Interference-aware Multipath Video Streaming in Vehicular Environments

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***Abstract*— The multipath transmission is one of the suitable transmission methods for high data rate oriented communication such as video streaming. Each video packets are split into smaller frames for parallel transmission via different paths. One path may interfere with another path due to these parallel transmissions. The multipath oriented interference is due to the route coupling which is one of the major challenges in vehicular traffic environments. The route coupling increases channel contention resulting in video packet collision. In this context, this paper proposes an Interference-aware Multipath Video Streaming (I-MVS) framework focusing on link and node disjoint optimal paths. Specifically, a multipath vehicular network model is derived. The model is utilized to develop interference-aware video streaming method considering angular driving statistics of vehicles. The quality of video streaming links is measured based on packet error rate considering non-circular transmission range oriented shadowing effects. Algorithms are developed as a complete operational I-MVS framework. The comparative performance evaluation attests the benefit of the proposed framework considering various video streaming related metrics.**

I. Introduction

Recent advancements in vehicular communication aims on providing improved on road safety and infotainment services for minimizing fatal traffic incidences and reducing emergency response time. Towards this end, designing innovative Intelligent Transportation Systems (ITS) has led to several contributions from both industry and academic researchers. It is to improve vehicular information dissemination protocols and mechanisms towards enhancing on road traffic safety and infotainment services. In recent developments, text message and beacon signal based information dissemination are widely explored. However, text oriented information is far from providing realistic view of on road real time traffic environments [1-3].

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The traffic video streaming has been explored in some recent research for realistic view oriented on-road safety and infotainment [4-8]. Video streaming provides traffic information that is more appealing, comprehensive and interactive as compared to text oriented information [9]. The On-Board-Unit (OBU) including Dedicate Short Range Communications (DSRC) device and Road Side Units (RSUs) enables video streaming in vehicular environments. The potential application includes pedestrians crossing the road, accident occurrence ahead on the road, emergency vehicle way finder, and advertisement of on-road grocery shops and gas stations. The video streaming in vehicular communication could be Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) oriented information dissemination. V2V is the communication between vehicles, which is facilitated by the OBU. Meanwhile, V2I is the communication between the vehicle and the 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 faces several challenges due to the high data rate of video packets, dynamic topology of traffic environments and constrained resources. The challenges harden when trying to achieve high quality video streaming due to a larger amount of video data. Considering the highlighted challenges, the protocols including both Forward Error Correction (FEC) and multipath solutions have been employed. The FEC and multipath solutions are often cross-layer based approach. Many researches based on FEC techniques generate duplicate packets during transmission, this leads to redundant packets and large bandwidth consumption [10-15]. Recent research on multipath video streaming based transmission, video frames were partitioned and transmitted through multiple paths [9, 16-21]. This approach minimizes high data rate issues in video transmission [22]. 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 causing packet loss. The loss of the video packets affects the quality of the video streaming. Therefore, to facilitate transmission of improved quality video streaming through avoidance or minimization of interference in multiple paths, the signal coverage of nodes in the multipath must be taken into consideration and most suitable geographic routing protocols must be selected [23, 24].

The geographical routing protocols use a vehicle's geographical location for making routing decisions [25, 26]. These routing decisions are often based on parameters such as direction, speed, and/or static forwarding region [27-30]. Several research studies have focused on direction and distance and have proposed Mobility-Aware routing protocols which are improved Greedy Forwarding protocol (MAGF) [31], forwarding decision based on Directional Greedy Routing (DGR) [32], and data forwarding based on Greedy Stateless Perimeter Routing considering Motion Vector (GSPR-MV) [33]. Some techniques which are based on static geographic region have also been suggested including Segment of vehicle node, quality of Link and Degree of connectivity based Geographic DIstance Routing (SLDGDIR) [28] and Voronoi Diagram-based Geographic Distance Routing (V-GEDIR) [27]. Despite the vast amount of literature on routing protocols, a greedy forwarding protocol for a fixed region supporting multipath video transmission is yet to be implemented.

Therefore, the article proposes a multipath video transmission protocol that considers path's route coupling effect in order to minimize interference between paths. The contributions put forward by this article are as follows:

1) A multipath vehicular model is derived focusing on dispersed vehicle selection in other to minimize route coupling in vehicular video streaming.
2) The model is enhanced considering angular driving statistics for selecting optimal vehicle with minimum route coupling effect.
3) The link quality of the next forwarding vehicle is further evaluated based on packet error rate to achieve quality video streaming.
4) The circular and the non-circular transmission range oriented shadowing effects are evaluated for the multipath video transmission.

In the rest of the paper- section 2 presents a comprehensive review of related literature, section 3 describes the proposed mathematical model and algorithms, section 4 presents the simulation results and their analyses, and finally, section 5 concludes the paper.

II. Related Work

In this section, a qualitative review on video streaming transmission in vehicular environments has been put forth by 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

The employment of MAC layer for achieving optimal functioning of the network has provided substantial benefits. The link layer is usually adjusted to manipulate frame sizes considering physical rules in order to attain an optimal stability between higher latency of smaller frames and the possible distortion , which has led to losing larger video frames [34]. Considering the MAC layer, parameters are adjusted based on retransmission so as to attain video transmission with better quality [35]. The FEC method 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 for the lost video packet, this can lead to an increase in the consumption of the network bandwidth, thus generating another problem. Asefi, et al. [36] suggested a video streaming, which is adaptive based on the multi-objective optimization mechanism employed. The optimization mechanism simultaneously minimizes the possibility of playback freezes and start-up delay of video streamed at a destination vehicle. The tuning of the MAC retransmission limit based on channel delay packet transmission rate minimizes the playback freezes and startup delay of the video streaming. However, the channel contention due to video data rate has not been adequately considered. Interestingly, another link layer based study is centered on WAVE-centric Hybrid Coordinating Function (W-HCF). This function employs controlled access abilities as a substitute to the primary contention access of the IEEE 802.11p. In addition, it uses vehicle geographic location data and planning among WAVE vehicle provider so as to augment the performance ability of the time-constrained and loss-aware multimedia information-based applications [37].

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 [38]. The mechanism chooses a fewer subset of rebroadcasting vehicles in order to reduce interference and attain higher video quality. Error recovery video streaming protocol that uses multi-channel to address packet is suggested [39]. The multi-channel is categorized into the reliable and non-reliable channel. However, channel contention has not been considered. Bucciol, et al. [13], 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 actual network for quicker video frame transmission from the sender to the destination vehicle. The sending vehicle is tagged as a relay vehicle. The relay vehicle is chosen towards the route of the destination vehicle. In Hsieh and Wang [40], a dynamic and robust overlay based on multiple hop for video streaming in vehicular network has been suggested. The idea is based on handling non-grouped and non-cooperating vehicles in communication. Further, another approach, which is based on heuristic replica assignment method for video transmission in the vehicular settings that is delay tolerant-based [41]. An overlay based on clustering scheme for Mobile-IP scheme is suggested to tackle the recurrent disruption and transmission of video fragments that are not valid. The clustering concept is based on segmenting vehicle that have similar mobility features and video flow transmission constraints. The clustered vehicles can learn and make decision based on whether or not a stored video can be deployed [42]. An adaptive cooperative streaming mechanism over a collaborative vehicle fleet considering mobile bandwidth aggregation strategy

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has been proposed [43]. The study addresses the issues in K-hop cooperative streaming. In Rezende, et al. [16], 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 non-static nature of vehicular network topology, frequent update of the overlay structure causes high communication overhead and can also lead to high energy consumption. In addition, the high rate of video data is not considered in the overlay transmission, hence congestion in the network might occur which can in turn lead to a reduced video quality.

B. Coding Oriented Video Streaming

It is an approach that is centered on integration of video compression methods alongside with optimal vehicle and path selection methods. These methods are developed to assure optimal quality in video streaming transmission. The Quality of Service (QoS) is considered for both compression and route path selection and formation in video streaming. The QoS is based on video quality requirements and the human eye perception. In generality, both the stringent requirements of the video streaming and VANETs limitations are considered to attain quality video transmission. The QoS and QoE methods focuses on parameters including jitter, packet loss, delay, and efficient bandwidth utilization in the video coding and video transmission. Further, the QoS and QoE method’s aim is to attain peak video streaming output that can be satisfactory to users. A coherent quality-aware multiple hop video data transmission scheme for video transmission in urban VANETs settings has been suggested [44]. It incorporates routing scheme for coherent delivery of video frames 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-aware user-driven video-on-demand service in a city multi-housed Peer-to-Peer-based (P2P) vehicular communication has been suggested in order to attain optimal QoE for video streaming. Optimal QoE is attained by focusing on bandwidth related issues [45]. In these services, vehicles utilize lower layer protocols for VANETs via wireless access in vehicular network interface. Further, it utilizes an upper layer P2P-based overlay situated above the cellular network. In another method, QoE-aware coding and routing methods are utilized to attain optimal path choice based on Mean Opinion Score (MOS) procedure for evaluating QoE [46]. This procedure is addressed based on four different stages including selection of path and request/reply packets, then proactive triggering of topology by the use of request/reply packet. Followed by, assessment of packet loss ratio, average loss burst and disqualified links. Further, a QoE-centric link-quality and receiver–aware transmission has been suggested for improving the quality of video while considering VANETs challenging environment [47]. In addition, a geographical receiver-based beaconless strategy has been suggested as a solution for transmitting video streams in vehicular network. However, this approach lacks the ability to segment the video high data rate and create load balancing in the network.

The multipath coding is a method that transmit sub-streams via designated multiple paths from source vehicle node to the destination vehicle node. Multipath coding-driven routing focuses on the reduction of the video size while considering the selection of optimal and reliable route for video transmission. In this, video frames are segmented into separate route for transmission purpose. The division of the frames minimizes the high data rate of the video stream, it also attain load balancing in the multiple paths. The multipath video transmission majorly centers on choice of path algorithm. It generally utilizes link disjoint and node disjoint methods for optimal transmission of video data. The multipath video transmission helps in attaining QoS. The following ways helps in the multipath QoS including delay aggregation, fault tolerance, optimized bandwidth and load balancing. A related method to the multipath is the multisource video streaming.

A Multipath Video transmission Solution in a VANETs environment, which is based on Link and Node disjoint (MSLND) has been proposed to tackle video streaming issues in FEC technique [9]. The MSLND employs retransmission of video frames, rather than forward error correction. Further, the disjoint which is based on link and node algorithm has been proposed to minimize interference in terms of route coupling. The interference in multipath transmission has led to video packet collision and wireless contention, which caused an unacceptable delay and packet loss rate. In MSLND, the inter-frames such as the P and B frames are transmitted by employing UDP protocol while the reference frames, which are I-frames are transmitted via TCP protocol. One of the shortcomings of the TCP is transmission delay. However, to improve the delay, an ETX-TCP concept has been incorporated for selecting optimal and suitable route for video transmission. Meanwhile, the proposed solution has higher capability in retransmission of video frames. It 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-driven multipath strategy for video transmission in a vehicular network (LIAITHON) has been suggested to do away with route coupling problem [48]. The strategy focuses on location factors to choose a vehicle along the optimal multipath for video frame transmission. In addition, the LIAITHON uses forwarding area approach for minimizing broadcast collision and congestion issues. The strategy for the dispersed vehicle estimation is centered on computing the level of nearness of vehicles in order to 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.

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A video transmission that considers multipath strategy based on error correction for vehicular network (LIAITHON+) has been suggested. The LIAITHON+ is an extension of the LIAITHON, which was discussed in the previous paragraph. The strategy is aimed at minimizing collision and improving on packet loss rate [18]. It utilizes three paths concept to share and forward the video data frames from source vehicle to destination vehicle. However, the three paths transmission strategy considered might not be realistic for multiple path selections since the angular geometry is less than 45 degrees, most of the nodes at this range of angle normally interfered. In De Felice, et al. [20], a Distributed Beaconless Dissemination (DBD) protocol for real time video streaming transmission in vehicular environment has been suggested. It is an incorporated framework which aims to attain QoE in video transmission protocol. In addition, DBD, extends the performance of the MAC layer in WAVE/IEEE 802.11p by solving the issue of false forwarding. In Li, et al. [49], a video streaming concept based on routing optimization and joint coding based on non-centralized coding of video and coding based on network has been proposed. The optimization is between video quality and network lifetime, which is centered on the knowledge concept of the wireless visual sensor network. Similarly, Zou, et al. [50] suggested a priority-based flow optimization in multipath and network coding based routing. Further, a Field-centric Anycast Routing (FAR) for real time video has been suggested. The anycast routing focuses on the dynamics of electrostatic field strategy which is based on Poisson theorem in multipath transmission [21].

An investigation based on probability of multiple paths video frame forwarding in a multiple radio wireless network has been presented [51]. In order to assess the delay metrics, probability generation function is employed in such a way that smallest data rate of the channel is utilized to improve the video sub-stream. Further, Zhu, *et al.* [52] proposed a multipath provisioning approach considering cloud-driven scalable coding for video transmission 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 [53]. The multipath concept employs concurrent transmission, which has led 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 transmission is created by a collection of set of p vehicles (nodes) where $p = 1, \ldots, n$ and each vehicle is fitted with a distinct radio interface. Further, the wireless channels obtainable in the network is represented as C, such that $C = 1, \ldots, c$ and C_{Max} is the maximum bandwidth of each wireless channel. The wireless protocol, which is WAVE/IEEE 802.11p offers 1–4Mbps for Japan, 250Kbps for Europe region and then 3–27Mbps for the United State of America. All vehicular nodes are dynamic with changing velocity. In addition, vehicles function with fixed transmission signal power hence, having the same communication coverage. Consequently, a connecting link l amid two vehicles is said to be active when it is running on a distinct channel. A connecting link l_1 is coupled if it occurs that a particular signal coverage of a vehicle's collision domain such that another connecting link l_2 of a different path lie in same channel allocated to l_1. The coupled or interfered signal area is a shared physical signal coverage area of the communication region of forwarder and collector vehicle.

Considering connectivity, a graph G with a number of Points and Edges (P, E). The constituent of P are termed vehicle and constituent of E are named as connecting links amid points of the graph. The VANETs topology has been considered as a dynamic graph. Thus, assume G is a graph with a number of paths M. Usually a path that belongs to a graph consist of sequence of various points p that is, group of vehicles $p_1, p_2, p_3, \ldots, p_k \ni p_i p_{i+1}$ with an edge E, which is the connecting link amid two points $\forall i = 1, \ldots, k-1$. The length L_{th} of a distinct path is the aggregate of all edges in the path. Therefore, it is inferred that an angle θ in between a chosen multiple paths is inversely proportional to the interference or route coupling of the coverage area of each point in the multiple paths M.

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

Hence, an estimation of the dispersed angle θ need to be considered before video data forwarding of via the selected multiple paths based on line of sight of source vehicle to the destination vehicle. The route coupling or interference in the multipath can be minimized using the aforementioned concept, hence quality video streaming can be attained. The significant challenges of video transmission in vehicular network 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 a need to extensively deliberate on the nature of video frames to be forwarded in a certain path and the type of protocol to transmit distinct video frame. In this study, a two paths video streaming approach, which split video frames into two distinct

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flow for transmission has been designed and developed. The split video frames are categorized into reference-frames (I-frames) and neighbor-frame (P and B-frames). The routing protocol considered is the greedy geographical routing protocol, which does not incur high network overhead when compared to M-AODV.

The categorization of the video frames based on the standard of the MPEG compression, which include I-frame, P-frame and B-frame as depicted in Fig. 2. I-frames normally contains important information of the entire video and is encoded with the essential information of complete frame. It can be encoded self-reliant without the reference frame retrieving the frames of video streaming. P-frames are decoded by considering either other P-frames or I-frame of the video stream. Meanwhile, B-frames relies on both previous and the next frame following the P-frame or I-frame. Consequently, B-frames and P-frames are reliant-frames dependent on reference frame of the video.

The combination of the three video frames makes a group of picture. The I-frame is the direct and indirect 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 video stream quality during the period of transmission, priority level needs to be assigned considering the significance of the video frame. For example, the I-frame is essential in predicting both B-frames and P-frames, hence I-frames have 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 B-frames and P-frames. Reference-frames and neighbor-frames of the video are transmitted on primary and secondary paths respectively, which is based on geographical routing protocol (greedy-based routing). Hence, the primary path is with higher priority because of the I-frame compared to the secondary path for B-frames and P-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 based on link signal power, Bandwidth Capacity (BC), Signal to Noise Ratio (PSNR) and packet error rate 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 [54]. 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. 1). In multipath video transmission, the angle between the SVN and the two relay nodes from the corresponding two paths need to be considered.

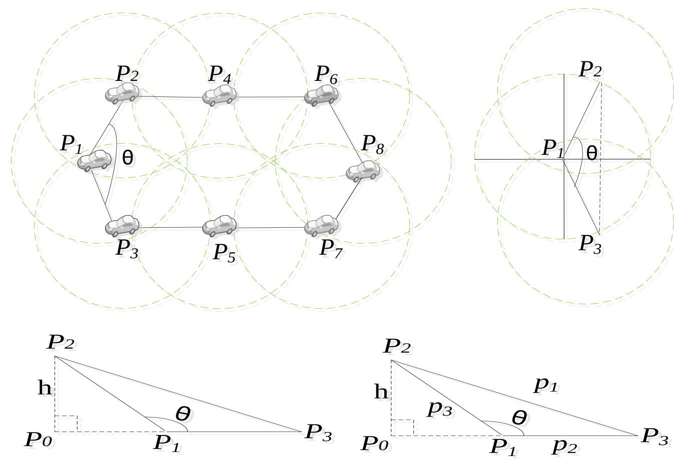

Fig. 1. Vehicular Communication Scenario Forms an Obtuse Triangle

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

$$\text{Area of } P_1P_2P_3 = [P_0P_2P_3] - [P_0P_2P_1] \quad (2)$$

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:

$$O_{area} = P_1P_2P_3 = {}^1\!/_2\, h \times b \quad (3)$$

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:

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

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

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 part, the signal coverage area of the vehicle node is explored for minimizing route coupling issue. A $SVN\ P_1$ is assumed to be at the center point of the diameter of the circular coverage area with two other vehicle nodes P_2P_3, and 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 are given as $90° > \theta < 180°$ until two vehicle nodes are found. The vehicle nodes are navigating in a network region and the presence of two vehicular nodes in the network region strictly obeys Poisson Distribution Function (PDF) considering vehicle node density λ. Considering the average density of vehicle nodes in a signal 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. [55] and Schmidt, et al. [56] 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 the vehicles is high, there is need for smaller transmission coverage in order to do away with interference, which leads to 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):

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

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

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

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:

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

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

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

D. Impact of Shadowing on Video Transmission

To achieve a more realistic probabilistic analysis of the availability of more than single vehicular node 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 signal coverage is employed for incorporating shadowing model considering obtuse triangle area. Transmission coverage is usually varied in terms of direction because of the impact of shadowing facing received signal power [57]. 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 considered Gaussian non-centralized random variable. The Fig.3 represent the description of the unblocked signal area and blocked signal area due to shadowing based on 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. The Log-normal distribution has been utilized because it precisely and perfectly models the difference in receive signal power that is due to shadowing [58]. Hence, by employing the distribution strategy, the likelihood 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)

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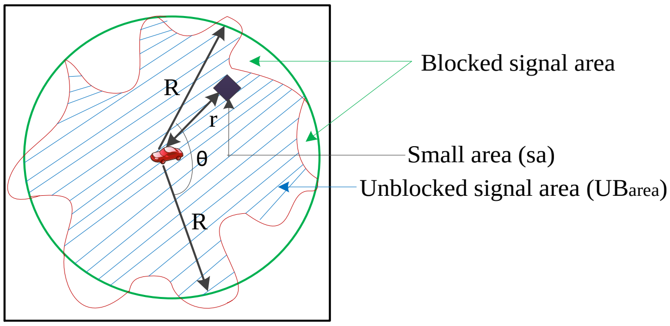

Fig. 2. Effect of Shadowing Circular Transmission Coverage

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

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^{SS}_{Oarea}, which is represented as follows in Eq. (15):

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

E. *Link Quality Model for Video Transmission*

In vehicular communication, vehicles have geographical information by using the 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 is utilized. Further, a shadowing concept that is more appropriate for vehicular communication is explored 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 depicted 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. The G_t and G_r are the antenna signal 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, a large size 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) is mathematically depicted in Eq. (17) as follows:

$$BC_D^V = \frac{\sum VD_T^Q}{PB_T} \quad (17)$$

Where VD_T^Q is the quantity of video data transmitted and PB_T is the playback period during video data transmission. In addition, signal to noise ratio (SNR) of connection 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):

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

The ap represents the amplitude of the fading channel using Rayleigh distribution, thermal noise signal power assumed as PS_{th} and PS_{inf} represents the interference signal power of the link. For purpose of exploring the packet error rate, the Bit Error Rate of the link (BER_l) is considered first, then the binary phase shift keying modulation is employed, which is shown in Eq. (19) as follows:

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

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

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

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

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

The length of the packet in bits is represented as LT and $f_q(w)$, which is the vehicle node dynamic function considering the

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stringent delay requirement for video delivery. Eq. (21) is the generic formula for PER_l caused due to link breakageand 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. The $z(w)$ represents the number of route changes and speed rate anticipated by the node in future to arrive a 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 is effective at minimum once in n retransmissions through multiple paths. Thus, the probability of efficient transmission is 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. Interference-aware Multipath Video Streaming Algorithm

In this subsection, the Interference-aware Multipath Video Streaming solution (I-MVS) algorithm is developed considering greedy-based geographical routing protocol. The I-MVS 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 I-MVS is presented as follows, starting with node disjoint algorithm, followed by next forwarding vehicle algorithm and then the main I-MVS algorithm.

The multipath video transmission concept considers node disjoint as in [9]. 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. This is done by matching all the vehicles 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 compared paths and the geometric angle relationship between nodes of the two paths. The matched vehicles 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 if all vehicle of the two selected paths are scanned, which is $O(n + m)$. In this situation, entire running complexity of the worst-case of Quick-sort procedure is $O(n^2)$. Although, Quicksort running complexity of the worst-case is avoidable, such that $n > m$. Hence, the worst-case running complexity is $O(n^2)$. The best-case situation of the Algorithm 1 happens if it occurs that fewer numbers of vehicles in a distinct path and the angle between the closest selected node is greater than 90° compared to another contending path. The best-case running complexity is $O(n)$, for the reason that single path is checked. In addition, running complexity of the best-case situation of Quick-sort is $O(n \log n)$. Hence, the running complexity of the best-case situation of vehicle-node disjoint algorithm is said to be $O(n \log n)$.

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: $\boldsymbol{If}\ \theta\ of\ the\ first\ two\ nodes{:}\ p_1\{i\}\ and\ p_2\{j\}\ is > 90° < 180°\ \boldsymbol{then}$
9: $Return\ (true)$
10: $\boldsymbol{Else\ if}\ Angle\ betweem\ p_1\{i\}\ and\ p_2\{j\}\ is \leq 90° \geq 180°\ \boldsymbol{then}$
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 $O(n \log n)$. Thus, the mean complexity of Algorithm 2 is $O(n \log n) + O(m+n)$. The worst-case situation of Algorithm 2 is if all the neighbor vehicles of a PFN of the two paths are scanned which is $O(n+m)$. For the worst-case scenario of quick-sort process, the complexity is $O(n^2)$. Even though, the computational complexity of the worst-case scenario for Quick-sort is avoidable 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 situation of the Algorithm 2 occurs if there are fewer number of neighbor nodes to PFN of the two paths. The best-case of the running complexity is $O(n)$, for the reason that only one or few neighbor nodes are, scanned from the two paths. In addition, the running complexity of the best-case situation of Quick-sort is $O(n \log n)$. Consequently, the running 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 Process p_1, p_2, i, j

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

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

In algorithm 3, the complete process of the I-MVS 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 **I-MVS**

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}: $Quality\ of\ single\ link\ of\ i^{th}\ vehicles\ in\ obtuse\ trian$
QV: $Qualified\ Vehicle\ is\ vehicle\ that\ fulfills\ all\ require$
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. $\boldsymbol{Initialization}$
   $SVOT = null$
   $VRN = null$
   $SVN = PFV$
   $\theta\ \ = 95°$
2. $SVOT =$ {vehicles in the transmission range of PFV}
3. $\boldsymbol{If}$ node disjoint and $\begin{pmatrix} SVN\ is\ neighbor \\ of\ DVN\ \text{and} \\ SVN == \\ VSN \end{pmatrix}$ $\boldsymbol{then}$
   Forward the video packet directly to DVN using two QV from VSN
   $\boldsymbol{Exit}$
4. **Else**
   While ($DVN \in$ SRV and $SVN \neq VSN = NFV$)
   Forward the video packet to DVN using two qualified link
   $\boldsymbol{End\ while}$
5. $\boldsymbol{Else}$

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 θ *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 each link
$$\text{Eq. (17): } BC_D^V = \frac{\sum VD_T^Q}{PB_T}$$
End for
7. **For** *each vehicle* $\in SVOT$
Calculate packet error rate PER_{Mpath}^n of neighbor n
$$PER_{path}^n = (1 - (1 - PER_l^n)^k)$$
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 I-MVS Algorithm

The I-MVS algorithm executes steps 1-13, whenever the vehicle source node SVN transmits video packet to a certain destination vehicle node (DVN) in the network. The step 1, is the initialization of variables. In the second step, the SVOT acquires information about the positions of their immediate neighbor's node position with reply timestamp. This information is 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 by 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 the understanding of the steps and logical flow in the algorithm. The computational complexity of the I-MVS 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 are generated by means of MATLAB to examine the effect of parameter variations on the mathematical functions. The corresponding set of values of different parameters needed to generate the results are 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. 3.

Considering the results shown in Fig. 3(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. 3(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. 3(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

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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.

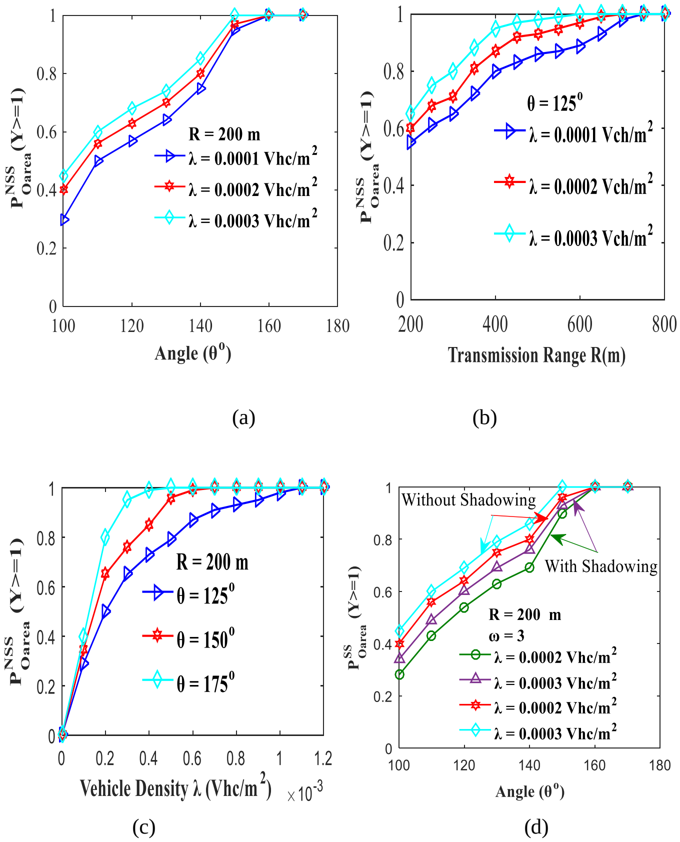

Fig. 3. The probability of availability of one or more vehicle in the obtuse triangle area (a) and (b) represents the availability of vehicle considering angle and transmission coverage respectively, (c) and (d) represents vehicle density and angle NSS and SS.

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. 3(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 result (see Fig. 4), we depict the probability of packet error rate in one hop coverage considering non-shadowing and shadowing settings.

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. 4(a, b, c and d). The result presented in Fig. 4(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. 4(a and b)) due to achieving load balancing, path diversity and minimization of interference between two paths. The whole of the observations has been employed for the selection of next forwarding vehicle with the best link quality for video streaming. Further, the result in Fig. 4(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.

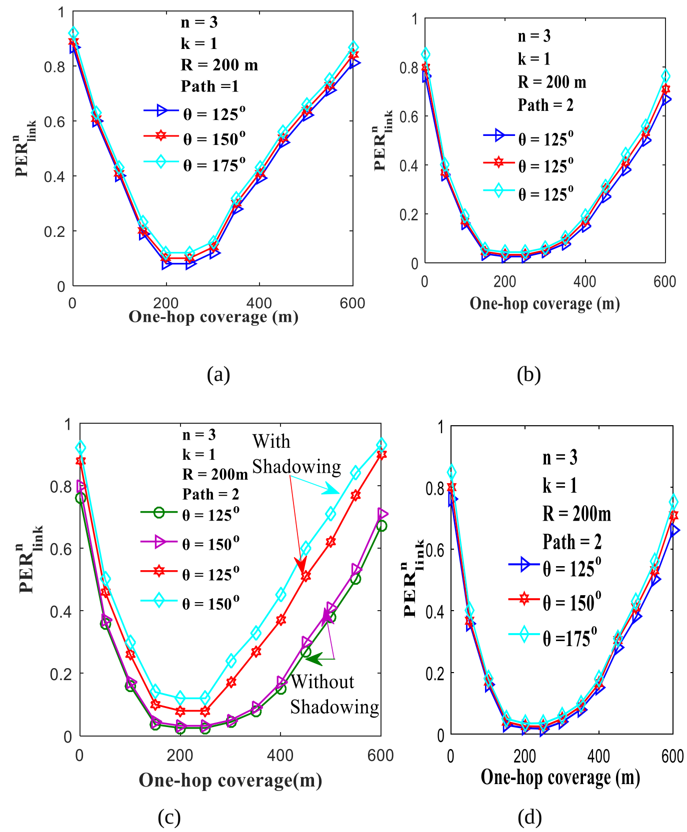

Fig. 4. Represent impact of parameters on PER_{path}^{n} (a) and (b) single and multipath in a non-shadowing settings, (c) and (d) single and multipath in shadowing settings.

B. *Simulation and Results Analysis*

The results of simulations conducted to examine the performance of I-MVS 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 I-MVS 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 I-MVS are compared with two baseline protocols namely, MSLND and FEC. First, we will discuss the simulation environment and setup.

1) *Simulation Settings*

I-MVS has been implemented using the network simulator NS-2.34 [59], Evalvid [60] and mobility model generator for VANETs (MOVE) from Simulation of Urban Mobilty (SUMO) [61]. 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

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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

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 I-MVS 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. 5). 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 I-MVS 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.

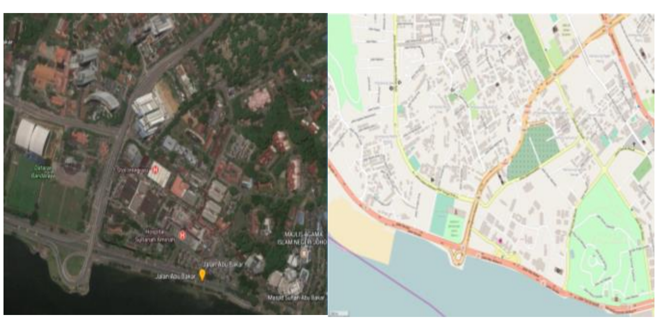

Fig. 5. City Map of Johor Bahru Malaysia

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 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. Table 1, presents simulation parameters and criteria considered for implementation of I-MVS protocol.

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	- I-MVS -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 the overall received video packets divided by the 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

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evaluation of all metrics is the same as that of the simple lane scenario.

2) Simulation Settings

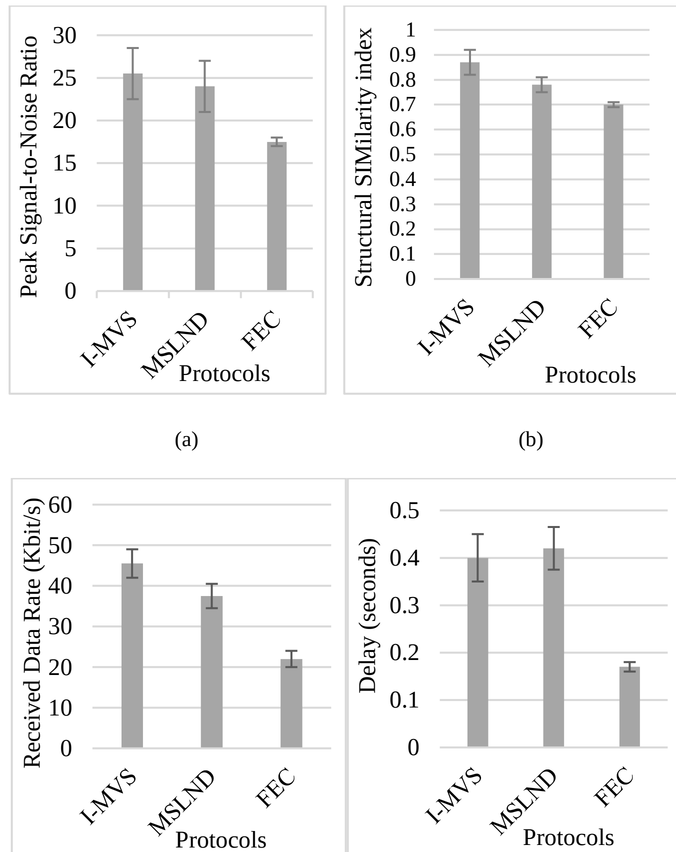
In this subsection, the following video quality metrics are employed to compare the performance of the I-MVS with the baseline protocol. The metrics include PSNR, SSIM index, received data rate and end-to-end delay. The details of these metrics have been discussed in our previous research paper [62].

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. 6(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. 6(a). Further, the results for Structural SIMilarity (SSIM) index are presented in Fig. 6(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 I-MVS offers a better video quality than that of MSLND and FEC. This is because I-MVS 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 maintaining the quality of other noticeable frames which are being 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. 6(c), I-MVS has a higher received data rate when compared with MSLND and FEC. The simple reason is that I-MVS considers interference at each selected node and 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.



(c) (d)

Fig. 6. 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.

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 I-MVS compared with MSLND and FEC are presented in Fig. 6(d). The result demonstrates that I-MVS achieves slightly lower mean delay as compared to the MSLND. Even though, the delay is relatively high, however it is lower than that of the MSLND. 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 as compared to that of the MSLND. Despite the high delay, I-MVS has not exceeded the allowed maximum delay of 0.5 seconds, which is realistic based on the human eye perception. Meanwhile, further research could be conducted in order to minimize the mean delay.

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 I-MVS 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 I-MVS on different vehicle densities. The results of the video quality obtained are presented in Figs. 7(a)-7(d). The Figs. 7(a) and (b), demonstrate that I-MVS 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. [9] 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 I-MVS attains a higher mean video quality as compared to that of MSLND and FEC in the simulation.

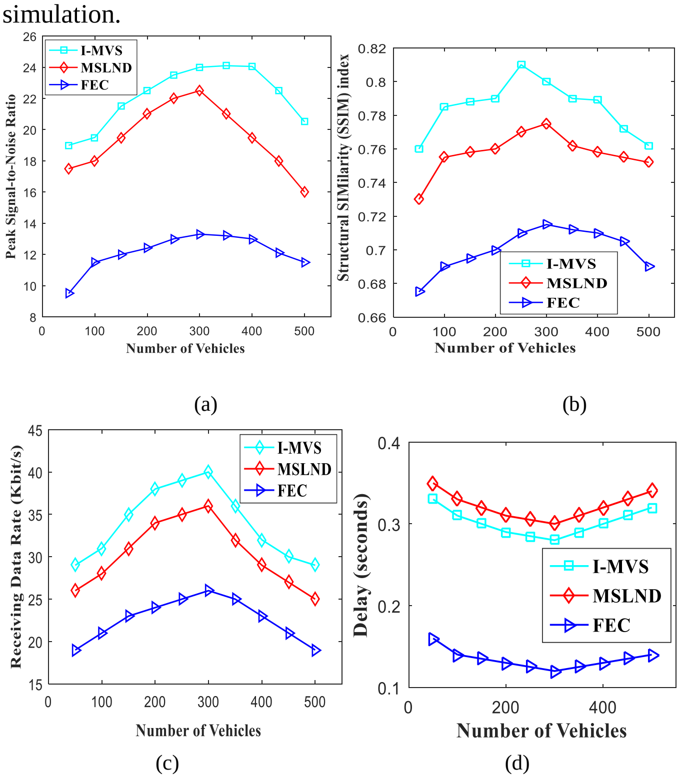


Fig. 7. The result of simple lane scenario. (a) and (b) represents the result of PSNR and SSIM index compared with different vehicle density respectively, (c) and (d) represents the result of receiving data rate and delay compared with different vehicle density respectively.

The receiving data rate result for the three different protocols is presented in Fig. 7(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 I-MVS. The simulation result demonstrates that the has the highest mean received data rate as 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. 7(d). The delay of I-MVS 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 I-MVS protocol can be improved.

V. Conclusion

In this paper, an interference-aware multipath video streaming framework considering node disjoint and link disjoint 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 the 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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