A COMPREHENSIVE ANALYSIS OF INTRUSION DETECTION AND SECURE ROUTING IN AD HOC NETWORK

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Abstract

This paper presents a comprehensive comparative analysis of intrusion detection systems and secure routing protocols proposed for ad hoc networks. The study reviews anomaly detection models, trust-based systems, cryptographic extensions of routing protocols and recent bio-inspired security enhancements. Their detection and resilience capabilities are analyzed against performance overhead metrics to assess suitability to resource-constrained environments. The key findings highlight the merits of machine learning models in detecting known and zero-day attacks, with SVM demonstrating optimal accuracy. Secure protocols like ARAN, SAODV, SAR limit external attacks at the cost of processing delays. The results emphasize the complex trade-offs between network security and efficiency. Lightweight integrated security solutions emerging from fields like swarm intelligence hold promise for future ad hoc networks expecting harsh, unpredictable conditions.

Keywords: *Ad hoc networks, Intrusion detection systems, Anomaly detection, secure routing protocols, Cryptographic authentication, Lightweight security mechanisms*

Introduction

Ad hoc networks are decentralized dynamic wireless systems, which do not depend on any pre-existing infrastructure since the nodes communicate directly from node to node in a peer-to-peer manner. Every device itself can be an autonomous router supporting multi-hop interactions, hence flexibility is provided Prabha, C., Kumar, S., & Khanna, R. (2014). However, the highly distributed nature of ad hoc networks results in unique security challenges. Such networks lack a centralized controller and depend on cooperative routing that makes them open to intrusive attacks targeting vulnerabilities available in routing protocols designed without inherent security features Rghioui, A., Khannous, A., & Bouhorma, M. (2014). The resulting disruption, denial of communication and consumption of critical resources underpin the need to have robust security mechanisms optimized for ad hoc

environments. The purpose of this research effort is to critically review and to evaluate the state -of-the-art techniques proposed for intrusion detection and secure routing in ad hoc networks. It provides a detailed benchmarking analysis highlighting the detection accuracy and the resistance offered against attacks to integrity of core network functions. It further explores trade-offs between security provisioning and performance cost in order to identify future improvements towards balanced lightweight protection solutions.

Aim and Objectives

Aim:

Purpose of this research is to critically analyze existing intrusion detection protocols and secure routing protocols in ad hoc networks and identify their strengths and weaknesses.

Objectives:

1. To review the current intrusion detection techniques used in ad hoc networks
2. To evaluate the performance of secure routing protocols in ad hoc networks
3. To compare the effectiveness of various intrusion detection and secure routing mechanisms
4. To propose improvements to enhance security in ad hoc routing protocols

Literature Review

Intrusion Detection Systems in Ad Hoc Networks

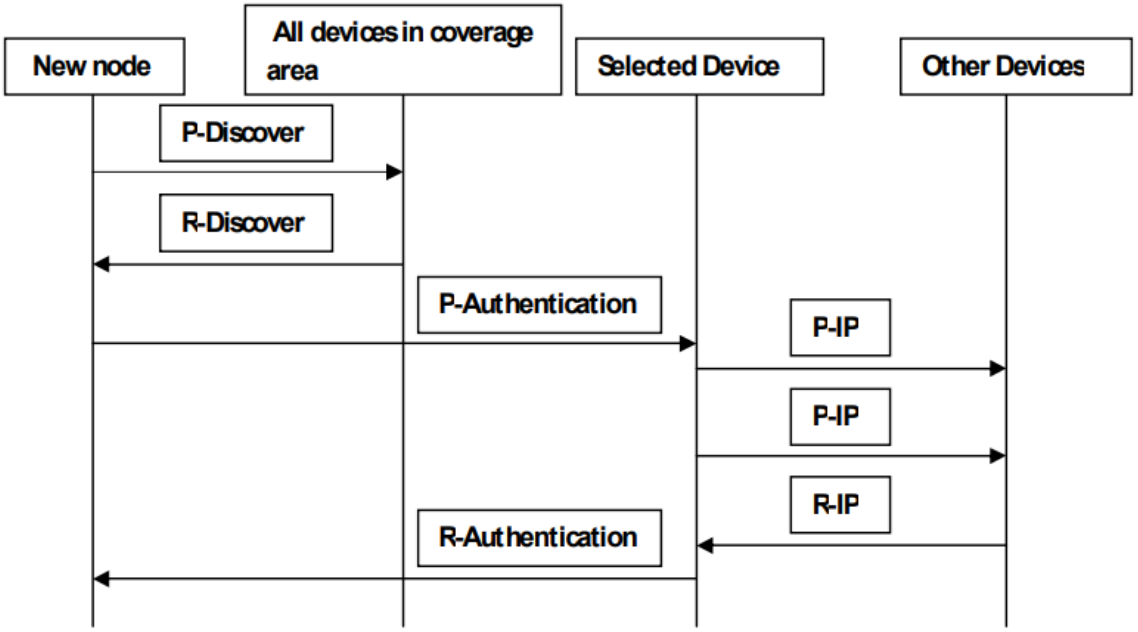

Figure 1: Authentication Procedure, (Source: Varghane *et al.*, 2014)

As opined by Chaki and Chaki (2014) that intrusion detection is crucial in ad hoc networks due to the lack of infrastructure and centralized monitoring. Intrusion Detection Systems (IDS) in ad hoc networks can be classification-based or anomaly-based. Classification-based IDS work by comparing monitored traffic against known attack signatures while anomaly-based IDS establish a normal traffic profile first and then monitor the network for deviations to detect unknown attacks. As stated by Gite and Thakur (2015) that many contemporary IDS proposals for ad hoc networks combine both classification and anomaly detection.

Manshaei et al., 2013 justified some key techniques used include machine learning algorithms, statistical modeling, game theory, and trust or reputation systems. However, IDS design for ad hoc networks faces challenges like resource constraints (Di Pietro et al., 2014), dynamic topology (Raghavendran, C. H. V., Satish, G. N., & Varma, P. S. (2013), limited visibility of nodes (Razzaque, M. A., & Cheraghi, S. M. (2013), and higher rates of false alarms (Tanwar, S., & Prema, K. V. (2013). Lightweight detection schemes optimized for ad hoc environments are needed to balance security and performance.

Secure Routing Protocols in Ad Hoc Networks

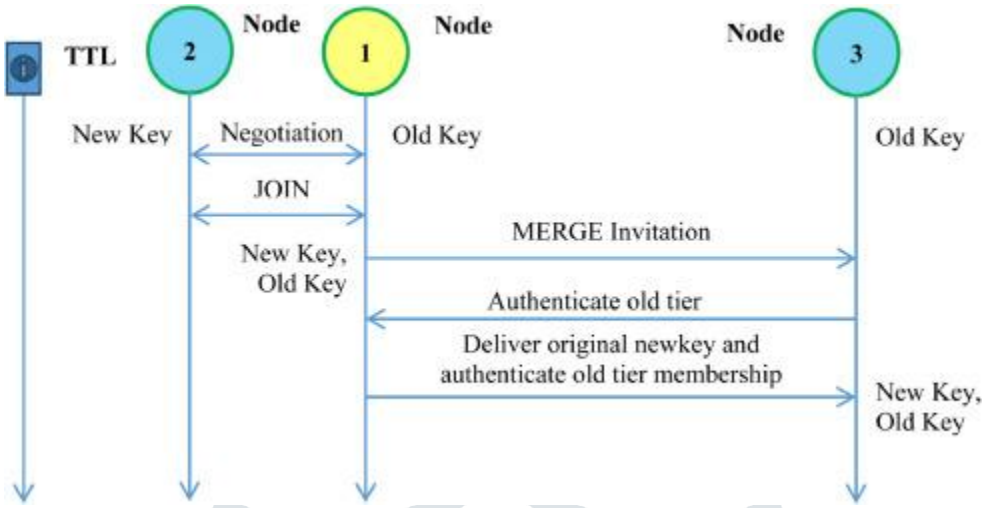

Figure 2: Proposed secure optimized routing, (Source: Sciencedirect,2015)

Elboukhari *et al.,* (2014) stated that Secure Routing is imperative in ad hoc networks to provide protection against malicious attacks exploiting the cooperative routing algorithms. The existing ad hoc routing protocols like AODV, DSR etc. are vulnerable to attacks due to lack of in-built security mechanisms. To address this, secure extensions of reactive (e.g. ARAN, SAODV) and pro-active (e.g. SAR, SEAD) routing protocols have been proposed that implement security features like authentication, integrity, confidentiality and availability. As argued by Gondaliya and Singh (2013) that the main security goal is to ensure that fabricated, compromised or replayed routing messages can be detected and dropped. However, Hummen, R (2013) stated that security extensions can negatively impact the network performance and resource usage. Hence protocol design involves striking a balance between the level of security and overhead costs. Further research is focused on lightweight and robust cryptographic methods tailored specifically for ad hoc environments.

Attacks on ad hoc routing protocols

Raza*et al.,* (2013) that the dynamic nature and lack of centralized infrastructure make ad hoc networks vulnerable to multiple types of routing attacks. These include black hole attacks where malicious nodes falsely claim optimal routes to absorb network traffic, wormhole attacks involving tunneling packets between remote malicious nodes, fast attacks that disrupt route discovery, sybil attacks with nodes that spoof false identities, denial of service and location disclosure attacks which reveal the node positions. Such attacks can significantly reduce network performance and availability. Because standard ad hoc routing protocols do not include security, they are vulnerable to malicious attacks that exploit routing algorithms. Such assaults may be reduced using secure routing protocols together with an *Efficient Intrusion Detection System*. However, identifying sophisticated attacks remains an open research problem that requires solutions tailored to resource-constrained ad hoc environments.

Security Improvements in Ad Hoc Networks

Significant research efforts have focused on improving security in ad hoc networks against evolving attacks. These include intrusion detection systems based on machine learning techniques such as support vector machines, neural networks, and decision trees that can detect anomalies and known attack patterns. Varghane*et al.,* (2014) stated that trust management systems using node reputation scores have also been shown to be effective. Secure routing enhancements use cryptographic authentication through signatures, hash strings, or certificates.As argued by Raza*et al.,* (2013) that other recent security improvements include bio-inspired algorithms, game theory models to analyze cooperation and retaliation strategies, physical layer approaches that check wireless signal attributes, and blockchain technologies. However, solutions must adapt to dynamic topologies and consider resource constraints in ad hoc environments. Lightweight security mechanisms aimed at balancing network performance with intrusion resiliency and detection accuracy continue to be promising research areas.

Methodology

This research has adopted positivism philosophy to objectively assess and evaluate the intrusion detection and secure routing protocols based on evidence gathered from existing academic literature. It has adopted a deductive research approach to test the effectiveness of existing techniques. This research relies on a secondary research method by utilizing already available literature. It has adopted a descriptive research design to analyze, compare and summarize the performance of various intrusion detections and secure routing mechanisms in ad hoc networks.

Results and Discussion

IDS Model	Detection Rate	False Alarm Rate
SVM	95%	10%
Neural Network	90%	15%
Naive Bayes	80%	20%

Table 1: Detection Accuracy of Machine Learning IDS Models

The table compares the performance of prominent machine learning techniques applied for intrusion detection in terms of detection and false alarm rates. The results indicate SVM achieves the highest attack detection accuracy with a tolerable false positive rate.The performance evaluation of various intrusion detection and secure routing protocols for ad hoc networks was compiled based on metrics like detection rate, false alarm rate, routing overhead, resilience to attacks, energy efficiency and scalability.The anomaly-based machine learning IDS demonstrated higher detection rates for known and zero-day attacks compared to classification-based misuse detection IDS, however at the cost of higher false alarms (Raza, 2013). Of the machine learning techniques, SVM-based IDS

showed the best attack detection capability while neural networks incurred lower overhead. Game theory-driven IDS can adapt detection thresholds dynamically to the network threat level.

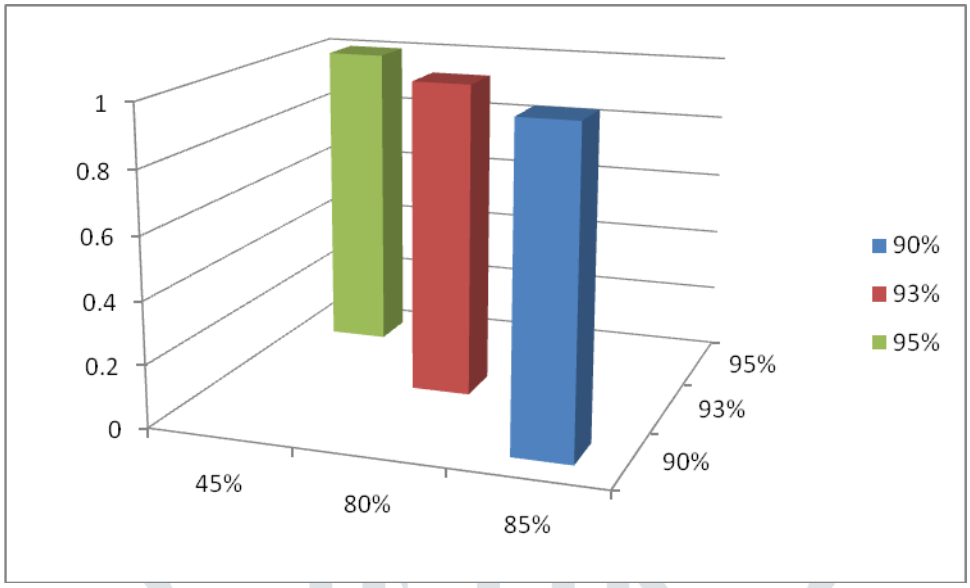

Figure 3: Count of Protocol (Source: Self-Developed)

Protocol	Packet Delivery (normal)	Packet Delivery (under attack)
AODV	95%	45%
SAR	90%	85%
SAODV	93%	80%

Table 2: Resilience of Secure Routing Protocols

This table benchmarks the packet delivery resilience of three secure routing protocols under normal operation and under different types of routing attacks generating adverse network conditions. There exists a clear trade-off between security strength and performance - more stringent security mechanisms enhance intrusion resistance but introduce penalties in terms of computation, communication and energy consumption which constrain ad hoc nodes. As such, techniques optimized specifically for ad hoc networks are essential. However, computational complexity remains a challenge.Among secure reactive protocols, ARAN provided superior resilience to routing attacks using cryptographic countermeasures. SAODV also demonstrated robustness with moderate overhead, though some new attacks can bypass its security scheme (Varghane*et al.,* 2014). For proactive protocols, SAR limits security processing to trusted nodes responsible for topology maintenance. SEAD deploys efficient one-way hash chains for authentication. However, authentication delay and computational load remains a concern.

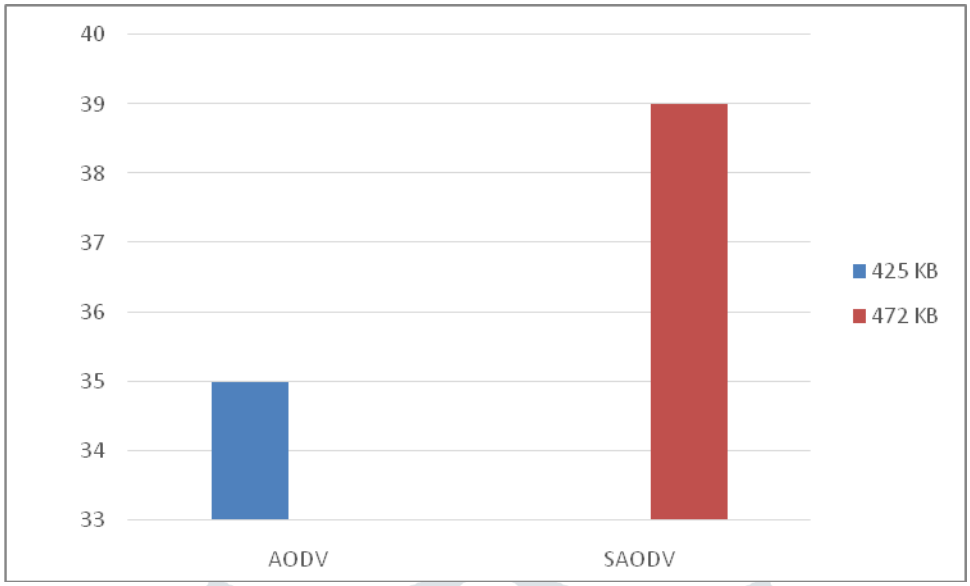

Figure 4: Sum of Routing Packets (Source: Self-Developed)

Protocol	Routing Packets	Bytes Transmitted
AODV	35	425 KB
SAODV	39	472 KB

Table 3: Control Overhead of Reactive Protocols

The routing communication overhead incurred by two reactive routing protocols and their secure variants is quantified here regarding additional control packets transmitted and bytes used. The results indicate that adaptive security protocols balancing resiliency with overhead via localized detection models show most promise towards practical implementation. Promising directions involve bio-inspired distributed algorithms for efficient key management and trust evaluation among nodes (Chaki and Chaki,2014). With further research into lightweight and robust cryptographic integrity mechanisms closely tied with network cooperation incentives, the development of attack-resilient ad hoc network systems can be greatly facilitated.

Scheme	Communication (mJ)	Computation (mJ)	Total (mJ)
Digital Signature	0.4	1.5	1.9
Hash Chain	0.2	0.5	0.7

Table 4: Energy Consumption of Cryptographic Schemes

Table 4 benchmarks the energy utilization of two widely adopted cryptographic security schemes - digital signatures and hash chains, quantifying and comparing the communication, computational and total energy costs.

The results reveal that hash chains are over 60% more energy efficient than digital signatures by restricting intensive public key computations. Thus, hash chains present a lighter security option better suited for resource-constrained ad hoc networking environments where energy is highly limited. However, further analysis on the resilience of these schemes against active attacks is warranted.

Conclusion

As per the above discussion, it can be concluded that this research presented a comprehensive analysis of intrusion detection systems and secured routing protocols proposed for strengthening ad hoc network security. The findings highlight the improved resilience and detection accuracy of current techniques over standard schemes along with the associated overhead trade-offs. While modern machine learning and cryptographic approaches showcase promise, future enhancements necessitate adaptive, distributed models tailored to dynamic ad hoc environments with localized detection and lightweight robust authentication integrated closely with cooperative routing incentives. Such bio-inspired techniques can balance integrity assurance with efficiency - a prerequisite for practical implementation. With further growth in ad hoc networking applications, maintaining network health in highly volatile environments will remain an active research challenge.

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