Interference-aware Multipath Video Streaming for Quality Delivery in Vehicular Environments

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Abstract— **The multipath transmission has been regarded as the most suitable transmission concept for high data rate packets such as video data. The video packets are split into different frames for transmission via different paths. The transmission is carried out concurrently, thus one path may interfere with another path. Considering the multipath video streaming, the issue of route coupling effect has been one of the major challenges of multipath transmission, especially in a vehicular network. The route coupling causes wireless contention and video packet collision. In this regard, this paper proposes a multipath video transmission protocol that considers path's route coupling effect in order to minimize interference between multiple paths. The route coupling minimization strategy is based on selecting two dispersed vehicles based on an angle by the source vehicle within it network coverage. The link and node disjoint concepts are incorporated into the dispersed vehicle selection. In order to further ascertain vehicles with zero or low interference, the link signal power and bandwidth capability have been employed. Concerning the dispersed vehicle selection and link signal power, mathematical derivations are presented with their numerical analysis. In addition, performance evaluation of the proposed scheme has been performed based on the simulation carried out. The various results obtained from the simulation are benchmarked with the baseline research works. The results demonstrate that the proposed Interference-aware Multipath Solution with Link and Node Disjoint (IMSLND) protocol for video streaming offers higher video quality when compared to the baseline research works.**

Index Terms— **Video streaming, multipath, vehicular network, interference, multimedia, Route coupling, VANETs.**

I. INTRODUCTION

RECENTLY the advancement in vehicular communication improves on on-road safety and infotainment services. The Intelligent Transportation Systems (ITS) are designed systems that minimize on-road accident and to enhances mechanisms for emergency response. This had led to several contributions by both industry and researchers to improve on protocols and mechanism that enhance on-road safety and infotainment services.

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In most of the recent contributions, text a message-based and beacon signal-based data are the most considered. However, the nature of the data does not provide a more realistic information on on-road accident and infotainment [1]. Therefore, streaming of video for on-road safety and infotainment has been considered in some research work [2-6]. Video data provides information that is more appealing, comprehensive, interactive and understanding to vehicle users [7]. The On-Board-Unit including Dedicate Short Range Communications (DSRC) device and RoadSide Units (RSUs) supports video streaming among vehicles. The streaming video can be related to a pedestrian crossing the road or accident occurrence ahead on the road. For the infotainment, advertisement of on-road grocery shops and gas stations can be displayed on OBU of users' vehicle. The video streaming in vehicular communication could be Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I). V2V is the communication between vehicles, which is facilitated by the OBU. Meanwhile, V2I is the communication between the vehicle and on-road device aided by RSUs. Thus, the video streaming is an important aspect of vehicular communication which improves users' onboard experience.

Video streaming in vehicular environment encounters several challenges due to the high data rate of video packets, the dynamic topology of VANETs and constrained resources. The challenges increase when trying to achieve high-quality video streaming due to a large amount of video data. considering the aforementioned challenges, we propose a protocol based on geographical routing that is capable of achieving high-quality video streaming in a vehicular network. Protocols including Forward Error Correction (FEC) and multipath solutions have been employed. Both the FEC and multipath solutions are often cross-layer based approach. Many research works that are based on FEC techniques generates duplicate packets during transmission, this lead to redundant packets and large bandwidth consumption [8-13]. In recent research work, which is based on multipath video streaming [7, 14-19]. It is an approach, which is based on partitioning video frames in order to transmit it through multiple paths (See Fig. 1). This approach minimizes the high data rate issues in video transmission [20]. Even though, in the multiple paths formation, the signal coverage of the nodes in different paths are not considered. Hence, this may lead to contention, collision, and congestion of video packets, which in turn causes video packet loss. The loss of the video packets affects the quality of the video streaming. Therefore, in order to have a quality video streaming, the signal coverage of nodes in the multipath and most suitable routing protocol must be taken into consideration during paths formation. Thus, the interference in multiple paths will be avoided or minimized.

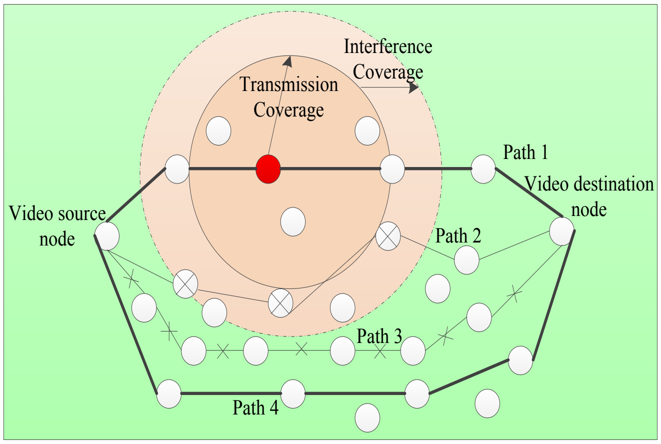


Fig. 1. The Multipath Video Streaming Scenario

Further, one of the most suitable routing protocol for vehicular communication is geographic-based routing protocol [21, 22]. It is based on the exploitation of a geographical position of a vehicle for making routing decision [23, 24]. The routing decisions are often based on parameters such as direction speed and, direction and/or static forwarding region [25-28]. Several research studies have focused on direction and distance such as Mobility-Aware which is an improvement on Greedy Forwarding protocol (MAGF) [29], forwarding decision based on Directional Greedy Routing (DGR) [30] and data forwarding based on Greedy Stateless Perimeter Routing considering Motion Vector (GSPR-MV) [31]. Some techniques which are based on the static geographic region have also been suggested including Segment of vehicle node, quality of Link and Degree of connectivity based Geographic DIstance Routing (SLDGDIR) [26] and Voronoi Diagram-based Geographic Distance Routing (V-GEDIR) [25]. Therefore, in our proposed protocol a fixed forwarding region with greedy forwarding approach is considered based on multipath video transmission.

Therefore, the article proposes a multipath video transmission protocol that considers path's route coupling effect in order to minimize interference between multiple paths. Precisely, the contributions in this article are highlighted as follows.

1) The route coupling minimization strategy designed and developed based on selection of two dispersed vehicles considering angle of separation by the source vehicle within it network coverage. The link and node disjoint concept is also incorporated for the dispersed vehicle selection.
2) In order to further ascertain vehicles with zero or minimal interference, the link signal power and bandwidth capability have been employed.
3) Concerning the dispersed vehicle selection and link signal power, mathematical derivations are presented with their numerical analysis.
4) In addition, performance evaluation of the proposed scheme has been performed based on the simulation carried out. The various results obtained from the simulation are benchmarked with the baseline research works.

Consequently, related questions that are aimed to be answered in this paper are as follows.

1) How to select two dispersed vehicles within the network coverage of a source vehicle that enables multiple transmissions with zero or minimal interference, which is due to route coupling?
2) How to form a multipath transmission that is link and node disjointed in order to minimize route coupling?
3) How to estimate the link signal power and bandwidth capability of vehicle's link in order to determine the quality of the link for video streaming in multipath vehicular network?
4) How to mathematically formulate the dispersion of the vehicles, the link signal power and bandwidth capability of the next forwarding vehicle's link?

The remaining parts of the paper are structured as follows. In section 2, we present a comprehensive review of related literature. Section 3, suggests our proposed mathematical model and algorithms. Section 4, presents the simulation results and their analysis, and finally, section 5 concludes the paper.

II. Related Work

In this section, a qualitative review of video streaming in vehicular environments is presented focusing on MAC and coding oriented video streaming. Section 2.1 and 2.2 discusses the MAC oriented and coding oriented video streaming respectively.

A. MAC Oriented Video Streaming

These approaches are based on link layer technology, the use of MAC layer in network optimization offers significant benefits. The layer is usually adjusted to modify frame sizes considering physical rules in order to attain an optimal balance between the higher delay of smaller frames and the potential distortion of losing larger video frames [32]. At the MAC layer, parameters are manipulated including retransmission in order to achieve robust and qualitative video transmission [33]. The FEC approach performs recovery and correction of the loss and damaged video packets during video transmission. However, FEC adds some redundant video packets in order to compensate the loss video packet, this leads to increase in bandwidth utilization of the network, hence creating another challenge. Asefi, et al. [34] suggested an adaptation scheme that employs multi-objective optimization structure, which concurrently reduces the likelihood of start-up delay and playback freeze of a streaming video at the destination vehicle. The start-up delay and playback freeze are reduced by turning the MAC retransmission limit in relation to channel delay packet transmission rate. However, delay due to packet loss has not been adequately considered. WAVE-based Hybrid Co-ordination Function (W-HCF) employs the controlled access capabilities instead of the basic contention-based access of the IEEE 802.11p. Also, it uses vehicle location information and coordination among WAVE providers in order to enhance the performance of delay constrained and loss-aware infotainment applications [35].

Further, a selective Rebroadcast mechanism for Video streaming over VANETs (ReViV) is proposed to relieve overloaded channels and assist in delivering video content in sparse network settings [36]. The mechanism chooses a fewer subset of rebroadcasting vehicles so as to reduce interference and attain higher video quality. Error recovery video streaming protocol that uses multi-channel to address packet is suggested [37]. The multi-channel is categorized into the reliable and non-reliable channel. However, channel contention has not been considered. Bucciol, et al. [11], suggested a solution, which is based on FEC and Interleaving Real-time Optimization (FIRO) approach to improve video streaming quality. However, in the MAC and FEC approaches, the challenges of the high data rate of the video data have not been adequately considered. Further, the issue of interference in MAC layer based on route coupling effect in multipath transmission has not been considered in previous work.

The overlay approach for video streaming is based on creating a replicate of the real network for faster video packet forwarding from source to destination. The forwarding vehicles are considered as the relay vehicles. The relay vehicles are selected along the path of the destination vehicle. In Hsieh and Wang [38], a robust and dynamic overlay multicast for multimedia streaming in vehicular communication has been suggested. The idea is based on handling non-grouped and non-cooperating vehicles in communication. Another approach is based on probabilistic replica placement approach for video streaming in the vehicular delay-tolerant network [39]. An overlay based on clustering scheme for Mobile-IP system has been proposed to tackle the frequent interruption and dissemination of invalid video fragments. The clustering strategy is based on grouping vehicle nodes that have the same moving characteristics and video supply requirements. The clustered nodes have the ability to learn and take a decision based on deploy-ability of a stored video [40]. A flexible cooperative streaming system over a cooperative vehicle fleet considering mobile bandwidth aggregation strategy has been proposed [41]. The study addresses the issues in K-hop cooperative streaming. In Rezende, et al. [14], a solution that employs reactive and scalable unicast has been presented to address the stringent requirement of video streaming in vehicular communication. However, route coupling effect in overlay approaches for video streaming.

However, the above discussion focusses more on the ability to select a vehicle node from replicated nodes in the overlay. Meanwhile, due to the dynamic nature of vehicular network frequent update of the overlay structure causes high communication overhead and can also lead to high energy consumption. In addition, the high data rate of video data is not considered in the overlay transmission, hence congestion in the network might occur which in turn lead to less video quality.

B. Coding Oriented Video Streaming

It is an approach that is center on the integrating video compression techniques with the best node and route selection techniques. This technique is designed to guarantee optimal video streaming quality. Both the video compression by partitioning and route selection and, formation for video streaming must consider Quality of Service (QoS) of the video based on standard and user perception. In generality, both the stringent requirements of the video streaming and VANETs limitations need to be considered to achieve qualitative video streaming delivery. The QoS/QoE based approach considers major QoS factors including delay, jitter, packet loss and efficient bandwidth utilization in the video coding and video transmission. In QoS/QoE approach, the target is often to derive peak result that will be acceptable to users of the streamed video. A Seamless quality-driven multi-hop data delivery scheme for video streaming in urban VANETs settings [42]. It incorporates network layer scheme for seamless delivery of video stream packets in VANETs settings. The routing scheme considers quality-driven parameters in order to deliver video streams from a dedicated network to a fixed destination through multi-hop communication.

A QoE-driven user-centric video-on-demand service in urban multi-homed P2P-based vehicular networks is suggested to provide a new service to achieve better QoE. Better QoE can be achieved by considering bandwidth issues [43]. In these services, vehicles create a lower layer VANETs through wireless access in vehicular environment interfaces. It generates an upper layer P2P chord overlay on top of the cellular network. In another approach, a QoE-centric coding and routing are employed to achieve better path selection by considering mean opinion score for QoE [44]. This approach is handled in four different categories including choosing of path and control packet, followed by event activation topology control packets and, banned links, and then estimation of packet loss and mean loss burst size. Further, a QoE-driven and link-quality receiver–based transmission is proposed for improving the quality of video while considering VANETs challenging environment [45]. In addition, a geographical receiver-based beaconless strategy is proposed as a solution for transmitting video streams in VANETs. However, this approach lacks the ability to segment the video high data rate and create load balancing in the network.

The multipath coding is an approach, which forwards sub-streams through different paths from sender vehicle to the receiver vehicle. Multipath coding-centric routing considers the compression of video while at the same time chooses most suitable and reliable paths for video stream forwarding. In multipath video scheme, video streaming flow is partitioned into distinct paths during transmission. It reduces the high video data rate, by achieving load balancing during video transmission. Multipath video streaming mainly focusses on path selection algorithm. It usually employs link/node disjoint approaches for efficient routing of video streams. The multipath supports attainment of QoS in the following ways including fault tolerance, load balancing and, bandwidth and delay aggregation. Another of its kind is multisource video transmission.

A Multipath Video Streaming solution for vehicular networks with Link disjoint and Node-disjoint (MSLND) is suggested to address FEC issues of video transmission in VANETs [7]. MSLND ensures retransmission, rather than the FEC. In addition, a multipath solution centered on the disjoint algorithm is also suggested to decrease the interference and contention, leading to an acceptable delay and a higher transmission rate. In this, inter-frames are transmitted through the UDP protocol while only I-frames are transmitted through the TCP protocol. To enhance the delay of TCP transmissions, an ETX-TCP algorithm is integrated to select the best and suitable paths for TCP transmission. However, despite its strength in retransmission of video streaming, the solution assumes that once there are link and node disjoint strategy in the multipath selection, then interference is avoided, this is not always true because nodes having interference between each order can be selected as node disjoint or link disjoint. Hence, an adequate solution that considers the vehicle position and estimates the level of the dispersed vehicle in order to minimize route coupling is required. In another study, a Location-centric multipath approach for streaming video over VANETs (LIAITHON) has been proposed to avoid route coupling effects [46]. The approach is centered on location parameters to select the best multiple paths for video stream forwarding. Further, it uses forwarding zone scheme for reducing collision and congestion problem. The approach used is based on calculating the degree of closeness of vehicle node in order minimize the route coupling effect. However, the vehicle is very dynamic in nature, hence they change position. Therefore, a more dynamic solution for minimizing route coupling, which minimizes interference need to be explored.

A multiple path solutions with error correction for video streaming over VANETs (LIAITHON+) is presented. The aim is to reduce collision and packet loss in high data rate networks [16]. LIAITHON+ employs 3 multiple paths approach to distribute the high data rate traffic into a set of paths. However, the forwarding strategy considered is not realistic for multiple path selections since the angular geometry is less the 45 degrees, most of the nodes at this range of angle normally interfered. De Felice, et al. [18] suggested a Distributed Beaconless Dissemination (DBD) routing protocol for pre-recorded video Data transmission over VANETs. It is an integrated framework that handles QoE of video services and routing protocol. DBD, further advances the performance of IEEE 802.11p/WAVE MAC layer, by resolving the spurious forwarding problem. Li, et al. [47] proposed a joint coding/routing optimization using Distributed Video Coding (DVC) and network coding (NC). The optimization is between video quality and network lifetime, which is centered on the information theory of wireless visual sensor network. Similarly, Zou, et al. [48] suggested a priority-based flow optimization in multipath and network coding based routing. Further, a Field-based Anycast Routing (FAR) routing for pre-recorded video, it centered on rapid multipath routing dynamics of an electrostatic potential field model based on Poisson's equation [19].

An analysis of the probabilistic multipath transmission of video streaming in the multi-radio wireless network has been presented [49]. A Probability Generation Function (PGF) is generated to assess the delay metrics, such that the least channel data rate to support a video sub-stream is obtained. Further [50], proposed a multi-path provisioning strategies considering cloud assisted scalable coding video streaming with QoS requirements. The strategies improve the performance of Scalable Video Coding (SVC). Also, a multipath strategy based on network proxy for video streaming has been proposed for vehicular communication [51]. The multipath concept employs concurrent transmission, which leads to interference due to route coupling effect. Some solutions have been proposed as mentioned in the literature but are not adequate. Hence, there is need to design and develop a multipath video transmission that considers the route coupling effect in order to minimize interference. The next is Section 3, which presents and discuss the proposed protocol.

III. Interference-aware Multipath video Streaming

The design and development of the interference-aware multipath video streaming protocol considering vehicle separation, link and node disjoint, and link signal power with bandwidth capability. The multipath network model is explained in Section 3.1.

A. *Multipath Network Model*

A vehicular communication is created by a set of N nodes (vehicles) where $N = 1, \dots, n$ and each vehicle are equipped with a single radio interface. The channels available in the network is denoted as C, where $C = 1, \dots, c$ and C_{Max} is the highest bandwidth of each channel. The IEEE 802.11p/WAVE protocol provides 1–4 *Mbps for Japan*, 250 Kbps for Europe and 3–27 *Mbps* for the USA. All nodes are assumed to be dynamic with varying speed. Further, nodes operate with different transmission power thus, having creating different transmission coverage. Therefore, a link l between two nodes is active if and only if, it is functioning on a single channel. The link $l_1$is interfered if there exists a certain coverage area of collision domain where another link l_2 lies in the same channel assigned to l_1. The interfered area is a shared physical coverage area of the transmission region of sender and receiver.

Considering connectivity, a graph G consist of Points and Edges(P, E). The elements of P are called nodes and elements of E are the connecting links between points of the graph. We consider vehicular network topology as a dynamic graph structure. Let G be a graph with a set of paths M. In general, a path in a graph constitute of series of distinct points p that is, set of nodes $p_1, p_2, p_3, \dots, p_k \ni p_i p_{i+1}$ with an edge E, which is the link between two different points $\forall i = 1, \dots, k-1$. The length l of a single path is the sum of all edges in the path. Hence, we infer that the angle θ between the selected multiple paths is inversely proportional to the interference of the coverage area of each point in the multiple paths M.

$$M_\theta \propto {}^{1}/_{I_C} \tag{1}$$

Therefore, if the angle θ is assumed and calculated before transmitting a video stream through the selected paths considering line of direction of relaying node. Hence, interference between multiple paths would be avoided and qualitative video streaming delivery would be achieved. The significant challenges of video streaming in vehicular communication is how to transmit video data with fewest video frame loss and minimum transmission delay. Due to the aforementioned challenges, a multipath video transmission is employed to achieve qualitative video streaming. The video frames are split into different paths in order to achieve fewer frame loss and minimum transmission delay. In most of the existing studies, video streaming using multipath mainly emphasizes on path selection algorithm without considering the nature of data transmitted. There is need to extensively consider the nature of video data transmitted in a one part and the type of protocol to transmit distinct video data. In this work, we have developed and designed a two paths video streaming scheme by splitting video stream into two distinct flows namely, reference-frame and neighbor-frame. The routing protocol considered is geographical routing protocol, which does not incur high network overhead when compared to M-AODV.

Considering the MPEG compression standard, video frames are categorized and defined as I-frames, P-frames, and B-frames (see Fig. 2). I-frames normally contains and encoded with important information of an entire frame. It can be encoded self-reliant without reference frame to retrieve frames of the video streaming. P-frames are decoded by considering either I-frame or P-frame, which need to be decoded with the reference frame of the video. Meanwhile, B-frames relies on both previous and the next frame following the I-frame or P-frame. Consequently, both P-frames and B-frames are dependent frames based on reference frames.

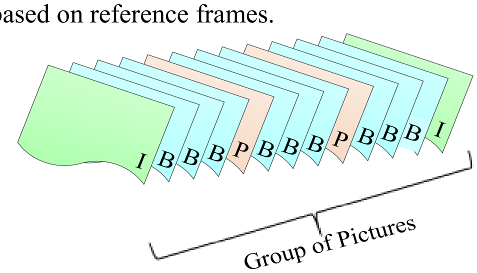


Fig. 2. Representation of MPEG video frames format.

A Group of Picture (GOP) is a combination of I-frames, P-frames, and B-frames (see Fig. 2). The I-frame is usually the indirect and direct reference frame of the P-frames and B-frames in the GOP. P-frames can also serve as a reference frame or predicted frame based on the other reference frame. If the source of the prediction is traced, an I-frame will be reached which does not depend on any reference frame. Thus, whenever an I-frame is lost or damaged, the entire GOP might be lost or damaged. Nevertheless, once transmission of I-frame is guaranteed, the quality of the entire GOP can be enhanced.

In order to maintain the quality of video at the period of transmission, priority level needs to be assigned based on the importance of the type of video data. For example, the I-frame is essential in predicting both P-frames and B-frames, therefore I-frames would have a higher priority on accessing and utilizing network resources. While P-frames and B-frames will have lesser priority in accessing and utilizing the same network resources. In this study, we partitioned the video streaming transmission into two namely, reference-frames, which represent I-frames, and neighbor-frames, which represents both P-frames and B-frames. Reference-frames and neighbor-frames are transmitted on primary and secondary paths respectively, which is based geographical routing protocol (greedy routing). Hence, the primary path has higher priority because of the I-frame compared to the secondary path for P-frames and B-frames.

Since the aim is to minimize interference due route coupling in multipath setup. There is need to estimate interference based on some parameters in the next hop vehicle of the multipath, the following parameters are considered for avoiding route interference including i) angle between the two first forwarding vehicles, which are neighbors to the source vehicle and ii) the link quality. The link quality is measured considering link signal power, bandwidth capacity (BC), packet error rate and the signal to noise ratio of the link. The parameters have been assigned with same weight function since every parameter is important for achieving qualitative link. The sum of the total weight score is one. The weight associated with each parameter is represented as follows.

$$Weight\ function = \begin{cases} 0.2 \rightarrow & Dispersed\ Angle \\ 0.2 \rightarrow & PER \\ 0.2 \rightarrow & SNR \\ 0.2 \rightarrow & BC \\ 0.2 \rightarrow & LSP \end{cases}$$

B. Interference in Multipath Video Streaming

The interference level of nodes in a multipath setup can be symmetrically reduced if the angle between the corresponding two nodes can be widened such that interference coverage of each node does not overlap with one another. In order to mathematically formulate the concept of the angle. We consider a line with a distinct endpoint $\overrightarrow{P_1P_2}$ where P_1 serve as a source vehicle node SVN and P_2 is the intermediary node (relay node). Since we are considering a two paths transmission, we consider another line P_3 connecting from P_1 that is $\overrightarrow{P_1P_3}$, hence, an angle is formed between two lines with the same endpoint which is calculated in degree and is named angle of the multipath (vertex), that is $\angle P_2P_1P_3$ (see Fig. 3). In multipath video transmission, the angle between the SVN and the two relay nodes from the corresponding two paths need to be considered.

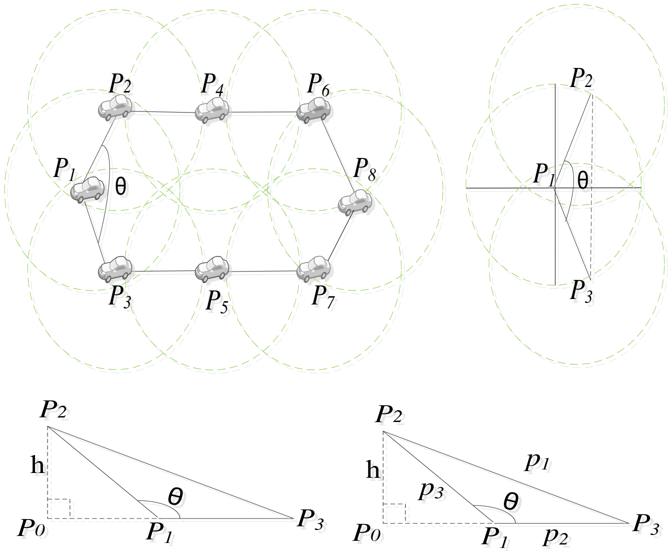


Fig. 3. Vehicular Communication Scenario Forms an Obtuse Triangle

The angle between the SVN and the two relay nodes of the selected paths is proportional to the interference coverage area of each node in the two paths. The suitable separating angle between P_1 and P_2, P_3 is an obtuse angle, since $\angle P_2P_1P_3 > 90°$ and $\angle P_2P_1P_3 < 180°$ which has the ability of reducing interference in the multipath communication.

First, let find the area of the obtuse triangle considering $\overrightarrow{P_1P_3}$ as the base of the triangle (see Eq. 2).

$$\text{Area of } P_1P_2P_3 = [P_0P_2P_3] - [P_0P_2P_1] \tag{2}$$

Where breadth of the obtuse triangle is $P_1P_3 = b$. Therefore, we deduced that area of the triangle is expressed as in Eq. 3:

$$O_{area} = P_1P_2P_3 = {}^{1}\!/_{2}\, h \times b \tag{3}$$

To estimate an angle of the multipath video packet forwarding, we need to calculate the obtuse angle where $90° > \theta < 180°$. Using cosine rule, an obtuse triangle with side dimensions $p_1p_2p_3$ can be used to calculate the multipath suitable angle, we consider θ for angle P_1, which is opposite side p_1 as follows:

$$\cos\theta = \frac{p_2^2+p_3^2-p_1^2}{2p_2p_3}$$

$$\theta = Cos^{-1}\left(\frac{p_2^2+p_3^2-p_1^2}{2p_2p_3}\right) \tag{4}$$

An angle is said to be obtuse, if and only if $\cos\theta < 0$. Hence, an obtuse triangle fulfils $p_2^2 + p_3^2 < p_1, p_3^2 + p_1^2 < p_2, and\ p_1^2 + p_2^2 < p_3$.

C. Probabilistic Model for Video Streaming

In this section, the circular transmission coverage area of the vehicle node is considered. A SVN P_1 is assumed to be at the center point of diameter of the circular coverage area with two other vehicle nodes P_2P_3, which they serve as relay nodes. They also form an obtuse angle with P_1 in order to reduce interference while creating two paths transmission for video streaming. The existence of three vehicle nodes that forms an obtuse triangle in the coverage area relies on obtuse angle θ, the vehicle node density λ and the transmission coverage, which are the two Radii $R_{p_2}^{p^3}$. The aim is to investigate the impact of parameters θ, λ and $R_{p_2}^{p^3}$ on the probability of finding at least two vehicles nodes, which forms an obtuse triangle. In order to achieve an obtuse triangle, a range of θ values is given as $90° > \theta < 180°$ until two vehicle nodes are found. The vehicle nodes are navigating in a two dimensional network region and presence of two vehicles in the network region strictly follows Poisson Distribution Function (PDF) considering vehicle node density λ. Considering the average density of vehicle nodes in a network coverage, the frequency of vehicle nodes available to form an obtuse angle is calculated by employing Poisson distribution. In addition, each vehicle node is independent and vehicle nodes are selected to serve as a relay node, which are chosen at random considering obtuse angle requirement.

Several research works have been conducted in order to minimize interference in data packet transmission in vehicular communication. However, few studies of multipath video data transmission have focused on interference in the routing process. The studies in Wang, et al. [52] and Schmidt, et al. [53] are basically on using received signal strength as the estimating factor to measure interference level of a link, which is not adequate to have qualitative video streaming transmission due to dynamic nature of VANET nodes. Therefore, we use a geometric angle estimation, which can assist in minimizing interference in a multipath video streaming transmission. The investigation deduced that large dispersion of angle θ that is $90° > \theta < 180°$ connected to the two paths reduces multipath interference. In addition, if the density of vehicles is high, there is need for smaller transmission coverage in order to do away with interference, which leads video data collision. Hence, we consider a value of radius $(200\ m)$ for the coverage area in this study.

Let assume Y represents the random variable which is the frequency of vehicle nodes that can form an obtuse triangle, then the probability of the availability of g vehicle nodes that forms an obtuse triangle area in a Non-Shadowing Setting (NSS) $P_{O_{area}}^{NSS}(Y = g)$ is calculated as shown in Eq. (5):

$$P_{O_{area}}^{NSS}(Y = g) = \frac{(\lambda \times O_{area})^g \times e^{-(\lambda \times O_{area})}}{g!} \tag{5}$$

By substituting O_{area} given in Eq. (3), then we have Equation (6):

$$P_{O_{area}}^{NSS}(Y = g) = \frac{[\lambda\left(\frac{1}{2}h(b)\right)]^g}{g!} \times e^{-\lambda\left(\frac{1}{2}h(b)\right)} \tag{6}$$

If we substitute $g = 0$, probability $P_{O_{area}}^{NSS}(Y = 0)$ of no vehicle available in the obtuse triangle area considering NSS, is expressed in Eq. (7) as follows:

$$P_{O_{area}}^{NSS}(Y = 0) = e^{-\lambda\left(\frac{1}{2}h(b)\right)} \tag{7}$$

The probability $P_{Oarea}^{NSS}(Y=1)$ of the presence of at least one vehicle node in the obtuse triangle area considering NSS is presented as follows in Eq. (8):

$$P_{Oarea}^{NSS}(Y=1) = 1 - e^{-\lambda\left(\frac{1}{2}h(b)\right)} \quad (8)$$

D. Impact of Shadowing on Video Transmission

To achieve a more realistic probabilistic analysis of the presence of more than one vehicle in an obtuse triangle area, shadowing settings must be considered. Shadowing is caused due to obstruction of huge vehicles, buildings, and other physical objects. These lead to non-circular transmission coverage. Therefore, non-circular transmission coverage is employed for integrating shadowing model considering obtuse triangle area. Transmission coverage is usually varied in terms of direction due to the impact of shadowing on the received signal power [54]. The received signal power is expressed as in Eq. (9):

$$PS_r = PS_t\left\{10\log_{10}K - 10\,\omega\log_{10}\frac{d}{d_0} - \tau\right\} \quad (9)$$

Constant K represents channel attenuation and antenna characteristics, path loss exponent is represented as ω. Distance between nodes and reference distance for nodes' antenna are denoted as d and d_0 respectively. Where τ is the Gaussian non-centralized random variable considered.

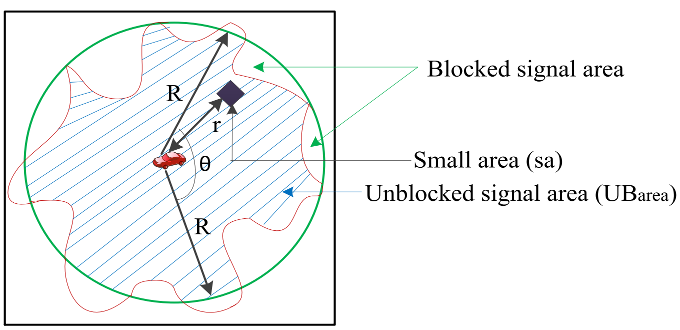


Fig. 4. Effect of Shadowing Circular Transmission Coverage

$$UB_{area} = \frac{1}{\pi R^2}\int_0^{2\pi}\int_0^{R} P(PS_r(r) \geq PS_{min})\; rdr\; d\theta \quad (10)$$

$PS_r(r)$ is the received signal power in sa at certain distance r. We employ Log-normal distribution, because it precisely and accurately models the difference in received signal power, which is due to shadowing [55]. Hence, by employing Log-normal distribution, the probability of PS_r at r being higher than PS_{min}, which is represented as $P(PS_r(r) \geq PS_{min})$ and is further mathematically modeled as in Eq. (11)

$$P(PS_r(r) \geq PS_{min}) = \varphi \times \left(\frac{PS_{min} - (PS_t + 10\log_{10}K - 10\omega\log_{10}({}^{r}/_{d_0}))}{\sigma_\tau}\right) \quad (11)$$

Where, $\varphi(t) = \int_t^{\infty}\frac{1}{\sqrt{2\pi}}e^{-\frac{y^2}{2}}dy$, and σ_τ is the variance of τ.

By considering Eq. (11), UB_{area} can be expressed as given in Eq. (12):

$$UB_{area} = \frac{2}{R^2}\int_0^{R}\varphi\left(y + z\log\frac{r}{R}\right) r\, dr \quad (12)$$

Where PS_r^{mean} denotes the average received signal power at certain distance R, $z = \frac{10\omega\log_{10}(e)}{\sigma_\tau}$ and $y = \frac{PS_{min} - PS_r^{mean}(R)}{\sigma_\tau}$. Eq. (12) is further simplified as in equation (13):

$$UB_{area} = \varphi(y) + e^{\left(\frac{2-2yz}{z^2}\right)\times\varphi\left(\frac{2-2yz}{z}\right)} \quad (13)$$

Further, we assume that $PS_r^{mean}(R) = PS_{min}$, Eq. (13) can be further simplified as in Eq. (14):

$$UB_{area} = \frac{1}{2} + e^{\frac{2}{z}\left(\frac{1}{z}\times\varphi\right)} \quad (14)$$

Eq. 11 is modified by introducing UB_{area} to find the probability of availability of one or more vehicles in an obtuse triangle area considering shadowing settings P_{Oarea}^{SS}, which is represented as follows in Eq. (15):

$$P_{Oarea}^{SS}(Y \geq 1) = 1 - e^{-\lambda\left(\frac{1}{2}h(b)\right)} \times \left(\frac{UB_{area}}{\pi R^2}\right) \quad (15)$$

E. Link Quality Model for Video Transmission

In vehicular communication, vehicles have geographical information through the use of GPS. The Link Quality (LQ) between a sender and a receiver vehicle can be approximated by considering the link signal power of the receiver, the bandwidth capacity, the packet error rate and the signal-to-noise ratio. The estimation of LQ has the ability to give an idea of the interference level of a next hop vehicle. The prediction of the interference level will assist in selecting the best vehicles in the multiple paths for the video packet transmission. To estimate the LQ, the receive signal power with the most widely acceptable two-ray ground reflection model has been employed. Further, a shadowing model which is more appropriate for vehicular communication environment is considered to predict actual LQ of the selected multiple paths in order to avoid paths with interference. The link received signal power between a transmitter and receiver vehicles are based on the two-ray ground reflection model, which is given as in Eq. (16):

$$PS_r = \frac{PS_t G_t G_r H_t^2 H_r^2}{\left(\sqrt{d_l^4}\right)^{1/2} \times S_l} \quad (16)$$

PS_r and PS_t are the received signal power of the receiver and transmitter respectively, G_t and G_r are the antenna gain of transmitting and receiving node, the H_t and H_r represents the height of transmitting and receiving nodes' antennas, d_l is the distance of the link between sender and receiver node, and S_l is the multipath system loss. Meanwhile, in practicality, the received signal power is not a sufficient parameter to determine the LQ and viability of the link for the relay node. Therefore, the bandwidth capacity, packet error rate and Signal to Noise Ratio (SNR) need to be estimated. Video data is normally large in size thus, large size of bandwidth is required for efficient and qualitative video streaming transmission. In video transmission, bandwidth estimation is regarded as the whole quantity of video data transmitted divided by the playback period. Thus, the

Bandwidth Capacity considering Video Data (BC_D^V) can be mathematically expressed in Eq. (17) as follows:

$$BC_D^V = \frac{\sum VD_T^Q}{PB_T} \tag{17}$$

Where VD_T^Q is the quantity of video data transmitted and PB_T is the playback period during video data transmission. The Signal to Noise Ratio (SNR) of the link is considered in respect to video streaming. As previously stated, qualitative video streaming transmission requires zero or minimum noise in the transmission link. The SNR is an essential parameter for link quality prediction, which is mathematically depicted as follows in Eq. (18):

$$SNR_l = \frac{ap^2 PS_r}{PS_{th} + ap^2 PS_{inf}} \tag{18}$$

The ap represents the amplitude of the fading channel using Rayleigh distribution, thermal noise signal power is assumed as PS_{th} and PS_{inf} represent the interference signal power of the link. In order to consider the packet error rate, we start from the Bit Error Rate of the link (BER_l), we use binary phase shift keying modulation which depicted in Eq. (19) as follows:

$$BER_l = \frac{\left(1 - \sqrt{\frac{SNR_l}{1+SNR_l}}\right)}{2} \tag{19}$$

In the case of Packet Error Rate of the link (PER_l) considering a single link, transmission is computed as demonstrated in Eq. (20):

$$PER_l = (1 - (1 - BER_l)^{LT}) \tag{20}$$

By considering vehicle nodes' dynamic functions for link breakage, then we present Eq. (21) as shown:

$$PER_l = (1 - (1 - BER_l)^{LT}) + \{f_q(w)\} \tag{21}$$

The length of the packet in bits is represented as LT and $f_q(w)$ is the vehicle node dynamic function considering the stringent delay requirement for video delivery. Eq. (21) is the generic formula for PER_l caused due to link breakage, which does not include link breakage due to dynamicity of the vehicles. The second part of Eq. (21) that is, $\{f_q(w)\}$ is the empirical function used to estimate PER_l probability because of abrupt route changing of vehicular nodes. Based on the function $f_q(w)$, it is assumed that it has previous knowledge component and can forecast future heuristic component. The mathematical representation of the function $f_q(w)$ is shown in Eq. (22):

$$f_q(w) = 1 - \left(\frac{1}{\{y(w)+z(w)\}}\right) \tag{22}$$

Where $y(w)$ is the frequency of different route change taken and speed rate by a node in the previous navigation. $z(w)$ represents the number of route changes and speed rate expected by the node in future to reach the destination using path with minimum cost. By using the aforementioned function, whenever there is frequency increase in either change of routes, speed rate or both, then the $\{y(w) + z(w)\}$ increases. The value of vehicle mobility function also increases within the range of $0 \geq f_q\ (w) \leq 1$. Video packets are retransmitted through multiple paths, whenever a transmission failure occur. A packet can be effective at least once in n retransmissions through multiple paths. The probability of effective transmission can be mathematically represented as $\sum_{i=1}^{n}(1 - PER_l)\, PER_l^{i-n}$. The retransmission attempt is indicated as i. Consequently, the PER_l^n over a single link based on multipath with n retransmission can be expressed as in Eq. (23) as follows:

$$PER_l^n = 1 - \sum_{i=0}^{n}(1 - PER_l)PER_l^i \tag{23}$$

Packet Error Rate PER_l^n of a multiple path with n retransmission in a single link, which is made up of k number of nodes is expressed as in Eq. (24):

$$PER_{path}^n = 1 - (1 - PER_l^n)^k \tag{24}$$

For k number of nodes in two paths link is mathematically formulated as presented in Eq. (25)

$$PER_{Mpath}^n = 1 - ((1 - PER_l^n)^k)^2 \tag{25}$$

Thus, we employ all the aforementioned derived parameters in order to select a qualitative link for video transmission in vehicular communication. By considering all the parameters, qualitative video streaming delivery can be attained. In the next section, we present some algorithms developed for the video streaming routing and further discuss their functionality and viability.

F. IMSLND Algorithm

In this subsection, the Interference-aware Multipath Video Streaming Solution with Link and Node disjoint (IMSLND) algorithm is developed based on the geographical routing protocol. The IMSLND algorithm includes node disjoint protocol, next forwarding vehicle protocol, and the multipath concept. The algorithm is aimed at reducing interference between multipath transmissions. It also minimizes forwarding overhead and improves the NFV selection criteria. The criteria are to avoid paths with interference while selecting the link with the best quality. The algorithm considers multipath angle that avoids interference during path selection, link quality, and next forwarding vehicle selection decision. The IMSLND is presented as follows, starting with node disjoint algorithm, followed by next forwarding vehicle algorithm and then the main IMSLND algorithm.

The multipath video transmission concept considers node disjoint as in [7]. The node disjoint strategy employs two paths, such that there is no common node between the paths during video transmission. It has a low collision possibility with stringent requirement when merged with link disjoint strategy. Consequently, node disjoint path selection strategy is suitable for collision-aware transmission such as video transmission in vehicular communication. The complexity of Algorithm 1 is presented as follow; since two paths are considered, then we have path 1 as p_1 with m length and path 2 as p_2 with n length. The Algorithm complexity is to decide and select two paths that are node disjoint and which node has higher angle of dispersion. Although, the angle of dispersion is only considered for the first two nodes which are selected by the SVN. It is by comparing all the nodes that exist in the two paths, which is $O(nm)$. In addition, since the comparison include sorting of the two possible paths by employing Quicksort, the mean complexity is $O(n \log n)$. Considering the sorted paths and the geometric angle relationship between nodes of the two paths, we compare the nodes in the two paths based on Algorithm 1. The mean complexity of Algorithm 1 is $O(n \log n) + O(m+n)$, $\exists\, n > m$. The worst-case situation of Algorithm 1 is when all nodes of the two selected paths are scanned, which is $O(n+m)$. In this situation, computation complexity of the worst case of Quicksort process is $O(n^2)$. Although, Quicksort computation complexity of the worst case can be avoided, where $n > m$. Hence, the worst case computation complexity is $O(n^2)$. The best-case situation of the Algorithm 1 occurs if there are fewer number of nodes in one path and the angle between the closest selected node is greater than 90° compared to the other path. The best-case computation complexity is $O(n)$, for the reason that only one path is scanned. In addition, computation complexity of the best-case situation of Quicksort is $O(n \log n)$. Therefore, the computation complexity of the best-case situation of the node disjoint algorithm is $O(n \log n)$.

Algorithm 1

Function 1	**Node Disjoint Vehicle Selection Algorithm**
Notation	p_1: Length of the first path
	p_2: Length of the second path
	i: Nodes in the first path
	j: Nodes in the second path
	θ: The angle between the two node disjoint paths
Input	p_1, p_2, i, j
Process	
1:	$\boldsymbol{Initialization}$
2:	$p_1 > 0$
3:	$p_2 > 0$
4:	$i, j = 0$
5:	$Identify\ (p_1)\ and\ sort\ (p_1)$
6:	$Identify\ (p_2)\ and\ sort\ (p_2)$
7:	$\boldsymbol{While}\ i < p_1\ or\ j < p_2\ \boldsymbol{do}$
8:	$\boldsymbol{If}\ \theta\ of\ the\ first\ two\ nodes$: $p_1\{i\}\ and\ p_2\{j$ $> 90° < 180°\ \boldsymbol{then}$
9:	$Return\ (true)$
10:	$\boldsymbol{Else\ if}\ Angle\ betweem\ p_1\{i\}\ and\ p_2\{j\}\ i$ $\leq 90° \geq 180°\ \boldsymbol{then}$
11:	$Return\ (false)$
12:	$\boldsymbol{If}\ p_1\{i\} = p_2\{j\}\ \boldsymbol{then}$
13:	$Return\ (false)$
14:	$\boldsymbol{Else\ if}\ p_1\{i\} < p_2\{j\}\ \boldsymbol{then}$
15:	$Increament\ i$
16:	$\boldsymbol{If}\ p_1\{i\} > p_2\{j\}\ \boldsymbol{then}$
17:	$Increament\ j$
18:	$\boldsymbol{Else}$
19:	$\boldsymbol{Execute}\ line\ 7$
20:	$\boldsymbol{End\ if}$
21:	$\boldsymbol{End\ while}$
22:	$Return\ (true)$
Output	$Two\ Paths\ Node\ Disjoint$

In this subsection, the concept of intermediate node selection after the two qualified nodes for the multipath are chosen based on the Azimuth triangle coordinates position of the selected node that is, next forwarding node. Each node calculates it the relative angle of direction to the neighbor nodes and selects a node that has the same coordinate position and satisfies the aforementioned parameters. This node is made as VRN, the process is continued in both paths until video packets get to the DVN. Note that, NFN is the same as the VRN. The complexity of this algorithm is related to that of the comparison complexity in Algorithm 1 that is the node disjoint algorithm. Considering the fact that, at the node selection only comparison is made based on the coordinate position and the parameters of the nodes. Hence, the complexity of the comparison is $O(nm)$, further, since the comparison include sorting then the mean complexity of the sorting is $O(n \log n)$. Therefore, the mean complexity of Algorithm 2 is $O(n \log n) + O(m+n)$. The worst case scenario of Algorithm 2 is when all the neighbor nodes of a PFN of the two paths are scanned which is $O(n+m)$. For the worst-case scenario of quicksort process, the complexity is $O(n^2)$. Even though, the computational complexity of the worst-case scenario for Quicksort can be avoided if the number of neighbor node is one or two and when the first scanned NFN is the most suitable node based on the coordinate position and parameters. Hence, in that situation the worst case computational complexity is $O(n)$. The best-case scenario of the Algorithm 2 occurs if there are fewer number of neighbor nodes to PFN of the two paths. The best-case computation complexity is $O(n)$, for the reason that only one or few neighbor nodes are, scanned from the two paths. In addition, computation complexity of the best-case situation of Quicksort is $O(n \log n)$. Therefore, the computation complexity of the best-case situation of the next forwarding node selection algorithm is $O(n \log n)$.

Algorithm2

Function 2	**Next Hope Vehicle Selection Algorithm**
Input	p_1, p_2, i, j
Process	
1:	$\boldsymbol{Initialization}$
2:	$p_1 > 0$
3:	$p_2 > 0$
4:	$i, j = 1$
5:	$NFN \in neighbor\ nodes\ of\ PFN$
6:	$\boldsymbol{While}\ VRN = PFV\ \boldsymbol{do}$
7:	$\boldsymbol{Calculate}\ PFN\ relative\ coordinate\ direction\ to\ NFN\ and\ parameters$
8:	$\boldsymbol{If}\ the\ NFN == VRN\ \boldsymbol{then}$
9:	$Return\ (true)$

10: ***Else if*** $NFN == DVN$ ***then***
11: $Return\ (false)$
12: ***Forward*** *to DVN without calculating coordinate direction and metrics*
13: ***End if***
14: ***End while***
15: $Return\ (true)$

Output $NFN\ among\ the\ intermediate\ nodes$

In algorithm 3, the complete process of the IMSLND protocol is logically presented. The video packet is forwarded from SVN through the intermediate nodes of the multiple paths, then to the DVN. The detailed discussion of the video streaming routing process is shown after the algorithm.

Algorithm 3 **IMSLND**

Notations
DVN: $Destination\ Vehicle\ Node$
SVN: $Source\ Vehicle\ Node$
PFV: $Present\ Forwarding\ Vehicle$
VSN: $Video\ Source\ Node$
$SVOT$: $Set\ of\ Vehicles\ in\ Obtuse\ Triangle$
NFV: $Next\ Forwarding\ Vehicle$
θ: $The\ angle\ between\ the\ two\ node\ disjoint\ paths$
Q_{link}: $Quality\ of\ single\ link\ of\ i^{th}\ vehicles\ in\ obtuse$
QV: $Qualified\ Vehicle\ is\ vehicle\ that\ fulfills\ all\ re$
SRV: $Set\ of\ Reachable\ Vehicles$
p_1: $Length\ of\ the\ first\ path$
p_2: $Length\ of\ the\ second\ path$

Input Process $PS_r, PS_t, H_t, H_r, G_t, G_r, d_l, S_l, b, h, \lambda$

1. ***Initialization***
$SVOT = null$
$VRN = null$
$SVN = PFV$
$\theta = 95°$
2. $SVOT = \{$vehicles in the transmission range of $PFV\}$
3. ***If*** node disjoint and $\begin{pmatrix} SVN\ is\ neighbor \\ of\ DVN \text{ and} \\ SVN == \\ VSN \end{pmatrix}$ ***then***
Forward the video packet directly to DVN using two QV from VSN
Exit
4. **Else**
While ($DVN \in$ SRV and $SVN \neq VSN = NFV$)
Forward the video packet to DVN using two qualified link
End while
5. ***Else***
While ($SVOT = null$)
a. ***Calculate*** obtuse triangle area using Eq. (3
$SVOT = \{vehicles\ in\ O_{area}\}$
b. ***If*** ($SVOT$ = null & $90° > \theta < 180°$) ***then***
$increment\ \theta\ by\ 5°$
Else
Wait for random quantity of time
End while
End if
6. ***For*** $each\ vehicle \in SVOT$
Calculate bandwidth capacity BC_D^V of eacl
Eq. (17): $BC_D^V = \dfrac{\sum VD_T^Q}{PB_T}$
End for
7. ***For*** $each\ vehicle \in SVOT$
Calculate packet error rate PER_{Mpath}^n of neigl
$PER_{path}^n = (1-(1-PER_l^n)^k)$
End for
8. ***For*** $each\ vehicle \in SVOT$
Calculate SNR of the neighbor node link using Eq. (18)
End for
9. $p_1(BC_D^V + PER_{path}^n + SNR) = Max\{BC_D^V(links(p_1)) + PER_{path}^n(links(p_1)) + SNR\}$
10. $p_2(BC_D^V + PER_{path}^n + SNR) = Max\{BC_D^V(links(p_2)) + PER_{path}^n(links(p_2)) + SNR\}$
11. $QV == NFV$
12. ***Transmit*** *the video packet to NFV up to DVN considering NFV selection process*
13. ***Exit***

Output $2 - NFV$ for $SVN = VSN$
$1 - NFV$ for $SVN \neq VSN$

G. Explanation of IMSLND Algorithm

The IMSLND algorithm executes steps 1-13, whenever the vehicle source node SVN wants to transmit video packet to a certain destination vehicle node (DVN) in the network. The step 1, is the initialization of variables. In the 2nd step, the SVOT acquires information about the positions of their immediate neighbors node position with reply timestamp. This information are used by the present forwarding vehicle PFV. In the 3rd step, the PFV inspect for whether DVN is in SVOT and if source vehicle node SVN is the same as video source node VSN, and if DVN is found among the SVOT set and SVN is the same as VSN, then PFV forward the video packet to NFN using available two qualified vehicle QV links. In step 4, if SVN is not the same as VSN and DVN are found among the SVOT set, then forward the video packet to NFV using available QV link. In the case where step 3 and 4 are not found, the algorithm executes step 5, in which a segment formed an obtuse triangle with sector using angle $90° > \theta < 180°$ is determined. The bandwidth capacity of each vehicle link in SVOT is computed in the 6th step. In the 7th step, the quality of each vehicle link in the SVOT based on PER is calculated. Also in the 8th step, the SNR is estimated to know the distance of the node and it signal quality. In the 9th-10th steps, the Next Forwarding Vehicle (NFV) is determined for the two paths based on Azimuth coordinate system in order to forward the video packet to the next node considering interference route coupling. In the 11th step, the NFV is the same as the QV, since the qualified vehicle is always chosen as the relay vehicle. In the 12th step, the video packet is delivered to the NFN which becomes the PFV. Meanwhile, in the 13th step, the video packet transmission is terminated. Step 1-4 and 6-13 are employed at vehicle hop until the video packet is delivered to DVN. Figure 5 is presented in order to aid understanding of the steps and logical flow in the algorithm. The computational complexity of the IMSLND algorithm is the sum of the total computation complexity of either worst case and or best-case scenario of Algorithm 1 and 2. Thus, the computation complexity entails both for comparison and sorting process.

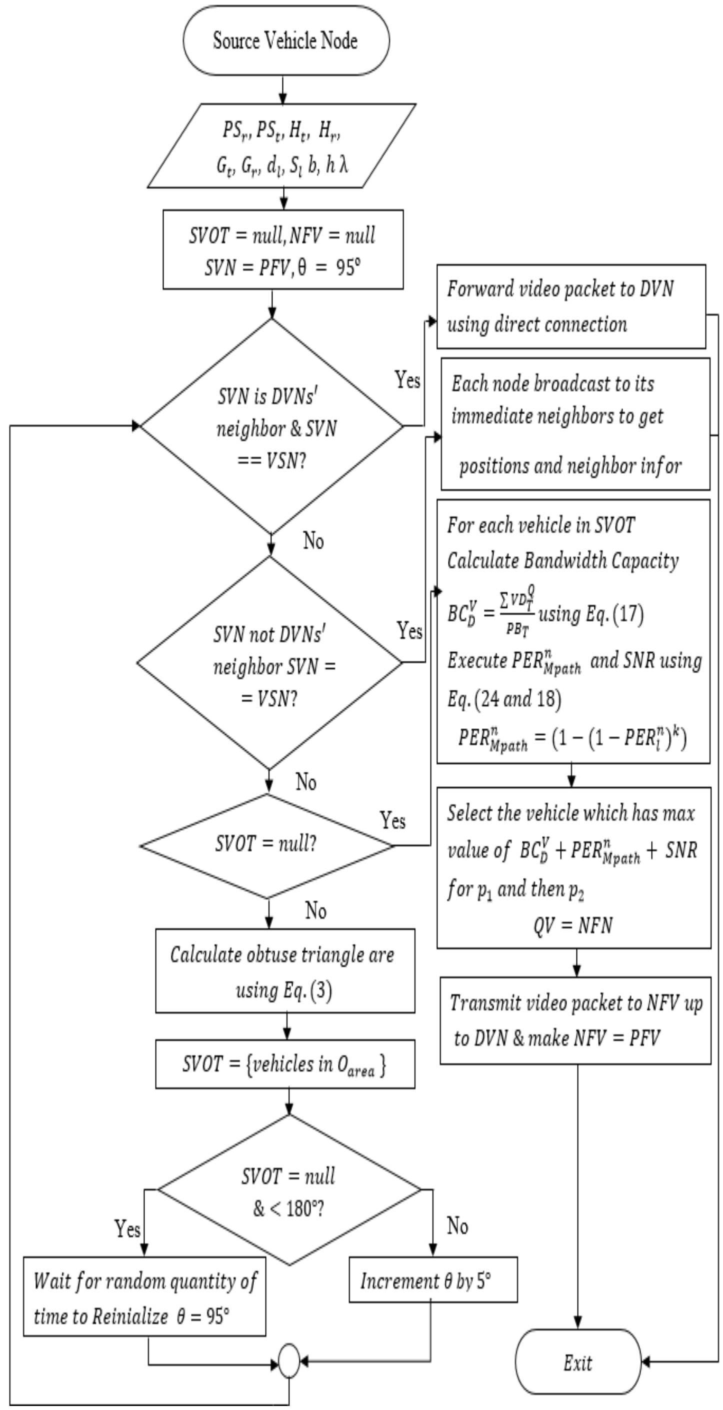
IV. Case Study-Based Experiment

In this section, experimental results obtained to examine the performance of the basic mathematical formulations and the suggested approach have been presented. The section is distinctively categorized into two subsections namely, subsection 4.1 and 4.2. Subsection 4.1, entails numerical results obtained for validating the mathematical formulations. While subsection 4.2, is the discussion of simulation results obtained and the benchmarking conducted.

A. Numerical Results

In this subsection, the numerical results have been generated using MATLAB to examine the effect of parameter variations on the mathematical formulations. The corresponding set of values of different parameters needed to generate the results have been stated in the various plots. The effect of parameter variations on the probability of availability of one or more nodes in an obtuse triangle area considering non-shadowing settings ($P_{Oarea}^{NSS}(Y \geq 1)$) and shadowing settings ($P_{Oarea}^{SS}(Y \geq 1)$) are depicted in Fig. 6.

Considering the results shown in Fig. 6(a), it demonstrates that for the offset angle $\theta = 125°$, the probability of availability of one or more vehicles in the obtuse angle area considering non-shadowing settings is 0.71 for vehicle density $\lambda = 0.0003$ vhc/m2. The value $\theta = 125°$ is considered to be the least threshold value to examine the performance of our proposed approach. The result shown in Fig. 6(b) demonstrates that for each of the vehicle densities considered, the probability $P_{Oarea}^{NSS}(Y \geq 1)$of availability of one or more vehicles in the obtuse angle area considering non-shadowing settings is greater than 0.7 for the transmission range of 350 m to 800 m. The result is used to analyze the performance of our proposed approach. In Fig. 5(c), the result shows that, for obtuse angle $\theta = 125°$, the propability $P_{Oarea}^{NSS}(Y \geq 1)$of availability of one or more vehicles in the obtuse angle area considering non-shadowing settings is greater than 0.6 for vehicle density $\lambda = 0.0003$ vhc/m2. Specifically, the probability $P_{Oarea}^{NSS}(Y \geq 1)$ rises with the increase in obtuse angle for any precise value of the density considered. For instance, when $\theta = 160°$, the probability $P_{Oarea}^{NSS}(Y \geq 1)$ attain a value of 1.0 at density $\lambda = 0.0003$ vhc/m2, which is the highest probability value.



Further, the effect of shadowing on the probability of availability of one or more vehicles in the obtuse triangle area has been depicted in the result Fig. 6(d). The result demonstrates that, shadowing has great effect on a smaller obtuse triangle angle. For example, when $\theta < 120°$, but with the rise in obtuse triangle angle $\theta > 130°$ the effect is minimized significantly. In the next diagram (see Fig. 7), we depict the probability of packet error rate in one hop coverage considering non-shadowing and shadowing settings.

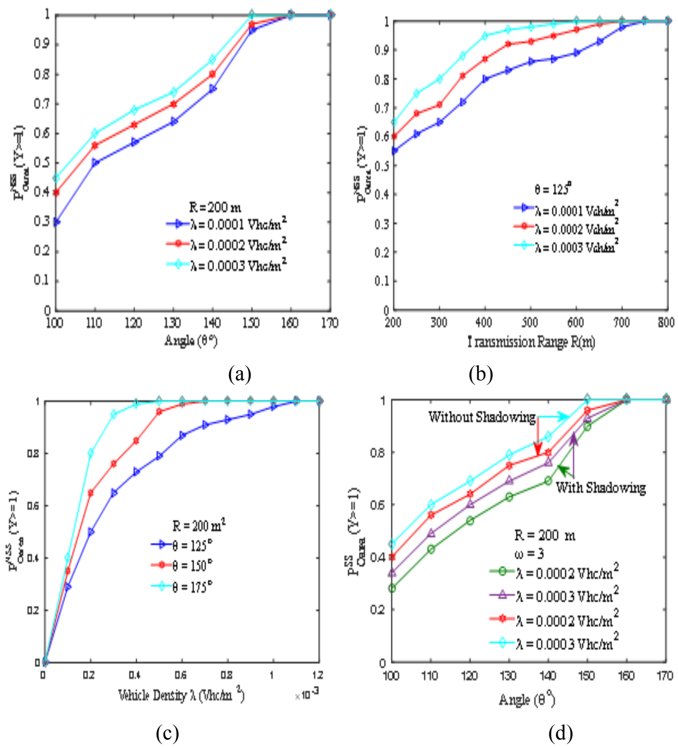


Fig. 6. The probability of availability of one or more vehicle in the obtuse triangle area (a) and (b) represents the availability of vehicle considering angle and transmission coverage respectively, (c) and (d) represents vehicle density and angle NSS and SS.

The results of the probability of packet error rate PER_{path}^{n} in both single and multiple paths PER_{Mpath}^{n} with n retransmission is shown in Fig. 7(a, b, c and d). The result presented in Fig. 7(a) depicts that packet error rate is at lowest when one-hop coverage is 200-250m for both single and multipath transmission at various values of θ. However, packet error rate for multipath is lower compared to that of the single path (see Fig. 7(a and b)) due to achieving load balancing, path diversity and minimization of interference between two paths. The whole of the observations have been employed for the selection of next forwarding vehicle with the best link quality for video streaming. Further, the result in Fig. 7(c) shows that the effect of shadowing on packet error rate is highly noticeable for single path, but lesser for multipath next forwarding vehicle transmission.

B. Simulation and Results Analysis

The results of simulations conducted to examine the performance of IMSLND are presented in this subsection. The performance is tested considering dynamicity and frequent position changes of vehicles in the network topology due to the high mobility of vehicle nodes. In addition, the performance of IMSLND is tested considering varied densities in an urban traffic setting. In the simulation, Peak Signal to Noise Ratio (PSNR), Structural Similarity (SSIM) index, Data Receiving Rate (DRR) and delay in the network have been measured. The results achieved for IMSLND are compared with two baseline protocols namely, MSLND and FEC. We first discuss the simulation environment and setup.

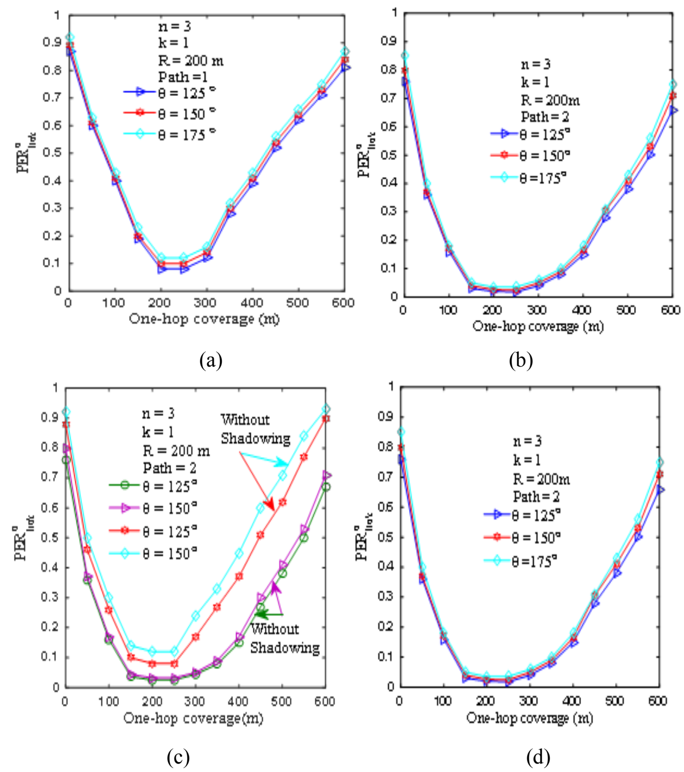


Fig. 7. Represent impact of parameters on PER_{path}^{n} (a) and (b) single and multipath in a non-shadowing settings, (c) and (d) single and multipath in shadowing settings.

1) Simulation Settings

IMSLND has been implemented using the network simulator NS-2.34 [56], Evalvid [57] and mobility model generator for VANETs (MOVE) from Simulation of Urban MObilty (SUMO) [58]. NS-2 is a standard network simulator, which has the capability of mimicking network traffic and communication scenarios for normal data and multimedia data. Evalvid is an acceptable video quality evaluation tool, which offers tool-sets of video files and framework for the assessment of video transmission. MOVE has the capability of generating realistic mobility model in an urban traffic setting. MOVE is developed on the upper layer of an open source micro traffic simulator. The necessary features of vehicle mobility traffic settings including a number of lanes and roads, number of direction flow in each road lanes, number of traffic lights and junctions, accelerations, the speed of vehicles, the probability of turning right or left of a vehicle at a specific junction have been put into consideration and implemented. By using the two key modules of MOVE including vehicle movement manager and road map manager. In addition, the mobility traces created using MOVE with the aid of SUMO is directly employed in NS-2 (See Fig. 8).

Two scenarios of vehicular traffic settings are considered including simple lane urban scenario and high-density urban scenario. In the simple lane scenario, all vehicles are on multiple lanes in the same direction of the road. The aim of using simple lane scenario is to examine the performance of IMSLND in low dense urban settings. Forty (40) vehicles are distributed across three (3) lanes of the road, which are navigating in the same direction. During navigation in the simulation scenario, a video is transmitted from source vehicle through multipath intermediate vehicles, then to the destination vehicle. The speed considered for each vehicle range from 2.78 to 13.89 m/s (10 to 50 km/h). The length and breadth of the simple lane scenario are 2,000 × 1,200 m2.

In the high-density urban scenario, map-based setup is considered, it is based on road network of Johor Bahru (Jalan Abu Bakar) Malaysia (see Fig. 9). An OpenStreetMap (OSM) satellite image of the city is generated and imported into SUMO that incorporates mobility and network information with the map. Afterward, design and configuration of trace files are generated in relation to vehicle traffic flow timing in the Johor Bahru map, which is produced to examine the performance of IMSLND in a simple lane and high-density urban traffic settings. The whole concept of building Johor Bahru city map on SUMO is based on OSM. In the high-density urban scenario, a number of vehicles in the simulation setup is varied from 100 to 500 in order to examine the performance of different network density. The simulation results are generated based on the mean average of all vehicles in the network. The simulation area covered by the high-density urban scenario is 2500 × 1800 m2.

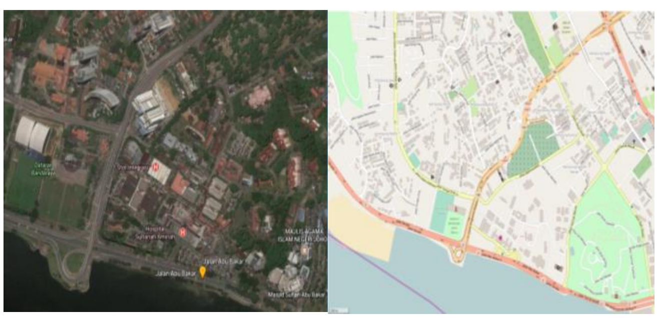


Fig. 9. City Map of Johor Bahru Malaysia

The selected video for transmission is the well-known bridge-far_cif, which has a streaming duration of 139 seconds, rather than silent_qcif and akiyo_cif with streaming duration of only 9 seconds, the bridge-far_cif is used so as to evaluate the long duration effect of different protocols. The considered metrics for examining the performance of the simulation include peak signal to noise ratio (PSNR), Structural SIMilarity (SSIM) index data receiving rate and delay. These metrics measure the quality of the transmitted video. Due to the fact that, video quality is defined by the transmission rate of the sender, hence, Data Receiving Rate (DRR) has also been measured. In the simulation, real-time video streaming is evaluated. Thus, the fixed data rate for the video transmission has been considered. All the different phases of the simulations are executed 25-30 times, which gives the advantage of taking the mean average of the results of the simulation. In order to attain reliable mean average results, 95% confidence level has been considered for the confidence interval. However, the complete procedure of the simulation has been shown in Fig 8.

Table 1, presents simulation parameters and criteria considered for implementation of IMSLND protocol.

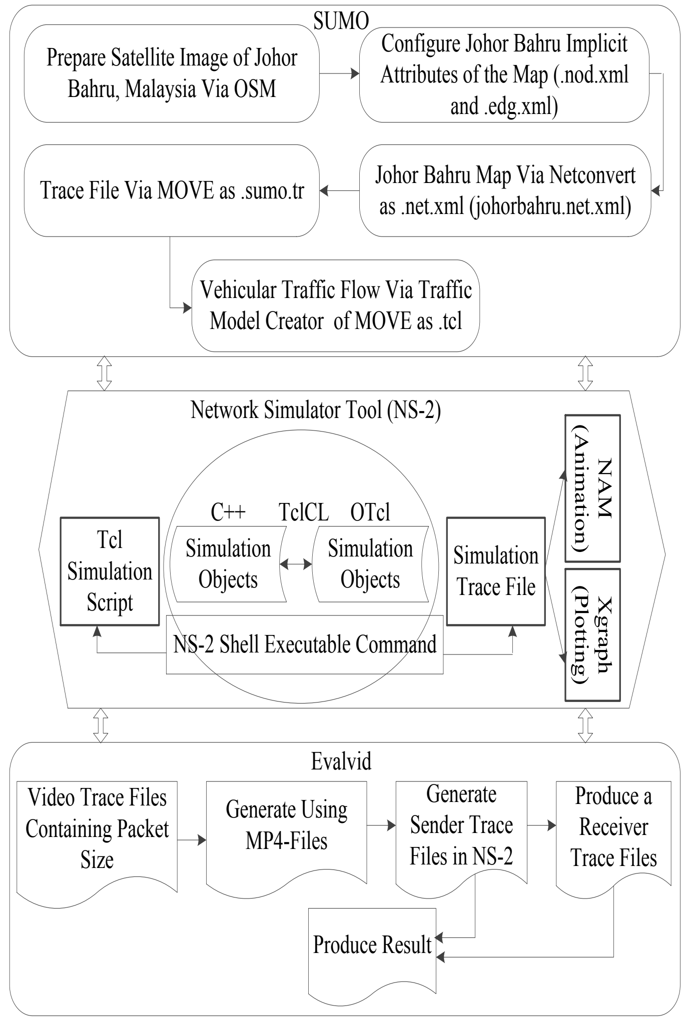


Fig. 8. Simulation Tools and Procedure

Table 1. Simulation Parameters

Parameters	**Values**
Simple lane area	2,000 × 1,200 m^2
Urban simulation area	2500 × 1800 m^2
Simulation time	600 s
Vehicle speed	2.78 to 13.89 m/s (10 to 50 km/h)
Number of vehicles	100 to 500
MAC protocol	IEEE 802.11p
Video resolution	352 × 288
Video play duration	139 s
Transmission range	200 m
Frequency	5.9 GHz
Propagation model	Shadowing
Antenna model	Omni-directional
Channel type	Wireless
Packet type	TCP and UDP
Hello packet timeout	1 second
Scenarios	-Simple Lanes and

	-High-density urban scenario
Benchmarked protocol	-IMSLND -MSLND -FEC
Metrics	PNSR, SSIM index, Data Receiving Rate, Delay

In the simulation setup, IEEE 802.11p has been considered, because is the standard Wireless Access in Vehicular Environment (WAVE) protocol. For the propagation model, shadowing model has been employed which is the most realistic model. Signal coverage of each node in the simulation has been set to 200 m. Three protocols have been compared including proposed protocol, MSLND, Forward Error Correction (FEC). For each scenario simulation, 600 s has been set because the time is greater than the whole time required for video transmission.

The PSNR and SSIM have been evaluated at the receivers' end in simple lane scenario. The Receiving data rate is estimated based on overall received video packets divided by overall transmission time. Delay is the summation of startup delay, propagation delay, transmitting delay, queuing delay and processing delay encountered during transmission. Considering simulation of urban scenario, the results are based on average outcomes of all nodes that received the video streams. The evaluation of all metrics is the same as that of the simple lane scenario.

2) Simulation Settings

In this subsection, the following video quality metrics are employed to compare the performance of the IMSLND with the baseline protocol are presented. The metrics include PSNR, SSIM index, received data rate and end-to-end delay.

i) Peak Signal to Noise Ratio: is an expression of the ratio between the maximum probable value of a signal and the power of distorting noise that affects the quality of its representation. Because, many signals have a very wide dynamic range, (ratio between the largest and smallest probable values of a variable quantity) [7, 37, 41]. The PSNR is generally expressed in terms of the logarithmic decibel scale, see Eq. (26) and (27).

$$PSNR = 10\log_{10}\left(\frac{MAX_f^2}{MSE}\right) \tag{26}$$

The Mean Square Error (MSE) can be expressed as:

$$MSE = \frac{1}{mn}\sum_0^{m-1}\sum_0^{n-1}\|f(i,j) - g(i,j)\| \tag{27}$$

Where f denotes matrix data of the original image, g represents matrix data of a degraded image in question. m Represents numbers of rows of pixels of the images and i represents the index of that row n represents the number of columns of pixels of the image and j represents the index of that column. MAX_f is the maximum signal value that exists in the original "known to be good" image.

ii) Structural Similarity index is an approach used to calculate the perceived similarity between the transmitted video images and the original video images. The calculation of the SSIM index is grouped into three including contrast, luminance, and structural assessment. Contrast assessment [59, 60] $Ct(a,b)$ is the difference of $\sigma_a\ and\ \sigma_b$ then, we have $Ct(a,b) = \frac{2\sigma_a\sigma_b+K_2}{\sigma_a^2+\sigma_b^2+K_2}$ while the Luminance assessment is denoted as $Ln(a,b) = \frac{2\mu_a\mu_b+K_1}{\mu_a^2+\mu_b^2+K_1}$ where K_1 and K_2 are constant. The structural assessment is carried out as $St(a,b)$ on the normalized signals $\frac{\frac{a-\mu_a}{\sigma_a and}(b-\mu_b)}{\sigma_b}$ Thus, $S(a,b) = f(Ct(a,b), Ln(a,b), St(a,b))$ then finally, Eq. (28) and (29) are depicted as follows:

$$SSIM(a,b) = \frac{(2\mu_a\mu_b+K_1)(2\sigma_{ab}+K_2)}{(\mu_a^2+\mu_b^2+K_1)(\sigma_a^2+\sigma_b^2+K_2)}. \tag{28}$$

$$MSSIM(a,b) = \frac{1}{M}\sum_{j=1}^{M} SSIM(a_j,b_j) \tag{29}$$

Where μ_a, μ_b represents local means, $\sigma_a\ and\ \sigma_b$ is the standard deviations, while σ_{ab} is the cross-covariance for video images a, b.

iii) Data Receiving Rate is the ratio between a number of data packets in video streaming generated at source vehicle and a number of the data packet in video streaming delivered to vehicles at destination [37]. The statistical formula used to calculate Data Received Rate (DRR) in terms of percentage can be expressed in Eq. (30) as follows:

$$DRR\% = \left\{\left(\sum_{i=1}^{n}\frac{PS}{PR}\right)\Big/N\right\} \times 100 \tag{30}$$

Where PS denotes number of data packet in video streaming sent in i^{th}simulation run and PR represents number of data packet in video streaming received in i^{th}simulation run.

iv) Delay: is the total time taken for a video stream to be transmitted from source to a specified destination [7]. The total delay time encompasses five major steps in video stream transmission including startup delay, propagation delay, transmission delay, queuing delay and processing delay. It can be represented mathematical in Eq. (31) as follows.

$$DL = N\sum D_{St}, D_{Pr}, D_{Tr}, D_{Qu}, D_{Prs} \tag{31}$$

Where N is the number of links (hops) in the network, D_{St} is the startup delay of the video stream. D_{Pr} is the propagation delay for transmitting a single bit from source to destination, D_{Tr} is the transmission delay of a video streaming packet transmitted from source to destination. D_{Qu} is the queuing delay for video stream before transmission and D_{Prs} is the processing delay encountered during video streaming from source to destination.

3) *Analysis of the Results*

The simulation results achieved for the proposed algorithm, which has 95% confidence interval have been presented. This subsection has been categorized into two (2) namely, subsection A and B. Subsection A consist of benchmark analysis of results achieved for simple lane scenario. Meanwhile, subsection B consist of benchmark analysis of results achieved for the urban scenario.

i) *Simple lane scenario:* In the case of simple lane scenario, the video transmission starts at approximately 45 seconds after the simulation starts. The playtime duration of the video is 139 seconds, which is the same as the time taken for the source node to transmit the video. Forty (40) vehicles are simulated in the simple lane scenario. The simulation results are depicted in Figs. 10(a) to 10(d). Peak Signal to Noise Ratio (PSNR) has been one of the most commonly employed metrics for evaluating the quality of a video after transmission. Comparison of PSNR results from the three different protocols is presented in Fig. 10(a). Further, the results for Structural SIMilarity (SSIM) index are presented in Fig. 10(b). SSIM is identified to have higher sensitivity to image degradation and stable with human eye perception when compared to PSNR. Considering both PSNR and SSIM results, it is clear that IMSLND offers a better video quality than that of MSLND and FEC. This is because IMSLND handles interference in the multipath transmission. Also, TCP is employed to guarantee the transmission of the I-frames, being that they are the most important frames in a single Group Of Picture (GOP). It also helps in maintenance of quality of other noticeable frames which are generated by the predicted frames including P-frames and B-frames. Furthermore, Forward Error Correction (FEC) also has the ability to guarantees the transmission of I-frames, by way of replicating the I-frames. Hence, FEC can realize higher video quality when compared with User Datagram Protocol (UDP). Because in UDP delivery and retransmission is not guaranteed. Conversely, FEC experiences more packet loss during video transmission due to a burst of transmitted packets which is caused because of replicated packets of FEC. Considering VANETs, FEC drawback is higher because of frequent change in vehicle position and constrained network resources.

The received data rate is another metric that estimates receiving capabilities at the receivers' end. In Fig. 10(c), IMSLND has a higher received data rate when compared with MSLND and FEC. The simple reason is that IMSLND considers interference at each selected node and also uses TCP protocol in order to ensure transmission, which minimizes the number of packet collision and contention, hence it reduces packet loss. Additionally, the link quality estimated at each node provides best node selection for video streaming, which leads to higher video delivery rate. The I-frames are specifically studied in the simulation, which shows that there is higher delivery of I-frame packets compared to that of MSLND and FEC.

The delay latency of the video transmitted is also a vital metric in the real-time video streaming. Delay in video transmission is unavoidable, however, it must be within an acceptable range of human eyes perception. The mean delay of IMSLND compared with MSLND and FEC are presented in Fig. 10(d). The result demonstrates that IMSLND achieves slightly lower mean delay compared to the MSLND. Even though, the delay is relatively high but is lower than that of the MSLND. However, the high delay is caused due to the use of TCP for I-frames transmission. In the simulation, it is observed that most of the delayed packets are TCP packets. It is an established fact that the major drawback of TCP is a higher delay. FEC has lower mean delay compared to that of the MSLND. Despite the high delay, IMSLND has not exceeded the allowed maximum delay of 0.5 seconds, which is realistic to the human eye perception. Meanwhile, further research could be conducted in order to minimize the mean delay.

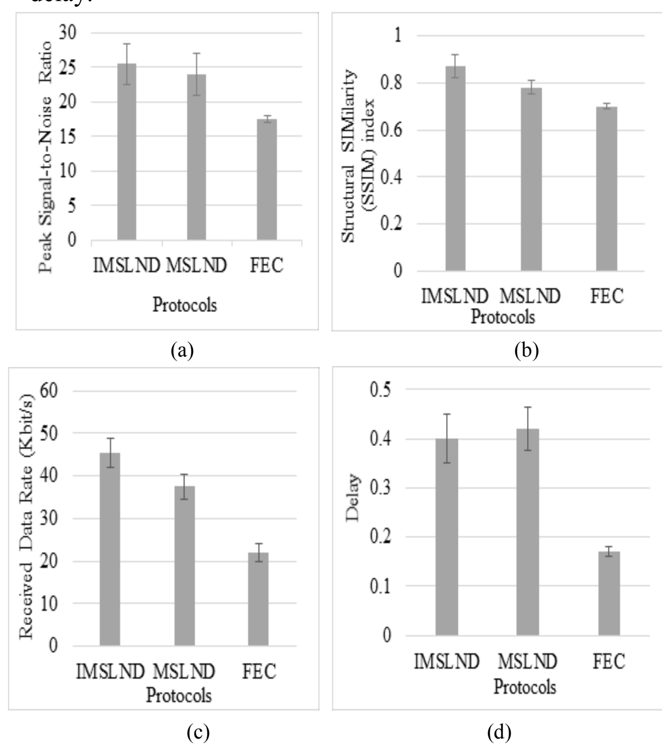
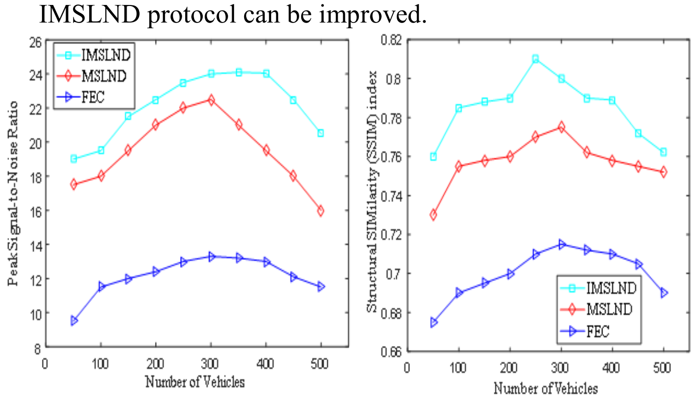


Fig. 10. The result of simple lane scenario. (a) and (b) represents the result of PSNR and SSIM index respectively, (c) and (d) represents the result of receiving data rate and delay respectively.

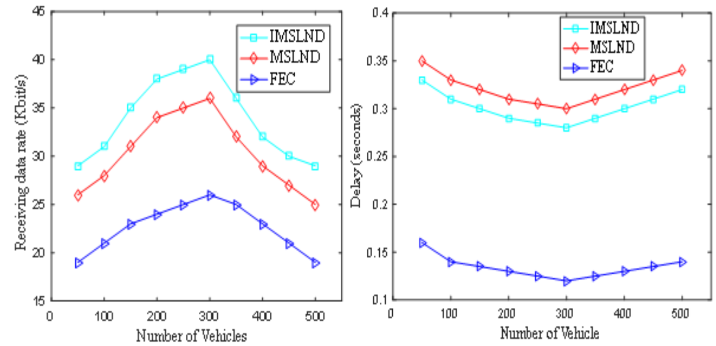
ii) *Dense urban scenario:* The second subsection is the urban scenario, where a large number of vehicles are employed and simulated. In this scenario, the settings of the topology are based on the map of Johor Bahru (Jalan Abu Bakar). The connection employed is based on V2V communication pattern, hence only ad-hoc routing is enabled. The simulation has been carried out by considering different numbers of vehicular nodes, so as to test the performance of IMSLND for different vehicular node densities. The results depicted in this subsection, are the average results of all transmitted and received video packet at the receiver end. It is believed that this will provides the actual performance of IMSLND on different vehicle densities. The results of the video quality obtained are presented in Figs. 11(a)-11(d). The Figs. 11(a) and (b), demonstrate that IMSLND protocol has the highest mean PSNR and mean SSIM index when compared to MSLND and FEC. Based on the simulation results, it is observed that the quality of the video increases as the number of vehicles increases from 50 to 300. Almost a stable video quality is experienced when the number of vehicles is between 300 to 400. The increased video quality achieved is because there is a substantial number of vehicles, which serves as a next forwarding vehicle for the video transmission. In addition, it is due to the node selection criteria considering interference at each node. However, the video quality starts to degrade as the density of vehicles is increased from 400 to 500. This is in connection with the increase in the number of video streaming request at the source vehicle, which is due to the increased density of vehicle in the network. Additionally, as stated by Xie, et al. [7] that large vehicle density causes link saturation due to the broadcasting of routing packets. The video quality of FEC decreases faster compared to the MSLND. However, the IMSLND attains a higher mean video quality compared to that of MSLND and FEC in the simulation.

The receiving data rate result for the three different protocol is presented in Fig. 11(c), which is the average number of successfully received video packet at the destination vehicle. The DRR is used to test and measure the performance of IMSLND. The simulation result demonstrates that the IMSLND has the highest mean received data rate compared to MSLND and FEC. One of the factors that determine video quality is the data receiving rate.

The delay observed in the simulation results for urban scenario slightly differ due to the increase in vehicle density, as shown in Fig. 11(d). The delay of IMSLND protocol is still high, but slightly less than that of the MSLND protocol. Nevertheless, the average delay obtained does not exceed the allowed limit of 0.5 seconds. The delay encountered in the simulation could be attributed to the intermittent disconnection of vehicles when the vehicles are fewer and the nature of TCP transmission. However, if RSUs are deployed to aid connection and the TCP transmission delay is handled, then the delay issue in IMSLND protocol can be improved.



(a) (b)



(c) (d)

Fig. 11. The result of simple lane scenario. (a) and (b) represents the result of PSNR and SSIM index compared with different vehicle density respectively, (c) and (d) represents the result of receiving data rate and delay compared with different vehicle density respectively.

V. Conclusion

In this paper, an interference-aware multipath video streaming solution considering node disjoint and link disjoint (IMSLND) protocol is proposed and simulated. The purpose of this paper is to minimize interference in a multipath video transmission in order to achieve high-quality video streaming in VANETs. The proposed protocol employs selection of dispersed vehicles with zero or minimal route coupling in multipath transmission. The link and node disjoint are also utilized to further enhance the dispersed vehicle selection to achieve minimal interference. Further, the link quality metrics including the link signal power and bandwidth capability of the multipath link. In addition, mathematical formulations are derived for dispersed vehicle selection and the link quality estimation, which is based on bandwidth capacity, packet error, SNR and received signal power. The proposed interference minimization protocol is useful for multipath video streaming by improving quality of video streaming. However, to further extend this paper, the future research work would focus on video streaming optimization considering delay parameters in order to improve video quality in VANETs communication.

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Conflict of Interest

The authors declare no conflict of interest.

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