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Combining MPLS with Ad-hoc routing protocols for a VANET congestion alert

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ABSTRACT

In recent years, the vehicle industry has heavily invested in adding communication capabilities to exchange data among vehicles through wireless technology. This is already implemented in cars deployed in large cities around the world, such as buses and police vehicles. The Vehicular Ad Hoc Network (VANET) simplifies network deployment for data exchange. This is due to its infrastructure, which does not require a pre-setup arrangement. Vehicles on the road can form a network to exchange data dynamically and handle the routing task of the data. The only major challenge is the high speed of the vehicles, which makes the network extremely dynamic and necessitates immediate data processing before the link is destroyed due to vehicle movement. Therefore, delays in processing data are critical. The delay occurs because of the IP-based addressing mode used in the routing tables, which creates overhead. An alternative approach for sophisticated IP-lookup table routing is Multiprotocol Label Switching (MPLS). It is a promising data forwarding technique that increases the speed and controls the data exchange by using labels to forward the data. This paper proposes a concept that combines the capabilities of a VANET network connected to an MPLS-based infrastructure located on roadsides through different scenarios in a simulation environment by using the OPNET modeller 14.5 simulator, and two sorts of ad hoc routing protocols, reactive and proactive, are compared. The results showed that the proposed concept provides an improvement in performance and can be used to detect vehicle congestion and alert drivers to avoid certain roads.

KEYWORDS: VANET, MPLS, AODV, Congestion

1 INTRODUCTION

Today, communication technologies have crept into all aspects of life, including the home, workplace, and even our roads. The Vehicular Ad hoc Network (VANET) has been a kind of network that has taken great interest in the last decade. VANETs are created by the spontaneous creation of a wireless network of mobile devices in the vehicle domain using the concepts of mobile ad hoc networks (MANETs), but with different peculiarities according to the mobility model and the speed of nodes [1].

The VANET's architecture design provides a network that has several communication ways. Vehicle-to-vehicle (V2V) uses direct connections without reliance on roadside units, mainly for safety, dissemination applications, and security. vehicle-to-infrastructure (V2I) or vehicle-to-roadside units (V2R) to exchange information and data applications. Additionally, hybrid models exist for both V2R and V2V communications. This type is enabled for long-distance connections to the internet or faraway vehicles [2].

In order to consider the main parameters that affect VANET, such as mobility, security, and scalability, VANET routing protocols need to be designed accordingly, and many VANET protocols were developed to improve performance and meet vehicle application requirements. The use of routing protocols is very important for exchanging data between vehicles or during the increase in vehicle density in VANET networks.

Traditional proactive routing protocols, such as Optimized Link State Routing Protocol (OLSR), provide paths to nodes (devices) that want to transmit data whenever needed, as nodes regularly update their routing tables. The disadvantage is seen in the overhead and consumption of resources in large networks [3]. On the other hand, reactive routing protocols such as Ad-hoc On-Demand Distance Vector Routing Protocol (AODV) conduct route discovery only when it is required, and the node utilizes the flooding mechanism to broadcast a request to all nearby nodes to find a new route, and the route remains valid until the route is no longer necessary [4]. The benefit is the small size of the routing table, which contains only the details of nodes lying in the path of the destination, while the disadvantage is frequent link breakage that requires repair, which in turn increases the delay.

IP-based routing protocols cause delays and do not suit the dynamic, speedy environment of VANET, especially if used on a large scale; therefore, an alternative approach is necessary to accommodate the unique characteristics of VANET. For this purpose, a cross-layer approach that involves more than one layer in the routing process is used to reduce the latency that harms the data exchange between V2V and V2R.

Multiprotocol label switching (MPLS) is a method known as layer 2.5, and it supports both data link and network layers in the OSI model (Open Systems Interconnection Model) [5]. It is used for communication between routers to construct a label-to-label mapping. Those labels are attached to the IPv4 packets to permit the routers to send the traffic by searching for the label instead of the destination IP address. The result of forwarded packets by label switching instead of using IP switching is a faster delivery of packets and enhanced data exchange speed and scalability [6].

Road congestion is one of the issues that researchers have investigated to find a method to exchange traffic information to avoid congestion escalation on other roads. This paper proposes a congestion alert mechanism to inform vehicles on different roads in the city to avoid a specific congested road by using VANET to communicate with roadside routers using IP-based routing protocols. The router then uses MPLS to inform other routers around the city about the congestion. The roadside router initiates the alert once the number of messages received from congested road vehicles exceeds a threshold. Several simulation scenarios were designed to examine the efficiency of the proposed method in comparison with IP-based routing using different routing protocols, and the results showed an improvement in performance metrics that enhanced congestion detection alerts exchanged between roadside base stations.

2 PAPER FORMAT

In the last decade, research on VANET enhancement intensified due to advancements in design and the increase in vehicle numbers on the road. One of the areas in which researchers focused was on the routing protocols in order to enhance the performance of VANET. Several research works were studied to enhance the view on areas that were concentrated on VANET and observe the outcomes.

Some of the research works explored and compared different types of routing protocols; for example, one research work investigated VANET's routing protocols with a focus on the topological and geographical aspects that provide V2V (vehicle to vehicle) and V2R (vehicle to roadside unit) connectivity to enable intelligent transportation systems (ITS). The authors concluded that further exploration was required about the performance and services provided when applied to VANET [7]. Furthermore, with the emergence of 5G technology, it becomes evident that communication between all devices in real time is possible. V2X (Vehicle-to-Everything) communication provides the opportunity for vehicles to use all available data gathered from surrounding devices for safer and more efficient driving; this advancement encouraged researchers to explore different enhancements with VANET [8].

Other authors attempted to evaluate VANET routing protocol performance through a realistic road traffic scenario and real-world vehicle trajectory data. Compared to the realistic between three routing protocols, two types of reactive routing protocols, Ad hoc On-Demand Distance Vector (AODV) and

Dynamic source routing protocol (DSR), that work on gateway discovery algorithms, and Greedy Perimeter Stateless Routing (GPSR), that works on geographical algorithm constantly updated topology data for all VANET nodes. A comparison was made using the Simulation of Urban Mobility (SUMO) and Network Simulator Version 2 (NS-2) based on various metrics, for example, throughput, packet loss, PDR (Packet Delivery Ratio), and delay. For real-time and Transmission Control Protocol (TCP) networks, the research performance of the AODV is best considered [9].

MPLS was also explored and used to prevent packet losses due to multiple node link defects that can move at any time. Offers fast re-routing of MPLS (FRR) as a method to decrease the high packet loss coming from the failure of the links in the MANET network. The fast-re-routing mechanism depends on pre-planning and needs the establishment of a backup connection or label-switching route, which is done through the NS-3 simulator using the AODV protocol. The resulting analysis showed a lower packet loss ratio and a minimum network delay after the connection failed. Also, the authors concluded that this approach can further improve other parameters such as packet disorder, jitter, bandwidth, etc. [10].

The purpose of using MPLS in the VANET, especially with a roadside backbone (RBN), is to improve the QoS, which is presented in [5]. A method is suggested to connect V2V communication with V2I, enable MPLS, and use the AODV routing protocol. Also, using the SUMO simulator based on Java software to simulate different vehicle mobility models for urban areas allows for data to be transported to the nearest base station and afterwards transmitted via Wired RBN, which is an MPLS domain. The result showed higher reliability in terms of throughput, E2E delay, and packet loss. The main advantages of MPLS, depending on the result, are the transport and reliability of key applications, such as sound and video in VANET.

Furthermore, authors in [11] integrated both technologies (mobile IP and MPLS) in VANET and compared them with other technologies, such as V2V and V2I MPLS enabled, with the SUMO simulator tool and AODV routing protocol. The primary goal is to enhance QoS in terms of latency, packet loss, and throughput for traffic and amusement applications in metropolitan environments with a high density of roadside units (RSUs). The concluded results showed an acceptable improvement in QoS for packet loss and throughput, but the overhead of mobile IP imposed by the communications between nodes caused a delay.

Many types of solutions have been suggested to improve the quality of services in multi-hop and dynamic environments. Also, packet loss and packet delay are considered issues in the VANET network. Compared three models based on wireless backbone infrastructure: MPLS-based networks, MI-VANET (mobile infrastructure-based VANET), and multi-layer models. The comparative analysis in terms of packet loss, throughput, and E2E delay. The authors concluded that MPLS-based models are efficient and can be a low-cost solution for low cost in vehicular networks [12].

3 THE PROPOSED VENET-MPLS DESIGN MECHANISM

In urban areas, congestion problems in road traffic are considered a recurring issue. Resources are wasted during a traffic jam, such as time, fuel, and a range of other resources. It can disseminate important information about the status of the traffic via VANET networks to ensure flexibility and simple circulation.

The assumed concept in this paper is that when the vehicles in a congested subnet inform the nearby routers alongside the road, they send signals to other VANETS around the city to alert them. Once the signal arrived in other subnets, the routers informed everyone inside the road about this. The proposed mechanism concept adds a layer to the roadside base station routers that handle the IP-based VANET messages received from congested road vehicles and then use the unique MPLS label to share it with other base stations around the city. Once received by any base station, it extracts the congestion alert and broadcasts the alert to all vehicles on the other roads using VANET IP-based routing, so the overall routing concept of alert messages consists of VANET-MPLS-VANET.

Several scenarios were designed for this purpose in a simulation environment using the OPNET Modeler (14.5) to examine the functionality of the proposed concept and then measure the performance metrics for different VANET routing protocols. Several scenarios were created with a network area of 10 x 10 km and two distant subnets that are connected through roadside base stations and an MPLS backbone.

3.1 Scenario One

In this scenario, each subnet has four roadside routers and a different number of vehicles. One of the subnets is classified as a congested subnet under the name "SE" and one is an uncongested subnet under the name "SW," in which they are connected through an MPLS backbone. For both VANETs, reactive and proactive (AODV and OLSR) routing protocols have been used. Several vehicles on the congested SE road (SE18, SE8, and SE22) send alerts to base stations, as seen in Figures 1 and 2a, and the details of the backbone system of the scenario are seen in Table 1.

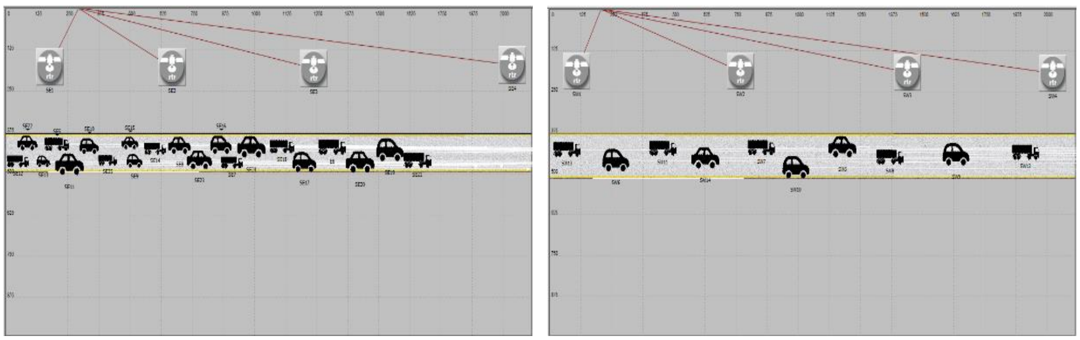

Figure 1: SE and SW Subnets

Table 1: The network component of scenario one

Network components	Quantity
LER routers	Two (LER1 and LER2)
LSR routers	Two (LSR1 and LSR2)
Ethernet16 switches	Two (Switch1 and Switch2)
100BaseT duplex links	used between the switches and LERs and also to connect the subnets to ethernet switches
PPP_Sonet_OC3 duplex links	Three responsible to attend between MPLS routers
wlan_ethernet_router	Four base stations labelled 1-4 based on subnet.
VANET_Station	21 inside congested subnet and various numbers inside other subnet

3.1.1 Compression of (VANET- traditional IP routing and VANET-MPLS)

In this case, the backbone connection between base stations was examined using MPLS vs. IP-based routing. In the MPLS case, the forwarding of packets is done based on the labels using a configured path known as the Label Switched Path (LSP). At the same time, traditional IP routing utilizes a hop-by-hop technique to forward packets depending on the destination IP address.

The goal of comparing MPLS and IP is to examine the performance metrics of both networks using AODV and OLSR routing protocols. The 802.11g wireless port connects the base stations to vehicles configured with an 11 Mbps data rate, while for the connection between base stations, the static MPLS E-LSP model is used for LSP (Label Switched Path) between MPLS routers, as seen as the blue connection in Figure 2a, from LER1 to LER2. This path is also established by the signalling protocol (LDP) in the

MPLS domain, and it is created according to the FEC setting that is assigned inside the ingress LER (LER1), and the packets follow this path in the MPLS network accordingly.

The LER1 represents the ingress router, and it maps the traffic that is going into the MPLS environment, while the LER2 is the MPLS egress router. When packets leave the network label inserted in the header of the packet by the ingress router and enter the MPLS domain, the packet is routed over LSP using Forwarding Equivalence Class (FEC). Bear in mind that on the same LSP, all packets that meet a specific FEC are forwarded through the LSRs (LSR1 and LSR2). Lastly, LER2 (the egress router) eliminates the label from the header of the packet and transmits the packet based on the IP address to the next node outside of the MPLS network.

3.1.2 Variable network simulation parameters

- Data rate: various data rates (1, 2, 6, 9, and 11 Mbps) are used for both routing to examine the performance of the network with a fixed number of vehicles and speed during a fixed simulation interval.
- Number of Vehicles: in this simulation, the density of the vehicles is examined through five experiments using an incremental number of vehicles (10, 20, 30, 40, and 50) for both AODV and OLSR protocols.
- Vehicle speed: it represents various speeds (60,70,80,90 and 100 km/h) that vehicles use to move from one location to another.

3.2 Scenario Two

This scenario compares the performance of two routing protocols, AODV and OLSR, used to deliver congestion alert messages over VANET-MPLS with an incremental number of subnets. The scenario consists of three cases in which the number of subnets (roads) is increased by one. In each case, a new subnet is added. The label for subnets (S_EAST) has 21 vehicles and two uncongested subnets, labelled (S_WEST) and (N_WEST), then in the next case another subnet is added as (N_EAST), and lastly another subnet is added as (S-South), with all added subnets containing 10 vehicles each Figure 2b shows the incremental addition of subnets for all cases.

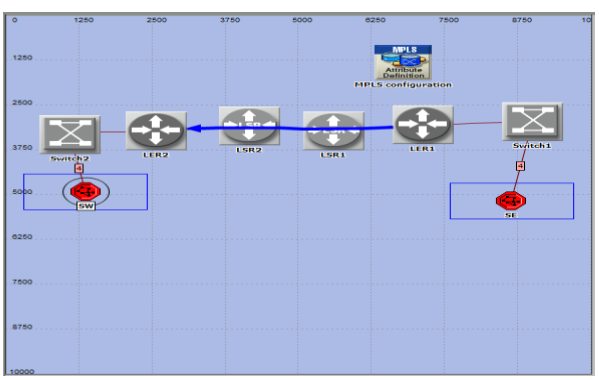

Figure 2a: The (VANET- MPLS) network setup

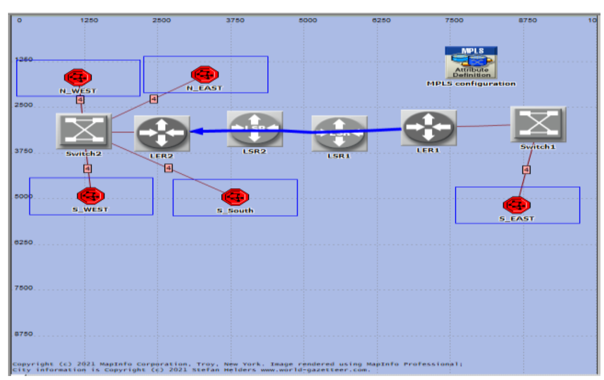

Figure 2b: scenario-2 with increased number of subnets

4 RESULTS AND ANALYSIS

This section explains the performance metrics, describes the results of each scenario separately, analyses the comparison of AODV and OLSR routing protocols, and discusses their impact on performance metrics. The OPNET Modeler 14.5 simulator has been used to collect the performance data for different scenarios.

4.1 Performance Metrics

The performance metrics used in the simulations of both scenarios consist of:

- End-to-End delay (E2E): The time it takes the packets to depart from the source until they arrive at their destination [13].
- W LAN Retransmission Attempts (packets): The overall number of retransmission attempts done by all WLAN MACs in the network until the packet is received or deleted based on the retrieval limit if it has been reached short or long. Additionally, retransmission attempts happen when packets are lost or dropped without reaching the network's destination nodes [14].
- Packet Delivery Ratio (PDR): It represents the ratio between the number of packets that are received by the destination and the number of packets that are sent by the source [15], as in eq. (1). Table 2 shows further parameter settings used for different scenarios.

$$PDR = \Sigma \frac{received\ \ packets\ at\ the\ destination}{transmitted\ packets\ \ by\ the\ source} \qquad (1)$$

Table 2: The general properties of scenario one

Parameter	Scenario one properties
Trajectory type	Mobility path with various time interval.
Distance between VANET vehicles	Within 10 meters
Data rate	Case -A, C and D (11 Mbps in each subnet) Case -B (1, 2, 6, 9, and 11 Mbps in each subnet)
Packet size (byte)	1024
Destination only flag	Enabled for AODV routing protocol
Gratitude route reply	Disabled for AODV routing protocol
always willingness	Enabled for OLSR routing protocol
Simulation duration	300 seconds

4.2 Simulation results

4.2.1 Comparing two networks (VANET- traditional IP routing) and (VANET-MPLS)

- E2E-delay (E2E): In this simulation, using MPLS shows an improvement in E2E delay of 18% in AODV and 34.5% in OLSR compared to IP-based routing. Additionally, the OLSR protocol in Figure-3a has a lower E2E- delay compared to AODV in both cases, which is because of its proactive nature, which provides routes whenever needed [16].
- WLAN Retransmission Attempts (packets): When a network link fails, the nodes attempt to retain the connection by retransmitting the packets that were lost during the communication. As a result, the growing number of retransmission packets on the network is mostly due to link failures. In both routing protocols, the traditional IP routing network has the largest number of retransmission packets compared to MPLS, as seen in Figure 3 b. (VANET-MPLS) in AODV enhances the network and reduces the value of retransmission packets by 11%. Similarly, in the OLSR protocol, it reduces packet retransmission attempts by 13%. Furthermore, in both networks (VANET-MPLS and VANET-IP),

OLSR has a lower average number of retransmission packets compared to AODV because OLSR employs the MPR selection method to find intermediary nodes between the source and destination.

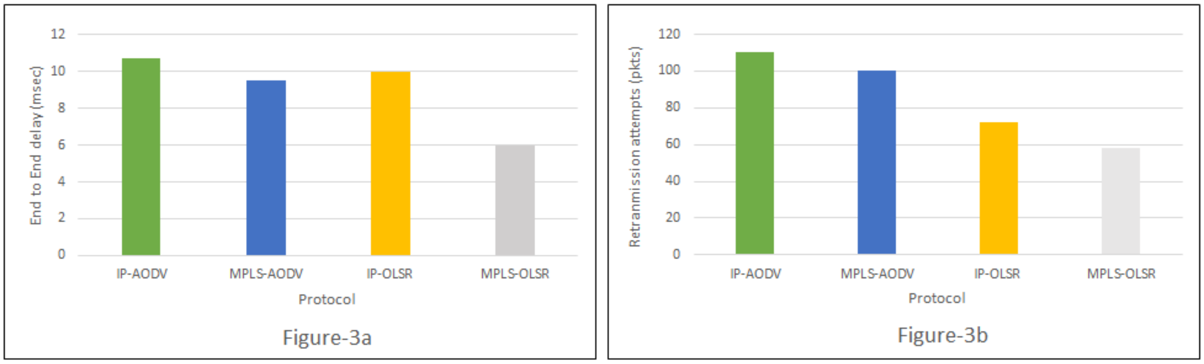

Figure 3: performance metric compression for scenario 1 (E2E delay and Retransmission attempts)

- Packet Delivery Ratio (PDR): Figure 4a shows the performance of OLSR and AODV in terms of the PDR records an average of 0.41 and 0.306 in (VANET -IP), respectively. Using MPLS increases the average packet delivery ratio for OLSR and AODV to 0.442 and 0.388, respectively. It can be observed that the AODV protocol has less PDR in (VANET- traditional IP routing) and (VANET-MPLS) compared to OLSR because AODV is an on-demand protocol, which implies that connections are established only when they are needed. Furthermore, the PDR is also affected by issues like link breaks during packet transmission [17].
- Figure 4b shows the AODV and OLSR throughput for scenario 1. AODV has a higher throughput of 77670 bits/sec compared to OLSR of 60033 bits/sec on average. This is due to the AODV dynamic in which it handles entries for active routes only. Furthermore, applying MPLS adds further enhancement to AODVs to 95432 compared to 67890 bits/sec for OLSR on average.

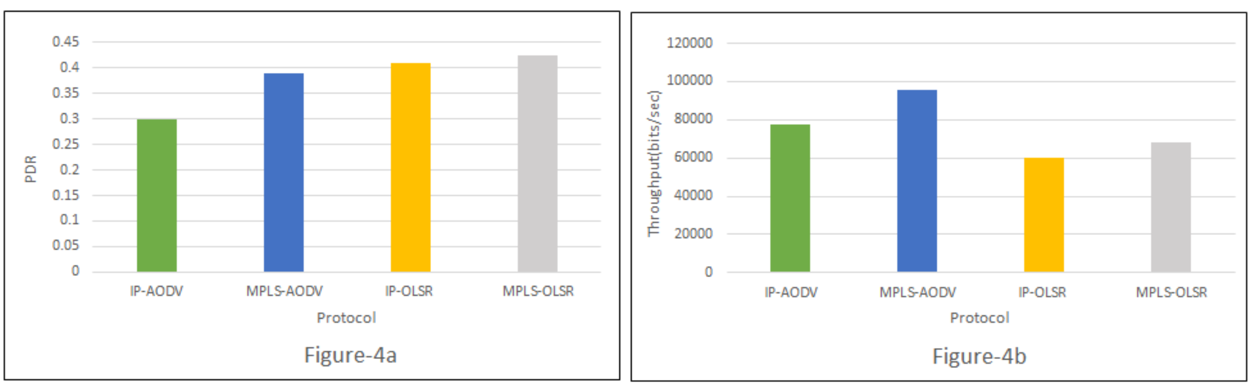

Figure 4: performance metric compression for scenario 1 (PDR and Throughput)

4.2.2 Varying data rate in VANET-MPLS

The simulation result of this scenario represents the behavior of the VANET-MPLS network with various data rates during the 300-second simulation time.

- End-to-End delay (E2E): As seen in Figure-4a, the delay gradually increases with data rate, and a sudden increase occurs after 4 Mpbs; this is due to the increase in the number of packets transmitted, which creates congestion that leads to packet collision which in return requires retransmission that leads to further delay. Furthermore, AODV has a slightly better result with an average delay of 11.2 msec compared to 12.7 msec for OLSR with 6.05 msec. This is due to the route repair feature of the AODV routing protocol that gives an advantage over OLSR, which starts a new route establishment.

- Packet Delivery Ratio (PDR): The rate of receiving data at the destination node decreases as the data rate increases due to the congestion of packets; meanwhile, as seen in the results in Figure-4b, AODV PDR shows an average of 0.4 compared to 0.362 for OLSR.

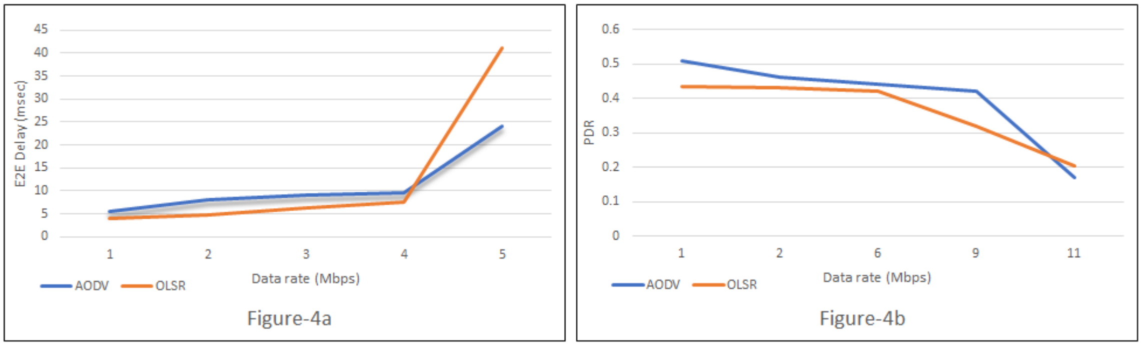

Figure 4: Performance metric compression for scenario 1 for various data rates.

4.2.3 Varying node density in VANET-MPLS

The simulation results represent the increment in the number of vehicles impacting the performance of the network.

- End-to-End delay (E2E): Simulation results in Figure-5a show an increase in delay measurements for various numbers of nodes in the two routing protocols. AODV has a lower delay of 15.4 msec compared to OLSR by 18.1 mSec on average, this is because the increase in the number of vehicles provides shorter paths to destination.
- Packet Delivery Ratio (PDR): Figure-5b shows that when the number of network vehicles grows, the PDR decreases. OLSR has a higher average of PDR than AODV when the node density expands and records about 0.14 PDR, while AODV has 0.1 on average.

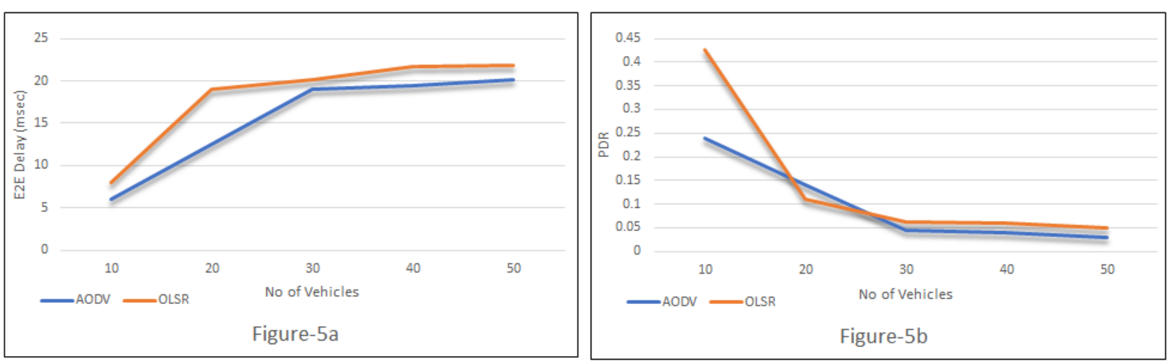

Figure 5: Performance metric compression for scenario one for various numbers of vehicles.

4.2.4 Varying node mobility in VANET-MPLS

The result of this simulation shows degradation in performance in general, which is due to the increase in mobility of the vehicles, which increases from 60- 100km/h.

- End-to-End delay (E2E): Figure 6a shows how OLSR maintains a smaller delay when it comes from variations in the mobility of nodes. At the same time, the delay of AODV increases with vehicle mobility and records an average of 14 mSec compared to 11.5 mSec for OLSR on average. This is due to various routing processes conducted in the AODV routing protocol. This is due to routing table issues that occur due to the frequency of link breakage because of vehicle mobility speed.

- Packet Delivery Ratio (PDR): Figure 6 b also shows that the average PDR for both protocols is closer, with OLSR PDR equal to 0.145 compared to 0.144 for AODV on average, as illustrated in Figure 6.

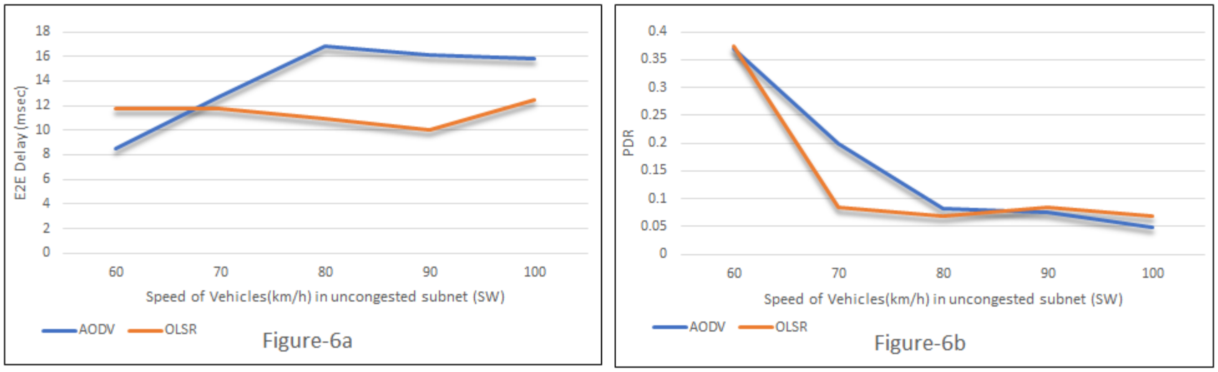

Figure 6: Performance metric compression for scenario one for various vehicle speeds.

4.3 Scenario Two

Simulations were carried out with the speed of vehicles at 80 km/h for all uncongested subnets and the remaining 10km/h for congested subnets. The scenario was simulated three times, adding a new subnet in each simulation to make a total of five subnets, as seen in Figure 2 b.

- End-to-End delay (E2E): The simulation results in Figure-7a show that an increase in the number of subnets leads to further delay for both AODV and OLSR. The latter has a lower delay of 9 mSec compared to 14 mSec for AODV on average. This is due to the stability of the OLSR routing protocol due to its proactive nature, in which routes are available all the time.
- WLAN Retransmission Attempts (packets): as seen in Figure-7b, the increase in the number of subnets leads to gradual decreases in retransmission attempts in general. AODV shows an average of 70 retransmission attempts compared to 129 in OLSR. This is due to AODV's routing table, which keeps track of different paths.

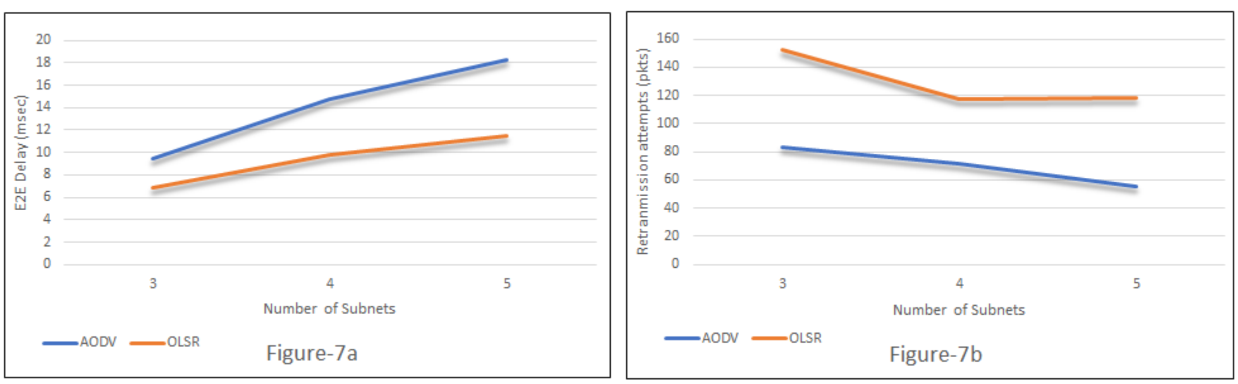

Figure 7: End to End delay and Retransmission attempts - Scenario two.

- Packet Delivery Ratio (PDR): because of lower retransmission attempts, AODV manages to have a better PDR of 0.13 while OLSR has 0.03 on average as illustrated in Figure 8.

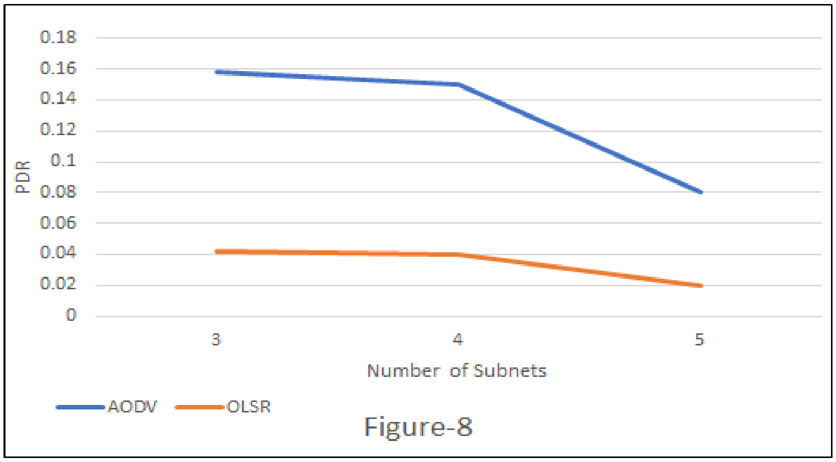

Figure 8: PDR - Scenario two.

5 CONCLUSION

The overall conclusion of the implementation of the proposed mechanism shows that the integration of VANET-MPLS as the backbone of various VANETs enhances performance compared with VANET-traditional IP routing, and performance varies based on the routing protocol used.

Proactive routing protocols (OLSR) show better performance in terms of PDR and delay compared to reactive routing protocols (AODV) at various speeds, which can be a factor on roads with multi speed lanes. On the other hand, AODV performs better and shows stability when the scalability of the network varies. This is an indication that different types of protocols can be used on different VANETs based on the nature of the road. The improvement in performance can be observed and implemented using several trials in each VANET. This mechanism can be improved further by modifying the routing protocols to detect congestion rather than just distributing the alert by permitting the vehicles to detect the congestion and then using this mechanism by sending an alert to the roadside base stations. Father improvement consists of exchanging this information with the user's smartphone devices and designing an app that plans the route based on congestion rather than the shortest path.

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