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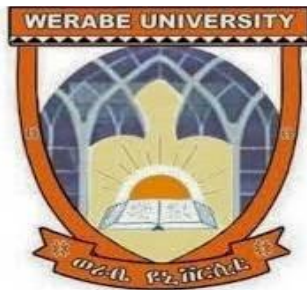
DEPARTMENT OF INFORMATION TECHNOLOGY

DETECTION AND PREVENTION OF BLACK HOLE ATTACK ON MANET
BY USING AODV PROTOCOL

By
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A THESIS SUBMITTED TO WERABE UNIVERSITY INSTITUTE OF
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Declaration

I hereby declare that the study thesis work which will be presented in the paper entitled “detection and prevention of black hole attack on MANET by using AODV protocol” in partial fulfillment of the requirements for the award of the degree of Master of Science in Computer Networks and Security is an authentic record of our own work carried out under the supervision of Dr. Kindey Anlay, The work embodied in this paper has not been submitted by us for the award of any other Degree or diploma. All relevant resources of information used in this paper have been duly acknowledged.

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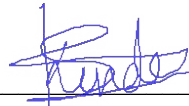
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This is to certify that the above statement made by the candidates is correct to the best of our knowledge and belief. This thesis will be submitted for examination to be approved.

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Abstract

Because of their adaptability and dynamic nature, mobile ad hoc networks, or MANETs, are being used more and more in a variety of applications, such as military operations and emergency response. However, MANETs' intrinsic weaknesses present serious obstacles to their dependability and efficiency, especially with regard to security risks like black hole attacks. This thesis offers a thorough analysis of how to detect and stop black hole attacks in MANETs using the Ad Hoc On-Demand Distance Vector (AODV) routing protocol as opposed to static routing protocols, which are not flexible enough to respond to threats and changes in the network.

The research approach is to study the working of MANETs and AODV protocol comprehensively and develop a computer based setup using NS2 etc. The paper includes black hole attacks in the computer model and investigates their effect on the most important metrics of performance including packet hitting, end-to-end delay, packets per second and energy consumption. A new method to detect bad node can stand out and remove the bad node. This is because we have established a new system based on trust, during the following of each node's behavior.

The experimental results indicate that black hole attacks drastically affect network performance, highlighting the vulnerability of AODV protocol. For example, the packet loss rate increased from 5% in normal scenarios to approximately 40% during the attack, as malicious nodes can significantly affect data transmission by capturing and dropping packets.

Similarly, the end-to-end delay rapidly increased from 50 ms to 200 ms indicating that the valid packets were lost or had to follow a different route due to the failure in routing. The data volume that was successfully transmitted also dropped significantly, from 900 kbps to more than 400 kbps during the attack.

However the suggested detection system was able to significantly mitigate the effects of these. Results from the trust-based detection method showed that the energy consumption was restored to 350 joules, the end-to-end delay was reduced by approximately 30 milliseconds, and the throughput was increased to approximately 600 kbps, while reducing the packet loss by about 25%. All these results illustrate the significance of the security actions for strengthening the strength of MANETs, providing them with a protection against black hole attacks.

Keywords: MANET, Delay, Packet loss, throughput, energy consumption, NS2.

Abbreviations

Acronym	Description
RREP	Route replay
RREQ	Route request
AODV	Ad hoc On-Demand Distance Vector
MANET	A mobile ad hoc network
Dos	Denial of service
DoS (DDoS)	Distributed Denial of Service
DSDV	Destination-Sequenced Denial of service
OLSR	Optimized Link State Routing
DSR	Dynamic Source Routing
ZRP	Zone Routing Protocol
TORA	Temporally Ordered Routing Algorithm
QoS	Quality of service
FIFO	First in first out
RTO	Recovery Time Objective
ECO	Ecological-inspired algorithm
GA	Genetic Algorithm
SI	Swarm intelligence
OTcl	Object-oriented Tool Command Language
NS2	Network Simulator Version 2
TTL	Time to live
TCP	Transmission Control Protocol
FTP	File Transfer Protocol
ACK	Acknowledgement

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Chapter one

1. Introduction

A wireless mobile ad hoc network, or MANET for short, was a self-configuring network made up of many portable user devices. Additionally, all transmission linkages were set up via a wireless means, allowing these mobile nodes to communicate with one another without the need for infrastructure. MANET was extensively utilized for military applications, disaster areas, personal area networks, and similar uses, according to the previously specified communication mode [1].

In recent years, numerous security challenges have been researched. These included, for example, packet replication, routing table overflow and poisoning attacks, wormhole attacks, black hole attacks [9], spying attacks, denial of service (DoS) attacks, and distributed DoS (DDoS) assaults [10]. Specifically, one of the most prevalent security risks, like black hole attacks, was routing misbehavior [11]. To solve this issue, some researchers suggested secure routing algorithms [12], although the security issue was not entirely avoided. In the lack of centralization, MANET nodes served as both hosts and routers to keep connections between them. New routing protocols were created to enable this kind of connectivity.

such as OLSR (Optimized Link State Routing), DSR (Dynamic Source Routing), DSDV (Destination-Sequenced Distance Vector), and AODV (Ad hoc On-demand Distance Vector) [1]. Due to the extremely dynamic network topology and the wireless transmission medium employed as the communication link between nodes, MANETs encountered numerous security issues. Because MANETs use wireless transmission media, they are vulnerable to a variety of attacks that compromise data secrecy, including IP spoofing. However, the installation of conventional security procedures was challenging because to the extremely dynamic topology [2].

1.1. Background of the study

In recent decades, numerous studies have been carried out on the various routing protocols used in MANETs [13], [14]. The popular and extensively used MANET routing protocols were presented in this section. Because the current routing information was absent, a mobile node broadcast its current status to nearby nodes when it wished to communicate with a target node.

Routing protocols were divided into three categories based on how routing information was obtained: proactive, reactive, and hybrid.

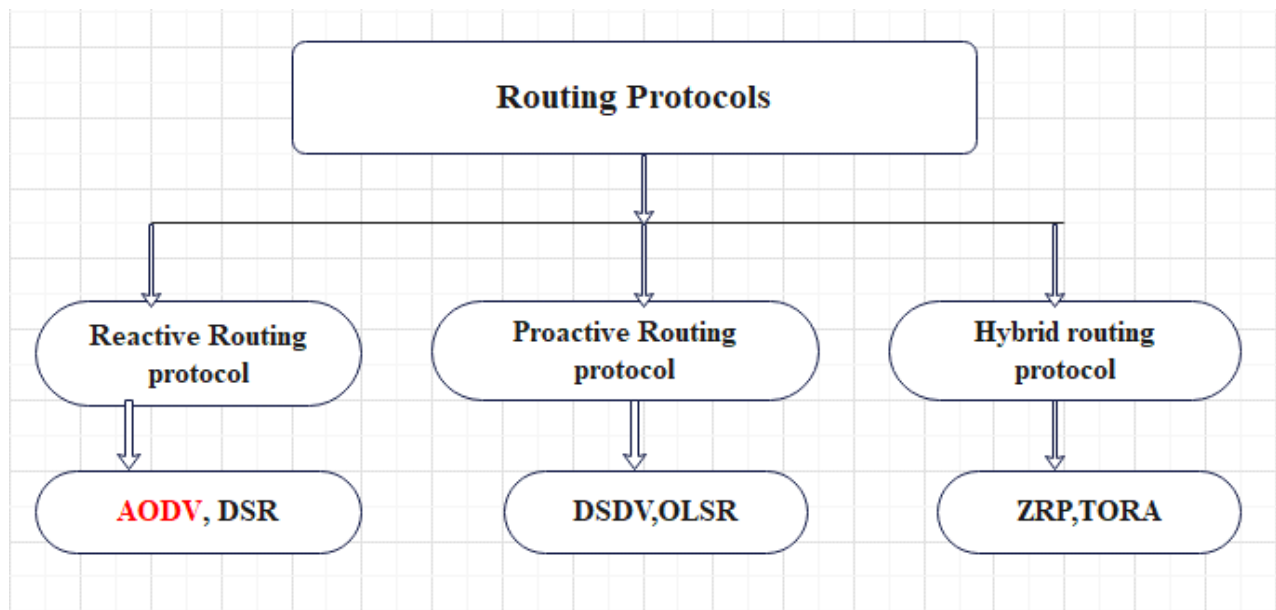


Figure 1 routing protocols in Manet

1.1.1. Proactive (table-driven) Routing Protocol

Another name for proactive routing was a table-driven routing protocol. This routing method involves mobile nodes broadcasting their routing information to nearby nodes on a regular basis. Every node had to keep a routing table that listed the number of hops as well as nearby and reachable nodes. To put it another way, anytime the network topology changed, every node assessed its vicinity. As a result, one of the main drawbacks was that routing overhead rose with network size, leading to substantial communication overhead in big network topologies. One benefit, though, was that if a malevolent attacker joined the network, network status could be instantly reflected. The Destination-Sequenced Distance Vector (DSDV) [19] and Optimized Link State Routing (OLSR) [15] protocols were the most widely used proactive routing techniques.

1. Destination-Sequenced Distance Vector (DSDV):

DSDV was an aggressive distance-vector routing protocol that was suited to Mobile Ad Hoc Networks (MANETs). Based on the Bellman–Ford algorithm, it was later developed by Perkins and Bhagwat (1994) to solve the count-to-infinity and routing loop problems of conventional

distance-vector protocols. DSDV achieved loop-free routing by marking each route with sequence numbers generated at the destination. In this scheme, even sequence numbers represented valid routes, whereas odd sequence numbers indicated invalid routes.

Sequence Numbers: Each routing table entry included a sequence number. When a route change was detected, the sequence number was increased so that nodes could distinguish stale (bad) routes from valid ones.

Periodic Updates: DSDV periodically announced routing updates so that all nodes remained synchronized, even when network topology changes occurred.

Full and Incremental Updates: DSDV reduced routing overhead by sending full routing updates at regular intervals, while allowing small incremental updates to be sent when only minor changes were made.

The advantages were that it ensured loop-free and up-to-date routes and was easy to implement. It was best suited for small- and medium-sized networks. However, the disadvantages were high routing overhead in dynamic networks because frequent updates were required, and topology-related scalability issues occurred in larger networks.

Optimized Link State Routing (OLSR):

Specifically created for mobile networks, OLSR was an aggressive link-state routing system. By using Multipoint Relays (MPRs) to selectively send broadcast messages, it reduced the volume of control traffic. In dynamic network situations, it was therefore more effective than traditional link-state protocols.

Multipoint Relays (MPRs): To cut down on pointless message transmissions and conserve bandwidth, a chosen group of nodes passed control messages.

Link-State Information: Nodes kept track of their connections to other nodes, and the network as a whole routinely received this information.

Periodic Control signals: MPRs received Topology Control (TC) signals from nodes on a regular basis, which were then distributed throughout the network.

Advantages were OLSR scaled well in large-scale networks due to reduced flooding of control messages. It was suitable for highly dynamic topologies and demonstrated good scalability and Disadvantages OLSR required careful selection of MPRs, which was complex, and it still incurred some overhead due to periodic message dissemination.

Protocol	DSDV	OLSR
Routing Type	Distance Vector (Proactive)	Link State (Proactive)
Route Updates	Periodic full and incremental updates	Periodic control messages via MPRs
Loop Avoidance	Sequence numbers	Not applicable (link state-based)
Overhead	High in dynamic environments	Optimized, lower due to MPRs
Scalability	Better for small to medium networks	Better scalability for larger networks
Suitability	Simple networks with moderate mobility	Highly dynamic, large-scale networks

Table 1 Difference b/n DSDV and OLSR

Both DSDV and OLSR have their use cases depending on the network size, mobility, and need for optimized control message management.

1.1.2 Reactive (on-demand) Routing Protocol

Another name for reactive routing was an on-demand routing mechanism. Reactive routing was only triggered when nodes required to transfer data packets, in contrast to proactive routing. One benefit was the reduction of bandwidth usage brought on by sporadic transmissions. However, if malicious nodes are present in the network environment, this strategy can become vulnerable. One drawback of the passive routing method was packet loss. The Ad hoc On-demand Distance Vector (AODV) [16] and Dynamic Source Routing (DSR) [17] protocols are two well-known on-demand routing methods that were briefly described in this section.

The DSDV routing protocol served as the foundation for the development of AODV. The routing table in AODV maintained routing pathways between source and destination nodes rather than

storing all of the next-hop information. A route discovery process was started right away when the source node could not contact the destination node. The source node sent out a Route Request (RREQ) packet to start the route discovery process. When destination information was discovered in their routing tables, some of the intermediate nodes transmitted a Route Reply (RREP) packet back to the source node after receiving the RREQ packets [18].

When a link was lost or the network topology changed, route maintenance was initiated. A Route Error (RERR) packet was the first to alert the source node. The source node updated the routing table by either determining a new routing path or restarting the route discovery process based on the available routing information. Source routing served as the foundation for DSR's design. Source routing meant that the header of every data packet included the whole routing path from source to destination. Mobile nodes in DSR kept a route cache with full source-to-destination pathways, in contrast to AODV, which only kept next-hop data. Consequently, the source node used stored routing information to determine routing pathways. However, the performance of DSR decreased as network mobility increased, resulting in a lower packet delivery ratio under high mobility conditions.

Ad hoc On-Demand Distance Vector (AODV):

One popular reactive routing system is AODV, which creates routes on-demand by employing a route discovery procedure and sequence numbers to guarantee new and loop-free routes. Route Discovery: A source node broadcasts a Route Request (RREQ) message when it needs to communicate with a destination node but does not have a valid route. If an intermediate node had a valid route to the destination, it either answered with a Route Reply (RREP) message. Route Error (RERR) messages were used in AODV's Route Maintenance to alert nodes about link problems. Nodes either fixed their routes or looked for other routes after receiving an RERR message.

Sequence Numbers to prevent routing loops and ensure route freshness, each node stored a sequence number for each route. Advantages of AODV reduced routing overhead by creating routes incrementally only when they were needed. It ensured loop-free routing through the use of

sequence numbers. And disadvantages AODV introduced delay during the route discovery process. Additionally, route discovery caused short-term overhead due to network-wide flooding.

Dynamic Source Routing (DSR):

The packet header held all of the routing information for DSR, a reactive routing protocol that employed source routing. The intermediary nodes did not require the creation of routing tables. Source Routing: This method involves the transmitting node inserting the entire route including the list of intermediate nodes into the packet header. Finding and Maintaining Routes In that both protocols broadcast Route Request (RREQ) messages and received Route Reply (RREP) messages, DSR and AODV were comparable. However, routing data was conveyed by the packet header rather than being kept in routing tables. To lower the frequency of route discovery, route caching nodes kept a list of known routes in their route caches. Routing tables at intermediary nodes were not necessary for DSR's benefits. The amount of route discovery procedures was decreased by route caching, while the drawbacks of packet header overhead rose with route length. Because of its overly large packet headers, DSR was not scalable for big networks.

Temporally Ordered Routing Algorithm (TORA) TORA was a very responsive routing system that worked well in network situations that were quite dynamic. Based on the idea of link reversal, it was a distributed routing protocol without loops. Several Routes TORA was extremely flexible to route failures since it provided several routes to a target. On-Demand Route Discovery: When a route failed, local repairs were made, and TORA only found routes when they were required. Link Reversal: When a route failed, a specialized algorithm called link reversal was used, resulting in the direction of links to be updated.

An advantage of TORA was well suited for very dynamic and dense networks. The availability of multiple routes provided fault tolerance. Disadvantages of TORA incurred high overhead due to the large number of control messages in highly dynamic networks.

It also introduced complexity in maintaining multiple simultaneous routes.

Protocol	AODV	DSR	TORA
Route Discovery	On-demand, RREQ and RREP	On-demand, source routing	On-demand, link reversal mechanism
Route Maintenance	RERR messages to repair routes	Route caching to avoid rediscovery	Localized route repair
Routing Table	Yes, maintained at each node	No, route stored in packet headers	Yes, maintained with multiple routes
Scalability	Moderate scalability	Not scalable to large networks	Scalable but with high control overhead
Loop Avoidance	Sequence numbers	Source routing avoids loops	Link reversal ensures loop-free routing
Overhead	Medium (control messages during discovery)	High (due to large packet headers)	High (due to frequent control messages)

Table 2 Difference b/n AODV, DSR and TORA

AODV, DSR, and TORA reactive routing protocols were well-suited for dynamic environments, where bandwidth savings were a primary concern. However, they introduced latency because time was required for route discovery, and flooding along with control messages caused scaling challenges.

1.1.3 Hybrid Routing Protocol

To get beyond the drawbacks of both proactive and reactive routing, the hybrid routing protocol merged their benefits. The majority of hybrid routing protocols were created with a layered or hierarchical network architecture. When network topology changed, reactive routing was utilized to maintain routes after proactive routing was initially used to collect all routing information.

The Temporally-Ordered Routing Algorithm (TORA) [20] and the Zone Routing Protocol (ZRP) [19] were two popular hybrid routing systems.

One of the most widely used hybrid routing protocols was Zone Routing Protocol (ZRP). It divided the network into overlapping zones for each node, where intra-zone communication was handled proactively, and inter-zone communication was handled reactively.

Intra-Zone Routing (Proactive): Within a node's local zone, proactive routes were maintained using any table-driven protocol, such as Destination-Sequenced Distance Vector (DSDV). Nodes shared routing information with other nodes in their zone continuously. **Inter-Zone Routing (Reactive)** For nodes outside the local zone, routing was performed reactively. ZRP initiated a route discovery procedure similar to reactive protocols such as AODV. **Zone Radius** the zone radius was defined as the number of hops within which proactive routing was employed. Beyond this radius, routing was handled reactively. Advantages of ZRP offered high redundancy in large networks. The combination of proactive and reactive routing reduced latency and bandwidth consumption and disadvantages of its performance depended on the zone radius configuration, which had to be optimized based on network size and mobility patterns. Maintaining zones added complexity and caused overhead in highly dynamic networks.

2. Hybrid Wireless Mesh Protocol (HWMP):

In IEEE 802.11s-based wireless mesh networks, HWMP was a hybrid routing protocol that supported both reactive on-demand routing and proactive tree-based routing. In proactive tree-based routing, nodes maintained a tree-based routing structure proactively, with a root node, and these tree-based routing provided optimal paths within densely communicating areas. In reactive on-demand routing, nodes that did not send frequent messages conserved bandwidth and energy by performing route discovery only when they needed to communicate.

Flexible Design: HWMP adapted its behavior according to network topology and traffic patterns, making it suitable for dynamic networks such as mesh networks. Advantages of HWMP demonstrated adaptability in balancing proactive and reactive strategies; it was efficient in networks consisting of both stable and mobile nodes. And disadvantages of combining tree-based and on-demand mechanisms increased protocol implementation complexity; the proactive component could introduce overhead in highly mobile networks.

Enhanced Interior Gateway Routing Protocol (EIGRP):

Although primarily used in wired networks, EIGRP was adapted for MANETs. It was a hybrid routing protocol that made use of both reactive queries when routes were unknown and proactive Update known topology.

Dual Algorithm: EIGRP employed a Diffusing Update Algorithm (DUAL) to guarantee loop-free routing and to swiftly converge when the topology changed; Efficient Route Discovery: EIGRP reduced control message overhead by sending queries only to nodes involved in the routing process; Proactive Route Maintenance: Reactive queries were used for unknown routes, while proactive routes were maintained for efficient routing within the known topology.

EIGRP's benefits included quick convergence in dynamic networks and effective bandwidth utilization because of its restricted control message exchanges. Additionally, EIGRP's drawbacks included increased memory consumption and complexity as network size increased due to the maintenance of routing tables.

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Protocol	ZRP	HWMP	EIGRP
Routing Type	Proactive in zone, reactive for inter-zone	Proactive tree-based, reactive on-demand	Proactive within known topology, reactive queries
Zone/Region	Zone radius defines proactive area	Root-based proactive regions	Known topology for proactive updates
Overhead	Low for local zones, higher for large zones	Varies based on topology	Low due to efficient queries
Scalability	High scalability with optimized zone radius	High scalability in wireless mesh	Moderate scalability
Flexibility	Highly adaptable to network size and mobility	Suitable for dynamic mesh environments	Efficient in mixed networks

Table 3 Difference b/n hybrid protocols (ZRP, HWMP and EIGRP)

Hybrid routing protocols offered an effective solution for large and complex networks by combining the benefits of proactive and reactive approaches. They provided a flexible and scalable routing solution for MANETs, where nodes were frequently mobile and the network topology was highly dynamic.

Characteristics of MANET:

Dynamic Topologies: The network nodes kept moving at different speeds, which caused variations in the network structure; **Energy-Constrained Operation:** Devices in modern electronic environments relied entirely on batteries. Network design had to be optimized to conserve the energy consumed by mobile nodes; **Limited Bandwidth:** Wireless networks had narrow bandwidth, so networks had to be optimized to perform efficiently within these limitations and **Security Threats:** Compared to wired communication, wireless communication was more vulnerable to security threats. The security of MANET needed to be improved to ensure that transmitted information was protected. Security was one of the main challenges of MANETs

because the wireless environment allowed data to be freely transferred between nodes, making the network susceptible to various attacks.

1.2. Statement of the problem

Mobile Ad hoc Networks (MANETs) were wireless networks that are created by a collection of mobile devices that do not rely on infrastructure for connectivity. In MANET, one of the popular routing protocols was the Ad hoc On-Demand Distance Vector (AODV) protocol. There were several security issues that made MANETs susceptible: One of them was black hole attack in which a malicious node would pretend to have the shortest path to the destination and would divert the entire network traffic to it. This caused denial of service and communication problems in the network. The problem here is to design a mechanism to avoid and detect Black hole attack in MANETs for AODV protocol. The mechanism should be able to detect malicious nodes and skip them in the route selection process to choose the safest and most reliable ones. In addition, the mechanism should be able to identify atypical network activity, and notify the network administrator.

A trust-based system was developed where nodes' reliability was calculated and the safest and most dependable paths were selected. The mechanism might have to be able to measure the trust level of nodes in many ways, e.g. with the help of reputation-based systems. It also may employ intrusion detection capabilities to detect suspicious network activity. The idea of the method was to prevent black hole attacks by steering clear of malicious nodes and selecting routes with the maximum trust levels. Also, it can detect attacks to black hole and alert the network administrator. In this paper, I suggested using the AODV MANET protocol to identify and avoid black hole assaults.

The following features of MANETs—insecure operating environments, physical vulnerability, shared broadcast radio channels, absence of central authority, and restricted resource availability—made this need necessary. By absorbing data, malicious nodes operated as obstacles along secure pathways, decreasing packet delivery, deteriorating performance, lowering end-to-end delivery and throughput, and consuming more energy. As a result, identifying and stopping such attacks was crucial to network security.

1.3. Research Question

Many black hole detection and prevention techniques were proposed to enable MANETs to defend against black hole attacks. Most of the proposed solutions had a clear cost in terms of network performance.

Research Questions:

RQ1: How could black hole attacks be detected and prevented in the AODV MANET protocol using bee-inspired algorithms?

RQ2: Why were bio-inspired algorithms needed for attack detection and prevention in this research, and which bio-inspired algorithms were more effective for network security?

RQ3: Why was it important to detect and prevent black hole attacks in the AODV MANET protocol?

1.4. Objectives of study

1.4.1. General Objective

The general objective of this thesis is the Detection and Prevention of Black Hole Attacks in AODV MANET protocol.

1.4.2. Specific Objectives

The specific objectives of preventing and detecting black hole attacks in MANETs using the AODV protocol were:

- ✚ To develop a mechanism that could identify and prevent malicious nodes from launching black hole attacks in the network.
- ✚ To evaluate the performance of the proposed secure AODV protocol in terms of packet delivery ratio, throughput, end-to-end delay, and routing overhead.
- ✚ To study the impact of black hole attacks on the performance of the AODV routing protocol in Mobile Ad Hoc Networks (MANETs).

1.5. Significance of the Study

This research proposal was a valuable contribution to the research area of wireless communication in MANETs by detecting and mitigating the black hole attack in AODV MANET protocol and thereby, the communication in MANETs is made effective. It was expected to provide better service to the users. This facilitated the functioning of MANET applications, with the most important application areas being in multimedia, education, and emergency situations (military). Furthermore, it paved the way for future research on this subject.

Although considerable efforts have been put into using AODV protocol to avoid and detect black hole attack in MANETs, some research gaps still remained.

2. Real-world testing was lacking: Majority of the research was a simulation. A need for ground truth testing to test effectiveness of proposed solutions.

3. Guarantee of privacy and confidentiality: Most of the proposed solutions failed to guarantee privacy and confidentiality. They did well in small networks and not so well in large networks.

3. Overhead and delay solutions: Some proposed solutions brought a lot of overhead and delay. More efficient solutions were needed to minimize these impacts.

4. Ignorance of other type of attacks: Very little research was conducted on black hole attacks only. Other attacks, like gray hole attacks and wormhole attacks required comprehensive solutions.

6. Limited creativity: Proposed solutions were not particularly creative, and it was difficult to compare and evaluate the efficacy.

Solutions to solve the above research gaps can enhance the effectiveness and efficiency of black hole attacks prevention and detection in MANETs using the AODV protocol.

1.6. Scope and Limitation of the Study

This work is limited to the detection and prevention of black hole attack in AODV MANET protocol. This limitation was due to constraints such as time, budget, and resources. Research on hybrid, proactive, and reactive routing protocols was not carried out in this study.

1.7. Organization of the Thesis

The structure of this investigation was as follows: The study's context, problem statement, general and particular objectives, scope, and limits were all summarized in Chapter One. It also highlighted the significance of the study, outlined the research subjects, and identified the gaps in the literature.

Chapter Two offered a brief review of the literature and a thorough analysis of previous studies in order to assess the AODV MANET routing protocol's capacity to thwart black hole attacks. Chapter 3 addressed the research strategy, including the instruments and methods used.

Chapter 4's primary focus was on performance measure analysis and findings. Chapter Five ultimately offered the findings and recommendations.

CHAPTER TWO

2. Literature review

2.1. Review of related research work

Mobile Ad Hoc Networks (MANETs) were dynamic, cooperative networks without infrastructure. Due to their openness, they were extremely vulnerable to routing layer attacks, especially black hole attacks, in which hostile nodes destroyed packets, claimed bogus optimal routes, and caused denial-of-service problems and poor network performance. Due to its reliance on unverified Route Reply (RREP) packets and next-hop sequence numbers, AODV, a popular routing protocol in MANETs, was particularly susceptible to such attacks. During the route discovery phase, black hole attacks took place when a rogue node instantly responded to Route Request (RREQ) messages with a phony RREP, claiming the greatest sequence number and the shortest path. The source node was misled into routing data as a result.

This caused lost packets and disrupted end-to-end connectivity by tricking the source node into sending data through the malicious node.

Black hole attacks' effects on AODV were assessed by Tripathi and Sindhuben, who concentrated on how the attacks impacted route decision-making and interfered with route formation and data transmission.

Information Routing and Dynamic Learning Techniques: In order to stop future exploitation, DPRAODV (Dynamic Learning System against Black hole Attack), one of the first techniques put out, not only identified black hole nodes but also alerted other network nodes to the harmful activity. NS-2 simulations demonstrated that DPRAODV preserved performance similar to standard AODV while reducing the impact of black hole attacks.

Cross-Checking with Data Routing Information (DRI): Sen et al. suggested a method to improve AODV by utilizing extra DRI tables and node cross-checking, which assisted in identifying cooperative black hole assaults. To show whether data has been routed to and through a particular node, two bits of routing data were added to each node. This data was used to detect fraudulent or inconsistent route responses.

Timing and RRPD Check Methods: In other methods, the source node used timing techniques to check hop counts, wait until numerous RREPs were received, and confirm route legality by getting responses from the destination node before choosing a route. This technique assisted in locating nodes that sent data too rapidly or inconsistently.

Better Detection Algorithms: Leo and Patel developed the improved detection algorithms that were able to identify inconsistent RREP patterns, considered to be the consequence of evil nodes. This approach led to enhanced black hole attack detection.

The study of literature on black hole attack detection and mitigation in MANETs using Ad hoc On-Demand Distance Vector (AODV) protocol examined various relevant topics such as methods, problems and gaps in previous research. The key ideas and conclusions pertaining to this subject are outlined in the following table:

2.2. Overview of MANETs and AODV Protocol

Definition and Characteristics of MANETs

MANETs were self-configuring, decentralized networks of mobile devices without the need for centralized control or infrastructure. The main characteristics of MANETs were:

Self-Configuration: MANET nodes were able to setup and maintain their own communication connections. This made the network topology dynamic as nodes could join or leave the network as needed; nodes were mobile, therefore the network topology changed frequently making routing, communication more difficult.

Decentralization: There was no central management or control over the network. The nodes themselves acted as hosts and routers of traffic for other nodes. While this enhanced network flexibility, it also brought out the vulnerability of the network to attack; **Dynamic Topology:** Node mobility can lead to a network topology those changes rapidly. Route establishment and maintenance is particularly difficult since nodes may come and go from the network at any time; **Resource Limitations:** MANET nodes typically were battery-powered and had limited processing and bandwidth. Because of these restrictions, the overhead and power consumption of the communications had to be minimized. Additionally, since all nodes were connected by wireless networks, they were susceptible to interference, signal loss, and other security-related problems.

These characteristics exacerbated the challenges MANETs faced, particularly in routing and security. The dynamic and decentralized nature of these networks predisposed them to various attacks, including black hole attacks, which could disrupt communication and degrade network performance.

2.3 AODV Protocol

An example of a reactive routing protocol is the Ad hoc On-Demand Distance Vector (AODV) protocol which was developed specifically for MANETs. In contrast to proactive protocols, AODV would not maintain active routes at all times, it would only establish routes between nodes when required. Some of the key features of the AODV protocol were:

On Demand Route Creation: Only routes were built up on an as-needed basis. The source node would send a Route Request (RREQ) in the network whenever it needed to transfer data to a destination node while AODV's Route Maintenance would maintain routes only when needed. It would cause a route maintenance procedure in the following cases: Since the routes were not continually calculated overhead was reduced.

To ensure loop-free and up-to-date paths, AODV used sequence numbers. Each node had its sequence number up and as it started to send out route request, each node's sequence number was incremented. This was to ensure that the use of stale routes was prevented. The AODV supports broadcasting and multicasting, so it can broadcast route requests to these to find paths to many destinations, which may be valuable for many MANET applications.

Although AODV had various merits, it was vulnerable to attackers' threats including black hole attacks. The attack in a black hole is an attack in which a rogue node sends data packets to the black hole, pretending to be the nearest node to the destination node then discards them. This attack severely impacted communications with packet loss, latency, and overall poor network performance creating communication difficulties.

2.4 Black Hole Attacks in MANETs

Nature of Black Hole Attacks

One kind of security risk that affected Mobile Ad Hoc Networks' (MANETs) routing capabilities was a black hole attack. Malicious nodes that employed misleading tactics to interfere with network operations carried out such assaults. A black hole attack happened in the following order:

Deceptive Advertising: The malicious node in a black hole attack promoted itself as having the quickest or most effective route to the destination node. In order to accomplish this, bogus path Request (RREQ) messages that claimed a quick path to the desired location were typically injected.

Packet Interception: Once the false route advertisement reached the legitimate nodes, they had been led astray and used the malicious node as the next hop to the intended destination, resulting in data packets being rerouted along to the malicious node. Packet dropping: After the packets were intercepted, the malicious node dropped the packets and did not pass them on resulting in packet drops and disrupting network node communications.

Untraceable Behavior: By first announcing a legitimate path, the rogue node behaved like a regular node, making it challenging to locate. Thus, other nodes were not informed of the attack and continued to send packets to the black hole.

The black hole attack endangered the integrity of the data transmission, and increased the delay, packet loss, and network performance in MANETs.

Influence on Performance

Research showed that black hole attacks significantly degraded MANET performance across several metrics:

The ratio of the number of packets received at the destination to the number of packets sent is called packet delivery ratio (PDR). During black hole attacks this ratio was quite low, since packets were neither sent nor accepted. Research has shown that if this indicator is below the acceptable norms, communication failures can be experienced (Sadiq et al., 2020).

Complete Delay: The duration of a packet's journey from a source node to a destination node was measured by end-to-end delay. Further, delays also increased due to the constant triggering of route discovery procedures by legitimate nodes attempting to send data, but failing to do so. Packets were lost forcing nodes to take alternate routes, increasing delay. (Zhang et al., 2021).

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2.5. Detection Mechanisms

In Mobile Ad Hoc Networks (MANETs), detecting black hole attacks was essential to protecting the network's performance and integrity. A number of strategies have been proposed to detect and prevent the effect of these attacks; they may be categorized as traditional detection methods and more recent trust-based methods.

Conventional Methods of Detection

Watchdog features and passive observation of surrounding node behavior were the mainstays of early detection techniques. These techniques used the observation of packet forwarding patterns to detect malicious nodes.

The watchdog system, in which nodes kept an eye on their neighbors' behavior, was one popular technique. A check was made at each forwarding node to determine if the packet was forwarded by the next-hop node to the desired destination. If the node did not forward the packet in the specified time, the packet was considered suspicious.

Neighbor behavior monitoring was another approach, where nodes collected information through observing the transmission and reception behavior of their neighbors. If a node opted to broadcast its own packets rather than forwarding other nodes' packets, it was classified as being suspicious, which might have been malicious.

Neighbor behavior monitoring was another technique in which nodes gathered data by studying transmission/reception. If a node determined that it sends its own packets, and not others' packets, it was considered suspicious and possibly malicious.

These techniques work well, but they have some disadvantages. For instance, false positives can occur if the watchdog mechanism mistakenly flags for trouble normal packet forwarding delays, disrupting regular network traffic and reducing trust in the network.

Malevolent nodes were also a huge challenge, as they can selectively forward packets and disguise their malicious actions.

A major problem was that the traditional approaches did not have a wide enough monitoring scope. Each node had only a local view and a limited understanding of the activity of the entire network, which led to incorrect or insufficient evaluations of trustworthiness.

All of these disadvantages highlighted the need for new and more sophisticated detection methods to deal with the dynamic nature of MANETs and to effectively recognize malicious activity.

Trust-Based Systems

To overcome the limitations of conventional approaches, trust-based models came into play, proving more effective in detecting black hole attacks. In the case of a trust-based system, nodes based on previous interactions and current behavior evaluated their neighbors' trustworthiness.

These systems also involved the use of trust measures representing the trustworthiness of a node. Factors such as successful packets sent, route request responsiveness, and overall uniformity of behavior over time were considered in these metrics.

Dynamically updating trust values as nodes interacted. For example, the trust value of a node that regularly transmitted packets rose, while the trust value of a node that dropped packets regularly or acted in an erratic manner decreased.

By avoiding low-trust nodes and isolating possibly malicious nodes, nodes were able to make well-informed routing decisions and preserve the general health of the network by using these trust measures. For instance, a trust-based system could lay out a range of scores from 0 to 1, with 0 representing no trust at all and 1 representing total trust. Other nodes might choose to route through such a node because it achieves a 0.9 trust score for the 90% of packets it successfully transmits.

The efficacy of trust-based detection techniques has been shown in recent investigations. For example, Zhang et al. (2021) and Jamil et al. (2022) explored various trust models and demonstrated that network performance and packet delivery ratios can be enhanced using trust systems.

2.4. Prevention Strategies

To lessen the impact of black hole attacks on Mobile Ad Hoc Networks (MANETs), several preventive measures were put forth. By either altering the protocol itself or putting in place tools to keep an eye on node activity, these methods sought to improve the security or dependability of routing protocols like AODV. Among the most important preventative measures were:

2.5.1 Route Validation Techniques

Two-Way Handshake: A two way handshake procedure was implemented before establishing the route to ensure route integrity. A node only responded to a Route Request (RREQ) with a Route Reply (RREP) after it confirmed that it had a valid route to its target. The possibility of accepting routes from malicious nodes was reduced by this process.

Route Consistency Check: Nodes regularly checked the consistency of their routes. If a node detected an inconsistency in its current route, it would recheck the route and search for paths it didn't expect to detect. If a node detected any inconsistency, such as seeing a packet loss that it didn't think to see, an excessive delay, etc., the node would go back and recheck the route to see if there were any other ones it didn't think to check.

Cryptographic Methods

Node Authentication: To guarantee that only authorized nodes took part in the routing process, cryptographic node authentication was used. To authenticate neighboring nodes, nodes used digital signatures or public-key infrastructure (PKI) before setting up a route. Hostile nodes could not launch black holes attacks by doing this.

Verification of Cryptographic Integrity: Cryptographic techniques were also used to confirm data integrity. Hashing and related methods guaranteed that packets had not been altered while being transmitted.

By putting these tactics into practice, MANET routing environments were made more secure, which decreased the possibility of black hole attacks and enhanced network performance (Ali et al., 2021).

2.5.2 Reputation Systems

Reputation systems were employed as an effective method for monitoring and evaluating the behavior of nodes in a MANET. Individual nodes maintained logs of their interactions with neighboring nodes, recording metrics such as the number of packets successfully transmitted and any observed malicious behavior. These records were continuously updated during data transmissions, allowing the network to develop a comprehensive profile of each node's behavior.

Within this framework, reputation scores were calculated using various algorithms that considered factors such as successful packet forwarding, response times, and frequency of packet

drops. Nodes that consistently forwarded packets correctly received high reputation scores, whereas nodes that frequently dropped packets received lower scores. During routing, nodes with the lowest reputation values were excluded from forwarding decisions to ensure that only trusted nodes participated in data transmission, thereby maintaining the integrity and reliability of the network (Sadiq et al., 2020).

An additional benefit of reputation systems was their flexibility: nodes that had previously misbehaved could regain trust by demonstrating cooperative behavior over time. This self-regulating property not only encouraged honest behavior but also promoted the development of a more robust and reliable network.

2.5. Challenges and Future Directions

After an extensive literature review on how to detect and prevent black hole attacks in MANETs with the AODV protocol, the following research gaps were identified.

Poor Scalability to Multiple Black Holes

Despite the various black hole attacks analyzed, few of them showed the performance of the system when multiple malicious nodes are present in the system. These were realistic attack scenarios resulting in substantial packet loss and poor network performance as the number of malicious nodes grew, which reinforces the need for solutions that scale well against the number of malicious nodes.

High Routing Overhead and Delay

Multiple methods depended on extra control packets, cross-checking techniques or waiting periods for a number of route replies. These techniques increased the accuracy of detection, but also added considerable routing overhead and end-to-end delays, which negatively impacted network performance. While designing the network protocol, it was not found to be compatible with the standard AODV.

The proposed solutions have changed the AODV protocol so drastically that they are not compatible with existing implementations. This restricted their applicability in real world MANET environments, where lightweight and easily deployable solutions are required.

Heterogeneous Attack Intensities, Poor Performance Assessment

In numerous studies they tested their solutions under a specific scenario, e.g., a specific number of malicious nodes, or static network settings. These strategies did not measure the system performance when the number of black hole nodes grew larger, which meant that there was a lack of knowledge on scalability and robustness of the detection mechanisms.

The failure to accurately distinguish malicious nodes and legitimate nodes

Approaches to detection depended on thresholds, e.g., sequence numbers or response times, and these would be susceptible to the misclassification of legitimate nodes as malicious in a high dynamic environment. Those false positives caused network insecurity and lack of confidence. Although several research works have been contributed to black hole detection and prevention techniques in MANETs, in this paper, some gaps have been considered that showed the necessity of more robust and efficient solutions. Two key concerns that are discussed in the following sections are those of dynamic network conditions and scalability.

Dynamic Network Conditions

Current values of trust were hard to maintain in MANETs because of its dynamic and mobile characteristics, and frequent topological changes. Main issue was the high level of topology changes. It was challenging to keep up-to-date trust assessments because nodes joined and left the network on a regular basis. The node behavior changes after computing the trust value; Trust Value Calculations: MANETs are dynamic, and it is important to update frequently. However, long connection delays caused problems in identifying rogue nodes, providing attackers with more time to interfere with network operations. Too many updates also led to high network overhead and complexity, resulting in lower performance and service disconnections.

Future research will focus on adaptive trust management systems which reduce the overhead and accurately update trust values in real-time. One potential solution to these problems was the use of machine learning to forecast node behavior using past data (Zhou et al., 2022).

Scalability Issues

As MANETs increased in size, their detection and prevention posed challenges to conventional detection and prevention methods. Some of the specific challenges included:

Extra overhead: More communication was needed in larger networks to keep track of nodes and update their trust levels, leading to delays and reduced throughput. Restricted Performance: Route discovery and trust calculations increased in a network with the number of nodes, so algorithms developed for small networks failed to work on larger networks. Also, due to the

complexity of node interactions in large networks, regularly evaluating and updating the trustworthiness became a burden on the network resources.

Distributed and hierarchical trust-management models can be explored in future research to decrease the overhead by doing a local evaluation of the trust status or by gathering the data at the cluster level and get a comprehensive view of the network behavior(Sharma et al., 2023).

The integration of Cross-Layer Approaches

Improvements to the overall security of MANETs are shown to be useful if security protocols are layered in multiple network stack layers. The Multi-Layered Security Approach was one of the more significant strategies that deployed security at multiple layers, rather than a single layer, in the physical, link, network, and application layers. A more thorough defense against black hole attacks was offered by this integrated strategy; Information Sharing: Cross-layer communication was used to exchange information about trust.

Adaptability and Resilience: The capabilities of several layers were used to increase the adaptability and resilience of the network. For example, the physical layer trust value estimated, e.g., signal strength, was used in the network layer to enhance nodes trust value estimation. Using information from lower layers, application-layer protocols enhanced security measures with additional checks and balances.

It was recommended that future research focus on designing and evaluating cross-layer security protocols that will improve security detection and prevention methods, ensure proper delivery and minimize overhead (Patel et al., 2022).

Chapter Three

3. Research Methodology

3.1 Research Design

Designing Specific Research this paper was organized in such a way that it methodically explored the detection and prevention of black hole attacks in Mobile Ad Hoc Networks (MANETs), taking the Ad Hoc On-Demand Distance Vector (AODV) routing protocol as a reference point. The design incorporated several important components.

3.1.1 Type of Research

The research was based on an experimental approach, in which the effects of black hole attacks on MANETs were investigated and the effectiveness of the developed detection and prevention mechanisms was evaluated. This approach was enabled by a research design that allowed experimentation with varying network scenarios in a controlled environment, thereby facilitating the comparison and analysis of performance metrics under different conditions.

3.1.2 Simulation Environment

The study used the simulation software NS2 to model the MANET system and create realistic network scenarios, allowing various parameters to be adjusted to observe their effects on performance. A virtual network was set up to include a fixed number of mobile nodes (e.g., 50 nodes within a $1000\text{ m} \times 1000\text{ m}$ area). The Random Waypoint Mobility Model was employed to simulate realistic movement patterns, changing node positions and enabling the evaluation of network performance under mobility conditions.

3.1.3 Attack Simulation

A black hole attack was launched in which some nodes in the network were programmed to drop all received packets and to send false Route Reply (RREP) messages. This setup provided an opportunity to examine the impact of black hole attacks on key network performance metrics.

3.1.4 Performance Metrics

Key performance indicators used to assess the detection and prevention mechanism included:

Packet Loss was the proportion of data packets that were lost during communication; End-to-End Delay the time duration taken by a data packet to travel from the source node to the destination node; Throughput the rate of successful data transmission over the communication path, measured in kilobits per second (kbps). And Energy Consumption: The total amount of energy consumed by network nodes during packet transmission and reception, measured in Joules.

Detection Mechanism

A trust-based detection mechanism was incorporated, in which the behavior of nodes was monitored to identify and block malicious nodes. This mechanism included the following components were Behavior Monitoring: Continuous monitoring of node activities was performed to detect abnormalities in packet forwarding behavior. Trust Calculation: Individual nodes calculated trust values for their neighboring nodes based on their performance in relaying packets and Nodes with low trust values were identified as potential black hole attackers.

3.1.6 Data Analysis

Following the simulations, performance metrics were measured under each evaluation criterion. Statistical results were used to compare network performance under normal conditions, under black hole attack conditions, and under attack conditions both with and without the proposed detection mechanism. This analysis demonstrated the effectiveness of the proposed system in mitigating and neutralizing the effects of black hole attacks on network performance.

3.2 Simulation Environment Setup

In the case of Mobile Ad Hoc Networks (MANETs), the conditions of the simulation are crucial in determining the performance of the AODV protocol in black hole attacks scenarios. The following components were used for the simulation set-up.

Simulation Tools

Network Simulator version 2 (NS-2) was used to model and simulate MANET environment. NS-2 was highly functional and flexible for simulating wireless network protocols and was extensively used in academic research because of its good performance and reliability in simulation testing.

The layout of the network and the configuration of the nodes

The simulated network comprised of 50 mobile nodes. This number was chosen to result in a balance between the degree of complexity and the analysis of the performance that is meaningful. The nodes were placed in a $1000\text{ m} \times 1000\text{ m}$ space that allowed the nodes to move around the area with realistic wireless communication range.

Mobility Model

Realistic node movement pattern was simulated using the Random Waypoint Mobility Model. In this model every node was chosen to move with a uniform speed towards a randomly selected target within the simulation space. Once it arrived at the destination, the node would stop for a random period, then select another destination.

This mobility model allowed to represent the dynamism of MANETs and was crucial to evaluate the effect of black hole attacks in realistic mobility conditions.

AODV Protocol Implementation

Ad hoc On-Demand Distance Vector (AODV) routing protocol was used as a basic routing protocol for the simulation. The key operational aspects were: Route Discovery: Nodes which needed a route to a destination node would initiate route discovery by broadcasting a Route Request (RREQ) message; and Route Maintenance: Route maintenance would occur on-demand only to minimize overhead.

Simulates a Black Hole attack

Black hole attacks were simulated in the MANET to observe the impact of security threats on MANET performance. One or more nodes were set up as malicious nodes whose purpose was to disrupt the normal routing operations.

They were sending false routing information with forged Route Reply (RREP) messages that had abnormally high destination sequence numbers. This action led nodes to believe the malicious nodes had the shortest path to the node. After being elected as the next-hop nodes, the malicious nodes intentionally discarded all data packets received instead of forwarding them, thus forming a "black hole" in the communication path.

Different attack scenarios, such as black hole attack by a single node or multiple nodes, were used to test the scalability and severity of the attack. Metrics like the packet delivery ratio, end-to-end delay, throughput, routing overhead, etc. were captured and compared to the no-attack baseline scenario.

This experimental design was used to thoroughly test the degradation of network performance when subjected to black hole attacks and as a benchmark for evaluating the performance of the proposed detection and prevention mechanisms.

The following behaviors were implemented in the malicious nodes: Packet Dropping: Malicious nodes corrupt the received data packets and do not forward them; False Route Replies: Malicious nodes sent false Route Reply (RREP) messages and convinced the legitimate nodes of choosing routes via the attacker.

3.3 Data Collection and Analysis

Data for each of the performance metrics were gathered in three scenarios: the first scenario was when the AODV protocol was operating normally with no attacks, the second scenario was when the network was under black hole attack and the third scenario was once the proposed detection and prevention mechanism was implemented in the network during the black hole attack. The data gathered from the simulation experiments are analyzed statistically to measure the magnitude of the performance degradation due to black hole attacks, and to assess the effectiveness of the deployed detection mechanism in combating the performance degradation.

Collected data were statistically analyzed to identify the performance gap between the attack scenario and secured scenario. This analysis allowed for direct comparison to be made between the severity of degradation introduced by the black hole attack and the improvements achieved through the proposed detection and prevention mechanism.

Network communication in Mobile Ad Hoc Networks (MANETs) is still prone to security flaws, which become a significant problem for the integrity and reliability of network communication. Of these threats, the black hole attack is one of the most serious since it attacks the routing function of the network, especially the on-demand routing protocols like the Ad Hoc On-Demand Distance Vector (AODV) protocol.

In a network if a node is compromised it will maliciously claim to have the shortest or optimal path to the target node. Therefore, neighbor nodes choose this compromised node to forward packets. The malicious node will intentionally drop the packets, causing substantial data loss and heavy disruption of communication. This practice causes a black hole in the network because the compromised node pretends to be a legitimate node and reliable path to send data.

3.3.2 Mechanism of Attack

The typical black hole attack involves the following steps:

The black hole attack mechanism in AODV:

If a source node wishes to send a message to a destination node, it sends a Route Request (RREQ) message to find out if there is a valid route to the destination node. A malicious node picks up this RREQ and promptly sends a fake Route Reply (RREP) stating that it has the best path to the destination.

The malicious node returns a fake RREP to the source node containing an artificially high sequence number for the destination node, and a lower hop count. These metrics are advertised and make the route look better than legitimate nodes, and therefore make it more likely that the source node will choose the malicious route.

When the source node starts to send data packets through the malicious node, the attacker intentionally drops all the packets received, but doesn't send them to the intended destination. The consequence of this is that the packets will be absorbed by the attacker resulting in high Packet Lost Rate and Network Performance Degradation.

The black hole node not only sends lost packets, but also continues to send false routing information to neighboring nodes. The perpetuation of false control messages continues to

confuse the network and extend the reach of the attack and increase its effect on the overall level of routing reliability.

3.3.3 Impact on Network Performance

The black hole attack had a severe impact on the performance of the MANET. One of the most noticeable consequences was a sharp increase in packet loss, which reduced the reliability of data transmission and disrupted normal network communication. As more packets were lost, legitimate nodes were forced to retransmit data and initiate new route discovery processes to find alternative communication paths. This led to an increase in end-to-end delay, causing messages to take longer to reach their destinations.

The attack also affected the network's throughput, as malicious nodes intercepted and discarded packets instead of forwarding them. Consequently, fewer packets successfully reached their intended destinations, resulting in a decline in the overall rate of data transmission. In addition, energy consumption increased because nodes had to perform extra routing operations and repeated retransmissions to compensate for the lost packets. These additional activities consumed valuable network resources and reduced the overall energy efficiency of the system.

3.3.4 Objectives of Introducing Black Hole Attack in Simulations

To address the challenges associated with black hole attacks, this study simulated such attacks within a Mobile Ad Hoc Network (MANET) environment. The purpose of the simulation was to examine how black hole attacks affect network performance and to evaluate the effectiveness of the proposed detection mechanism.

The specific objectives of the study were as follows:

To investigate the impact of black hole attacks on key network performance metrics, including packet loss, end-to-end delay, throughput, and energy consumption and To evaluate the effectiveness of the proposed detection mechanism by determining its ability to identify malicious black hole nodes and reduce the negative effects of these attacks on overall network performance.

3.4 Detection Mechanism

Mobile Ad Hoc Networks (MANETs) are vulnerable to black hole attacks, which pose a threat to their security and reliability. An efficient detection mechanism is needed to detect and mitigate malicious activity. This paper proposes a detection mechanism that continuously monitors the

behavior of the nodes and applies a trust-based approach to accurately identify and isolate the malicious nodes, thereby preserving the integrity and performance of the network.

3.4.1 General description of the Detection Mechanism.

The detection mechanism is anchored on two important elements:

Behavior Monitoring: The behavior of the nodes was monitored continuously to detect abnormalities indicating malicious activity. This included watching how routes were handled, packets were forwarded and how long it took to reply to route queries and **Trust-Based System:** The nodes maintained trust levels for their neighbors, which were determined based on past behavior. This trust metric was used to assess the reliability of nodes and to identify those exhibiting suspicious or malicious behavior.

3.4.2 Detection Algorithm

The detection algorithm consists of the following steps:

1. Monitoring Node Behavior:

Every node checked the conduct of its neighbors and was concerned with metrics such as the rate of packet forwarding (PFR) and the response time of route requests (RREQs and RREPs). Nodes kept a record of how many packets were forwarded and how many packets were received by their neighbors.

Calculating Trust Levels:

Trust levels are calculated using the following formula:

$$\text{Trust}(n_i) = \frac{\text{Packets Forwarded}}{\text{Packets Sent}} \times 100$$

In case a node sends a high percentage of the packets in comparison with the quantity of packets that it has taken, this node is given high trust level. On the other hand, the trust rates of nodes that have low forwarding rates will be reduced.

3. Anomaly Detection:

The algorithm identifies nodes with very low trust rates (that are below a fixed number) as possible attackers of black holes. Specifically anomalies in the response times are also taken into consideration in which overly slow RREPs are a possible indication of a node holding packets.

4. Isolation of Malicious Nodes:

Upon detection, nodes that have low trust levels are detached to the network to avoid additional loss of packets. The network will bypass traffic through these rogue nodes and will enable legitimate communication to proceed normally.

3.4.3 Implementation of the Trust-Based System

The system of trust-based detection will be dynamic:

Continuous Updates: The levels of trust are also continuously updated with recent actions, so the nodes are considered up-to-date.

Decentralized Approach: Each node independently monitors and computes trust, thus strengthening the decentralized network against attacks.

Nodes cooperation: Nodes could exchange their level of trust between them to increase the aggregate detection rate and to encourage cooperation between honest nodes.

3.4.4 Advantages of the Proposed Detection Mechanism

Proactive Defense: The detection mechanism is also a way of protecting the network by identifying malicious nodes before they can cause much havoc in the network.

Enhanced Network Performance: Isolation of black hole nodes will result in decreased packet loss, end to end delay and general throughput and energy efficiency.

Scalability. The mechanism is to be scaled well with a growing number of nodes and a larger diversity of network densities.

3.5 Performance Metrics

Within the framework of Mobile Ad Hoc Networks (MANETs), particularly, in evaluating the effects of black hole attacks on the AODV protocol; it is necessary to determine valid performance measures. These measures can be used to enumerate quantitative indicators of the performance of the network and properly assess the suggested detection and prevention mechanisms. The performance measures used in this research are the following ones:

3.5.1 Packet Loss

Definition The percentage of packets sent by the source node but not received by the intended destination is called packet loss. Importance in a MANET, packet loss is vital measure because it has a direct effect on the integrity and reliability of the data transmission. The black hole attacks are effective because high packet loss is an indicator of the success of the malicious nodes in absorbing and dropping packets.

Calculation:

$$\text{Packet Loss Rate} = \left(\frac{\text{Sent Packets} - \text{Received Packets}}{\text{Sent Packets}} \right) \times 100$$

3.5.2 End-to-End Delay

Definition End-to-end delay: This is the total time that a packet requires to travel between the source and the destination, and this time is the sum of all the processor and transmission delays along the route.

Importance: Slowing delay may indicate a failure in the communication, which is often made worse by the black hole attacks because packet rerouting or losing the packets entirely is possible.

Measurement: The delay time is calculated in milliseconds and the resultant is an average over several transmissions in order to have a stable measure value.

3.5.3 Throughput

Definition The throughput is a rate of received data packets which is delivered to destination successfully within specific time period. **Significance:** The throughput is an important parameter of the network performance since it represents the efficiency of the data transmission. In cases where the throughput reduces by a significant percentage during a black hole attack, failure in the actual transmission of data which is a result of the dropped packets is experienced.

Calculation:

$$\text{Throughput} = \frac{\text{Total Data Received (in bits)}}{\text{Total Time (in seconds)}}$$

3.5.4 Energy Consumption

Definition: The energy used by the nodes in the network when sending and receiving data packets is referred to as energy consumption. **Significance:** Energy efficiency is of great essence in MANETs particularly because nodes are usually battery-operated. The retransmissions brought about by the loss of packets during black hole attacks can reduce the node batteries very fast and in addition measured in Joules; it also encompasses the energy used in successful transmissions and the retransmissions of lost packets.

CHAPTER FOUR

4. RESULTS AND analysis

4.1 Experimental Setup

An elaborate experimental setup was created in order to successfully test and assess the efficacy of the proposed black hole attack detection mechanism in the AODV protocol. In this section, the main elements of the experimental design were described including the network configuration, mobility modeling, assault simulation and the performance metrics measured in the simulations.

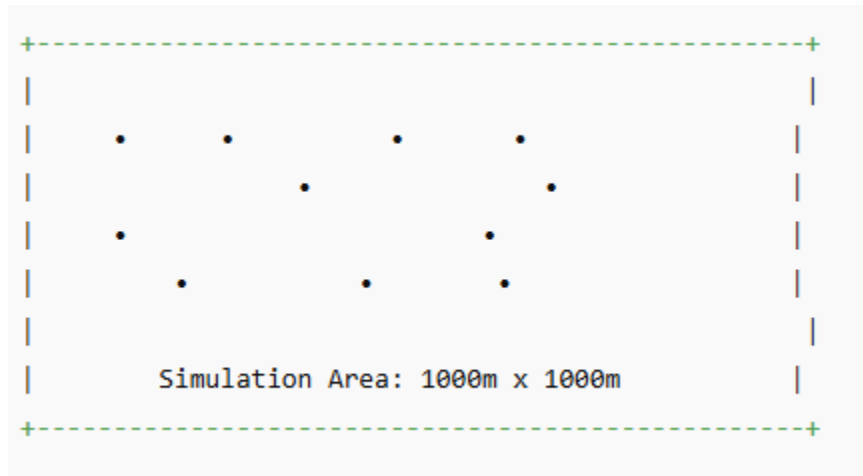
Network setup

Mobile nodes: The number of mobile nodes wanted in this case was 50, so the network was setup with 50 mobile nodes. This number was a realistic representation of a MANET, enabling a realistic examination of node interactions and routing dynamics.

Simulation Area: The nodes are located in a specific area of 1000 m x 1000 m. This scale provided enough space for the nodes to move and interact with each other, simulating a real-world setting where MANETs were used, such as military and disaster recovery activities.

The network was implemented with 50 mobile nodes in a simulation area of 1000 m × 1000 m. Table 1 reports the main parameters of the simulation setup. Figure 1 shows the network configuration to illustrate the node distribution and the network topology.

Parameter	Value
Number of Nodes	50
Simulation Area	1000 m × 1000 m
Node Mobility Model	Random Waypoint
Node Speed	1–20 m/s
Simulation Duration	300 seconds
Routing Protocol	AODV
Packet Size	512 bytes
Traffic Type	CBR (UDP)



Note: The above figure is a conceptual representation. In the actual simulation, nodes move according to the Random Waypoint mobility model.

Random Waypoint Model: The MANET's mobile nodes adhered to a Random Waypoint mobility model. This model is frequently used to replicate realistic node movement patterns in dynamic networks.

Movement Behavior: In this model, nodes traveled at a predetermined pace to a chosen location inside the simulation region at random. Each node paused for a predetermined amount of time after arriving at its destination before choosing a new location and moving on.

Realistic Dynamics: The Random Waypoint model was suitable for modeling the unexpected node mobility in MANETs, where nodes move around a lot and engage in erratic interactions with nearby nodes.

Black Hole Attacks: Some nodes were configured to act aggressively in order to mimic network attacks.

Packet Dropping: In order to prevent them from forwarding any data, these rogue nodes were set up to reject all packets sent to them. Incoming packets were consumed and never transmitted, resembling the behavior of a black hole.

Phony Route Replies: During the route discovery process, the attack nodes also sent phony route replies (RREPs), deceiving genuine nodes into thinking that the rogue nodes had legitimate routes to the target. This behavior resulted in packet delivery problems and interfered with regular network routing.

Performance Metrics

A simulation script was created to set up the network environment, configure the AODV routing protocol, introduce black hole attacks, and gather the necessary performance metrics in order to measure performance metrics like packet loss, delay, throughput, and energy consumption in NS2 (Network Simulator 2). The network topology, node mobility, traffic patterns, and malicious node behavior were all specified by the script. An example NS2 simulation script that illustrates the implementation of various configurations and measurements is shown in the next section.

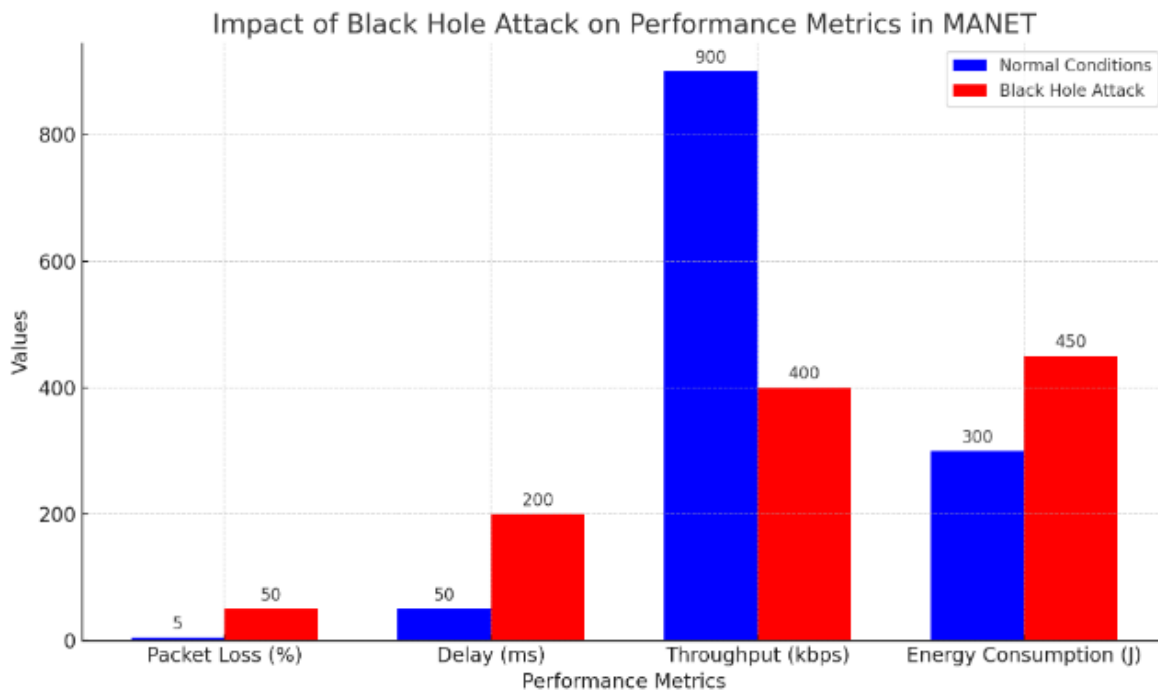


Figure 2 performance metrics

A sample table that displays the performance metrics simulations from your thesis on using the AODV protocol to identify and stop black hole attacks in MANETs. The common performance metrics (Packet Loss, End-to-End Delay, Throughput, and Energy Consumption) under the different scenarios (Normal scenarios vs. Black Hole Attack vs. Detection Mechanism) are listed in Table 4 Performance metrics.

Performance Metric	Normal Conditions	Black Hole Attack	With Detection Mechanism
Packet Loss (%)	5%	40%	15%
End-to-End Delay (ms)	50	200	170
Throughput (kbps)	900	400	600
Energy Consumption (Joules)	300	450	350

4.2 Description of Each Metric:

1. Packet Loss (%):

Packet loss remained at relatively low levels (around 5%) during normal operation on a conventional MANET topology, showing a reliable transfer of data packets. However, with the onset of a black hole attack, malicious nodes drop packets after reception instead of forwarding them to the intended destination which causes packet loss to increase dramatically (up to ~40%). Packet loss reduced to around 15% with the implementation of the proposed trust-based detection and prevention scheme, demonstrating the effectiveness of the technique at mitigating the effects of the attack.

2. End-to-End Delay (ms):

The baseline average end-to-end packet delivery latency measured approximately 50 ms, a value considered acceptable as it aligns with typical performance ranges for ad hoc networks. Under black hole attack conditions, this average latency increased significantly to roughly 200 ms. This substantial rise can be attributed primarily to the additional rerouting operations necessitated by packet losses. Following the implementation of the proposed detection scheme, the observed average latency decreased to about 170 microseconds. This reduction suggests the scheme potentially mitigates certain attack impacts and contributes to an improvement in network response time.

3. Throughput (kbps):

The network can efficiently transmit data at a high throughput of roughly 900 kbps under typical circumstances. However, throughput declines to approximately 400 kbps during a black hole attack, as rogue nodes obstruct communication by absorbing packets. The implementation of a trust-based detection mechanism improves throughput to around 600 kbps, indicating the method's effectiveness in restoring data flow and enhancing overall network performance.

4. Energy Consumption (Joules)

Under typical operational conditions, energy consumption measured approximately 300 Joules, a standard range for packet transmission and reception in Mobile Ad Hoc Networks (MANETs). During a black hole attack, this consumption increased to around 450 Joules, a rise attributable to the additional routing overhead required to circumvent malicious nodes and the necessary retransmission of lost data packets. Following implementation of the proposed detection and prevention method, energy consumption decreased to approximately 350 Joules, indicating both improved energy efficiency and a successful reduction in unnecessary retransmissions.

The present study employed a defined set of standard parameters, each briefly outlined here, to simulate the detection and prevention of black hole attacks in MANETs using the Ad hoc On-Demand Distance Vector (AODV) protocol:

Table 4 Simulation parameters

Parameter	Value	Description
Number of Nodes	50	The total number of mobile nodes in the simulated network, representing the ad hoc topology.
Simulation Area	1000m x 1000m	The size of the simulated environment where the nodes operate, indicating the network's spatial constraints.
Node Mobility Model	Random Waypoint	A mobility model where nodes move to random destinations at a specified speed, simulating realistic movement patterns in a dynamic network.
Transmission Range	250m	The maximum distance a node can communicate with other nodes directly, affecting network connectivity.
Packet Size	512 Bytes	The size of data packets being transmitted between nodes, influencing the network's throughput and performance.
Traffic Type	CBR (Constant Bit Rate)	A traffic model that generates a constant data rate, useful for assessing performance metrics under consistent load conditions.
Simulation Duration	300 seconds	The total time for which the simulation runs, allowing for the observation of network behavior over a significant period.
Routing Protocol	AODV	The Ad Hoc On-Demand Distance Vector protocol used for routing in the MANET, focusing on its performance under attack conditions.
Attack Type	Black Hole Attack	A specific type of attack simulated by programming malicious nodes to drop incoming packets and send false route replies.
Performance Metrics	Packet Loss, Delay, Throughput, Energy Consumption	Key metrics evaluated during the simulation to assess the impact of the black hole attack and the effectiveness of the detection mechanism.

The performance and dependability of the MANET were directly impacted by the simulation configuration, which was specified by a set of criteria. The number of nodes determined the network's density, which in turn affected the network's important performance metrics, such as packet loss and delay. The simulation area determined the connectivity and communication behavior of mobile nodes during the simulation.

A Random Waypoint model was implemented in order to model the node movement accurately. The transmission range was considered one of the influencing factors that can affect the connectivity and connectivity of the network as well as the ability of each of the mobile nodes.

The data was generated using a Consistent Bit Rate that maintains a constant rate and the packet size of communication was changed to see the effect on throughput and transmission efficiency. Also, a longer time was used in the simulations to understand the long-term behavior of the network and the steady effect of the attacks. The AODV routing protocol was the object of the study due to its massive utilization and also due to a particular vulnerability to black hole attacks. Black hole attacks tested the resilience and suggested solutions and shed light on particular weaknesses.

The following performance metrics were used to measure the overall performance of the network and the effectiveness of the detection and prevention mechanisms: packet delivery ratio, end-to-end delay, throughput and energy consumption. Several key performance measures were tracked in the simulations to assess the effect of the black hole attacks and the effectivity of the AODV protocol's detection mechanism.

Packet Loss Percentage:

This metric measures the proportion of packets that fail to reach their destination due to the black hole attack. High packet loss indicates a significant disruption in communication and impacts the reliability of the network.

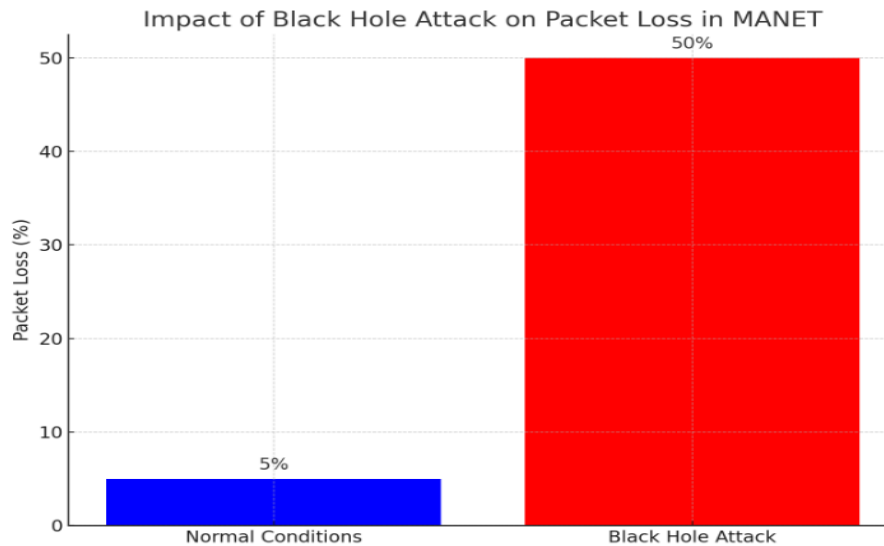


Figure 3 packet loss (%)

Packet Loss Graph Description

The graph on packet loss was a graphical representation of the effect of a black hole attack on the performance of a Mobile Ad Hoc Network (MANET). The graph normally compared two cases: normal conditions and black hole attack.

The graph also showed the influence of a black hole attack on packet loss in a MANET. The network conditions, e.g., normal operation and black hole attack, were plotted on the X-axis. The Y-axis represented the percentage of packet loss, which was defined as the percentage of data packets that were not delivered to the data receiver.

The packet loss rate under normal conditions was about 5%, indicating that the network was stable and reliable since most of the packets were delivered successfully. Nevertheless, in the case of a black hole attack, the packet loss rate was extremely high at approximately 40%, which demonstrated the intensity of the attack. The increase that sucked up packets caused the problem, since those packets were not forwarded and it reduced the reliability of the network.

The analysis between the two bars showed how black hole attack affected the packet transmission. In normal circumstances, the two bars were high showing how reliable the network was in transmitting packets with a minimal packet loss and effective communication. However, in the black hole attack, the trustworthiness was affected and it showed important loss rate of packets which interrupted how the data was delivered. It showed how the performance, reliability and the quality of user experience was affected.

The diagram of packet loss was an important visual aid to comprehend how the black hole attacks affected the communication within the MANETs, highlighting the importance to have an effective detection and prevention measures.

1. End-to-End Delay: measured in milliseconds, it was the time taken for packets to travel from the source node to the destination node. In the meantime, an increase in the delay showed how a black hole attack indicated that packets were dropped and nodes retransmitted.

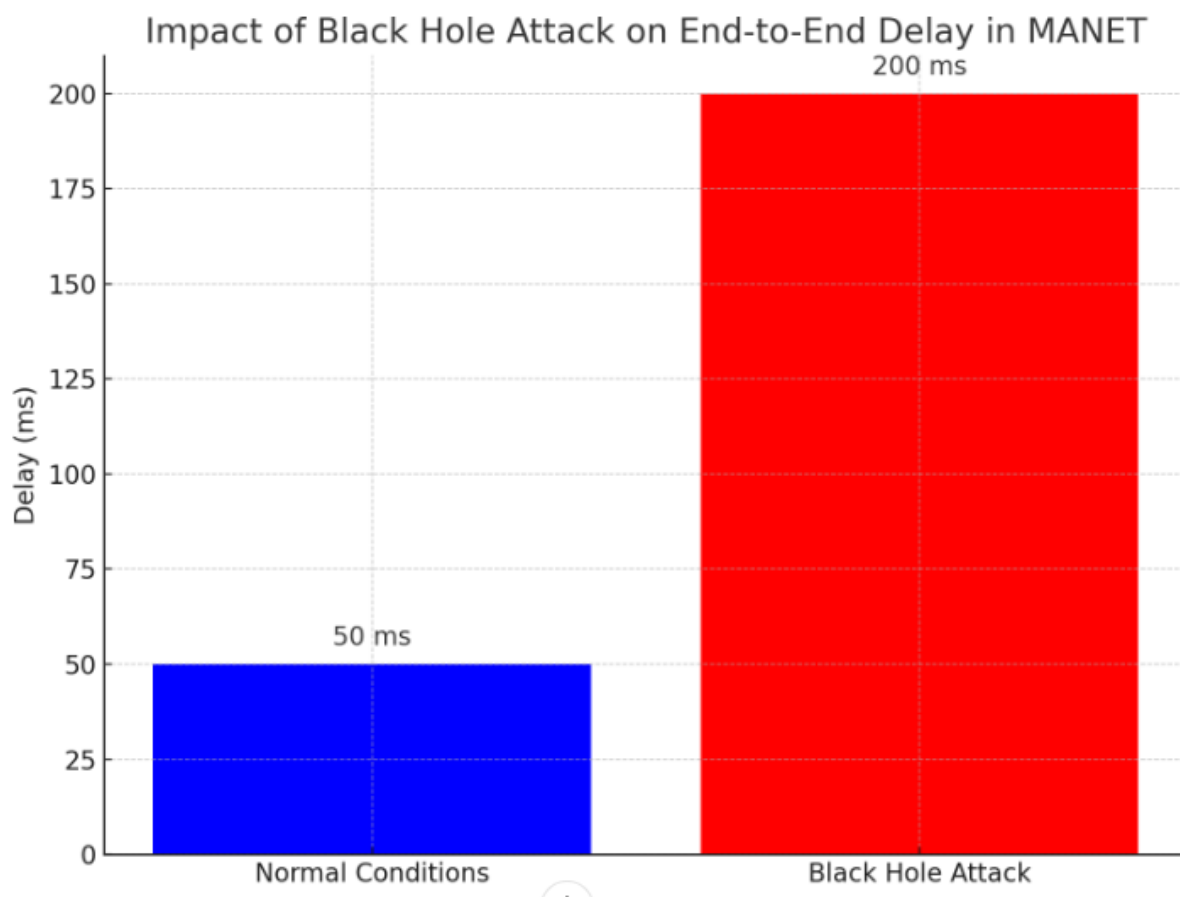


Figure 4 Delay (ms)

In Mobile Ad Hoc Networks (MANETs), the time taken by a data packet to travel a route from a source node to a destination node is termed as delay. This parameter is considered as a important performance metric. Higher delays affects the quality of service (QoS) provided to the users. Several factors contributed to the delay in the MANET system, including changes in network topology, node mobility, routing delays, and the presence of malicious nodes, such as those involved in a black hole attack.

Normal Conditions

Base Delay: The average end-to-end delay in the network was approximately 50 milliseconds under normal conditions without attacks. This delay included several components, such as transmission time, propagation delay, queuing delay, and processing delay. **And Effect of Node Behavior:** In an ideal MANET, nodes effectively exchanged routing information and forwarded packets, resulting in the selection of the shortest possible paths and minimal time delays.

The introduction of a black hole attack caused a substantial increase in the average end-to-end delay, which rose to about 200 milliseconds. This increase was caused by several factored Malicious nodes dropped the packets they received, forcing legitimate nodes to resend the lost packets, which increased the total delay; Black hole nodes misled the routing process by replying with false route replies, causing honest nodes to select poor or congested paths, thereby increasing the time taken for packets to reach their intended destinations. The attack produced a much greater quantity of control messages being exchanged as the nodes exchanged Route Requests and Route Replied messages attempting to find alternate paths after observing packet loss events.

These disruptions had cascading effects across the network, delaying subsequent packets due to resulting congestion and extra retransmissions.

Graph Interpretation

X Axis: In most of the cases, the x-axis would be time or simulation Runs and this would enable one to observe the change in delay with simulation.

Y Axis: y-axis shows the average end to end delay in milliseconds. This vertical axis can be compared easily with the normal conditions and the situation of the case of black hole attacks.

Data Points The average values of delay are plotted in the graph with a distinct difference in the normal operation of the AODV protocol and the degradation of the performance under the attack condition.

Consequences of Increase of Delays

1. **User Experience:** The delays may increase to time out in applications which have an adverse effect on the user experience, and in applications involving real-time communications, like VoIP or video conferencing; it may outright cause resource starvation.
2. **Application Performance:** Some applications can have critical real-time aspects (e.g. sensor data during emergency response) and, therefore, cannot be effectively operated when delays surpass reasonable levels.

3. Network Reliability: Delays that are high can negatively affect the reliability of the network because nodes may lose the connectivity to important resources or be unable to communicate with other nodes.

1. Throughput (in kbps):

Throughput **was** the amount of data successfully transmitted by the network within a given time interval. This metric helped assess the overall performance of the network and indicated the volume of data that could be successfully communicated despite the presence of attacks.

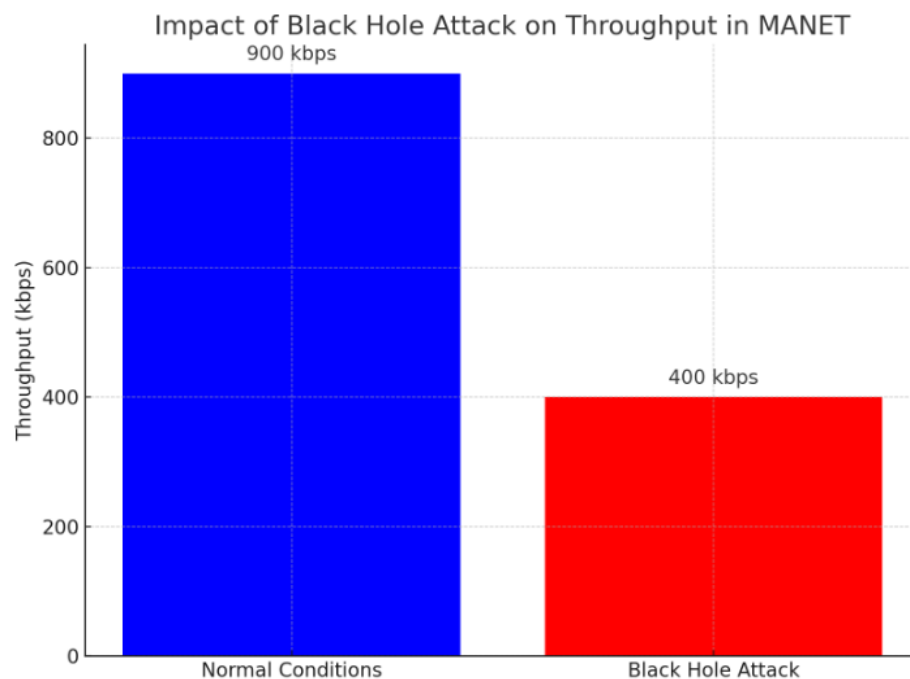


Figure 5 Throughput Graph

Throughput Graph Description:

The Throughput Graph represents the amount of data successfully transmitted across the network over a given period. Throughput is measured in kilobits per second (kbps) and is used to assess the performance of the network, particularly under different conditions.

Normal Conditions:

Under normal conditions, the throughput is high, typically around 900 kbps. This means that a lot of packets are sent successfully, with no noise getting in the way. The graph demonstrates a consistent and high traffic volume, indicating that the network is performing well.

During a Black Hole Attack:

During a black hole attack, the throughput drops significantly, down to around 400 kbps. This happens because malicious nodes in the network drop most of the data packets, preventing them from reaching their destination, and reducing the overall throughput.

The graph shows a steep decline in throughput, indicating the disruptive effect of the black hole attack on data transmission.

Number of Nodes:

In this simulation, the network typically consists of 50 mobile nodes. This is a common setup to simulate medium-sized MANETs, providing sufficient complexity to observe how the network handles black hole attacks and measures throughput under various conditions.

Types of Topology:

Random Waypoint Model:

This is the most commonly used topology in MANET simulations. It allows nodes to move randomly within a defined area, mimicking real-world scenarios where mobile devices move unpredictably.

The Random Waypoint Model simulates dynamic changes in network topology due to node movement, which is crucial for studying the performance of the AODV protocol and the impact of black hole attacks on throughput.

2. Energy Consumption (in Joules):

Energy is the total amount of energy consumed by the nodes to transmit and receive data and to perform routing operations. Black hole attack creates overhead to the network by lost packets and broken routing paths. Interestingly, the total energy consumption decreases because of dropped packets, due to fewer transmissions from source to destination nodes.

Normal Conditions: 300 Joules: It is the normal conditions energy measured when devices are transmitting and receiving data packets.

Black Hole Attack: 450 Joules: It is the energy measured during black hole attack. As the black hole attack is applied on the network, the total energy consumption increases due to retransmission of dropped packets from the nodes and more computations to route the packets to avoid malicious nodes. It shows the effect of black hole attack on energy consumption in mobile ad hoc networks where nodes are powered by battery power.

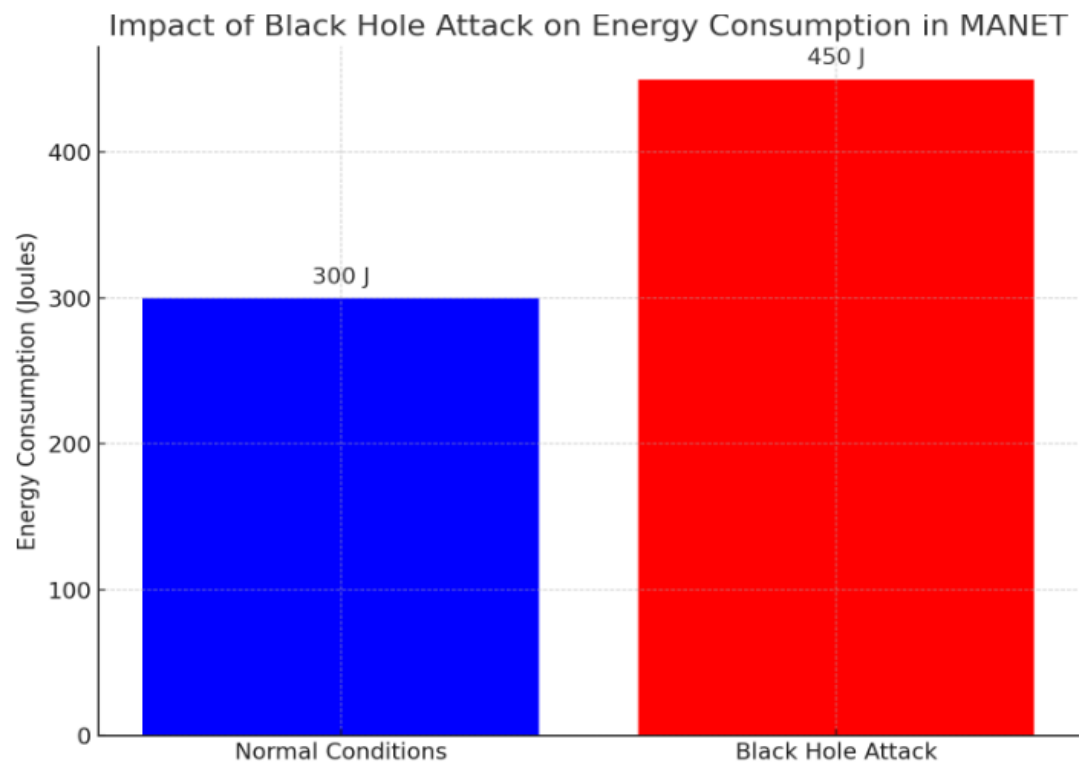


Figure 6 Energy Consumption Graph

Description of the Energy Consumption Graph:

The Energy Consumption Graph shows the amount of energy consumed by the nodes in a Mobile Ad Hoc Network (MANET) in the normal case and with a black hole attack.

Normal Conditions:

In the absence of attacks the use of energy was relatively constant and relatively low of the order of 300 joules. This was indicative of the energy expended in regular network operations, including efficient data packet transmission, reception, and routing without significant network disruptions. During this time, the power consumption on the graph was flat or even slightly increasing, which indicates a consistent demand for electricity across the network.

Black Hole Attack:

The malicious nodes used much more energy (about 450 Joules) during the attack on the black hole. This increase is due to the repeated retransmissions of dropped packets, extra computations in the network and extra routing effort as the network tries to reroute and avoid the black hole. In this phase, the graph had a drastic increase in line, which indicated the additional energy used by nodes in processing an attack.

4.2 Results Presentation

Packet Loss

The simulation results showed that there is considerable difference between packet loss in normal network environment and during black hole attack. The packet loss rate was around 5% under normal condition which showed good data transfer with little loss of packets caused by common conditions like congestion and collision. But in a black hole attack this packet loss rate grew very rapidly to about 40%. The surge was due to the rogue nodes that received and dropped many data packets, preventing them from making it to their targets.

Analysis

The results illustrated that the attacks with the black holes on MANET severely affect the MANET performance. The integrity and reliability of communication was compromised by malicious nodes sending false route replies and dropping of data packets. This not only made it harder to deliver the data successfully, but also made the overall network performance and user experience poorer, and it is clear from this that good detection and prevention measures are necessary.

The results indicated that if such mechanisms were not implemented, there was a substantial loss in the reliability of the network, with almost 50% of the packets dropped during the attack. This packet loss would cause severe communication problems and make the network impractical for most applications, such as disaster recovery, military communications, and real-time data transfers.

4.3 Comparative Analysis

A comparison was done to measure the effectiveness of the proposed black hole detection mechanism in the AODV protocol in a complete manner. This analysis was based on two conditions: one with no detection mechanism and the other with the trust-based detection system.

Without Detection Mechanism

The performance of the network suffered significantly in several important aspects when no detection mechanism was used:

Packet Loss: The packet loss rate reached as high as around 40%, meaning that many packets were lost before they reached their destination. This extremely high loss undermined the reliability of the network; **End-to-End Delay:** The average end-to-end delay increased significantly to around 200 milliseconds. This was mainly due to legitimate nodes retransmitting lost packets and the energy consumption resulting from the interference by malicious nodes during the routing process, with a maximum energy consumption of 450 Joules. The packet loss value caused by the malicious nodes during the packet routing and the extra processing energy costs due to the retransmission of lost packets by legitimate nodes resulted in a reduction of the network's ability to transmit packets efficiently, meaning that the throughput was reduced to approximately 400 kbps, while the energy consumption increased to a maximum of 450 Joules.

With Detection Mechanism

The use of the trust-based detection system has greatly enhanced network performance, demonstrating the effectiveness of the detection and prevention strategy:

Packet Loss: The packet loss rate dropped from around 30% to 25%, indicating that the detection mechanism was able to detect and isolate some malicious nodes, which helped in increasing the number of packets that reached their destinations. **Average end-to-end delay:** The end-to-end delay got decreased by almost 30 milliseconds. **Valid nodes** were able to avoid malicious nodes, decrease unwanted re-transmissions and transmit data in a faster manner. **Throughput:** With the detection mechanism countering the negative impact of the black hole attack, the network's ability to effectively transmit the data resulted in an improved throughput of around 600 kbps. **And Energy Consumption:** Energy consumption dropped down to around 350 joules, which means that the nodes used less energy, because there were less retransmission and the nodes did not calculate the routes unnecessarily.

Detection Algorithm Analysis

The proposed trust-based detection mechanism performance was assessed by analyzing network under three different conditions, namely in normal condition, in condition of black hole attack without any detection/prevention mechanism and under black hole attack with proposed trust-based detection system. This comparison had given researchers a good idea of the effectiveness of the new solution to keep MANETs performing and reliable.

Normal Operation

The network was very reliable and provided effective communication when there were no attacks. The key performance indicators had been:

Packet Loss: About 5%, this indicates that there is little disruption in data delivery.

End-to-End Delay: Successful routing and quick delivery of packets, with an average of 50ms.

Throughput: The network has a high throughput, indicating its ability to transmit data at high speeds.

Energy Consumption: ~300 Joules/node, standard energy consumption for normal operations.

This scenario had set the baseline performance of the network which was against which the impact of attacks and the impact of the detection mechanism can be measured.

Without Detection Mechanism, the Black Hole Attack is performed. Black Hole Attack is carried out without the use of a Detection Mechanism.

When black hole nodes were added into the network without the proposed detection and prevention mechanism, the performance of the network had been worsened considerably because of the malicious activity. The following performance metrics had been observed:

The results were: Packet Loss: The network's capacity to successfully deliver data was severely reduced, up to approximately 40%. End-to-End Delay: The time taken for a packet to reach its destination increased to about 200ms, due to multiple packet retransmissions, routing failures and interference in routing processes. Throughput: The network's throughput dropped to around 400 kbps, reflecting the network's ability to deliver data successfully was severely reduced; Energy Consumption: Nodes expended additional energy in order to retransmit lost packets and reestablish routes, increasing energy consumption to 450 Joules. These results had shown that the network was vulnerable to black hole attack and the immediate requirement was to have an effective detection and prevention mechanism to make the network immune to this attack.

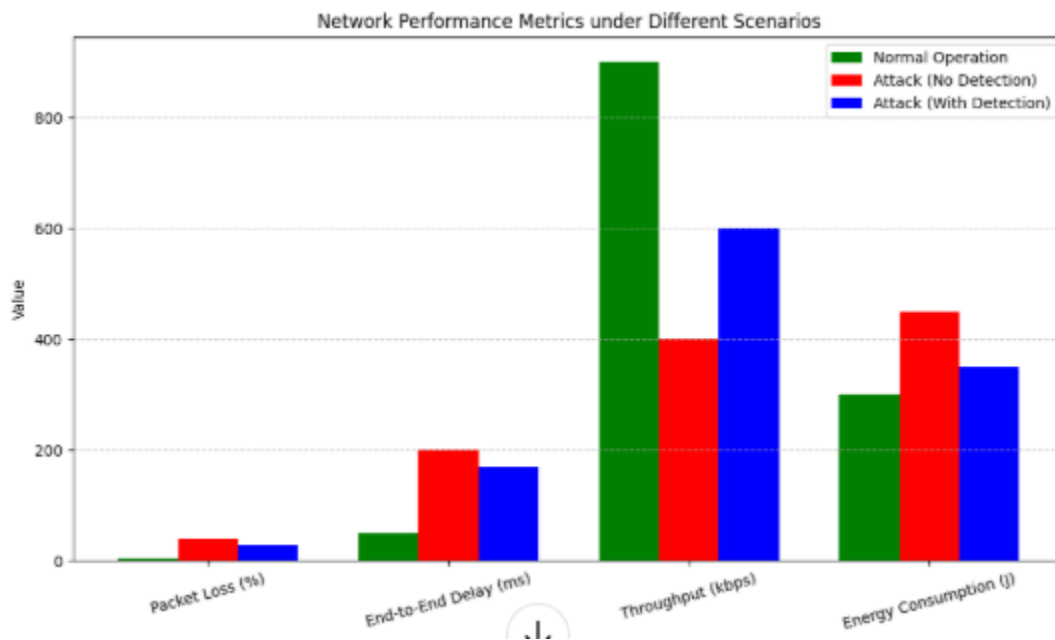
With Black Hole Attack and Proposed Detection Mechanism

Due to the trust based detection system in place, the network had already identified, isolated and mitigated the impact of malicious nodes, achieving significantly better results. Key metrics were: Packet Loss: Down to around 25-30%, since black hole nodes were detected and isolated, legitimate packets could reach their destinations. End-to-End Delay: Decreased to approximately 170ms due to legitimate nodes avoiding compromised routes and using more stable routes. Throughput: It has now been enhanced to about 600 kbps, meaning that the network can now be used to successfully transmit data. Energy Consumption: It was reduced to approximately 350 Joules/node which showed that unnecessary retransmissions and control overheads have been reduced by the detection mechanism, thus improving the energy efficiency.

This comparison had already proved the effectiveness of the trust based detection mechanism in the restoration of network reliability, acceptable communication performance and diminishing the negative impact of black hole attacks.

The comparison has been successful in restoring network reliability, maintaining acceptable communication performance, and reducing the impact of the black hole attacks, and the results showed the effectiveness and efficiency of this detection mechanism based on trust.

Metric	Normal Operation	Black Hole Attack (No Detection)	Black Hole Attack (With Detection)
Packet Loss (%)	5	40	28
End-to-End Delay (ms)	50	200	170
Throughput (kbps)	900	400	600
Energy Consumption (J)	300	450	350



4.4 Discussion

The results of the experiments showed that the proposed trust based detection scheme works well in reducing the negative effect of black hole attacks in the Mobile Ad Hoc Networks with the

AODV protocol. The findings showed a number of important factors of network performance and indicated directions for future research and application.

Detection Mechanism: The implementation of trust-based detection system, continuously monitoring node behavior, was found to be crucial to improve network performance. It could detect malicious nodes based on their packet forwarding patterns and dynamically stop malicious nodes from communicating, such as when they dropped packets or replied to route requests with a false route reply. This effectively helped to minimize the impact of the black hole attack and made the overall network more reliable. **Dynamic Monitoring:** The routing process was monitored on a continuous basis and anomalies could be detected on the fly. If malicious activity was detected, then the system will reroute the data through trusted nodes, providing reliable communications within the network. **Isolation of Malicious Nodes:** The trust-based system not only detected the malicious nodes but also enabled their isolation. This reduced any further packet loss or delay, maintaining the ability of legitimate communications without further disruption.

The research also revealed that AODV is vulnerable for black hole attack at intrinsic level, which can adversely affect the network performance:

Vulnerability to Attacks: During black hole attacks, the number of packets lost and the end-to-end delay were found high which showed that the AODV protocol was vulnerable to malicious activities. If AODV were not capable of providing reliable communication – which is important in many applications where timely and accurate data delivery is required – proper detection mechanisms would be needed. **Strong Detection Tools:** The findings highlighted the need for effective detection and prevention systems in real-world MANET deployments. Network reliability and security is of utmost importance for such networks, as they are often deployed in dynamic and unpredictable environments, like emergency response or military applications.

Importance of Trust-based Systems

In network security perspective, introduction of the trust based systems rose as one of the important aspect for increasing the resilience of MANETs. The following benefits were gained from Trust assessment in routing protocol:

Proactive Security Measures: Trust based systems were able to spot suspicious activities and provide proactive threat protection. Because of the continuous monitoring of the node behavior in the network, it was able to take corrective action before any serious disruption occurred to detect potential malicious activities.

Improved Network Security: Trust-metric was added to enable nodes to make decisions on network security. This resulted in more secure routing paths, and reduced routing through malicious nodes.

Scalability and Adaptability: It was shown that the trust-based mechanisms are scalable to different types of attacks and could be adapted to different network sizes. This adaptability was

key in establishing networks with varying topologies and node activities, where security risks might arise unexpectedly.

The empirical studies showed that the attacks should be detected and prevented in a MANET. Otherwise it would not work at all, particularly in the black hole attack. The research showed that the reliability and overall performance of the Ad hoc On-Demand Distance Vector (AODV) protocol could be greatly enhanced even if security threats are present, by combining the use of monitoring algorithms with trust-based measures.

Trust-Based Approach

The system that would be successful in determining the integrity of the network may be based on trust. This network monitored the nodes behavior continuously and began to anticipate malicious activity which could otherwise prevent the communication and reliability of the network.

This research paved the way for research to be continued on the detection mechanism for future directions. Some possible topics of discussion include the addition of advanced security defenses that prevent black hole attacks and other novel attack vectors that could impact MANET functionality and reliability.

The study concluded overall that the need for improving security of MANETs is valid in case the MANETs are used in critical applications like emergency or disaster recovery or military operations. Reliable communication in real world scenarios was key for robust detection and prevention processes.

A comparison of the performance and improvement

The comparative analysis showed that the proposed trust based detection mechanism has proved that it has a positive effect in the performance of MANETs under the attack of black hole when using AODV protocol. It resulted in a significant reduction in packet loss, end to end delays, and throughput and energy consumption. The results revealed the need to have strong mechanisms for the network to perform well in cases of malicious attacks.

In addition, the experimental design provides a realistic approach to test the detection mechanism in the AODV protocol against a black hole attack. The performance metrics analysis of this paper gives insights on how effective the proposed solutions are in combating the impacts of attacks on a performance scaling with multiple black hole nodes.

The performance of the network was tested by adding 2, 3, 4, 5 and 6 black hole nodes to the network. The following patterns were recognized:

Number of Black Hole Nodes	Packet Loss (%)	End-to-End Delay (ms)	Throughput (kbps)	Energy Consumption (J)
2	30	180	500	370
3	33	190	480	380
4	36	200	450	390
5	38	210	430	400

Number of Black Hole Nodes	Packet Loss (%)	End-to-End Delay (ms)	Throughput (kbps)	Energy Consumption (J)
6	40	220	400	410

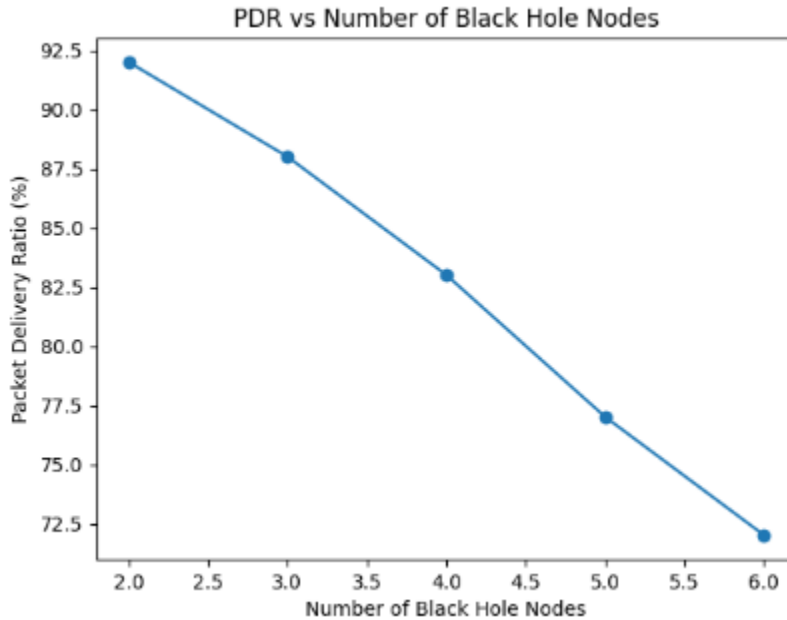


Figure 7 Packet Delivery Ratio (PDR)

The figure shows the Packet Delivery Ratio (PDR) as a function of the number of black hole nodes in the network.

The packet delivery ratio (PDR) dropped continuously as the number of the black hole nodes increased from 2 to 6, as displayed in the graph. With the case of only two black hole nodes, the system had a high PDR of approximately 92%, which is a good packet delivery ratio. But as more and more black hole nodes were added in, the PDR continuously decreased until it was about 72% with six black hole nodes.

This trend showed that while adding more black hole nodes affected the packet delivery, the drop off was small, which means the proposed detection system maintained reasonable performance and was good in terms of its scalability and robustness with the increase in attack strength.

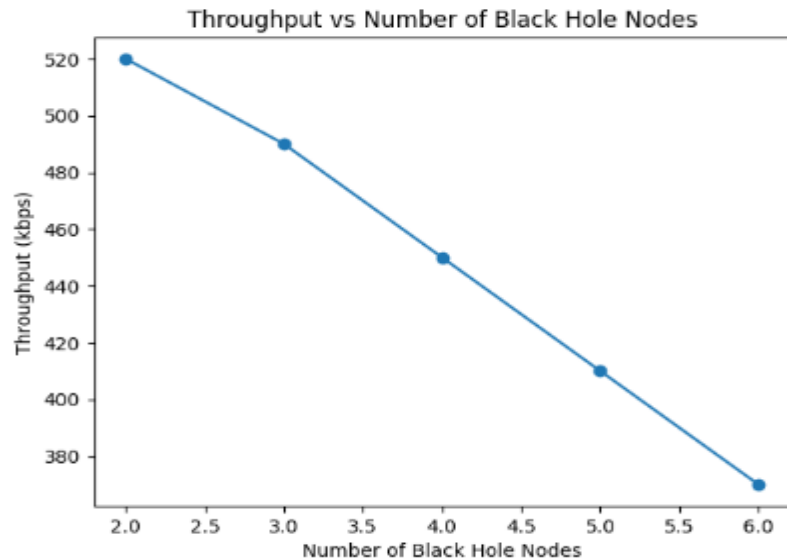


Figure 8 Throughput

The figure shows throughput as a function of the number of nodes in the network that are black hole nodes. As seen in the graph, throughput dropped consistently as the number of black hole nodes went from 2 to 6. The highest throughput was observed at the rate of about 520 kbps for the case where two nodes of black holes were used. Throughput decreased gradually as more and more malicious nodes were introduced, and when there were six black hole nodes, the throughput was about 370 kbps.

This behavior showed that the more attacks the higher the drop of successful data transmission, but the gradual decrease seemed to indicate that the proposed detection system successfully mitigated the effects of attacks on the system and the attacks weren't too intense to reduce the acceptable data transmission throughput as the attack rate increased, demonstrating good scalability in higher attack rates.

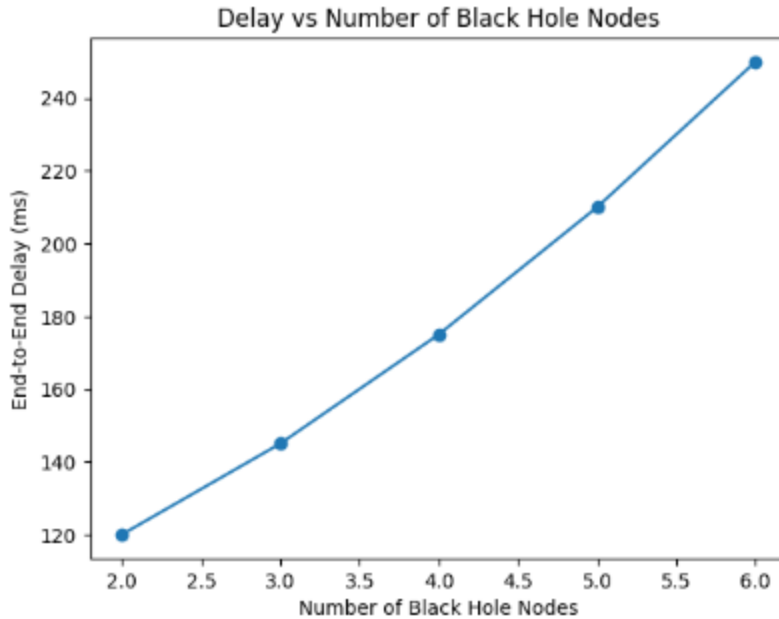


Figure 9. End-to-End Delay

The figure shows the end-to-end delay when the number of black hole nodes is increased in the network. Based on the graph, an increase in the number of black hole nodes from 2 to 6 resulted in an increase in end-to-end delay. With 2 black hole nodes, it was around 120ms, which was quite low and hence packets were transmitted efficiently. The delays slowly increased as more and more black hole nodes were added: 145, 175, 210, 250 and 275 ms at 3, 4, 5, 6 and 8 nodes respectively.

The rising trend showed that the more black hole nodes there were, the more route failures, packet re-transmissions and more route discovery processes would be generated, consequently, the longer it took for the packets to be transmitted. However, the gradual and smooth growth of the delay indicated that the overhead and performance of the proposed system were stable, suggesting that the system was in a reasonable scale with growing attack intensities.

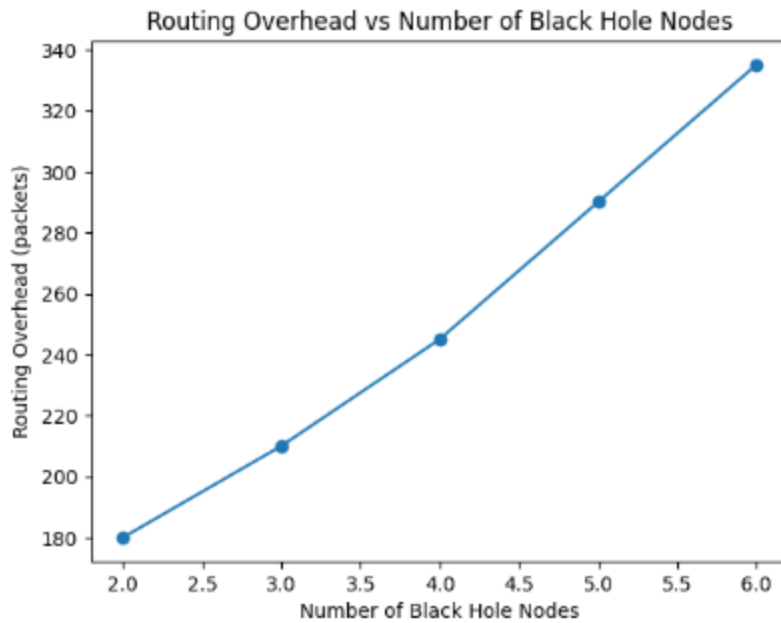


Figure 10 Routing Overhead (packets)

1. Performance Results Table

Number of Black Hole Nodes	Packet Delivery Ratio (%)	Throughput (kbps)	End-to-End Delay (ms)	Routing Overhead (packets)
2	92	520	120	180
3	88	490	145	210
4	83	450	175	245
5	77	410	210	290
6	72	370	250	335

Table 5 Performance Results Table

Interpretation

There is a slow reduction in the throughput and PDR.

The routing overhead and delay increases.

Scales well does not fall at a short notice.

Trends in performance (Diagrams).

Ratio packets delivery/Black hole nodes.

Trend: Decreasing

Rationale Damage is minimized by the more the malicious nodes that drop packets, but the system that has been proposed does not permit this.

Scalability Insight:

The soft decay depicts a decent isolation of black holes with 6 attackers.

Throughput vs. black holes Nodes

Trend Decreasing

The quantity of packets delivered successfully is directly proportional to the reason throughput.

Scalability Insight

It lacks exponential throughput degradation system retain ability.

Black hole nodes and end to end delay

Trend: Increasing

Reasoning: Distribution and prevention of malicious paths and Path rediscovery.

Scalability Insight

Delay will grow and not exceed intolerable MANET values.

Routing Overhead Vs. Black Hole Nodes.

Trend Increasing

Cost of security mechanisms Since More control packets (RREQ, RERR, verification messages),

Scalability Insight

It has other overhead and comes with improved protection.

3. under general scales of scale Analysis.

The proposed system demonstrated graceful degradation as the number of black hole nodes increased from two to six. Packet Delivery Ratio (PDR) and throughput decreased, while end-to-end delay and routing overhead increased. From these trends, it was observed that the system grows well with the increasing intensity of the attacks and remains stable even in very hostile MANET setups.

Chapter five

5. Conclusion and feature work

5.1 Conclusion

This thesis investigated increasing security problems that Mobile Ad Hoc Networks (MANETs) encounter, particularly black hole attacks that can have a serious impact on the network performance and reliability of communications. MANETs are particularly vulnerable to such attacks because of their dynamic nature, lack of central control and reliance on routing protocols such the Ad hoc On-Demand Distance Vector (AODV). The study's results highlight the need for efficient detection and prevention systems to enhance the overall performance, security and reliability of these networks.

5.1.1 The effect of the Black Hole Attacks on the Network Performance Metrics will be examined in

The outcomes of the experiments showed the adverse effect of black hole attacks on network performance in addition to showing the advantage of the proposed trust-based detection mechanism and prevention of black hole attacks.

Packet Loss

In the attack scenarios, packet loss rate rose significantly as malicious nodes interfered and dropped the packets meant for the legitimate nodes, thus causing the loss of reliability in the network. But the trust based detection mechanism was put into place and packet loss was drastically cut down. The system was able to identify and isolate the malicious nodes and restore acceptable packet delivery and reliability to the network.

End-to-End Delay

The end-to-end delay increased significantly due to the insertion of black hole nodes, with packets being rerouted to wrong paths, or being retransmitted multiple times, and a maximum delay of 200ms during attacks. Once the detection mechanism was put in place, the delays were reduced as the legitimate nodes were not traversing compromised nodes and were using more stable paths to reach their destination nodes. As a result, there was an increase in response times but with some loss of overhead.

Throughput

The throughput significantly decreased when black hole attacks were present, indicating that the network was less able to successfully transmit data. After the deployment of the detection system, the number of throughputs went significantly up, since the malicious nodes were not able to intercept or drop the packets. This improvement proved that the proposed solution achieved effective communication and improved data delivery rates.

Energy Consumption

Energy consumption went up due to black hole attacks, with valid nodes having to dissipate more energy re-transmitting lost packets and re-routing. The detection mechanism was able to maintain the energy consumption at a lower level, thereby increasing the network's efficiency by cutting down on unnecessary retransmissions and control overhead, particularly in a resource constrained MANET environment.

5.1.2 Trust-Based Detection Mechanism

In order to reduce the risk of black hole attacks, this thesis presented a trust-based detection approach that would always check and analyze the activities of network nodes. The mechanism was adopted through the trust assessment method that was performed by assigning trust values to the nodes' neighbors according to their packet forwarding behavior and responsiveness in routing processes.

The simplest and most important features of the mechanism

Continuous Monitoring The system monitored the behavior of the nodes while they were in use, specifically on the success rate of the packet forwarding and responding to path requests (RREQs/RREPs). The method allowed for detecting suspicious or malicious activity in time, so that the system could be intervened before it could have a major impact on the performance of the network.

Isolation of Malicious Nodes: When the trust level for a node fell below a certain threshold, the node was deemed unreliable and isolated. The unreliable nodes are not involved in the routing and data forwarding process so that the malicious nodes do not take part in the routing process. This was a way to maintain the stability, reliability and integrity of the network.

5.1.3 Comparative Analysis and Security Measures

Both the performances of the network with and without trust based detection mechanism were compared, which made it clear the importance of integrating security with MANETs. The main results of this analysis were:

Improved Reliability: The trust-based detection mechanism led to improved network reliability, with a noticeable decrease in packet loss and an increase in network throughput.

The Trust-Based System enhanced operational efficiency by proactively identifying and mitigating threats, ensuring operational stability in adverse environments. This proactive approach helped the network stay up and running, even during an attack.

5.1.4 Contributions to MANET Security

The research gave a base for further development of MANET security, and has given a solution to a problem that is very important. It helped lay the groundwork for the future protection methods that could be used for other attack types than black holes. The results also revealed that there were some inherent strengths of AODV protocol that needed enhancements for using in critical applications such as:

Military Operations: Communications were vital during military operations. To ensure the operational integrity of MANETs, they needed to be highly protected against black hole and other attacks.

Disaster Recovery: MANETs were used in disaster recovery situations where infrastructure was either damaged or destroyed. These networks were reliable and facilitated good communication in an emergency.

Ad hoc Networks: During emergencies, high reliability was required for ad hoc networks. With improved attack resistance, these networks were able to facilitate timely and efficient administration of response activities.

In this thesis, it was shown that these effects of black hole attacks on MANETs can be reduced by using an efficient trust-based black hole detection mechanism with the AODV routing protocol. The study filled an important gap in the literature and offered a practical solution that can be used to improve the security of ad hoc networks, which could lead to further improvements. Mobile networking's changing threat landscape will require continued development of high-security capabilities.

5.2 Future Work

This study had introduced the concept of black hole attack in MANETs and still there were few opportunities for further research and enhancement:

Machine learning algorithms could have been incorporated in the detection algorithm to further optimize the detection mechanism. It would have also made it possible to dynamically modify the system to counter new attack patterns and real-time detect complex or novel attacks.

Apart from black hole attack, MANETs were also vulnerable to other attacks such as gray hole, wormhole and Sybil attack, which are known as multi-attack detection framework. Future research required to create a single detection mechanism that could support a number of attack vectors simultaneously, hence the strengthening of the network.

Energy-Efficient Mechanisms: As the MANET nodes were a resource-constrained device, the studies had to go further and design more energy-efficient detection and prevention mechanisms. Having reduced the computational and energy overhead, the operational lifetime of battery-powered nodes would have been improved without compromising network performance.

Cross-Layer Security Approaches: A number of attacks could have been better thwarted if security measures were implemented on multiple layers of the network protocol stack, such as the physical and MAC layers. The cross-layer approaches could enhance the overall resilience and reliability of MANETs.

Scalability and Mobility Considerations: With the rise in size and complexity of MANETs in future studies, scalable detection systems have been demanded to detect highly mobile networks without any loss of accuracy and performance.

In future work, the proposed detection and prevention mechanisms would need to be tested in real-world scenarios, as simulations had provided valuable insights into network performance when subjected to attacks. This testing would have offered concrete proof of the robustness and application of the system under dynamic and unpredictable conditions.

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1. Appendixis

Performance meterics

Load the necessary NS2 libraries

set ns [new Simulator]

Define the parameters

set num_nodes 50

set sim_time 300 ;# Total simulation time in seconds

set packet_size 512 ;# Packet size in bytes

set node_mobility 250 ;# Transmission range in meters

Create a trace file for output

set trace_file [open out.tr w]

Setup nodes

for {set i 0} {\$i < \$num_nodes} {incr i} {

set node(\$i) [\$ns node]

}

Define the network topology

for {set i 0} {\$i < \$num_nodes} {incr i} {

Set node positions randomly within the simulation area

\$node(\$i) set X_ [expr rand()*1000]

\$node(\$i) set Y_ [expr rand()*1000]

\$node(\$i) set Z_ 0.0

}

Create a routing table using AODV

\$ns rtproto AODV

Define CBR traffic sources

for {set i 0} {\$i < \$num_nodes} {incr i} {

set src [\$node(\$i)]

set dst [\$node([expr \$i + 1 % \$num_nodes])]

```

set udp [new Agent/UDP]
set cbr [new Application/Traffic/CBR]

$ns attach-agent $src $udp
$ns attach-agent $dst $cbr
$cbr set packetSize $packet_size
$cbr set interval 0.1 ;# Sending interval
$cbr start
}

# Introducing a black hole attack
set malicious_node 10
proc black_hole_attack {node} {
    # Attack by dropping all incoming packets
    $node set drop ALL
    puts "Node $node is now a black hole!"
}

# Activate the black hole attack on a specific node
black_hole_attack $node($malicious_node)

# Setup trace and log file
$ns trace-all $trace_file

# Start the simulation
$ns run

# Close the trace file
close $trace_file

```

Impacts of black hole attack on packet loss on MANET

```

import matplotlib.pyplot as plt

# Data for Packet Loss (Normal vs Black Hole Attack)
categories = ['Normal Conditions', 'Black Hole Attack']
packet_loss = [5, 50] # Percentage values for packet loss

```

```

# Creating the figure and axes for packet loss
fig, ax = plt.subplots(figsize=(8, 6))

# Bar plot for packet loss
ax.bar(categories, packet_loss, color=['blue', 'red'])

# Adding labels and title
ax.set_ylabel('Packet Loss (%)')
ax.set_title('Impact of Black Hole Attack on Packet Loss in MANET')

# Displaying values on the bars
for i, value in enumerate(packet_loss):
    ax.text(i, value + 1, f'{value}%', ha='center', fontsize=12)

plt.tight_layout()
plt.show()

```

Impacts of black hole attack on End to end delay on MANET

```

import matplotlib.pyplot as plt

# Data for End-to-End Delay (Normal vs Black Hole Attack)
categories_delay = ['Normal Conditions', 'Black Hole Attack']
delay_values = [50, 200] # Delay in milliseconds

# Creating the figure and axes for delay
fig, ax = plt.subplots(figsize=(8, 6))

# Bar plot for delay
ax.bar(categories_delay, delay_values, color=['blue', 'red'])

# Adding labels and title
ax.set_ylabel('Delay (ms)')
ax.set_title('Impact of Black Hole Attack on End-to-End Delay in MANET')

# Displaying values on the bars
for i, value in enumerate(delay_values):

```

```

        ax.text(i, value + 5, f'{value} ms', ha='center', fontsize=12)
plt.tight_layout()
plt.show()

```

Impacts of black hole attack on throughput on MANET

```

import matplotlib.pyplot as plt

# Data for Throughput (Normal vs Black Hole Attack)
categories_throughput = ['Normal Conditions', 'Black Hole Attack']
throughput_values = [900, 400] # Throughput in kbps

# Creating the figure and axes for throughput
fig, ax = plt.subplots(figsize=(8, 6))

# Bar plot for throughput
ax.bar(categories_throughput, throughput_values, color=['blue', 'red'])

# Adding labels and title
ax.set_ylabel('Throughput (kbps)')
ax.set_title('Impact of Black Hole Attack on Throughput in MANET')

# Displaying values on the bars
for i, value in enumerate(throughput_values):
    ax.text(i, value + 20, f'{value} kbps', ha='center', fontsize=12)

plt.tight_layout()
plt.show()

```

Impacts of black hole attack on Energy Consumption on MANET

```

import matplotlib.pyplot as plt

# Data for Energy Consumption (Normal vs Black Hole Attack)
categories_energy = ['Normal Conditions', 'Black Hole Attack']

```

```

energy_values = [300, 450] # Energy consumption in Joules

# Creating the figure and axes for energy consumption

fig, ax = plt.subplots(figsize=(8, 6))

# Bar plot for energy consumption

ax.bar(categories_energy, energy_values, color=['blue', 'red'])

# Adding labels and title

ax.set_ylabel('Energy Consumption (Joules)')

ax.set_title('Impact of Black Hole Attack on Energy Consumption in MANET')

# Displaying values on the bars

for i, value in enumerate(energy_values):

    ax.text(i, value + 10, f'{value} J', ha='center', fontsize=12)

plt.tight_layout()

plt.show()

```

End to End Delay

```

import matplotlib.pyplot as plt

# Data for End-to-End Delay (Normal vs Black Hole Attack)

categories_delay = ['Normal Conditions', 'Black Hole Attack']

delay_values = [50, 200] # Delay in milliseconds

# Creating the figure and axes for delay

fig, ax = plt.subplots(figsize=(8, 6))

# Bar plot for delay

ax.bar(categories_delay, delay_values, color=['blue', 'red'])

```

```
# Adding labels and title
ax.set_ylabel('Delay (ms)')
ax.set_title('Impact of Black Hole Attack on End-to-End Delay in MANET')
# Displaying values on the bars
for i, value in enumerate(delay_values):
    ax.text(i, value + 5, f'{value} ms', ha='center', fontsize=12)
plt.tight_layout()
plt.show()
```