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Detect Packet Forward Algorithm for Intrusion Discovery in MANET using Misbehaviour Report Authentication

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Abstract: Mobile ad-hoc network is a kind of wireless ad-hoc network, and is a self-configuring network of mobile routers connected by wireless links the union of which forms an arbitrary topology. Mobility and scalability brought by wireless network made it possible in many applications, Digital signatures frequently used for distribution of messages from sender to receiver ,It certificate serve as a proof of an authentication for individual data packets. The DPF e is designed to resolve the weakness of Watchdog when it fails to detect misbehaving nodes with the presence of false misbehaviour report. The core of DPF algorithm is to authenticate whether the destination node has received the reported missing packet through a different route. With the improvements of the technology and cut in hardware costs, we are witnessing a current trend of expanding MANETs into industrial applications. To adjust to such trend, we strongly believe that it is vital to address its potential security issues. In this paper, we propose and implement a new intrusion-detection system named Enhanced Adaptive Acknowledgment (EAACK) specially designed for MANETs. Compared to contemporary approaches, EAACK demonstrates higher malicious- behavior-detection rates in certain circumstances while does not greatly affect the network performances.

Keywords: Digital signature, Intrusion detection, MRA.

I. Introduction

Due to their natural mobility and scalability, wireless networks are always preferred since the first day of their invention. Owing to the improved technology and reduced costs, wireless networks have gained much more preferences over wired networks in the past few decades. By definition, Mobile Ad hoc Network (MANET) is a collection of mobile nodes equipped with both a wireless Transmitter and a receiver that communicate with each other via bidirectional wireless links either directly or indirectly. Industrial remote access and control via wireless networks are becoming more and more popular these days [35]. One of the major advantages of wireless networks is its ability to allow data communication between different parties and still maintain their mobility. However, this communication is limited to the range of transmitters. This means that two nodes cannot communicate with each other when the distance between the two nodes is beyond the communication range of their own. MANET solves this problem by allowing intermediate parties to relay data transmissions. This is achieved by dividing MANET into two types of networks, namely, single-hop and multihop. In a single-hop network, all nodes within the same radio range communicate directly with each other. On the other hand, in a multichip network, nodes rely on other intermediate nodes to transmit if the destination node is out of their radio range. In contrary to the traditional wireless network, MANET has a decentralized network infrastructure. MANET does not require a fixed infrastructure; thus, all nodes are free to move randomly [10], [27], [29]. MANET is capable of creating a self-configuring and self-maintaining network without the help of a centralized infrastructure, which is often infeasible in critical mission applications like military conflict or emergency recovery.

II. Background

A. IDS in MANETs

As discussed before, due to the limitations of most MANET routing protocols, nodes in MANETs assume that other nodes always cooperate with each other to relay data. This assumption leaves the attackers with the opportunities to achieve significant impact on the network with just one or two compromised nodes. To address this problem, an IDS should be added to enhance the security level of MANETs. If MANET can detect the attackers as soon as they enter the network, we will be able to completely eliminate the potential damages caused by compromised nodes at the first time. IDSs usually act as the second layer in MANETs, and they are a great complement to existing proactive approaches [27]. Anantvalee and Wu [4] presented a very thorough survey on contemporary IDSs in MANETs. In this section, we mainly describe three existing approaches, namely, Watchdog [17], TWOACK [15], andAdaptive ACKnowledgment (AACK) [25].

1) Watchdog: Marti et al. [17] proposed a scheme named Watchdog that aims to improve the throughput of network with the presence of malicious nodes. In fact, the Watchdog scheme is consisted of two parts, namely, Watchdog and Pathrater. Watchdog serves as an IDS for MANETs. It is responsible for detecting malicious node misbehaviors in the network. Watchdog detects malicious misbehaviors by promiscuously listening to its next hop's transmission. If a Watchdog node overhears that its next node fails to forward the packet within a certain period of time, it increases its failure counter. Whenever a node's failure counter exceeds a predefined threshold, the Watchdog node reports it as misbehaving. In this case, the Path rater cooperates with the routing protocols to avoid the reported nodes in future transmission. Many following research studies and implementations have proved that the Watchdog scheme is efficient. Furthermore, compared to some other schemes, Watchdog is capable of detecting malicious nodes rather than links. These advantages have made the Watchdog scheme a popular choice in the field. Many MANET IDSs are either based on or developed as a improvement to the Watchdog scheme [15], [20], [21], [25]. Nevertheless, as pointed out by Marti et al. [17], the Watchdog scheme fails to detect malicious misbehaviors with the presence
of the following: 1) ambiguous collisions; 2) receiver collisions;3) limited transmission power; 4) false misbehavior report;5) collusion; and 6) partial dropping.

2) TWOACK: With respect to the six weaknesses of the Watchdog scheme, many researchers proposed new approaches to solve these issues. TWOACK proposed by Liu et al. [16] is one of the most important approaches among them. On 1. TWOACK scheme: Each node is required to send back an acknowledgment packet to the node that is two hops away from it. The contrary to many other schemes, TWOACK is neither an enhancement nor a Watchdog-based scheme. Aiming to resolve the receiver collision and limited transmission power problems of Watchdog, TWOACK detects misbehaving links by acknowledging every data packet transmitted over every three consecutive nodes along the path from the source to the destination. Upon retrieval of a packet, each node along the route is required to send back an acknowledgment packet to the node that is two hops away from it down the route. TWOACK is required to work on routing protocols such as Dynamic Source Routing (DSR) [11]. The working process of Node A first forwards Packet 1 to node B, and then, node B forwards Packet 1 to node C. When node C receives Packet 1, as it is two hops away from node A, node C is obliged to generate a TWOACK packet, which contains reverse route from node A to node C, and sends it back to node A. The retrieval of this TWOACK packet at node A indicates that the transmission of Packet 1 from node A to node C is successful. Otherwise, if this TWOACK packet is not received in a predefined time period, both nodes B and C are reported malicious. The same process applies to every three consecutive nodes along the rest of the route. The TWOACK scheme successfully solves the receiver collision and limited transmission power problems posed by Watchdog. However, the acknowledgment process required in every packet transmission process added a significant amount of unwanted network overhead. Due to the limited battery power nature of MANETs, such redundant transmission process can easily degrade the life span of the entire network. However, many research studies are working in energy harvesting to deal with this problem [25], [28], [29].

3) AACK: Based on TWOACK, Sheltami et al. [25] proposed a new scheme called AACK. Similar to TWOACK, AACK is an acknowledgment-based network layer scheme which can be considered as a combination of a scheme called TACK (identical to TWOACK) and an end-to-end acknowledgment scheme called Acknowledge (ACK). Compared to TWOACK, AACK significantly reduced network overhead while still capable of maintaining or even surpassing the same network throughput. The end-to-end acknowledgment scheme .the source node S sends out Packet 1 without any overhead except 2 b of flag indicating the packet type. All the intermediate nodes simply forward this packet. When the destination node D receives Packet 1, it is required to send back an ACK acknowledgment packet to the source node S along the reverse order of the node.ACK scheme: The destination node is required to send acknowledgment packets to the source node. same route. Within a predefined time period, if the source node S receives this ACK acknowledgment packet, then the packet transmission from node S to node D is successful. Otherwise, the source node S will switch to TACK scheme by sending out a TACK packet. The concept of adopting a hybrid scheme in AACK greatly reduces the network overhead, but both TWOACK and AACK still suffer from the problem that they fail to detect malicious nodes with the presence of false misbehavior report and forged acknowledgment packets.

B. Digital Signature

Digital signatures have always been an integral part of cryptography in history. Cryptography is the study of mathematical techniques related to aspects of information security such as confidentiality, data integrity, entity authentication, and data origin authentication [18]. The development of cryptography technique has a long and fascinating history. The pursuit of secure communication has been conducted by human being since 4000 years ago in Egypt, according to Kahn's book [30] in 1963. Such development dramatically accelerated since the World War II, which some believe is largely due to the globalization process. The security in MANETs is defined as a combination of processes, procedures, and systems used to ensure confidentiality, authentication, integrity, availability, and nonrepudiation [18]. Digital signature is a widely adopted approach to ensure the authentication, integrity, and nonrepudiation of MANETs. It can be generalized as a data string, which associates a message (in digital form) with some originating entity, or an electronic analog of a written signature [33]. Digital signature schemes can be mainly divided into the following two categories.

1) Digital signature with appendix: The original message is required in the signature verification algorithm. Examples include a digital signature algorithm (DPF) [33].

2) Digital signature with message recovery: This type of scheme does not require any other information besides the signature itself in the verification process. Examples include RSA [23]. Communication with digital signature. In this research work, we implemented both DPF and RSA in our proposed EAACK scheme. The main purpose of this implementation is to compare their performances in MANETs.

The general flow of data communication with digital signature is shown in 3. First, a fixed-length message digest is computed through a preagreed hash function H for every message m. This process can be described as H(m) = d. (1) Second, the sender Alice needs to apply its own private key Pr−Alice on the computed message digest d. The result is a signature SigAlice, which is attached to message m and Alice's secret private key ,SPr−Alice (d) = SigAlice. (2) To ensure the validity of the digital signature, the sender Alice is obliged to always keep her private key Pr−Alice as a secret without revealing to anyone else. Otherwise, if the attacker Eve gets this secret private key, she can intercept the message and easily forge malicious messages with Alice's signature and send them to Bob. As these malicious messages are digitally signed by Alice, Bob sees them as legit and authentic messages from Alice. Thus, Eve can readily achieve malicious attacks to Bob or even the entire network. Next, Alice can send a message m along with the signature SigAlice to Bob via an unsecured channel. Bob then computes the received message m_ against the preagreed hash function H to get the message digest.

III. Problem Definition

Our proposed approach EAACK is designed to tackle three of the six weaknesses of Watchdog scheme, namely, false misbehavior, limited transmission power, and receiver collision. In this section, we discuss these three weaknesses in detail.

Receiver collisions: Both nodes B and X are trying to send Packet 1and Packet 2, respectively, to node C at the same time.

Limited transmission power: Node B limits its transmission power so that the packet transmission can be overheard by node A but too weak to reach node C.

False misbehavior report: Node A sends back a misbehavior report even though node B forwarded the packet to node C.

In a typical example of receiver collisions, after node A sends Packet 1 to node B, it tries to overhear if node B forwarded this packet to node C; meanwhile, node X is forwarding Packet 2 to node C. In such case, node A overhears that node B has successfully forwarded Packet 1 to node C but failed to detect that node C did not receive this packet due to a collision between Packet 1 and Packet 2 at node C. In the case of limited transmission power, in order to preserve its own battery resources, node B intentionally limits its transmission power so that it is strong enough to be overheard by node A but not strong enough to be received by node C, For false misbehavior report, although node A successfully overheard that node B forwarded Packet 1 to node C, node A still reported node B as misbehaving, the open medium and remote distribution of typical MANETs, Attackers can easily capture and compromise one or two nodes to achieve this false misbehavior report attack. As discussed in previous sections, TWOACK and AACK solve two of these three weaknesses, namely, receiver collision and limited transmission power. However, both of them are vulnerable to the false misbehavior attack. In this research work, our goal is to propose new IDS specially designed for MANETs, which solves not only receiver collision and limited transmission power but also the false misbehavior problem. Furthermore, we extend our research to adopt a digital signature scheme during the packet transmission process. As in all acknowledgment-based IDSs, it is vital to ensure the integrity and authenticity of all acknowledgment packets.

IV. Scheme Description

In this section, we describe our proposed EAACK scheme in detail. The approach described in this research paper is based on our previous work [12], where the backbone of EAACK was proposed and evaluated through implementation. We extend it with the introduction of digital signature to prevent the attacker from forging acknowledgment packets.

EAACK is consisted of three major parts, namely, ACK, secure ACK (S-ACK), and misbehavior report authentication (MRA). In order to distinguish different packet types in different schemes, we included a 2-b packet header in EAACK. According to the Internet draft of DSR [11], there is 6 b reserved in the DSR header. In EAACK, we use 2 b of the 6 b to flag different types of packets. We assume that the link between each node in the network is bidirectional. Furthermore, for each communication process, both the source node and the destination node are not malicious. Unless specified, all acknowledgment packets described in this research are required to be digitally signed by its sender and verified by its receiver.

A. ACK

ACK is basically an end-to-end acknowledgment scheme. It acts as a part of the hybrid scheme in EAACK, aiming to reduce network overhead when no network misbehavior is detected. In 8, in ACK mode, node S first sends out an ACK data packet Pad1 to the destination node D. If all the intermediate nodes along the route between nodes S and D are cooperative and node D successfully receives Pad1, node D is required to send back an ACK acknowledgment packet Pak1 along the same route but in a reverse order. Within a predefined time period, if node S receives Pak1, then the packet transmission from node S to node D is successful. Otherwise, node S will switch to S-ACK mode by sending out an S-ACK data packet to detect the misbehaving nodes in the route.

ACK scheme: The destination node is required to send back an acknowledgment packet to the source node when it receives a new packet.

B. S-ACK

The S-ACK scheme is an improved version of the TWOACK scheme proposed by Liu et al. [16]. The principle is to let every three consecutive nodes work in a group to detect misbehaving nodes. For every three consecutive nodes in the route, the third node is required to send an S-ACK acknowledgment packet to the first node. The intention of introducing S-ACK mode is to detect misbehaving nodes in the presence of receiver collision or limited transmission power in S-ACK mode, the three consecutive nodes (i.e., F1, F2, and F3) work in a group to detect misbehaving nodes in the network. Node F1 first sends out S-ACK data packet Psad1 to node F2. Then, node F2 forwards this packet to node F3. When node F3 receives Psad1, as it is the third node in this three-node group, node F3 is required to send back an S-ACK acknowledgment packet Psak1 to node F2. Node F2 forwards Psak1 back to node F1. If node F1 does not receive this acknowledgment packet within a predefined time period, both nodes F2 and F3 are reported as malicious. Moreover, a misbehavior report will be generated by node F1 and sent to the source node S. Nevertheless, unlike the TWOACK scheme, where the source node immediately trusts the misbehavior report, EAACK requires the source node to switch to MRA mode and confirm this misbehavior report. This is a vital step to detect false misbehavior report in our proposed scheme.

C. DPF

The DPF algorithm is designed to resolve the weakness of Watchdog when it fails to detect misbehaving nodes with the presence of false misbehavior report. The false misbehavior report can be generated by malicious attackers to falsely report innocent nodes as malicious. This attack can be lethal to the entire network when the attackers break down sufficient nodes and thus cause a network division. The core of DPF algorithm is to authenticate whether the destination node has received the reported missing packet through a different route. To initiate the MRA mode, the source node first searches its local knowledge base and seeks for an alternative route to the destination node. If there is no other that exists, the source node starts a DSR routing request to find another route. Due to the nature of MANETs, it is common to find out multiple routes between two nodes. By adopting an alternative route to the destination node, we Circumvent the misbehavior reporter node. When the destination node receives an MRA packet, it searches its local knowledge base and compares if the reported packet was received. If it is already received, then it is safe to conclude that this is a false misbehavior report and whoever generated this report is marked as malicious. Otherwise, the misbehavior report is trusted and accepted. By the adoption of DPF algorithm, EAACK is capable of detecting malicious nodes despite the existence of false misbehavior report.

D. Digital Signature

EAACK is an acknowledgment-based IDS. All three parts of EAACK, namely, ACK, S-ACK, and MRA, are acknowledgment-based detection schemes. They all rely on acknowledgment packets to detect misbehaviors in the network. Thus, it is extremely important to ensure that all acknowledgment packets in EAACK are authentic and untainted. Otherwise, if the attackers are smart enough to forge acknowledgment packets, all of the three schemes will be vulnerable. With regard to this urgent concern, we incorporated digital signature in our proposed scheme. In order to ensure the integrity of the IDS, EAACK requires all acknowledgment packets to be digitally signed before they are sent out and verified until they are accepted. However, we fully understand the extra resources that are required with the introduction of digital signature in MANETs. To address this concern, we implemented both DPF [33] and RSA [23] digital signature schemes in our proposed approach. The goal is to find the most optimal solution for using digital signature in MANETs.

V. Performance Evaluation

Scenario 1: malicious nodes drop all the packets that pass through it. The results that are based on PDR, we observe that all acknowledgment-based IDSs perform better than the Watchdog scheme. Our proposed scheme EAACK surpassed Watchdog’s performance by 35% when there are 40% of malicious nodes in the network. From the results, we conclude that acknowledgment-based schemes, including TWOACK, AACK, and EAACK, are able to detect misbehaviours with the presence of receiver collision and limited transmission power. However, when the number of malicious nodes reaches 40%, our proposed scheme EAACK’s performance is lower than those of TWOACK and AACK. We generalize it as a result of the introduction of DPF algorithm, when it takes too long to receive an MRA acknowledgment from the destination node that the waiting time exceeds the predefined threshold. We observe that DSR and Watchdog scheme achieve the best performance, as they do not require acknowledgment scheme to detect misbehaviours. For the rest of the IDSs, AACK has the lowest overhead. This is largely due to its hybrid architecture, which significantly reduces network overhead. Although EAACK requires digital signature at all acknowledgment process, it still manages to maintain lower network overhead in most cases. We conclude that this happens as a result of the introduction of our hybrid scheme. Scenario 2: we set all malicious nodes to send out false misbehavior report to the source node whenever it is possible. This scenario setting is designed to test the IDS’s performance under the false misbehavior report. When malicious nodes are 19%, EAACK performs 2% better than AACK and TWOACK. When the malicious nodes are at 20% and 39%, EAACK outperforms all the other schemes and maintains the PDR to over 92%. We believe that the introduction of DPF algorithm mainly contributes to this performance. EAACK is the only scheme that is capable of detecting false misbehavior report. In terms of RO, owing to the hybrid scheme, EAACK maintains a lower network overhead compared to TWOACK in most cases, However, RO rises rapidly with the increase of malicious nodes. It is due to the fact that more malicious nodes require a lot more acknowledgment packets and digital signatures.

DPF and RSA: In all of the three scenarios, we witness that the DPF scheme always produces slightly less network overhead than RSA does. This is easy to understand because the signature size of DPF is much smaller than the signature size of RSA. However, it is interesting to observe that the RO differences between RSA and DPF schemes vary with different numbers of malicious nodes. The more malicious nodes there are, the more ROs the RSA scheme produces. We assume that this is due to the fact that more malicious nodes require more acknowledgment packets, thus increasing the ratio of digital signature in the whole network overhead. With respect to this result, we find DPF as a more desirable digital signature scheme in MANETs. The reason is that data transmission in MANETs consumes the most battery power. Although the DPF scheme requires more computational power to verify than RSA, considering the trade off between battery power and performance, DPF is still preferable.

VI. Conclusion and Future Work

Packet-dropping attack has always been a major threat to the security in MANETs. In this research paper, we have proposed a novel IDS named EAACK protocol specially designed for MANETs and compared it against other popular mechanisms in different scenarios through simulations. The results demonstrated positive performances against Watchdog, TWOACK, and AACK in the cases of receiver collision, limited transmission power, and false misbehavior report. Furthermore, in an effort to prevent the attackers from initiating forged acknowledgment attacks, we extended our research to incorporate digital signature in our proposed scheme. Although it generates more ROs in some cases, as demonstrated in our experiment, it can vastly improve the network’s PDR when the attackers are smart enough to forge acknowledgment packets. We think that this tradeoff is worthwhile when network security is the top priority. In order to seek the optimal DPF s in MANETs, we implemented both DPF and RSA schemes in our simulation. Eventually, we arrived to the conclusion that the DPF scheme is more suitable to be implemented in MANETs. To increase the merits of our research work.

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