do not relay route replies
2. Do not relay data packets
1. Drop data packets

Table 1: Attack Tree: Save own resources

All the security features of ARAN fail to detect or defend against these attacks, as they focus only on the detection of malicious nodes' attacks and not the authenticated selfish nodes' attacks. ARAN protocol assumes that authenticated nodes are to cooperate and work together to provide the routing functionalities.

3.2 Proposed Reputation-based Scheme

3.2.1 Introduction

As nodes in mobile ad hoc networks have a limited transmission range, they expect their neighbors to relay packets meant for far off destinations. These networks are based on the fundamental assumption that if a node promises to relay a packet, it will relay it and will not cheat. This assumption becomes invalid when the nodes in the network have tangential or contradictory goals. The reputations of the nodes, based on their past history of relaying packets, can be used by their neighbors to ensure that the packet will be relayed by the node. In the upcoming subsections, a discussion of a simple reputation-based scheme to detect and defend against authenticated selfish nodes' attacks in MANETs built upon the ARAN protocol is presented. Sometimes authenticated nodes are congested and they cannot fulfill all control packets broadcasted in the MANET so they choose not to reply to other requests in order to do their own assigned load according to their battery,

performance and congestion status. My scheme do not forward control packets, by considering the reputation value of the node asking others to forward its packets. If the packet has originated from a low-reputed node, the packet is put back at the end of the queue of the current node and if the packet has originated from a high-reputed node, the current node sends the data packet to the next hop in the route as soon as possible. This scheme helps in encouraging the nodes to participate and cooperate in the ad hoc network effectively. Moreover attacks in which authenticated nodes promise to route data packets by replying to control packets showing their interest in cooperation in forwarding these data packets but then they become selfish and start dropping the data packets. This is done by giving incentives to the participating nodes for their cooperation. The proposed scheme is called Reputed-ARAN. Different from global indirect reputation-based schemes like Confidant and Core, the proposed solution uses local direct reputations only like in Ocean reputation-based scheme. Each node keeps only the reputation values of all direct nodes it dealt with. These reputation values are based on the node's firsthand experience with other nodes. My work is partially following the same methodology about reputation systems for AODV.

3.2.2 Design Requirements

The following requirements are set while designing the reputation-based scheme to be integrated with the ARAN protocol:

➔The reputation information should be easy to use and the nodes should be able to ascertain the best available nodes for routing without requiring human intervention.

➔The system should not have a low performance cost because low routing efficiency can drastically affect the efficiency of the applications running on the ad hoc network.

➔Nodes should be able to punish other selfish nodes in the MANET by providing them with a bad reputation.

➔The system should be built so that there is an injection of motivation to encourage cooperation among nodes.

➔The collection and storage of nodes' reputation values are done in a decentralized way.

➔The system must succeed in increasing the average throughput of the mobile ad hoc network or at least maintain it.

3.2.3 Main Idea of the Reputation System

In the proposed reputation scheme, all the nodes in the mobile ad hoc network will be assigned an initial value of null (0) as in the Ocean reputation-based scheme. Also, the functionality of the normal ARAN routing protocol in the authenticated route setup phase will be modified so that instead of the destination unicasts a RREP to the first received RDP packet of a specific sender only, the destination will uncast a RREP for each RDP packet it receives and forward this RREP on the reverse-path. The next-hop node will relay this RREP. This process continues until the RREP reaches the sender. After that, the source node sends the data packet to the node with the highest reputation. Then the intermediate node forwards the data packet to the next hop with the highest reputation and the process is repeated till the packet reaches its destination. The destination acknowledges the data packet (DACK) to the source that updates its reputation table by giving a recommendation of (+1) to the first hop of the reverse path. All the intermediate nodes in the route give a recommendation of (+1) to their respective next hop in the route and update their local reputation tables. If there is a selfish node in the route, the data packet does not reach its destination. As a result, the source does not receive any DACK for the data packet in appropriate time. So, the source gives a recommendation of (-2) to the first hop on the route. The intermediate nodes also give a recommendation (-2) to their next hop in the route up to the node that dropped the packet. As a consequence, all the nodes between the selfish node and the sender, including the selfish node, get a recommendation of (-2). The idea of giving (-2) to selfish nodes per each data packet dropping is due to the fact that negative behavior should be given greater weight than positive behavior. In addition, this way prevents a selfish node from dropping alternate packets in order to keep its reputation constant. This makes it more difficult for a selfish node to build up a good reputation to attack for a sustained period of time [23]. Moreover, the selfish node will be isolated if its reputation reached a threshold of (-40) as in the Ocean reputation-based scheme. In the following table, the default Reputed-ARAN parameters are listed:

Initial Reputation	0
Positive Recommendation	+1
Negative Recommendation	-2
Self fish Drop Threshold	-40
Re-induction Time out	5 Minutes

Table 2: Reputed-ARAN Default parameters

The proposed protocol will be structured into the following four main phases, which will be explained in the subsequent subsections:

- Route Lookup Phase
- Data Transfer Phase
- Reputation Phase
- Timeout Phase

3.2.3.1 *Route Lookup Phase*

This phase mainly incorporates the authenticated route discovery and route setup phases of the normal ARAN secure routing protocol. In this phase, if a source node S has packets for the destination node D, the source node broadcasts a route discovery packet (RDP) for a route from node S to node D. Each intermediate node interested in cooperating to route this control packet broadcasts it throughout the mobile ad hoc network; in addition, each intermediate node inserts a record of the source, nonce, destination and previous-hop of this packet in its routing records. This process continues until this RDP packet reaches the destination. Then the destination unicasts a route

reply packet (RREP) for each RDP packet it receives back using the reverse-path. Each intermediate node receiving this RREP updates its routing table for the next-hop of the route reply packet and then unicasts this RREP in the reverse-path using the earlier-stored previous-hop node information. This process repeats until the RREP packet reaches the source node S. Finally, the source node S inserts a record for the destination node D in its routing table for each received RREP.

In the below fig., the route lookup phase is presented in details, illustrating the two phases of it, the authenticated route discovery phase and the authenticated route setup phase.

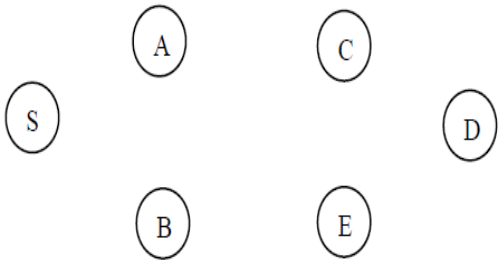

Fig. 4: A MANET Environment

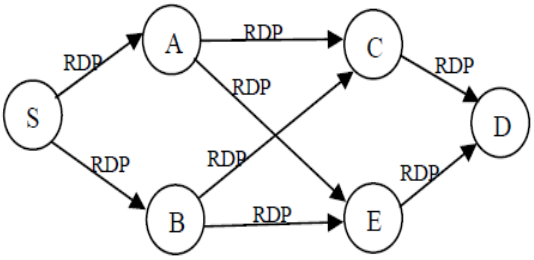

Fig. 5: Broadcasting RDP

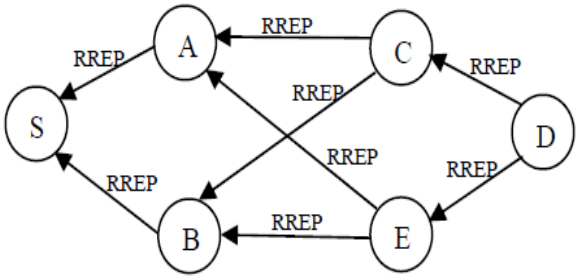

Fig. 6: Replying to each RDP

3.2.3.2 *Data Transfer Phase*

At this time, the source node S and the other intermediate nodes have many RREPs for the same RDP packet sent earlier. So, the source node S chooses the highly-reputed next-hop node for its data transfer. If two next-hop nodes have the same reputation, S will choose one of them randomly, stores its information in the sent-table as the path for its data transfer. Also, the source node will start a timer before it should receive a data acknowledgement (DACK) from the destination for this data packet. Afterwards, the chosen next-hop node will again choose the highly-reputed next-hop node from its routing table and will store its information in its sent-table as the path of this data transfer. Also, this chosen node will start a timer, before which it should receive the DACK from the destination for this data packet. This process continues till the data packet reaches the destination node D. And of course in this phase, if the data packet has originated from a low-reputed node, the packet is put back at the end of the queue of the current node. If the packet has originated from a high-reputed node, the current node sends the data packet to the next highly-reputed hop in the route discovered in the previous phase as soon as possible. Once the packet reaches its destination, the destination node D sends a signed data acknowledgement packet to the source S. The DACK traverses the same route as the data packet, but in the reverse direction.

In the following fig., the data transfer phase is illustrated:

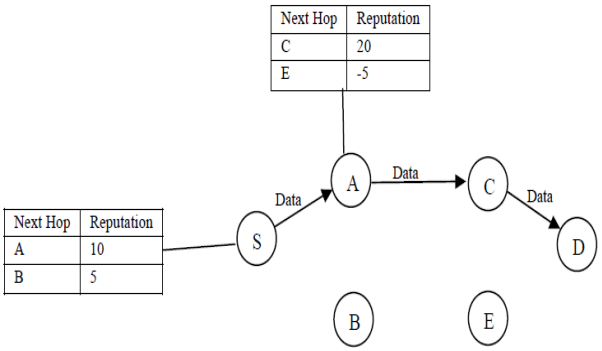

Fig. 7: Choosing the highly-reputed next-hop node

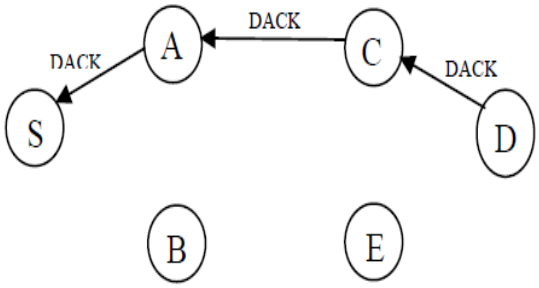

Fig.8: Sending Data Acknowledgement for each received data packet

3.2.3.3 *Reputation Phase*

In this phase, when an Intermediate node receives a data acknowledgement packet (DACK), it retrieves the record, inserted in the data transfer phase, corresponding to this data packet then it increments the reputation of the next hop node. In addition, it deletes this data packet entry from its sent-table. Once the DACK packet reaches node S, it deletes this entry from its sent-table and gives a recommendation of (+1) to the node that delivered the acknowledgement.

3.2.3.4 Timeout Phase

In this phase, once the timer for a given data packet expires at a node; the node retrieves the entry corresponding to this data transfer operation returned by the timer from its sent-table. Then, the node gives a negative recommendation (-2) to the next-hop node and deletes the entry from the sent-table. Later on, when the intermediate nodes' timers up to the node that dropped the packet expire, they give a negative recommendation to their next hop node and delete the entry from their sent-table. As a consequence, all the nodes between the selfish node and the sender, including the selfish node, get a recommendation of (-2). Now, if the reputation of the next-hop node goes below the threshold (-40), the current node deactivates this node in its routing table and sends an error message RERR to the upstream nodes in the route. Then the original ARAN protocol handles it. Now, it is the responsibility of the sender to reinitiate the route discovery again. In addition, the node whose reputation

value reached (-40) is now temporally weeded out of the MANET for five minutes and it later joins the network with a value of (0) so that to treat it as a newly joined node in the network.

Conclusion

Throughout this thesis, a discussion of existing mobile ad hoc networks' routing protocols' types and their advantages and disadvantages was given and a list of existing proactive, reactive and secure MANET routing protocols was compiled. Then, the different types of attacks targeting MANET routing protocols' security were explored. Also, the difference between malicious and selfish nodes and their associated attacks were discussed and a presentation of the fundamental requirements for the design of a secure routing protocol to defend against these security breaches was given. Furthermore, a comparison between some the existing secure mobile ad hoc routing protocols was presented. Then, an in-depth talk about the Authenticated Routing for Ad Hoc Networks protocol (ARAN) as one of the secure routing protocols built following the fundamental secure routing protocols design methodology was given. Afterwards, a discussion of how ARAN defends against most of the attacks that are conducted by malicious nodes such as spoofing, fabrication, modification and disclosure ones was presented. That resulted in proving that the currently existing specification of the ARAN secure routing MANET protocol does not defend against attacks performed by authenticated selfish nodes. Thus, I moved on discussing the different existing MANET cooperation enforcement schemes by stating their types: the virtual currency-based and the reputation-based schemes. In this proposal, the different phases of the proposed reputation-based scheme were explained. Then, an analysis of the various forms of selfish attacks that the proposed reputation-based scheme defends against was presented. Also, some time was invested in surveying the different simulation packages that are used in mobile ad hoc networks. The solution presented in this thesis only cover a subset of all threats and is far from providing a comprehensive answer to the many security problems in the MANETs field. Last but not least, according to the many simulations that were performed, the newly proposed reputation-based scheme, built on top of normal ARAN secure routing protocol, achieves a higher throughput than the normal ARAN in the presence of selfish nodes. Thus, the proposed design, Reputed-ARAN, proves to be more efficient and more secure than normal ARAN secure routing protocol in defending against both malicious and authenticated selfish nodes.

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