Performance Evaluation on Modified AODV Protocols

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***Abstrac*t—Ad hoc On-demand Distance Vector (AODV) is one of reactive routing protocol in Mobile Ad hoc Network (MANET) and many variants are developed based on modifying this protocol. Purposes of modification were mostly related to security and performance improvement, yet the additional processes being introduced in the modification could incur overheads to the modified AODV. The purpose of this paper is to evaluate some of the modified AODV protocols performance by examining their effectiveness in alleviating the black hole attack and further examining the effect of mitigation methods used on overhead. The performance analysis focuses on two conditions, i.e. no-attack and under-attack. Three modified AODV protocols were studied, namely idsAODV, HDAODV and EAODV, and a new modified protocol is proposed. Using NS-2 network simulator, the performance of these protocols under no-attack and under-attack scenarios were collected and analyzed. Simulations were conducted by varying the pause times in random waypoint mobility model. The performance results are presented using comparative analysis based on different performance matrices such as throughput, Packet Delivery Ratio, End-to-end delay, Network Routing Load and Energy usage. The results show that the three modified AODV protocols give positive effect to network performance in both conditions - under-attack and no-attack environment. EAODV protocol outperforms other modified protocols with highest network performance, but with longer delay and higher energy usage than the other modified protocols.**

***Keywords-** AODV; idsAODV; HDAODV; EAODV; Wireless network; MANET; modified AODV; security; performance; protocol overhead*

I. INTRODUCTION

Mobile ad hoc network (MANET) is a self organized and dynamic wireless network [1]. It operates arbitrarily and freely by a group of wireless nodes to exchange information without depending on a central administrator or established infrastructure. In this network, nodes are also functioning as a router and always move in a random fashion which makes the network topology frequently changing [2]. Ordinary routing protocols, which are used in wired networks, cannot be simply used because the network topology is dynamic. Ad hoc routing protocols have been introduced in MANETs, many of them have been developed in the past one decade, and they are classified into three main categories based on the route discovery method [3].They are described briefly as follows;

- Table driven or proactive routing protocols - Each node has routing tables to maintain the network topology information. The Node periodically exchanges routing information to update the network topology into the routing table. Whenever a node needs a route to the destination it uses existing topology information available in the routing table, and if the information is not found, it runs an appropriate route discovery algorithm on the topology to update the information it maintains.
- On-demand or reactive routing protocols - Each node has a routing table but do not maintain the network topology information periodically. Route discovery algorithm is used to acquire the route when it is needed. Therefore, this protocol does not need to exchange routing information periodically.
- Hybrid routing protocols - It is a combination of the best features in the above two categories depending on the routing zone. Nodes within a geographical region or have a certain distance from the source node is considered to be within the routing zone. A table-driven approach is used for routing within routing zone, and an on-demand approach is used for nodes which stay outside the routing zone.

In this paper, we focus the study on on-demand routing protocols, specifically related to a protocol called Ad hoc On-demand Destination Vector (AODV) [4]. This protocol has been studied by many network researchers, and many modified AODV protocols have been proposed for various objectives as described in [8]. In general, the modified AODV protocols mostly are related to improvement. For example, AODV is susceptible to various attacks such as black hole, worm hole and jelly fish because it is designed without security consideration [5].To overcome this problem, many AODV variants were proposed by modifying normal AODV protocol as secured protocol [6]. In most modification, it will involve adding or removing certain process, which can lead to a certain level of overhead to existing process.

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The purpose of this paper is to examine the overhead impact on some modified AODV protocols and identify its effect to the network performance. The performance analysis looks into two possible environments – normal and hostile conditions. Normal condition refers to the environment when there is no-attack on the network and hostile condition refers to the environment when the network is under-attack. We examined three modified protocols which mitigate black hole attacks. The first protocol was proposed by Deng [8], which is known as HDAODV; second was proposed by Dokurer [9], which also known as idsAODV and the last is our own recently proposed protocol called EAODV [10].

The NS-2 network simulator [7] was used to simulate various scenarios and we collected the resulting data for analysis. For comparative analysis, the performance metrics were set based on Throughput, Delay, Packet Delivery Ratio, Energy and Network Routing Load ratio.

The rest of the paper is organized as follows: Section 2 gives an overview of the AODV and modified AODV routing protocols. Simulation setup is described in section 3. Section 4 presents the analysis of the results performed on the aforementioned modified AODV protocols under-attack and no-attack conditions. Section 5 concludes the paper.

II. AODV AND MODIFIED AODV ROUTING PROTOCOLS

A. Ad hoc on demand distance vector (AODV)

AODV is a reactive routing protocol which will perform route discovery process based on demand [4]. During route discovery process, two control packets, Route Request (RREQ) and Route Reply (RREP) are used in the protocol exchange flow to find and update the routing path. Information regarding the next hop nodes in the routing path is stored in the routing tables of those nodes which participate in the routing path.

The procedure to establish the route in AODV protocol is as follows. Assuming that node S intends to send data to node D but S does not have information to D. Thus, to establish the connection, node S initiates a route discovery process by broadcasting a RREQ packet to the network. The RREQ packet carries a sequence number which will indicate the "freshness" of route information so that intermediate nodes can evaluate the information and reply to the requests with up-to-date route information. When an intermediate node receives the RREQ packet, and the packet has higher sequence number, the node will update its routing table with new route entry to establish a reverse path, which will be used by route reply. If the information about node D is not available, the node will rebroadcast the request until the RREQ is received either by node D or by an intermediate node that has recently established route to node D otherwise route reply RREP packet will be generated.

The RREP packet also has a sequence number to maintain the up-to-date routing information. After node D receives the RREQ from its neighbours, if the update condition is made, node D updates its routing table with neighbour node address (i.e. next hop node) which is the entry node for node S. Node D generates RREP packet and sends the packet to node S via next hop node in the reverse direction. If the next hop node is not the source node D, the RREP packet is forwarded using reverse path until node S is reached.

B. HDAODV

Deng H.et al. [8] proposed a method to overcome black hole attack by disabling the reply message from the intermediate node. This method avoids intermediate node from sending out RREP and hence, only trusts the reply from actual destination node. It is clearly seen that, this modified protocol is based on the assumption that malicious node normally come from intermediate node. HDAODV protocol is implemented by modifying the mechanism to generate RREP in AODV protocol. In this modification, if the nodes are considered as an intermediate node, they are not allowed to generate any RREP packet. This method is believed to potentially cause an undesirable increase in the routing delay in large networks and may potentially give a malicious node the ability to take advantage by replying message instead of the destination node. Furthermore, this mitigation method by Deng et al. has yet to be tested to proof the effectiveness to alleviate the black hole attacks.

C. idsAODV

Dokurer [9] proposed idsAODV, which is another modified AODV that is designed to reduce the adverse effect of black hole attack. The protocol mitigation method is implemented by modifying the routing update mechanism in AODV protocol. The process to ignore the first establishment route is added to the logical expression in routing update process. The main strategy is that when the network is under attack, multiple RREP from a different path is generated. This protocol assumes that the first RREP message that arrived at a node is from a malicious node, and hence the mitigation method in idsAODV is to ignore this RREP to avoid false route entry being updated to the routing table. This method is able to improve the packet delivery but there is at least one limitation, for example, if the second RREP message received at a source node comes from a malicious node, it is not able to avoid or stop it.

D. Enhance AODV (EAODV)

The EAODV [10] is an enhancement of author proposed protocol called ERDA [11]. Similar to idsAODV, the mitigation method used in EAODV protocol also uses multiple RREP from a different path to alleviate the effect of black hole by allowing multiple routing update processes. The main strategy is, by assuming the actual destination node at any point of time will send the RREP, all previous route entry including from malicious nodes will be overwritten by latest incoming RREP. The updating process will continue until RREP from the actual destination node is received. Subsequently, the process detection and isolation starts to analyze all received RREPs using heuristic method adopted from [12] followed by the process of isolating suspected malicious nodes. EAODV protocol is implemented by modifying the AODV routing update mechanism involving two processes to mitigate the black hole attack; namely, 1) changing the routing update logic expression and 2) adding detection and isolation process. We could foresee at least one limitation; i.e. EAODV adds two processes in the mitigation methods that cause extra delay and energy usage.

III. RELATED WORKS

A lot of attention has been given to study the performance of modified AODV in various scenarios. Humaira Nishat et al. [13] evaluated one of modified AODV protocol called R-AODV [14] and comparing its performance with the normal AODV. R-AODV improved AODV routing performance by using multi-reverse path, which will reduce RREQ transmission. Simulation results using NS-2 showed that R-AODV outperforms AODV in terms of throughput, average delay and packet delivery ratio by varying nodes velocity. However, this study focused only on performance under normal operation, i.e. without any attack.

Umaparvathi and Dharmishtan [15], studied the performance of Ad hoc On-demand Multi-path Distance Vector (AOMDV) [16], which is another modified AODV protocol. The AOMDV employs multi path on demand routing to overcome the black hole attack on AODV. This protocol modifies the control packet structure for fault tolerance purpose. The results showed that AOMDV able was able to reduce the effect of black hole during an attack, however during normal operation (with no attack), its performance was lower as compared to normal AODV in terms of PDR and throughput. This means that the overhead in AOMDV has a direct effect on performance during normal operation.

.Periyasamy and Karthikeyan [17] also evaluated AOMDV protocol to determine the performance in various scenarios and traffic pattern using NS-2 simulation. Instead of comparing the performance with normal AODV, this performance evaluation use various mobility models and traffic pattern in the form of comparative analysis. Four different mobility models and two traffic patterns were used in the simulation. The results showed that CBR and TCP traffic on AOMDV protocol works better in Reference Point Group Model (RPGM) environment as compared to other models. However, this study did not cover the performance when the network is under attack.

Rani A. and Dave M. [18] introduced and evaluated Modified AODV for Load Balancing using NS-2 simulation. They compared modified-AODV with normal AODV to determine the NRL, Average delay and average throughput by varying the number of sources and queue length. The simulation results showed that the modifications was able to improve average throughput and reduce normalized routing load by keeping track of the aggregate interface queue length. However, the modifications to AODV are more useful to moderately loaded traffic in high mobility networks. Similar to previous studies, this study also did not cover the performance when the network is under attack.

Simaremare H. and Sari R.F [19] evaluated the performance of two modified AODV protocols, AODV-UI and PHR-AODV using NS-2. The performance evaluation was aimed at determining the efficiency and security of the two modified protocols under DDOS, Black hole and Malicious attacks. The simulation results showed AODV-UI outperformed PHR-AODV performance for packet delivery ratio; packet lost and end-to-end delay. It is also noted that in the study, PHR-AODV performance was better under black hole attack. However, this study only focused on the performance when the network is under attack.

IV. EVALUATION METHOD

A. Simulation Environment

In this study, performance evaluation was conducted in two environments; 1) no-attack 2) under-attack. Black hole was used as attack model with one malicious attack for the under-attack environment. All simulations were executed using simulation setup as described in Table1. The normal AODV protocol can model the node behaviour as a normal node or as malicious node.

In the simulation model, the network was using IEEE 802.11 MAC layer wireless link with Two Ray Ground radio propagation model. Varying scenarios of 25 wireless nodes were created randomly with various mobility behaviours and each simulation was run for 200 sec. The type of mobility model being used is the random waypoint model, since it is the most widely used model in many previous studies. The node mobility speed from the current position to target position was assigned randomly up to 10 m/sec. This speed range is used to represent a normal movement of a walking person up to running of vehicle in the campus area with the size of 1000x1000 sq. meters. Traffic pattern was generated using Constant Bit Rate (CBR) as the data source and transports it using UDP protocol. Five CBR traffic were randomly transmitted at the rate of 4 packets per sec with the size of 512 bytes long per packet. In this study, mobility pause times were used as independent variable by varying the pause duration for 0, 10, 20, 30, 40, 50, 60, 70, 80 and 90 sec.

Data was extracted from the trace files using awk script and exported to spreadsheet to get the statistics of throughput, delay, packet delivery ratio, network routing load and energy usage.

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Simulator	NS-2 version 2.34
MAC Type	IEEE 802.11
Simulation Time	200s
Number of nodes	25
Routing Protocol	AODV, EAODV, HDAODV, idsAODV
Initial Energy	5000 J
Tx Power	250 mW
Rx Power	200 mW
Mobility model	Random way point
Traffic Model	5 CBR data sources
Pause time	0,10,20,30,40,50,60,70,80,90 s
Mobility	Up to 10 m/s
Terrain	1000 x 1000m
Transmission Range	250m
Black hole attack Model	1 Malicious nodes

B. Performance metrics

The following metrics were used for evaluating the performance in this study similar to the one used in many previous performance evaluation works.

1) *Throughput*
It is the average rate of successful transmitted data packets in bytes per second within runtime.

2) *Delay*
It is the average time (in second) taken to send the data packets across the network from source to destination node. The time taken includes all possible delays such as buffering, queuing, retransmission, propagation and transfer times.

3) *Packet Delivery Ratio (PDR)*
It is the average ratio (in percentage) of the total number of packets received by the destination to the total number of data packets sent by the source.

4) *Normalized routing load (NRL)*
It is the average ratio of total routing control packets transmitted (in bytes) to total data packet received at the destination.

5) *Energy usage*
It is the average energy (in Joules) used by the node in the network.

V. SIMULATION RESULTS AND ANALYSIS

In this section, we present a comparative analysis of AODV and modified AODV protocols in two different environments, i.e. no-attack and under-attack conditions. Normal AODV performance is used as a baseline for examining the effect of overhead in modified AODv protocols.

A. Throughput

When there is no attack in the network, the average throughput under AODV, EAODV and HDAODV protocols show no significant difference (14.1 Kbytes/sec) as depicted in Fig. 1. Under the idsAODV protocol, the throughput is slightly low (13.8 Kbytes/sec) as compared to other protocols. This result indicates that during the absence of black hole attack, the mitigation method overhead in EAODV and HDAODV do not significantly affect the throughput of the network as compared to the method in idsAODV protocol during normal operations.

Referring to the same figure, when the network is under attack condition, normal AODV throughput has dropped drastically to 2.1 Kbytes/sec. However, for modified protocols, average throughputs under EAODV, HDAODV and idsAODV are 12.0, 7.2 and 5.2 Kbytes/sec respectively. This result shows, under modified protocols the throughput performance during the attack have been improved with varying degree. Amongst modified AODV protocols, our EAODV protocol has the highest throughput. Hence, we conclude that the mitigation method in EAODV protocol is more effective than HDAODV and idsAODV in alleviating the effect of black hole attack, and this has been proven by the significant improvement on the throughput.

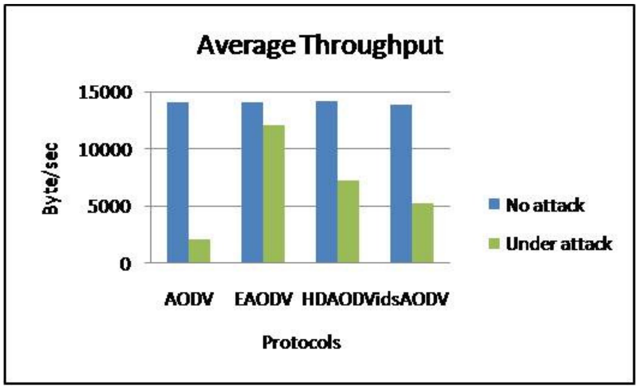

Fig. 1. Average Throughput for no-attack and under-attack environments

B. Delay

Fig. 2 shows the average end-to-end delay during the network in no-attack condition, whereby EAODV and HDAODV average delay have same performance level with AODV (0.41 second). Yet, for the idsAODV protocols, the average delay is slightly lower (0.34 second) than EAODV and HDAODV protocols. We noted that idsAODV perfomed better due to the routing path in idsAODV is established without having to do a proper checking at routing update mechanism after ignoring the first establish route. Furthermore, when both EAODV and HDAODV are compared with normal AODV, they are at the same performance level, thus relatively no overhead exist in these protocols during no-attack.

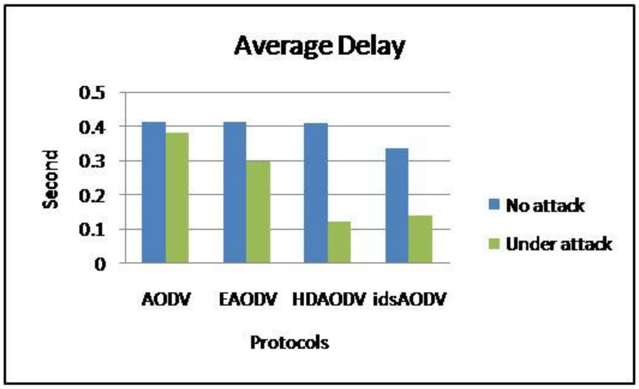

Fig. 2. Average Delay under no-attack and under-attack environment

Refering to the same figure, the performance during the network under attack shows that HDAODV protocol provides better performace (0.12 second) in terms of less average delay as compared to other protocols as shown in Fig. 2. The average delays for AODV, EAODV and idsAODV are 0.38, 0.30 and 0.14 second respectively. The HDAODV has the lowest delay when the network is under-attack condition mainly because it does not check RREP packet from intermidiate nodes, which could pose potential risk.

C. Packet Delivery Ratio (PDR)

Fig. 3 shows that when there is no attack in the network, the PDR performance for all the modified AODV protocols i.e. AODV, EAODV and HDAODV show no difference (about 85%). Again as in previous observations, in idsAODV the PDR shows slightly lower (82%) as compared others. We can safely say that the ignoring technique in idsAODV has affected the delivery performance, whereby even if only one valid path is available and it will be ignored.

However, the PDR performance quite a different story when the network is under attack. The average PDR for normal AODV has dropped drastically to its lowest at 11%. Comparatively, the other modified AODV performed differently and better as compared to normal AODV, namely for EAODV (70%), HDAODV (41%), and idsAODV (28%) respectively. Hence, the mitigation methods used in modified AODV protocols have improved the PDR performance during the attack.

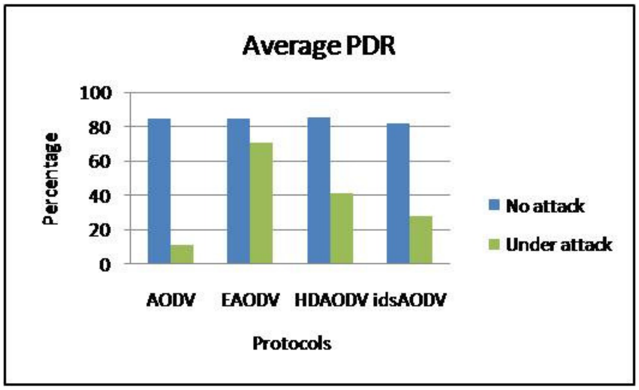

Fig. 3. Packet Delivery Ratio under no-attack and under-attack environment

It is worth mentioning that EAODV protocol has shown to have higher PDR as compared to HDAODV and idsAODV protocols. Hence, we can safely say that the method in EAODV protocol is more effective than HDAODV and idsAODV in mitigating the black hole attack.

D. *Energy usage*

Recall that, refers to average energy (in Joules) used by the node in the network. Fig. 4 shows the results of energy usage by each protocol. During no-attack condition, different amount of energy are consumed; AODV and EAODV consumed same amount of energy (2772J), HDAODV (2728J) and idsAODV (2898J), respectively. This result implies that the overhead of idsAODV mitigation method consumes more energy which could potentially affect the performance during normal operation.

When the network is under attack, packet transmissions between source and destination node normally drop, which is lead to less transmission acivities amongst nodes. As a result, the energy usage will also drop as what has been shown under normal AODV (1931J). However, under modified AODV protocols, the energy usage has slightly incerased due to the inceasing number of packet transmission activities. EAODV consumes 2424J, HDAODV consumes 2167J and idsAODV consumes 2347J. The result also shows that EAODV mitigation process consumes more energy although the network is under attack as compared to HDAODV and idsAODV. This is expected because energy is needed to produce the high PDR and throughput in the network.

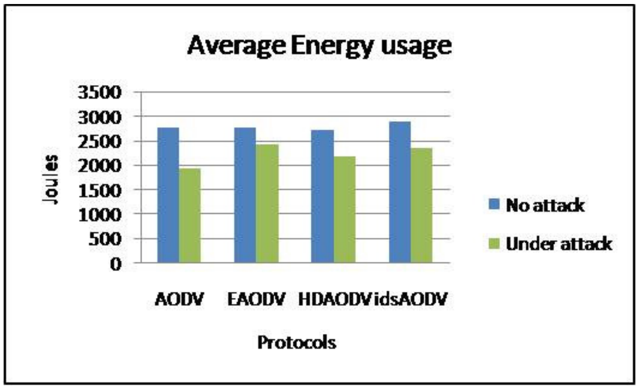

Fig. 4. Average Energy usage under no-attack and under-attack environment

E. *Network Routing Load (NRL)*

In Fig. 5 shows the performance of NRL ratio. When there is no attack in the network, the NRL for AODV, EAODV, HDAODV and idsAODV reachs 0.41, 0.41, 0.42 and 0.42 respectively. This result shows that there is no difference in NRL for EAODV and normal AODV; but for HDAODV and idsAODV the NRL is slightly high as compared to AODV and EAODV.

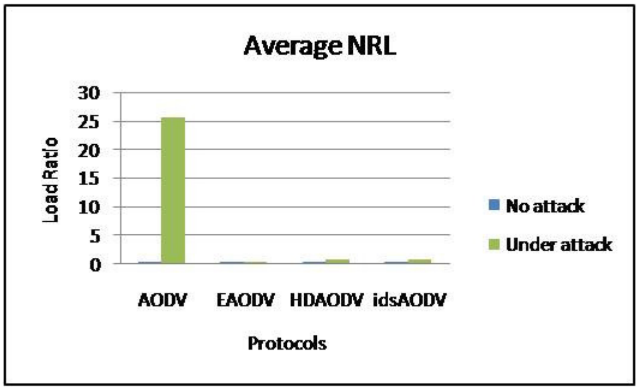

Fig. 5. Average Network Routing Load under no-attack and attack environment

When there is an attack to the network, NRL for normal AODV has shooted up to 25.65, and this is attributed to the generation of more control messages. The NRL is relatively much lower ration in modified protocols, where EAODV (0.40) is lower than HDAODV (0.75) and idsAODV (0.74). This result has shown the significant effect made by the modified AODV protocols on the NRL performance although the network is under attack.

F. *Overall Comparison of Modified AODV Performance*

Table 2 shows the overall comparison of modified AODV top performance. We can safely say that based on the results of our study, EAODV protocol outperforms other modified protocols, but with the limitations of having longer delay and higher energy usage.

TABLE 2. MODIFIED AODV TOP PERFORMANCE SUMMARY

Performance Metrics	No-attack	Under-attack
High Throughput	EAODV and HDAODV	EAODV
Low Delay	idsAODV	HDAODV
High PDR	EAODV and HDAODV	EAODV
Low Energy	HDAODV	HDAODV
Low NRL	EAODV	EAODV

VI. CONCLUSIONS AND FUTURE WORK

This paper has presented the performance analysis of three modified AODV protocols under two conditions, i.e. no-attack and under-attack. Three modified AODV protocols under this analysis are idsAODV, HDAODV and EAODV. These modified AODV protocols have been embedded with different mitigation methods to alleviate the black hole effect in AODV network. This paper focuses on network overhead effects on the network performance during the absence and presence of black hole in the network. We performed simulations and the performance results were presented based on different performance metrics such as throughput, Packet Delivery Ratio, End-to-end delay, Network routing load and energy usage. The results showed that the three modified AODV protocols give positive effect to network performance whether network is under-attack or no-attack in comparison with normal AODV performance. EAODV have the potential of becoming a preferred protocol to mitigate Black Hole problem, but we need to address longer delay and higher energy usage.

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