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Performance Prediction for AODV, AOMDV, and hybrid protocols in the high-Density Networks

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Abstract. Today, the intelligent transportation system (ITS) plays an important role in smart cities to decrease over-population problems, traffic congestion, free passage of emergency vehicles, and unseen obstacles. ITS allows communication between vehicles which leads to the efficient and reliable routing protocol for what is called Vehicular Ad-Hoc Network (VANET). In this paper, the performance of the Ad-hoc on-demand Distance Vector (AODV), Ad-hoc on-demand Multipath Distance Vector (AOMDV), and hybrid protocols have been analysed based on different network densities. Then their prediction are measured in the high-density areas using linear regression techniques with performance parameters of Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average End-to-End delay (AE2ED), and Average Throughput (ATP). The results show that when using AODV and AOMDV together as hybrid protocol in the same environment with a number of nodes greater than 200 nodes, the PDR, NRL, and ATP are better than AODV and AOMDV separately. The PDR and ATP decrease when the network density increases, and vice versa with NRL and AE2ED. The performance parameters results are implemented in MATLAB version R2019b (9.7) to visualize the graphs.

KEYWORDS: VANET, Normalized routing Load, Throughput; Average End-to-End Delay, high-density network.

1. INTRODUCTION

In recent years, the need to build smart cities with Intelligent Transportation System (ITS) is important, especially to decrease over-population problems, traffic congestion, enhance environmental pollution by decreasing carbon emissions, mitigate road incidents, over-speed, free passage of emergency vehicles, and unseen obstacles, and conserve energy and relieve congestion [1]. ITS is an integral part of smart cities, allowing interaction and intercommunications between vehicles [2].

The possibility of exchanging data between vehicles over an ad-hoc network environment is called Vehicular Ad-Hoc Network (VANET), which is a subclass of the Mobile Ad-Hoc Network (MANET) that uses vehicles instead of mobile nodes.

The vehicles are moving separately in any direction so that the network topology is changing continuously. Such as the reactive routing protocols that update the routing table when require to create the connection to the destination on-demand. As Ad-hoc, On-demand Distance Vector (AODV) protocol has been modified to reduce packet loss and end-to-end delay. One of the modifications of AODV is Ad-hoc on-demand Multipath Distance Vector (AOMDV) protocol, a multipath, disjoint path, and loop-free protocol. The hybrid protocols, AODV and AOMDV, have the same routing table with hop count in AODV and AOMDV uses advertisement hop count. In AODV, the first route request (RREQ) is used while the others are dropped. AOMDV reserves multiple paths with no common path between the source and destination nodes [2].

This paper focuses on performance analysis and predicting the performance of the VANET routing protocols, AODV, AOMDV, and hybrid protocol with different traffic density areas. To find an efficient routing protocol in a high-density area. From discussions with Egyptian traffic engineers, approximately 400 vehicles occupy the condensed intersection area, so the experiment is executed with a number of vehicles from 50 nodes to 450 nodes. In addition, using the linear regression model to predict the best routing protocol with each performance parameter. The performance parameters that are used are Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average End-to-End delay (AE2ED), and Average Throughput (ATP) due to the change in the network density of the AODV protocol, AOMDV protocol, and hybrid protocol of AODV and AOMDV together.

The approach of this work is to measure the performance metrics (PDR, NRL, AE2ED, and ATP) at initial node energy of 50 joules, using a network simulator (NS-2.34) for the (AODV, AOMDV and hybrid protocol). Then by using the linear regression model to predict the performance in high-density network. The results show When half of the nodes use AODV, and the other half use the AOMDV and number of nodes greater than 200 nodes the PDR, NRL, and ATP are better than AODV and AOMDV separately. The PDR and ATP have a negative linear coefficient while NRL and AE2ED have a positive coefficient.

This paper is organized as follows. Section 2 linear regression model. Section 3 related work is described. Section 4 Simulation Environment. Section 4 presents the simulation results and discussion. Section 5 presents the conclusion and future works.

2.Simple Linear Regression Model

It is a statistical technique, a data model, for predicting the impact of changes in one variable, which is called the effect or dependent variable, on another variable, which is called the cause, independent, or predictor variable. Regression analysis helps us to understand how much the dependent variable changes with a change in one or more independent variables. Linear Regression refers to a group of techniques for fitting and studying the straight-line relationship between two variables. If there is one independent variable, it is called a simple linear regression; if there are more, it is called a multiple linear regression model [3], in equation (1):

$$\mathbf{y=\beta_0+\beta_1\,x+\beta_2\,x^2+\cdots+\beta_n\,x^n} \quad \mathbf{(1)}$$

To know the coefficients for a polynomial of degree n that is the best fit for the data in y of equation (1) uses the MATLAB function *Polyfit* (y, x, n). It evaluates y at each value of x. It returns the coefficients in βs ($\beta_{n,}$ $\beta_{n-1\ldots}$ β_0) are in descending powers, and the length of β is n+1 scalar vector and n is the degree of polynomial equation (1).

In simple form, equation (1) can be expressed as follows:

$$y = \beta_0 + \beta_1 x + \epsilon \quad \mathbf{(2)}$$

Where β_0 is the y-intercept, β_1 is the slope, or regression coefficient, and ϵ is the error term. For n observed values using the following equation (3).

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ . \\ y_n \end{pmatrix} = \begin{pmatrix} 1 & x_1 \\ 1 & x_2 \\ \vdots & \vdots \\ . & . \\ 1 & x_n \end{pmatrix} \begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix} + \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ . \\ \epsilon_n \end{pmatrix} \quad (3)$$

To know if there is, a relationship exists between the variables, correlation analysis is used. To measure the strength of the relationship between two variables and their association with each other the Pearson correlation coefficient (r) is used to find the strength and the direction of the relationship between variables. It can be calculated by using the following equation (4) [1]:

$$r = \frac{N\sum_{k=1}^{N} xiyi - (\sum_{k=1}^{N} xi)(\sum_{k=1}^{N} yi)}{\sqrt{(\sum_{k=1}^{N}(xi)^2 - (\sum_{k=1}^{N} xi)^2)\,(\sum_{k=1}^{N}(xyi)^2 - (\sum_{k=1}^{N} yi)^2)}} \quad (4)$$

Where N is sample size, x_i is the independent variable and y_i is the dependent variable.

$\Sigma x_i y_i$ = the sum of the products of paired scores

Σx = the sum of x scores

Σy = the sum of y scores

Σx^2 = the sum of squared x scores

Σy^2 = the sum of squared y scores

r values should be between -1 and +1 and the relationship is strong if it is near to these values.

To know how well the regression model predicts responses for new observations i.e. the goodness of fit, the coefficient of determination (r^2) is applied. It describe the fit of model to the data analysis. It is expressed as a percentage between 0 that indicates that there is no correlation at all and 1, which indicates that the correlation is perfect.

3.Related work

In [4], it aims to find the best VANET protocol between (AODV, AOMDV, Dynamic Source Routing "DSR," and DSDV) with varying traffic densities in different regions that work in a real-map model. In terms of PDR and NRL. The outcome result suggests that AODV and AOMDV are the most suitable of the four protocols for the real-time scenario. Values were obtained for PDR for both ranges of between 96 and 99% approximately, while the values obtained for NRL for all participating protocols were nearly within the same range except for DSR, which had an exceptionally low NRL.

To suggest the relevant and efficient routing protocols between (AOMDV, AODV, and DSDV) in a high traffic density area with respect to time is presented in [5] from the Freeway Performance Measurement System (PeMS) database and assigning this extracted information into a microscopic mobility model in terms of AE2ED, and ATP. The simulation results prove that the performance of AOMDV is greater in comparison to DSDV and AODV protocols in high traffic density areas. The AOMDV protocol improves overall network performance by achieving maximum throughput and minimum end-to-end delay.

In [6], the performance parameters of Dynamic Source Routing (DSR), Destination-Sequenced Distance Vector (DSDV), and AODV were differentiated. The used performance parameters are ATP, PDR, and NRL. The generated results affirmed that the PDR and ATP of AODV were better than DSDV and DSR, while AODV and DSR performed better in the condition of fast mobility. In addition to that, the NRL of DSR was less than that of AODV.

Two routing protocols (AODV and AOMDV) are assessed in terms of PDR in [7], with speeds varying from 10 m/s to 30 m/s. The results demonstrate there is no difference between AODV and AOMDV at low speed, while at high speed; the PDR of the AOMDV protocol exceeds that of AODV. The performance is degraded when the speed is increased for hybrid protocol of AODV and AOMDV. After adding the probabilistic relay (PR) to both protocols (AODV-PR, and AOMDV-PR), AODV-PR considerably adds to a 3–6% improvement in PDR due to probabilistic relay, which obviously aids in the recovery of failed packet transmission at variant vehicle speeds. AOMDV-PR improves by 2–5% compared to the original AOMDV at high speeds of 20–30 m/s.

The optimizing selection of the best possible routing protocol AODV or DSR for providing reliability to data packet dissemination in an efficient way was concluded in [8]. The performance evaluation is based on the impact of network sizes and routing protocols on packet loss, in performance metrics (PDR, packet loss ratio, AE2ED and ATP) using different network sizes. Results indicated that the performance is improved by using the DSR routing protocol compared to AODV in terms of improved PDR, higher throughput, lower packet loss, and reduced delay even for a large network of vehicles.

The performance parameters of PDR, ATP, AE2ED, and jitter in [9] are estimated for AODV and DSR VANET routing protocols. The results concluded that the AODV is better than DSR, and by varying the area size, the performance was affected more compared to the network density. The routing protocols

AODV and optimized link state routing (OLSR) were assessed in [10] in the low and high-density networks. The results concluded that the OLSR is better than AODV in both scenarios.

The routing protocols optimized link state routing (OLSR), Geographic Routing Protocol (GRP), AODV, multicast ad hoc on-demand distance vector routing protocol (MAODV), and OLSR are estimated in [11]. The results concluded that for ATP, AE2ED, overhead, and bandwidth utilization the GPR is more efficient than the OLSR and AODV. Also, for low-speed and density scenarios, the OLSR and DSDV are more efficient than AODV. When the vehicles speed increases, DSDV performs less efficiently than AODV and DSR. Moreover, MAODV is more efficient than AODV; the OLSR possessed proactive naturally, thus it has the best average results for latency.

The experiments used Constant Bit Rate (CBR) for the protocols (Geographic Perimeter Stateless Routing (GPSR), AODV, and DSR) to estimate the PDR and the message overhead. The obtained results showed that the GPSR, AODV, and DSR protocols CBR outperforms in both metrics, as discussed in [12]. The evaluation of AODV, GPR, DSR, and OLSR besides V2V communications with and without RSU is presented in [13]. The results revealed that the AODV protocol needs to update the shortest path frequently so that it is more efficient than other protocols in terms of NRL, E2ED, and re-transmission attempts.

The protocols AODV and OLSR had been evaluated in [14] under the basic common geographical crossroad topology, using two scenarios; low and high-density crossroad. In terms of ATP, PDR, and E2ED. For both scenarios with low congestion in ATP, PDR, and latency performance metrics the results showed that OLSR more efficient than AODV. When the congestion occurs, the E2ED of both protocols is negligible.

In paper [15], it compares (AODV, AOMDV, DSR, and DSDV) protocols using the NS-2 simulator for metrics (ATP, E2ED, and PDR). The simulation takes 200s with vehicles maximum speed at 100Km/h and network density of (10, 20, 30, 40, 50, 60, and 70) vehicles. The results demonstrate for PDR the DSDV is worst when increase nodes while AODV has suitable in ATP for small and large network density. DSDV has the worst PDR by increasing nodes while AODV is suitable in throughput for the small and large environments, but it consumes more power in the transmission. AOMDV has a middle pattern for all metrics. DSR has the highest E2ED.

It reveals from [16] the performance analysis of (AODV, AOMDV and DSR) in comparison with DSDV in terms of PDR, packet loss, number of dropped packets. The results showed MANET routing protocols could be implemented on VANET, but with the increase of vehicles density and velocity, the performance parameters are decreased.

The goal of [17] is to quantify the effects of increasing the sending rate of the source node from 2 to 4 packets per second (PPS) for 50 mobile nodes with pause times varying at (0, 150, 300, 450, 600, 750, 900) seconds in a simulation area of 1000 * 300 m^2 using a node movement model and a CBR source traffic model for routing protocols (AODV, DSR, and DSDV) on the NS-2 simulator and the performance The simulation results are the average of five different output readings. The experiment was done in a 1000 x 300 m^2 area. The results show that DSR and AODV had better PDR than DSDV. AODV gets better performance in AE2ED than DSR and DSDV. The minimum NRL of DSR is lower than that of AODV and DSDV.

In [18], the AOMDV routing protocol is compared to AODV, DSDV, and DSR in terms of (NRL, E2ED, speed, network connection, pause time, received packets, dropped packets, latency, and simulation time under different network conditions, such as different vehicle speeds, simulation times, time pauses, and concurrent connections were simulated using the Linux platform (Ubuntu release 16.5), the network simulator NS-2 version 2.35, and many concurrent network connections (5, 10, 12, 15, 18, 20, 25, and 30). Data packets have been sent from 31 vehicles in an area of 971×591 m^2. The simulation lasts for 100s. AOMDV performs best at higher speed rates as compared to AODV in terms of E2ED, ATP, and NRL. However, AODV is also best suitable when the speed of network nodes is low.

At [19] propose an improved AODV routing protocol. It is similar to AODV with two-step optimization. An enhancement in the route discovery phase by selecting some stable link nodes with others is chosen to forward the route request (RREQ) packet. In addition to the route selection process, in case of there are multiple routes between the source nodes to the destination the packets transmitted through the most stable route based on the link weight calculation with the longest exist life, otherwise, the route with the minimal route weight will be selected. The results show that the proposed protocol has a better PDR and less NRL.

In [20] presents a detailed evaluation of throughput (ATP) and latency (AE2ED) measurements for VANET routing protocols (AODV, DSR, and DSDV) when varying network-density, by simulating using OMNET++ 4.7.1 and generating scenarios by the Veins net Mobility model. Sent Data packets from (50, 150, 250, 350, and 450) vehicles and transmission range were 250 m under different mobility scenarios highway map, Real-world map, and the Manhattan grid. The results showed the DSR outperformed in performance compared to AODV and DSDV. In real-world and Manhattan grids, DSR has the maximum throughput, but it suffers in the case of the highway, and it has the minimum latency for the three scenarios. The AODV outperforms throughput as compared to DSDV in the case of the highway.

The aim of the paper [21] is to apply multichannel transmission technology and optimize its use in VANETs to reduce delay, increase throughput and reduce packet loss. The framework for user mobility modeling (VanetMobiSim) is used for the generation of scenarios for NS-2.35 for 900s, with in simulation area 1000*1000 m^2 with version of speed between (15 - 20) m/s and data packets were sent from (10, 20, 30, and 40) vehicles. It has been observed that the results of MAODV outperform AODV when the packet delivery ratio is concerned.

In paper [22] proposed to Stop Time, Speed, and Direction to modify to hop count of the AOMDV in the route discovery phase to select the next-hop and create a new VANET routing protocol (SSD-AOMDV). The performance of SSD-AOMDV relative to AOMDV is compared, in terms of AE2ED, PDR, and NRL based on Network Simulator version 2.34 that used VanetMobiSim model for scenario generation for 400s, the network density of (60, 70, and 90) vehicles that have variation in speed from (10 to 90) km/h in an area of 2000*2000 m^2. The results showed that SSD-AOMDV outperform the performance of AOMDV.

For (AODV, AOMDV, DSR and DSDV) VANET Routing protocols, the Performance Evaluation was carried out in [23] using NS-2.34 with variation of vehicles' speed. The metrics are (Packet Loss Ratio (PLR), ATP, PDR, E2ED, and NRL). The results showed AE2ED and ATP for DSR that has more PLR and lesser NRL. The AOMDV and AODV had better PDR and minimal PLR.

4. Simulation Environment

A. Performance Metrics

The paper experiment uses the following performance metrics:

- *Packet Delivery Ratio (PDR):* It is the ratio of total data packets received successfully at all the destination nodes to the total data packets sent from all the source nodes [2].
- *Normalized Routing Load (NRL)*: It is the ratio of all routing control packets send by all nodes to the number of received data packets at the destination nodes. High NRL reduces the packet delivery to the destination [3].
- Average End-to-End Delay (AE2ED): It is the average time for each successful data transmission to route through the network from a source to its destination [6]. Lower

AE2ED indicates to the protocol has high performance [5].

- Average Throughput (ATP): It is the average number of packets successfully delivered from source to destination node in the Time Interval Length (TIL) [4]. High ATP shows better performance.

B. Simulation Model

The Network simulator (version NS-2.34) is a discrete-event network software simulator written in C++ programming language with Object Tool Common Language (OTCL) that can be run in different operating systems. It offers a visual tracing of movements nodes with a Network animator (NAM) file and saves the results into a trace file (.tr) [24].

This paper uses Linux operating system (Ubuntu 16.04) on an Intel Xeon processor with 48 GB RAM. The experiment is executed using a scenario generator (NSG version 2.1), that generates an OTCL simulation script. Then using the MATLAB software for graphical visualization of the performance parameters and implements the linear regression line with the best fit based on the value of r^2 calculations.

This paper uses the network density size as the predictor variable (x variable) and the performance metric as the response variable (y variable).

C. Simulation Setup

In this paper, the VANET routing protocols (AODV, AOMDV, and hybrid) with the simulation parameters listed in Table (I) are evaluated with a 50% concurrent network connection from the number of vehicles at different network densities (50, 100, 150, 200, 250, 300, 350, 400, and 450) of vehicles.

TABLE I. SIMULATION PARAMETERS OF NETWORK

Simulator Parameter	Values
Network Simulator	NS-2 version 2.34
Antenna Model	Antenna/ Omni Antenna
Radio-propagation model	Propagation/ Two Ray Ground
Channel type	Channel/ Wireless Channel
Interface queue type	Queue/Drop Tail/PriQueue
MAC type	Mac/802.11
Routing protocol	AODV, AOMDV, and hybrid.
Number of Vehicles	50,100,150,200,250,300,350,400, 450
No. of Connections	50% of Number of Vehicles.
Vehicles Speed	Min 10 m/s, Max 40 m/s
Simulation time	100 Seconds
Simulation area	(2*1) = 2 km^2
Packet Size	512 Packets per Second
Initial node energy	50 Joules

D. Results and discussion

The results of the performance parameters of AODV, AOMDV, and hybrid protocols are evaluated based on the variation of network density from (50,100, 150, 200, 250, 300, 350, 400, and 450) Nodes. For hybrid protocol, half the nodes use AODV and another half use the AOMDV. The performance metrics are Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average end-to-end delay (AE2ED), and Average Throughput (ATP) with the number of connections is 50% from the Network Size. The results are presented based on:

- The metric parameter vs the network size graph.
- The relative performance of protocols based on the linear regression model graph.

The results are discussed for four cases as follows in table (II):

TABLE II. SIMULATION CASES OF EXPERIMENTS

Cases	**Network size (X)**	**Parameter RRSE (Y)**	**No. of Connections**
Case 1	(50,100, 150, 200, 250, 300, 350, 400 and 450 Nodes)	PDR	50% from the Network Size (50,100, 150, 200, 250, 300, 350, 400 and 450 Nodes)
Case 2		NRL	
Case 3		AETED	
Case 4		ATP	

Case (1): The Packet Delivery Ratio (PDR):

In general, the performance is better when PDR is high. Figure (1) shows the PDR results for AODV, AOMDV, and hybrid protocols together at different network sizes. The PDR is decreased as the number of nodes are increased for all protocols. When the number of nodes is less than 200 nodes then the AODV is the best in PDR than AOMDV and hybrid protocols except at 100 nodes. However, when the number of nodes is at least is 200 nodes the hybrid protocol is the best than AODV or AOMDV separately.

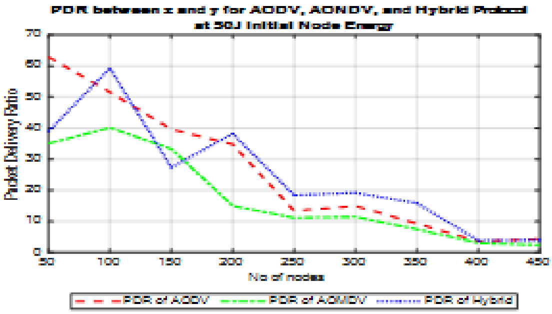

Figure 1. PDR VS network density for AODV, AOMDV, and hybrid

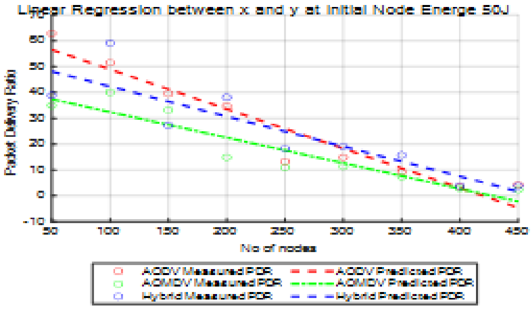

Figure 2. PDR Linear regression for AODV,AOMDV and hybrid at 50J

Figure (2) shows the scoter diagram and the linear relationship between the network density, the number of nodes as the x-axis and the PDR as the y-axis for AODV and AOMDV and hybrid protocol.

The regression coefficient (r) sign is negative, which indicates when the network density increases, the PDR decreases for AODV, AOMDV, and hybrid. AODV has $r^2 = 0.98$, which means that for one unit change in the number of nodes there is a 98% decrease in the PDR. On the other hand, AOMDV equals 0.91 and for hybrid protocol, it is 0.80.

Case (2): Normalized Routing Load (NRL):

The NRL is better when it is a low value, which indicates a better packet delivery to the destinations. The effect of variation of network density on the NRL is shown in figure (3). It is observed that the NRL of hybrid of AODV and AOMDV together is better than each separately. The NRL of AOMDV is better than AODV for all nodes less than 400 nodes except for 200 nodes the NRL of AODV is better than it. Because AOMDV generates a lower routing overhead, for that reason, the hybrid protocol is faster and more efficient than AODV or AOMDV separately.

The linear regression for NRL is presented in figure (4). For AODV, AOMDV, and the hybrid, the regression coefficient sign is positive. It tells as number of nodes, network density size increases, the NRL increases. The relationship is very strong for AODV, AOMDV, and hybrid protocol because of r^2 has 0.84, 097 and 0.88 respectively.

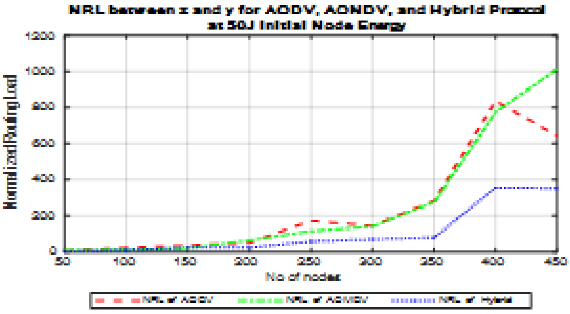

Figure 3. NRL VS network density for AODV, AOMDV, and hybrid

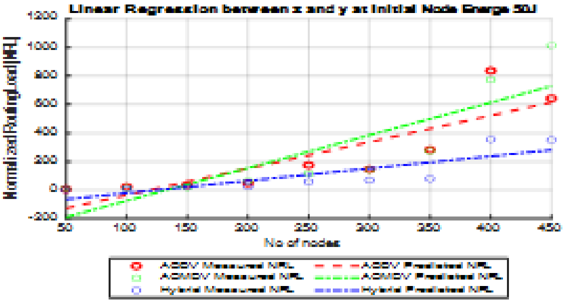

Figure 4. NRL Linear regression for AODV,AOMDV and hybrid at 50J

Case (3): Average end-to-end delay (AE2ED):

The lower values of AE2ED are better in performance than the higher values. Figure (5) presents the results for the AE2ED at a different network density. It is observed that, with all number of nodes except at 200 nodes, the AOMDV present the lowest delay than AODV and the hybrid protocol.

For a smaller network density with less than 100 nodes, the hybrid protocol is the worst one. On the other side, for a number of nodes from 200 to less than 450 nodes the AODV is the worst protocol.

The scatter graphs for the linear regression of varying the network density and AE2ED is presented in figure (6). The regression coefficient sign is positive for AODV, AOMDV and the hybrid protocol. The relationship is very strong for AODV, AOMDV, and the hybrid protocol because of r^2 has 0.84, 086 and 0.87 respectively.

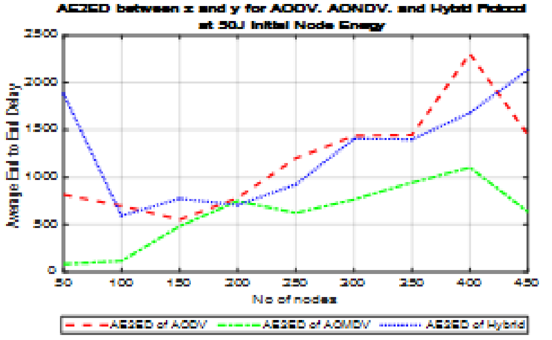

Figure 5. AE2ED Linear regression for AODV, AOMDV and hybrid at 50J

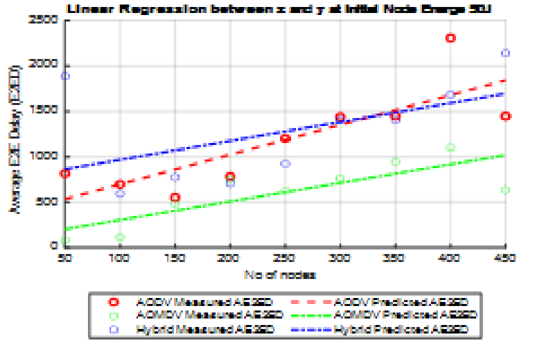

Figure 6. AE2ED Linear regression for AODV,AOMDV and hybrid at 50J

Case(4): Average Throughput (ATP):

The ATP is better when it has a higher value than others do. Figure (7) presents the results for the ATP at the different numbers of nodes. It is observed that the best ATP for the hybrid protocol when the number of nodes is greater than 150 nodes with respect to AODV and AOMDV separately. The best protocol is the hybrid for network density greater than 150 nodes while the worst one is AOMDV for all the nodes. On the other side, AODV is in the middle between AOMDV and both together except when the number of nodes are less than 100 nodes.

The scoter diagram and the linear relationship between number of nodes as x-axis and the APT as y-axis for AODV, AOMDV both together is plotted in figure (8). The relationship is very strong for AODV, AOMDV, and the hybrid protocol because of r^2 has 0.81, 083 and 0.67 respectively.

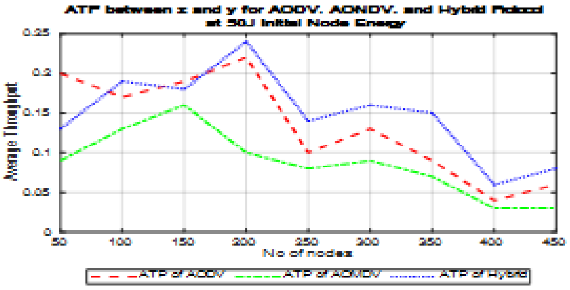

Figure 7. ATP VS network density for AODV, AOMDV, and hybrid

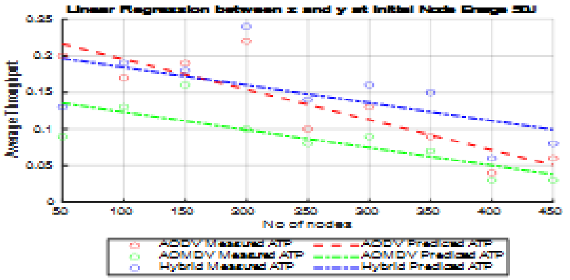

Figure 8. ATP Linear regression fo AODV,AOMDV and hybrid at 50J

5.Conclusion:

The intelligent transportation system (ITS) is an advanced application that aims to provide traffic services, especially with the growth of vehicles on the network. The researchers are driven to improve road safety by finding an efficient and fast routing protocol. In this paper, the performance metrics of packet delivery ratio (PDR), normalised routing load (NRL), average end-to-end delay (AE2ED), and average throughput (ATP) are calculated for AODV, AOMDV, and when half the nodes use AODV and the other half use AOMDV, so-called hybrid protocol at an initial node energy of 50 joules and the number of connections is 50% of the network density size, using the NS-2.34 simulator and draw the graphs using MATLAB version R2019b (9.7) to visualise the graphs.

The paper aims to find which protocol from AODV, AOMDV, or the hybrid protocol is suitable for high network density areas. In addition to the linear regression model of these protocols, for high network density with greater than 200 nodes, when the nodes use the hybrid protocol, PDR, NRL, and ATP are better than those for AODV and AOMDV are separately. While the AE2ED is better for AOMDV when the number of nodes is greater than 200 nodes.

The linear regression prediction model for PDR and ATP for AODV, AOMDV and the hybrid protocols have a negative regression coefficient, while AE2ED and NRL have a positive regression coefficient. For PDR, PDR is higher in regression for network density less than 300 nodes, and for ATP, network density is less than 150 nodes for AODV. The protocol AOMDV is better for NRL with a network density of less than 150 nodes and better for AE2ED for all nodes. For the hybrid, PDR is better for network densities greater than 300 nodes and for 150 nodes for ATP.

For PDR, when the network density is greater than 200 nodes, the PDR of AODV is better for a smaller network density of fewer than 100 nodes. The NRL is better for hybrid protocol together when network density is greater than 150 nodes; otherwise, the AOMDV protocol is better. The AOMDV is better for all nodes except around 200 nodes. The two together are better.

Future work directions will be to carry out the evaluation of these protocols with transmission range variation and speed variation using other performance parameters such as packet loss and residual energy. In addition, the effect of the distance between nodes with either AODV or AOMDV or the hybrid protocol on the same environment is also explored.

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