Video Streaming over Vehicular Ad Hoc Networks: A Comparative Study and Future Perspectives

Kayhan Z. Ghafoor

Department of Software Engineering, College of Engineering, Salahaddin University
Kirkuk Road Erbil, Kurdistan Region – F.R. Iraq

***Abstract*—Vehicular Ad Hoc Network (VANET) is emerged as an important research area that provide ubiquitous short-range connectivity among moving vehicles. This network enables efficient traffic safety and infotainment applications. One of the promising applications is video transmission in vehicle- to-vehicle or vehicle-to-infrastructure environments. But, video streaming over vehicular environment is a daunting task due to high movement of vehicles. This paper presents a survey on state-of-arts of video streaming over VANET. Furthermore, taxonomy of vehicular video transmission is highlighted in this paper with special focus on significant applications and their requirements with challenges, video content sharing, multi-source video streaming and video broadcast services. The comparative study of the paper compares the video streaming schemes based on type of error resilient technique, objective of study, summary of their study, the utilized simulator and the type of video sharing. Lastly, we discussed the open issues and research directions related to video communication over VANET.**

***Index Terms*—Applications of VANET video transmission, Cooperative collision avoidance, Vehicular networks, Video streaming.**

I. INTRODUCTION

Recent technology booming have a key role in developing various types of networks and then deploying them based on their specific applications. In the past decade, Vehicular Ad Hoc Network (VANET) has experienced more attention from the academia and automotive industries (Zeadally, et al., 2012; Bernsen and Manivannan, 2008).

Vehicular network is a type of wireless ad hoc network that enables ubiquitous connectivity among vehicles in the vicinity. At the present time, the importance of vehicular network is tremendously increased because of its unprecedented applications in transportation system - such as traffic management, safety, and efficiency as well as on-road infotainment (Hartenstein and Laberteaux, 2009). These traffic applications would appear through the existence of VANET because of its prompt convergence with Intelligent Transportation System (ITS). The promising future of vehicular network is a motive for automotive manufactures, researchers and governments to increase their efforts toward creating a standardized platform for vehicular communications. Particularly, the 5.9 GHz spectrum band has been allocated for licensed Short Range Communication (DSRC) between vehicles (Lochert, et al., 2007; Karadimas and Matolak, 2014). In the near future, more vehicles will be embedded with devices that facilitate communication between vehicles, such as Wire- less Access in Vehicular Environment (WAVE) (ITS-Standards, 1996). When vehicles are equipped with WAVE, they can communicate with nearby cars and access points within their coverage area. However, although many steps have been taken towards fulfilling the aforementioned applications efficiently, many challenging issue still remain to be solved due to its high topology changes, unreliable communication channel between vehicles and scarce of on-board resources (Whaiduzzaman, et al., 2014; Kakkasageri and Manvi, 2014; Dias, Rodriguesand and Zhou 2014).

Nowadays it is observed that car industries are manufacturing intelligent vehicles which are embedded with efficient storage, have good computation power and have the capability to communicate with other devices (Wired, 2014). Passengers also can use Internet inside their vehicle by using the emergence mobile internet technology like Long Term Evolution (LTE). Thus, in the near future road users can ubiquitously communicate with nearby wireless nodes and this will improve the driving safety, traffic efficiency and environment pollution (Chen, et al., 2010; Tripp-Barba, et al., 2014). However, these applications would provide clear vision to the drivers and passengers if high quality video is exchanged among nearby vehicles.

ARO-The Scientific Journal of Koya University
Volume IV, No 2(2016), Article ID: ARO.10128, 12 pages
DOI: 10.14500/aro.10128
Received 22 February 2016; Accepted 16 April 2016
Review paper: Published 22 October 2016
Corresponding author's e-mail: kayhan@ieee.org

We are motivated because video streaming over vehicular networks is significant to satisfy the passenger and driver requirements. Video camera has been embedded in many premium vehicles and trucks. This camera is not only provide a clear vision to the driver of the truck, but also increases the traffic awareness of nearby vehicle drivers if the video frames are shared with them. Moreover, video camera is installed in all intersections and all of them are embedded with wireless device. Thus, establishing a network of these cameras can be useful for tele-medicine. For example, a video camera captures traffic accident at the intersection and then it is forwarded to nearest hospital for required medicine (Wu and Ma, 2013; Asefi, 2011; Chaqfeh, Lakas and Jawhar, 2014; Chen, et al., 2014). Infotainment applications of video communication among vehicles are also helpful to make this emerging network quickly penetrate in the market. One of the interesting comfort-related applications is commercial advertisement on the road. For instance, a vehicle may visit a place for shopping purpose and it will receive video frames on current sales and special offers nearby supermarkets and shops (Wu and Ma, 2013; Asefi, 2011).

Although video streaming over vehicular networks is advanced and a become room for research, unfortunately there is no comprehensive survey to help the readers understand thoroughly the recent techniques of video streaming. In line with the growing interest of video streaming over VANET, this paper firstly presents a concise description of the background of vehicular networks and especially highlighting the video transmission over VANET. This is followed by presenting and elaboration of a comprehensive taxonomy for video streaming techniques in VANET. That is, multi-source video streaming, video broadcast and video content sharing. Then, each type of the aforementioned classification will be demonstrated and the motivation behind their design as well as trace the performance evaluation of the existing techniques. Finally, the paper discusses the possible future research directions. To the best of our knowledge, this review article is the first research study on advances of video streaming in vehicular networks.

The rest of the paper is structured as follow: Section II highlights vehicular networks. Section III thoroughly discusses the applications, requirements and challenges of video transmission among vehicles. An overview and motivation of video streaming over VANET are discussed in section IV, where we thoroughly highlighted the existing protocols under the categorization of multi-source video streaming, video broadcast and video content sharing, Section V discusses the prospective research opportunities and directions. Finally, Section VI concludes the paper and discusses important recommendations.

II. The Vehicular Network

Recently, auto car makers are made their efforts to design smart vehicles for the purpose of achieving safe and comfortable driving experience. These car innovations are observed in new cars as they are equipped with GPS, short range collision avoidance system, front and back camera, and embedded wireless sensors (Chen, et al., 2014). These facilities are necessary to warn the drivers for any possible abnormal road conditions and vehicle's mechanical defects. Moreover, vehicles have efficient on-board power, computation and communication capability (Xie, et al., 2007; Tonguz and Boban, 2010; Soldo, et al., 2008).

With these smart vehicles, cars are able to talk to each other and be aware about their neighbors. Thus, vehicular networks are a promising field of study and gained the attention of many researchers from both academia and industry. The deployment of such important system will open up a flourish path for safer driving experience (European-ITS, 2009). For instance, vehicles in the vicinity can exchange information for collision avoidance and traffic flow control. This will probably decrease death tolls on the roads. To support such important technology, an association of thirteen automobile companies assured that V2V has potential to reduce traffic accidents tremendously and hence save lives of people. For this reason, FCC allocated 5.9 GHz spectrum band for licensed Short Range Communication (DSRC) between vehicles.

III. Video Streaming Over Vehicular Networks: Applications and Requirements

This section presents prospective applications and implementation scenarios of video streaming over VANET (Belyaev, et al., 2014; Boukerche, et al., 2009; Belyaev, et al., 2014; Lin, et al., 2009). Table 1 presents video transmission applications and requirements which will be discussed in the following subsections.

A. Overtaken Maneuver

One main concern of traffic safety is wrong overtaking maneuver in highway or urban areas, which causes serious accidents. In real traffic scenarios, an accident due to wrong overtaking leads to a series of vehicle to vehicle crashes. This seriously obstructs the traffic fluidity and results the road congestion or another accident. These traffic accidents can be simply avoided if vehicular network technology is enabled between vehicles (Toledo-Moreo, et al., 2009; De Sousa Vieira, et al., 2013; Ruder, et al., 2002; Yasmeen, et al., 2015). More importantly, live video streaming from trucks to the following vehicles increases driver's aware- ness about oncoming vehicles and it is helpful to the driver for any overtaking decision. The crucial requirement of such system is strict end-to-end delay be- tween obstructing vehicle and overtaking cars. As it is mentioned by Vinel, et al., (2012), the required delay should not exceed 200 ms with acceptable perceived video quality. However, there are several challenges for real time video streaming over vehicular networks, such as unreliability of the wireless channel, shadowing and multi-path fading.

B. Pedestrian Crossing Assistance

Pedestrian is the ordinary people who use the roads and experience risk due to carelessness and erroneousness of drivers or pedestrian themselves. One of the most glaring problems of transportation system is pedestrian-vehicle crashes since it is considered as a threat to human lives.

C. Public Transport Assistance

Recently the fuel cost is increasing as well as the researchers have alerted the high pollution of the environment due to carbon dioxide emission. These reasons made the people to use public transportation and their safety should be strictly considered. Uncommon vehicles (like ambulance, garbage truck or public bus) are embedded with video camera to provide cognizance capability to the drivers. The live video output of the camera would be useful to the vehicles which are close to the premium vehicle. In rare traffic scenarios, the vehicles that overtake the buses might hit the disembarking passengers. As it is illustrated in Fig. 1, vehicle number 2 might crash with the passenger who is just get off from the bus and intends to cross the road. This vehicular network application is considered as an important urban safety service that prevents passenger death or injury.

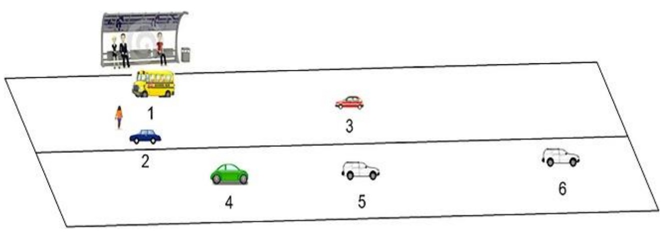

Fig. 1. Public Transport assistance.

The transmitted video should exhibit a strict low latency and good visual quality since this application treats the human lives. However, the main challenge with this scenario is the effect of Doppler phenomena that causes the frequency shifting between transmitter and receiver.

D. Video Surveillance

Nowadays anti-social behavior such as crimes, robbery, irritating people and terror acts are tremendously increased. Real time video surveillance in- side/outside vehicles are very crucial to prevent such behaviors. In this scenario, a vehicle transmits coded video to the infrastructure network and that video could be a call for traffic accident or heath condition of the passengers of crashed car. Furthermore, live video on moving public transport is streamed to the control center to abolish any crimes (Ahmad and Habibi, 2010). But, live video streaming for surveillance purpose is a daunting task due to harsh environment of vehicular network such as high mobility, large obstacles and bipolar traffic conditions.

E. Video Communication for Entertainment

Promising applications in vehicular network have been classified to traffic safety and management, and infotainment applications. The latter one provides comfort and entertainment- related information and useful advertisement to the passengers. This application contributes the success of vehicular network and speedup its market penetration (Campolo and Molinaro, 2011; Myllyniemi, Vehkapera and Peltola, 2007; Ghafoor and Bakar, 2010). Moreover, both academia and industry are approved the benefits of video communication for infotainment and advertisement services. Table I outlines the video transmission applications and requirements.

TABLE I
VIDEO TRANSMISSION: APPLICATIONS AND REQUIREMENTS

Video transmission applications	Benefits	Network Architecture	Requirements		Challenges
			End-to-end delay	Perceived video quality	
Overtaking maneuver	Highway traffic safety	Vehicle-to-Vehicle	Delay between video capturing and displaying should not exceed 200 ms.	The video quality should be acceptable	Obstruction of video transmission signal due to moving obstacles (vehicles) and high speed of vehicles.
Pedestrain crossing assistance	Urban traffic safety	Vehicle-to-Vehicle	Strict low latency	Acceptable video quality	Mobility is not a big concern since vehicle travel in low speed in pedestrian crossing areas. Moving or static obstacles are considered as great challenges.
Public transport assistance	Public transportation traffic safety	Vehicle-to-Vehicle	Strict low delay	Acceptable video quality	T bus stations, public transport vehicles broadcast live video to overtaken cars. In this case, Doppler frequency shifting would be the main issue.
Video surveillance	Public urban or highway security	Vehicle-to-Infrastructure	Delay should not exceed 6 sec as it is acceptable for video surveillance	Visual quality of not less than 25 dB is good	Mobility of in-road enabled video surveillance of wireless channel and obstacles
Video communication for entertainment	Infotainment	Vehicle-to-Vehicle and Vehicle-to-Infrastructure	Low latency	Average video quality of 29 dB is acceptable	High mobility of vehicles, radio obstacles, Doppler effect due to relative speed of vehicles.

As illustrated in Table I, infotainment relies on both V2V and V2I network architectures. Vehicles can exchange video information like games for entertainment while in V2I the infrastructure advertises contextual information about tourist places, updated news or locations that traffic jam occurs. Such video transmission requires low delay and acceptable video quality as (29 dB). However, the delay and video quality for infotainment applications is not as strict as in the traffic safety services. The main challenge of video transmission in such harsh environment is the rapidly changing of network topology and radio obstacles.

IV. Video Streaming Over Vehicular Network

Video streaming over vehicular networks is a need for many applications. Video disseminating of news or commercial related information to the drivers/passengers can be considered as an important application for transportation systems. For safety applications video frames can be used to clearly show the traffic scene in the accident area. Also, video contents can save life of thousands during search and rescue operation in any unexpected event.

Video services are considered as one of the challenging issue in mobile wire- less networks (Bohrloch, et al., 2011). There are different factors that affect the vehicular network performance like high vehicle mobility, fast change of topology and fast and slow fading due to multi-path signal dissemination. The high speed of vehicles causes frequent connectivity interruption which leads to performance degradation.

As compared to data transfer application and even voice-over-IP or video conferencing, video content streaming requires bounded end-to-end delay and sufficient bandwidth. These requirements have long been addressed in cable networks while they still a room for research in mobile wireless networks like VANET. This is because vehicles use a shared medium and this will shrink the utilized bandwidth. With the challenges of VANET, providing a satisfactory perceived video quality to the client's needs more research. The overall structure of video streaming schemes is depicted in Fig. 2.

A. Video Content Sharing Mechanisms

As discussed in the aforementioned section, video streaming over vehicular network is a challenging task (Tal and Muntean, 2012; Park, et al., 2006; Ghafoor, et al., 2012; Venkataraman, et al., 2010; Dias, et al., 2011). The problem is more glaringly appear when a video data is transmitted via multi-hop towards a destination. The reason is that video data could not tolerate high end-to-end delay between source and destination. Thus, for smooth playback of video data at the destination tightly relies on the selection of most reliable and stable path toward the video receiver. On the other hand, vehicles are frequently changing their point of attachment from one network to the other and this leads to the intermittent of video streaming continuity. To tackle the aforementioned issues, the authors in (Asefi, 2011) proposed quality-aware geographical packet forwarding from a infrastructure network to the destination vehicle on the road. The startup delay and Peak Signal to Noise Ratio (PSNR) of delivered video frames are utilized as metrics for delivering video packets towards the destination. At the receiver, video playback depends on the collection and playback phases. The collection phase is defined as storing of incoming packets when the buffer is empty while the playback phase starts once the buffer is filled with threshold number of packets. Moreover, PSNR is used to select a high quality path with minimum end-to-end video frame distortion.

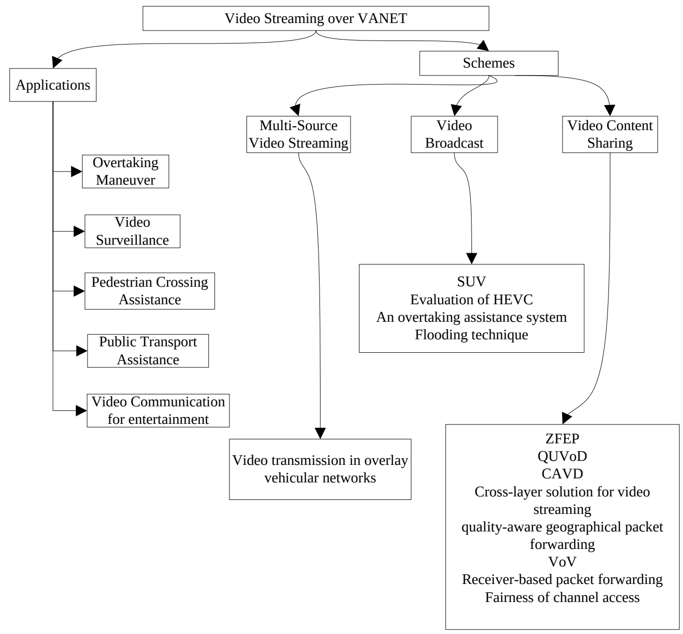

Fig. 2. Taxonomy of the literature on video streaming over VANET.

In vehicular environment, the destination vehicle usually moves from the coverage of one Access Point (AP) to the other one. Thus, the authors in (Asefi, 2011) also tackled IP mobility management for the purpose of improving visual quality of transmitted video, when the destination vehicle changes its point of attachment from one AP to the other one. Fig. 3 shows the vehicular network topology that is considered by the proposed solution. As can be seen, the radio communication range of every AP is 350 m and the APs are spaced with a distance of 1.2 Km. With this settings, two nearby APs could not cover 600 m distance and multi-hop V2V would be used for packet forwarding toward the infrastructure network. Simulation result shows that the proposed method improves the quality of transmitted video especially in dense traffic scenario than sparse distribution of vehicles.

To support video streaming from the Road Side Unit (RSU) to the destination vehicle, the authors in (Xing and Cai, 2012) proposed adaptive video streaming algorithm that composed of three main functions: neighbor discovery, next hop selection strategy, and video quality adaptation scheme. Firstly, the adaptive video streaming algorithm enables the vehicles to handshake and synchronizes by using beacon message. Through beacon message communication, vehicles can learn about their one-hop and two-hop neighbors. However, beacon message generates overhead on the wireless channel among vehicles. To tackle this problem, the authors bounded the number of neighbors to Z . In the other words, if the number of nearby vehicles exceeds Z , the overhead mitigation mechanism randomly selects Z neighbors.

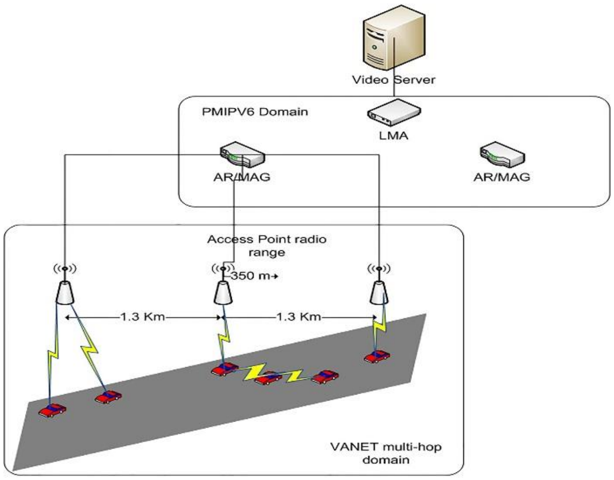

Fig. 3. VANET V2V and V2I scenario for the proposed mechanism in (Asefi, 2011).

In the second algorithm, the vehicle, which receives video data, searches for the next candidate relay vehicle within its radio coverage. A vehicle V C is considered as a best candidate if it has a highest link data rate (closest to the RSU) with the RSU. In addition, it is necessary to mention that the Scalable Video Coding (SVC) is used to encode the video frames into layers. In SVC, each video frame is coded into layers; a base layer and several enhancement layers. Base layer is very significant in the process of successful video file decoding at the receiver while enhancement layers have the role of improving the quality of video frames. In the other words, despite packet losses of the enhancement layer, the receiver can decode the video frames successfully.

The third part of proposed algorithm adapts the perceived video quality with the link data rate between a vehicle with the serving RSU and the receiver buffer level. More particularly, a vehicle adapts the requested number of enhancement layers from a RSU with respect of its buffer level and link data rate between itself and the RSU. To clarify, the link data rate is important for the receiver vehicle to support the acceptable video quality. Likewise, the receiver buffer level is crucial to be considered for video quality level tuning. The reason is that sometimes a vehicle may experience no connection with the RSU. In this case, the vehicle should buffer enough video frames for smooth playback in later time.

The authors conducted a performance evaluation of the proposed algorithm in MATLAB® and highway vehicular scenario with two lanes. The evaluation also considered real video traces of "Big Buck Bunny" which is consisted of 600 video segments. For benchmarking, the authors compared the proposed algorithm with the non-cooperative relaying mechanism by using startup latency, interruption ratio and average playback quality. The adaptive video streaming performs the best in terms of the aforementioned metrics as compared to the non-cooperative relaying approach.

Peer-to-peer (P2P) content distribution is witnessed to be a groundbreaking trend in vehicular networks. One of applications of P2P multimedia services is the vehicular Video-on-Demand (VoD) that provides edited video file to the vehicles on the road. Enhancement of Quality-of-Experience (QoE) of VoD applications is a pressing need. In this context, the authors in (Xu, et al., 2013) proposed inter- active quality-aware user-centric mobile VoD mechanism for VANET (QUVoD). As can be seen in Fig. 4, the QUVoD is based on multi-homed P2P/VANET architecture and mechanisms for storing video frames, video segment retrieval, and multi-path packet forwarding. Simulation results show the better performance of the proposed algorithms as compared with the state-of-the-arts solutions.

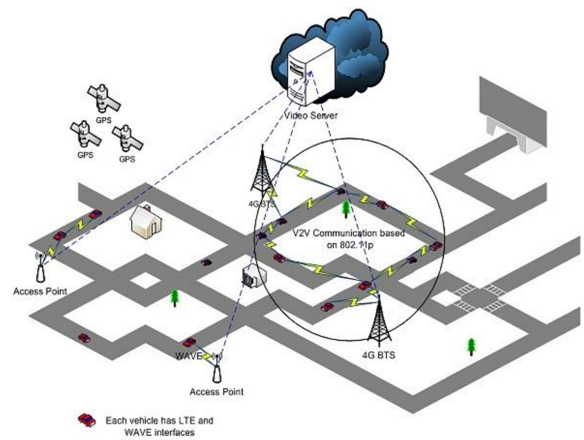

Fig. 4. QUVoD system for vehicular networks.

Traffic control system in world's countries use wireless enabled camera in order to let them be aware the traffic violation, car accidents or unusual transportation conditions. For instance, if a car crash occurs in urban or high- way vehicular environment, traffic control center informs nearest medical center to send ambulance to the accident area. With wireless enabled camera, paramedics could realize the required medical equipment to the accident scene. To achieve this scenario, the authors in (Wu and Ma, 2013) proposed existing traffic camera assisted (CAVD) live video streaming in VANETs. The purpose of CAVD is to stream the video frames from the accident spot to the mobile target vehicle (ambulance). For this purpose, they developed a scheme to optimally select intersection cameras using Optimal Buffering Point (OBP). Thus, the camera- based wireless network could forward the video frames with minimum start- up delay, reasonable perceived video quality and playback performance. In the performance analysis, the authors assured the superiority of their method as compared to the architecture of V3 that introduced by Guo, et al. (2005) - which streams video from a static node to the vehicles - and Trajectory-based statistical forwarding (TSF) (Jeong, et al., 2010).

As illustrated in Fig. 5, cameras are installed in all road junctions to monitor the traffic condition at the intersections. Each camera is equipped with wireless device to enable its communication with other devices. More precisely, each camera could get the traffic information- vehicular arrival rate, speed and density- for each road segment and tag this information with time and then broadcast to all camera network. In this way, all cameras are aware about the traffic information of the whole city. Likewise, vehicles that they travel nearby the cameras will get such traffic information through wireless interface of the installed camera.

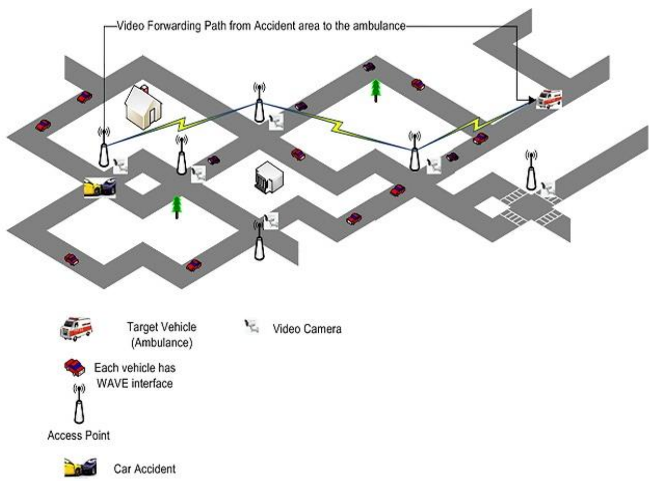

Fig. 5. Video streaming from accident area to the ambulance.

As it is witnessed by many researchers the network congestion will increase channel access delay at the MAC layer and hence some video frames will lately reach the destination. Thus, these delayed frames are not useful in recovering video file at the destination. To this end, the authors in (Puangpronpitag, Kasabai and Suwannasa, 2013) proposed the cross- layer solution for video streaming in a VANET application, which is overtaking assistance system. This V2V application uses windshield camera that mounted on vehicles. As illustrated in Fig. 6, the driver vision of vehicles 1 and 4 are blocked due to trucks 2 and 3. In this case, the video of the front scene is recorded by the trucks 2 and 3 and then streamed to the vehicles 1 and 4. With the help of this received video, the drivers of vehicles 1 and 4 can decide whether to overtake the trucks.

The proposed method adapts the video traffic with the current network capacity. More clarified, if the collision rate in the medium exceeds during a frame F transmission, discard this F frame and transcode frame F +1 and reduce the frame rate to half value. Usually if the time delay of a frame F exceeds the threshold value, this frame is useless in the decoding process of a video file. Thus, it is logical to skip this frame. Besides that, frame rate at the application layer is reduced if there is congestion in the network level. The frame rates of 30, 15, and 7.5 frames/second have been used in the performance evaluation. The simulation analysis was done in OMNeT++ packet level simulator with IEEE 802.11p MAC layer. The results show the acceptable network latency that is within the range of standard video frame delay - which is 100 ms - (Baldi and Ofek, 2000).

In some places on the highway or urban areas, vehicles want to download video files such as video news and entertainment games. In such environment, V2V is susceptible to intermittent connectivity likewise infrastructure is not promptly existing.

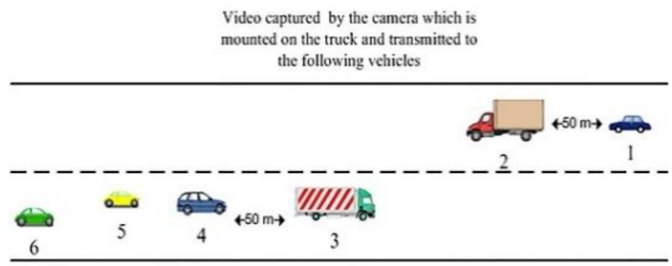

Fig. 6. Video streaming service to assist drivers during car overtaking.

For this case, exploiting both V2V and V2I is a significant need to support large file size downloading from neighbor vehicles or nearby infrastructure. To this end, the authors in (Sou, et al., 2011) proposed a Zone-based Frame Exchange Protocol (ZFEP) for video sharing among nearby peers. The idea of ZFEP is to exploit V2V and V2I for video communication among vehicles. For instance, drivers/passengers can exploit infrastructure to download video frames when neighbor vehicles are not exist in the area.

The users conducted numerical simulation and the results show their method is superior in terms of download speed and video quality. In another attempt, the same authors in (Shieh, et al., 2011) presented a mechanism for video frame sharing (VFSM) for sparse vehicular network. They improved the efficiency of video downloading from road side unit by enabling cooperation among vehicles that they have compatible interest. In such a way, vehicles can request video frames from the infrastructure using V2I whereas sharing the downloaded video with neighbor vehicles using V2V.

Toward the task of an efficient video dissemination in sparse and dense traffic conditions, the authors in (Maia, et al., 2013) proposed video transmission over VANET (VoV). In dense traffic condition, a mechanism has been developed for broad-cast overhead mitigation. The designed method partitioned the radio range to forwarding zones. A vehicle determines whether it's in the forwarding zone or not to compute the waiting time. The highest priority is given to vehicles that they are inside the forwarding zone and have farthest distance to the source. However, if the source faces the intermittent connectivity, that vehicle stores the message in its local cache for a limited period of time. Besides that, a vehicle that stores the messages inform nearby vehicles about the stored packets. This is done by piggybacking received message ID in the period of beacon exchanging and sending them to the vehicles in the vicinity.

Federal Communication Commission provided seven nonoverlapping channels in the frequency band of 5.85 GHz. One of these seven channels is allocated to transmit control information like beacon and event-driven messages. The rest of channels are used to transmit non-safety information. As all channels have one antenna, a transceiver hops from a SCH to the CCH or vice-versa. This channel switching generates a synchronization problem in IEEE 802.11p. As illustrated in Fig.7, MAC layer fetches a sequence of packets from the upper layer and at this moment the CCH channel is active for transmission. In this case, the received packets are saved in the local buffer of a vehicle until the SCH would be active. When the SCH become active, the MAC layer tries to forward all cached packets at the early first moments of SCH activation and this also happen in the nearby vehicles. Since all the vehicles want to transmit their buffered packets, the network performance will be drastically deteriorated. To address the aforementioned problem, the authors in (Maia, et al., 2013) proposed a rate control mechanism that finds out the rate at which the VoV should send packets down to the MAC layer.

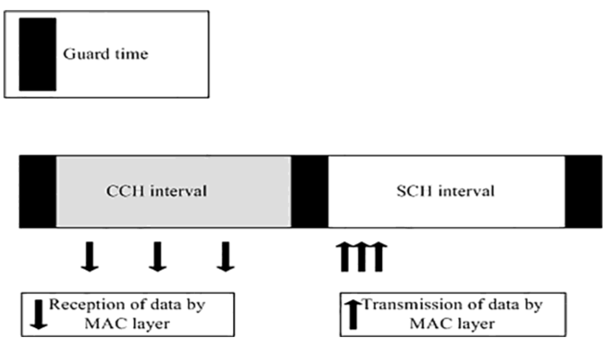

Fig. 7. Large number of packet transmission at the beginning of service channel.

Rezende, C. (2012) proposed receiver-based packet forwarding mechanism for video streaming in vehicular networks. Each relay vehicle uses the distance to the destination and contact time to calculate the waiting time that is utilized for vehicle’s self-election. Particularly, the contact time represents a limited time window in which the winner relay vehicle will continue to forward packets without re-self-election of intermediate vehicle that occur in each single hop. This time window can be computed by the location tracking mechanism to predict the vehicle’s future location and hence estimate the time window among neighbor vehicles. In such way, their method is trading-off between link stability and fast advancement of video packets transmission toward the destination.

The performance evaluation of the proposed solution and state-of-the-arts (normal receiver-based algorithm and Guided Gossiping (GG)) is simulated in NS2 and freeway mobility model. GG disseminates the packet toward the destination while receiver-based mechanism uses greedy metric for relay self- election. For the transmitted video, the MPEG video file with 300 frames and with resolution of 360×486 is used. The cost metric is measured by a ratio of total number of transmissions to packets sent. Simulation result shows that the proposed solution outperforms the benchmark schemes as it can forward more packets successfully with less frame loss and acceptable delay.

Following their work on improved receiver-based packet forwarding to minimize delay of routed video packets towards destination, Rezende et al. (2013) evaluated the performance, in terms of successful delivery rate and enhancement of video transmission quality, of two erasure techniques named random linear network coding (Li, et al., 2003) and XOR-based coding (Li, et al., 2004). The performance evaluation was done using freeway mobility model and NS2 simulation tool. Results have shown the XOR-based coding successfully forwards more packet than random linear network coding with similar rate of redundancy. Thus, in XOR-based mechanism, the majority video file content is recovered at the receiver vehicle.

The authors in (Xu, et al., 2012) implemented the performance analysis of different routing protocols (AODV, DSDV, GPSR) for video transmission over realistic VANET environment. The utilized simulation tool is incorporated myEvalvid (Ke, et al., 2006), NS2 (NS, 2011) and VANETMobiSim (VANETMobiSim, 2014). After conducting a comparative simulation in VANET-EvalVid realistic environment, the authors shows the superior performance of GPSR protocol with respect to the AODV and DSDV for good visual quality of video frames. They also demonstrated that the quality of transmitted video is better in dense traffic condition than sparse distribution of vehicles.

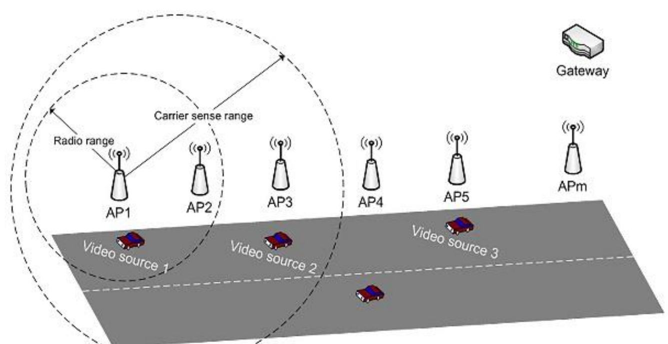

Fig. 8. Channel access starvation scenario in 802.11p.

As it is illustrated in a VANET scenario in Fig. 8, three vehicles under the radio coverage of three different APs are transmitting video frames towards the gateway. In this scenario, AP3 is starved of gaining the channel since the AP1 , AP2 , AP4 and AP5 are transmitting video packets toward the gateway. Thus, channel access starvation happens with the Carrier Sense Multiple Access (CSMA) of 802.11p. In an attempt, the authors in (Bellalta, et al., 2014) tried to improve the fairness of accessing the wireless channel between nearby vehicles. They also evaluated multi-hop video streaming from IEEE 802.11p enabled vehicular

http://dx.doi.org/10.14500/aro.10128

surveillance network to the traffic management center. In their evaluation, Scalable Video Coding (H.264/SVC) and non-standard scalable video coding three dimensional discrete wavelet transmission (3-D DWT) (Belyaev, et al., 2013).

The transmitted video from the target vehicle/vehicles, which is multi-hops far away from the gateway, is assessed by end-to-end distortion. Moreover, they show that tuning of video data rate of a target vehicle is crucial and depends on the vehicular traffic density and location of participating vehicles.

B. Video Broadcast Mechanisms

Applications of video broadcast from a source to vehicles in the vicinity is very necessary. With this service, vehicles can be updated with latest news, traffic and tourist information, on-road advertisement, and video-application sharing. To efficiently broadcast video applications to urban vehicles, Soldo, et al. (2011) proposed Streaming Urban Video (SUV). The SUV enables video communication in V2V fashion. To achieve this, each relay vehicle utilizes the positional information and sensed power level to dynamically select the next candidate node. Moreover, the data channel is used to stream video and best- effort traffic based on the Time Division Multiple Access (TDMA) structure. More particularly, the data channel is organized as constant time frames with n number of similar time slots. In their work, the authors used graph-coloring algorithm to compute the value of time slots and a group of relay vehicles that they transmit over the specified time slot. They also proposed a collision resolution mechanism to handle the possible packet collisions in the link layer level.

In highways or urban scenarios, the drivers frequently need to overtake other vehicles that they comparatively drive slowly. In this case, sometimes the drivers of overtaking vehicles might underestimate the speed of the oncoming platoon of vehicles. Thus, an overtaking assistance system is very necessary as it helps the drivers to see on time and rightfully estimate the oncoming traffic. In recent studies, researchers highlighted two methods of cooperative overtaking assistance system: real time video transmission or beacon based system. In the former one, the video scene is captured by the windshield camera and then transmitted to the followed vehicles. In the second case, beacon messages with the carrying the positional information is exchanged among vehicles that will provide awareness to the drivers for the information of nearby vehicles. As illustrated in Fig. 9, truck 1 streams video about oncoming traffic to the following vehicles (such as vehicle 2) as well as the vehicles are aware about other vehicles in the vicinity by using beacon message communication. But, in such scenario when two platoons of vehicles reach each other, the overloading on the SCH would occur and thereby the transmitted video quality from truck 1 to the followed vehicles would degrade. To address this problem, Vinel, et al. (2012) combined the aforementioned two methods of overtaking assistance system. In essence, beacon message is useful to provide the information on oncoming platoon of vehicles through the CCH and this data can be used by a vehicle to estimate the channel throughput. Then, a vehicle can use channel through- put as a metric to adapt its video bit rate to the channel variation. With this joint beaconing and video streaming -assisted overtaking system, the end-to-end latency and visual quality of transmitted video are significantly improved.

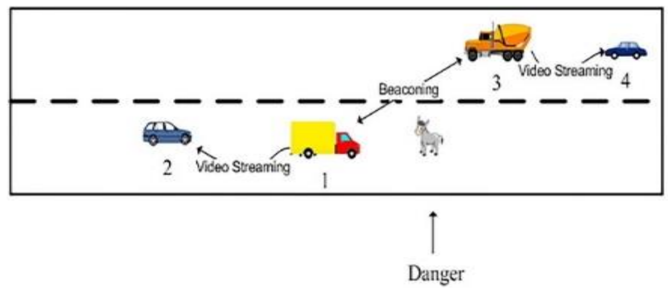

Fig. 9. Cooperative overtaking assistance system based on video streaming and beaconing.

Researchers are continuously devoting their efforts to improve the video compression standards. One of these new standards is High Efficiency Video Coding (HEVC) (Sullivan, et al., 2012) that doubles the coding efficiency of previous standard H.246/Advanced Video Coding (H.246/AVC). To show the efficiency and performance of HEVC VANET environment, Pinol, et al. (2011) evaluated the HEVC considering error-prone vehicular scenarios.

The simulation was done in OMNeT++ (OMNeT++, 2011) packet level simulator with SUMO mobility modeler. SUMO is considered as an efficient mobility model that simulates the movement behavior of vehicles, finding efficient trajectory of cars, interaction between vehicles and roads/ other vehicles and intersections. OMNeT++ supports the operation of service (SCH) and control channels (CCH) (multi-channel) in 802.11p. Another important characteristic of the used simulator is the ability to model obstacles that obstructs the communicated radio signal between vehicles. The authors developed a module to identify the video server and receivers. A server announces the video-related application through the CCH every 1 second. After receiving the existence of video services, the video receiver switches to a suitable SCH and hence downloads the video frames. Moreover, the “Race Horse” video sequence has been used with a frame transmission rate of 30 fps. The results of the experiments show the high sensitivity of HEVC to packet losses.

In the similar attempt, the authors in (Torres, et al., 2014) evaluated few flooding techniques for transmission of video frames over multi-hop and different vehicular densities. The evaluated flooding techniques were counter based algorithm, distance based scheme, backfire based algorithm (Osafune, Lin and Lenardi, 2006) and DECA algorithm (Nakorn and Rojviboonchai, 2013). For this evaluation purpose, the authors use OMNeT++ packet level simulator and SUMO mobility model. Based on the simulation, they found that backfire algorithm, which is efficiently reduces the collision in the wireless medium as well as delivers more packets with low delay.

C. Multi-source Video Streaming Mechanisms

Following the trend of improving video streaming over VANET, the authors in (Qadri, et al., 2010) developed a method of video transmission in overlay vehicular environment. They used joint Multi-Description Coding (MDC) (Wang, Reibman and Lin, 2005) and spatial Flexible Macroblock Ordering (FMO) (Lambert, et al., 2006) to protect the video frames from the error-prone wireless channel. In FMO, which is considered as an error resilient mechanism for H.264/AVC, the video frames are divided into several slices in order to recover the lost macroblocks of neighbor slices.

The evaluation is based on the GloMoSim (Zeng, Bagrodia and Gerla, 1998) simulator and additive propagation model (Takai, Martin and Bagrodia, 2001) that uses a path loss model with multi-path fading in order to take into account consideration the signal obstruction and attenuation. The Rician fading model is used to incorporate the multi-path interference to the vehicles communication, which includes one line of sight and several non-line of sight components in the received signal. Moreover, the macro and micro mobility modeling are used to represent the realistic vehicular movement, behavior of drivers and urban street layout. Results show that different mobility models will affect the overhead and packet loss in the network. For instance, incorporating a precise driver behavior into vehicular mobility model will decrease packet loss in the network while including a lane changing model results a high movement of vehicles and leads to higher degradation of network performance. Furthermore, when the error of the wireless channel increases, the fading component (non-line of sight) of Rician distribution increases too. As consequence, the network performance is degraded, showing the effect of multi-path fading on the performance of the network.

V. Research Directions and Open Issues

The state of the arts video streaming over VANET solutions is reviewed, compared and criticized. These schemes can be counted as a foundation for video transmission in vehicular environments. However, they do not address many open issues yet. The following are some of the research directions.

Realistic Vehicular Network Scenarios: As it can be observed in the existing literature, the video streaming schemes were simulated in unrealistic scenarios, i.e., vehicular communications without considering wireless shadowing and fading channel deterioration. The difference between simulation experiments using realistic and unrealistic vehicular topologies may result in the expense of human lives which is not affordable. Therefore, the state of the arts solutions need to be reevaluated using realistic vehicular scenarios.

Considering Radio Obstacles in VANET: In highway or urban sites, obstacles like trucks (moving obstacles) and buildings (static obstacles) are exist. These radio obstacles obstruct the radio signal and hence will cause high video packet loss. Thus, considering radio obstacles in the proposed solutions is necessary.

Erasure coding: Transmitting video over such harsh environment is a daunting task. Error correction techniques need to be used to compensate the packet losses at the receiver. For instance, network coding, Multiple Description Coding (MDC) or forward error correction are suitable in vehicular network to boost the reliability of video packet transmission especially protecting most crucial information like I-frame.

Adaptive Video Streaming: Most video streaming solutions would not consider the characteristics of vehicular network. For instance, video streaming schemes is necessary to adapt with the traffic density or velocity of vehicles as both of them affect their scalability.

Video streaming over multi-radio enabled vehicular networks: Next Generation Network (NGN) aims to integrate different radio access technologies in order to provide seamless mobility and QoS at anywhere and anytime. Thus, it is crucial to design efficient video streaming scheme over different wireless access technologies (WiFi, WiMAX and LTE) and decision for optimal selection between them in heterogeneous vehicular networks.

VI. Conclusion

This paper presents a comprehensive review on new research direction, video streaming over VANET. More specifically, this survey discusses and highlights the taxonomy of video streaming protocols, significant applications and their requirements and challenges, and comparative study among existing solutions in the literature. Based on this review outcome, it can be observed that efforts have been made to develop efficient and VANET adaptive video streaming protocols. However, Table II shows the defects for most video streaming schemes since they utilized simulation or mathematical modeling. It is noteworthy that practical implementation verifies the assumptions made in the simulation as well as provides believability of the results which are obtained from simulation and mathematical analysis. Thus, considering more realistic vehicular environment, conducting test-bed experiments on video streaming, developing efficient video streaming protocols and embedding erasure coding in the developed schemes are worth the effort in the future research opportunities.

 http://dx.doi.org/10.14500/aro.10128

TABLE II
VIDEO STREAMING SCHEMES AND THEIR DEFECTS

Algorithm	Error Resilient Technique	Objective	Type of Video Sharing	Simulator and Video File	Evaluation Parameters	Simulation Results
Rezende et al. (2012)	None	Selecting more stable and shortest path	Video streaming unicast	NS2 and MPEG Akiyo CIF	Frame loss, delay and cost scenario	Their algorithm performs better in terms of frame loss, delay and cost of transmissions
Rezende, Almulla and Boukerche (2013)	Random linear network coding and XOR-based coding	Performance evaluation of two coding scheme	Video streaming unicast	NS2 and MPEG Akiyo CIF	Frame loss, delivery ratio and delay	XOR-based coding performs better as compared to the Random linear network coding
Soldo et al. (2011)	Multiple Description Coding	Efficient video Broadcast from one source to all vehicles	Broadcast	None	None	Comparisons with existing literature are not conducted in the paper
Puangpronpitag, Kasabai and Suwannasa, (2013)	Coded with H.264 standard	Suppressing MAC-level congestion by skipping frames, transcoding to next frames and halving the frame rate	Unicast	OMNeT++ and Fore- man CIF	Network latency	Comparisons with existing literature are not conducted in the paper
Xing, and Cai (2012)	Coded with Scalable Video Coding	To improve video quality of experience level by adaptively requesting number of enhancement video layers	Unicast	MATLAB® and video traces of Big Buck Bunny	Startup latency, interruption ratio and average playback quality	Performs better as compared to the non-corporative scheme
Vinel et al. (2012)	None	To improve video qual- ity and end-to-end de- lay by adapting video bit rate with the channel variation rate	Broadcast	Theoretical analysis	Throughput and PSNR	Improves the video quality and end-to-end latency
Maia et al. (2013)	None	To improve video dissemination by broadcast suppression, store and forward mechanism, and control of packet transmission rate	Broadcast	OMNeT++ and Akiyo CIF	Average frame loss, transmitted data message and average frame delay	Improves successful packet delivery rate
Wu and Ma (2013)	None	To improve start-up delay and required visual quality by using camera network to forward video packets through optimal path	Unicast	NS2 and foreman-qcif	Average start-up delay, average PSNR and average number of freezes	Improves startup delay and perceived video quality
Bellalta, et al. (2014)	Flexible macroblock ordering with two slice groups	To improve end-to-end distortion of target vehicle by dynamic adaptation of its video bit rate with vehicle density and position of participated vehicles	Unicast	Test-bed experiments and Tampere-04 (640×480, 300 frames)	Throughput and PSNR	Selecting best target vehicle's video bit rate provides good visual quality, this selection depends on the number of vehicles and their Position
Qadri, et al. (2010)	joint Multi-Description Coding (MDC) and spatial Flexible Macroblock Ordering (FMO)	To show the feasibility of multi-source video streaming under different conditions, mobility modeling, wireless channel condition and network size	Multi-source video streaming to a specific destination	GloMoSim and QCIF (176×144)	Control overhead, packet loss ratio, end-to-end delay and PSNR	Realistic mobility model, driver behavior and probabilistic fading model significantly affect network performance
Xu, et al. (2012)	None	To test the performance of several routing protocols in VANET environment	Unicast	NS 2.28 and Foreman (400 frames)	Frame loss rate and average PSNR	GPSR is more reliable for video streaming in dense traffic than AODV and DSDV routing protocols

REFERENCES

Ahmad, I. and Habibi, D., 2010. High utility video surveillance system on public transport using WiMAX technology In: *2010 IEEE Wireless Communication and Networking Conference*, Sydney, NSW, 2010, pp. 1-5.

Asefi, M., 2011. *Quality-driven cross-layer protocols for video streaming over vehicular ad-hoc networks.* Ph.D., University of Waterloo.

Baldi, M. and Ofek, Y., 2000. End-to-end delay analysis of videoconferencing over packet-switched networks. *IEEE/ACM Transactions on Networking,* 8(4), pp.479-492.

Bellalta, B., Belyaev, E., Jonsson, M. and Vinel, A., 2014. Performance Evaluation of IEEE 802.11 p-Enabled Vehicular Video Surveillance System. *IEEE Communications Letter,* 18(4), pp.1-4.

Belyaev, E., Egiazarian, K. and Gabbouj, M., 2013. A low-complexity bit-plane entropy coding and rate control for 3-D DWT based video coding. *IEEE Transaction on Multimedia,* 15(8), pp.1786-1799.

Belyaev, E., Vinel, A., Jonsson, M. and Sjoberg, K., 2014. Live video streaming in IEEE 802.11 p vehicular networks: demonstration of an automotive surveillance application. In*: 2014 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS).* Toronto, ON, 2014, pp.131-132. doi: 10.1109/INFCOMW.2014.6849190

Belyaev, E. et al., 2014. Robust vehicle-to-infrastructure video transmission for road surveillance applications. *IEEE Transactions on Vehicular Technology,* (99), pp.1-15.

Bernsen, J. and Manivannan, D., 2008. Unicast Routing Protocols for Vehicular Ad hoc Networks: A Critical Comparison and Classification. *Pervasive and Mobile Computing,* Elsevier. 5(1), pp.1-18.

Bohrloch, T. et al., 2011. A methodology to evaluate video streaming performance in 802.11 e based MANETs. *In: The 10th International Conference Ad-hoc, Mobile, and Wireless Networks.* Paderborn, Germany, July 18-20, 2011, pp. 276-289.

Boukerche, A., Rezende, C. and Pazzi, R. W., 2009. Improving neighbor localization in vehicular ad hoc networks to avoid overhead from periodic messages. In: *Global Telecommunications Conference, 2009. GLOBECOM 2009.* IEEE, Honolulu, HI, 2009, pp.1-6. *doi: 10.1109/GLOCOM.2009.5425636*

Campolo, C. and Molinaro, A., 2011. On vehicle-to-roadside communications in 802.11 p/WAVE VANETs. In: *2011 IEEE Wireless Communications and Networking Conference*. Cancun, Quintana Roo, 2011, pp.1010-1015. doi: 10.1109/WCNC.2011.5779273

Chaqfeh, M., Lakas, A. and Jawhar, I., 2014. A survey on data dissemination in vehicular ad hoc networks. *Vehicular Communications,* 1(4), pp.214-225.

Chen, M., Mau, D.O., Zhang, Y., Taleb, T. and Leung, V.C.M., 2014. VENDNET: VEhicular Named Data NETwork. *Vehicular Communications,* 1(4), pp. 208-213.

Chen, P.-Y., Liu, J.-W. and Chen, W.-T., 2010. A Fuel-Saving and Pollution-Reducing Dynamic Taxi-Sharing Protocol in VANETs. In: *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*, Ottawa, ON, 2010, pp.1-5. doi: 10.1109/VETECF.2010.5594422

De Sousa Vieira, A. S., Celestino Jnior, J., Patel, A. and Taghavi, M., 2013. Driver assistance system towards overtaking in vehicular ad hoc networks. In: *AICT 2013: The Ninth Advanced International Conference on Telecommunications*, pp.100-107.

Dias, J. A. et al., 2011. Performance assessment of fragmentation mechanisms for vehicular delay-tolerant networks. *EURASIP Journal on Wireless Communications and Networking,* 2011(1), pp.1-14.

Dias, J. A., Rodrigues, J. J. and Zhou, L., 2014. Cooperation advances on vehicular communications: A survey. *Vehicular Communications,* 1(1), pp.22-32.

European-ITS, 2009. *EITS-Technical Report 102 638 v1.1.1.*

Ghafoor, K. and Bakar, K., 2010. Inter-Vehicle Communication Protocols for Multimedia Transmission. In: IMECS 2010: International MultiConference of Engineers and Computer Scientis 2010 Vol II. Hong Kong, pp.1234-1239, 17-19 March.

Ghafoor, K.Z., Abu Bakar, K., Zainuddin, Z.M., Chih-Heng K. and Gonzalez, A.J., 2012. Reliable Video Geocasting over Vehicular Ad Hoc Networks. *Ad Hoc and Sensor Wireless Networks,* 15, pp. 201-221.

Guo, M., Ammar, M. H. and Zegura, E. W., 2005. V3: A vehicle-to-vehicle live video streaming architecture. *Pervasive and Mobile Computin*, 1(4), pp.404-424.

Hartenstein, H. and Laberteaux, K. P., 2009. A tutorial survey on vehicular ad hoc networks. *IEEE Communications Magazine,* 46(6), pp. 164-171.

ITS-Standards, 1996. *Intelligent Transportation Systems.*

J. Jeong, J., Guo, S., Gu, Y., He, T. and Du, D.H.C., 2010. TSF: Trajectory-Based Statistical Forwarding for Infrastructure-to-Vehicle Data Delivery in Vehicular Networks. In: *2010 IEEE 30th International Conference on Distributed Computing Systems (ICDCS).* Genova, 2010, pp.557-566. doi: 10.1109/ICDCS.2010.24

Kakkasageri, M. and Manvi, S., 2014. Regression based critical information aggregation and dissemination in VANETs: A cognitive agent approach. *Vehicular Communications,* 1(4), pp.168-180.

Karadimas, P. and Matolak, D., 2014. Generic stochastic modeling of vehicle-to-vehicle wireless channels. *Vehicular Communications,* 1(4), pp. 153-167.

Ke, C.-H., Lin, C.-H., Shieh, C.-K. and Hwang, W.-S., 2006. A novel realistic simulation tool for video transmission over wireless network. In: IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC'06), Taichung, pp. 7.doi: 10.1109/SUTC.2006.1636186

Lambert, P., De Neve, W., Dhondt, Y. and Van de Walle, R., 2006. Flexible macroblock ordering in H. 264/AVC. *Journal of Visual Communication and Image Representation,* Elsevier, 17(2), pp.358-375.

Li, F. and Wang, Y., 2007. Routing in Vehicular Ad hoc Networks: A Survey. *IEEE Vehicular Technology Magazine,* 2(2), pp.12-22.

Li, J. et al., 2004. On-the-fly verification of rateless erasure codes for efficient content distribution. In: *2004 IEEE Symposium on Security and Privacy*, 2004. pp.226-240. doi: 10.1109/SECPRI.2004.1301326

Lin, C.-H.et al., 2009. An adaptive cross-layer mapping algorithm for MPEG-4 video transmission over IEEE 802.11 e WLAN. *Telecommunication Systems*, 42(3-4. Springer), pp.223-234.

Li, S.-Y., Yeung, R. W. and Cai, N., 2003. Linear network coding. *IEEE Transactions on Information Theory,* 49(2), pp. 371-381. IEEE.

Lochert, C., Scheuermann, B., Caliskan, M. and Mauve, M., 2007. The feasibility of information dissemination in vehicular ad-hoc networks. In: *2007 Fourth Annual Conference on Wireless on Demand Network Systems and Services,* Oberguyrgl, 2007, pp.92-99. doi: 10.1109/WONS.2007.340478

Maia, G., Rezende, C, Villas A.L. and Loureiro, A., 2013. Traffic Aware Video Dissemination over Vehicular Ad Hoc Networks. In: The 16th ACM International Conference on Modeling, Analysis & Simulation of Wireless and Mobile Systems, At Barcelona, Spain pp.419-426. doi: 10.1145/2507924.2507962

Myllyniemi, M., Vehkapera, J. and Peltola, J., 2007. Fuzzy Logic-based Cross-layer Controller for Wireless Video Transmission. In: *Computers and Communications, 2007. ISCC 2007. 12th IEEE Symposium on*, Santiago, Portugal, 2007, pp.21-26. doi: 10.1109/ISCC.2007.4381641

Nakorn, K. N. and Rojviboonchai, K., 2013. DECA-bewa: Density-Aware Reliable Broadcasting Protocol in VANETs. *IEICE transactions on communications,* 96(5), pp.1112-1121.

OMNeT++, 2011. *OMNeT++ Simulator.*

Osafune, T., Lin, L. and Lenardi, M., 2006. Multi-hop vehicular broadcast (MHVB). In: *2006 6th International Conference on ITS Telecommunications.* Chengdu, 2006, pp.757-760. doi: 10.1109/ITST.2006.289011

Park, J.-S.et al., 2006. *Emergency related video streaming in VANET using network coding.* UCLA CSD Technical Report, pp.102-103.

Pedestrian and Center, B. I., 2014. *Pedestrian and Bicyclist Crash Statistics. Final Report; Michigan Department of Transportation.*

Piñol, P., Torres, A., López, O., Martínez, M. and M. P. Malumbres, M.P., 2011. Evaluating HEVC video delivery in VANET scenarios. In: *Wireless Days (WD), 2013 IFIP*, Valencia, 2013, pp.1-6. doi: 10.1109/WD.2013.6686539

Puangpronpitag, S., Kasabai, P. and Suwannasa, A., 2013. Cross-layer optimization of Vehicle-to-Vehicle video streaming for overtaking maneuver assistance systems. In: *2013 Fifth International Conference on Ubiquitous and Future Networks (ICUFN)*, Da Nang, 2013, pp.345-349. doi: 10.1109/ICUFN.2013.6614839

Qadri, N. N., Fleury, M., Altaf, M. and Ghanbari, M., 2010. Multi-source video streaming in a wireless vehicular ad hoc network. *IET on Communications,* 4(11), pp.1300-1311.

Rezende, C., Almulla, M. and Boukerche, A., 2013. The use of Erasure Coding for video streaming unicast over Vehicular Ad Hoc Networks. In: *Local Computer Networks (LCN), 2013 IEEE 38th Conference on*, Sydney, NSW, 2013, pp.715-718. doi: 10.1109/LCN.2013.6761318

Rezende, C., Ramos, H.S., Pazzi, R.W., Boukerche, A., Frery, A.C. and Loureiro, A.A.F., 2012. *Virtus: A resilient location-aware video unicast scheme for vehicular networks.* 2012 *IEEE International Conference on Communications (ICC)*, pp.698-702. doi: 10.1109/ICC.2012.6364470

Ruder, M., Enkelmann, W. and Garnitz, R., 2002. Highway lane change assistant. In: *Intelligent Vehicle Symposium, 2002. IEEE*, 2002, pp. 240-244 vol.1. doi: 10.1109/IVS.2002.1187958

Shieh, W.-C., Sou, S.-I. and Tsai, S.-Y., 2011. A study of video frame sharing in sparse vehicular networks. In*: Parallel and Distributed Systems (ICPADS), 2011 IEEE 17th International Conference on*, Tainan, 2011, pp.444-448. doi: 10.1109/ICPADS.2011.15

Soldo, F., Casetti, C., Chiasserini, C.-F. and Chaparro, P., 2008. Streaming media distribution in VANETs. In: *IEEE GLOBECOM 2008 - 2008 IEEE Global Telecommunications Conference*, New Orleans, LO, 2008, pp.1-6. doi: 10.1109/GLOCOM.2008.ECP.126

Soldo, F., Casetti, C., Chiasserini, C. and Chaparro, P. A., 2011. Video streaming distribution in VANETs. *IEEE Transactions on Parallel and Distributed Systems,* 22(7), pp.1085-1091.

Sou, S.-I., Shieh, W.-C. and Lee, Y., 2011. A video frame exchange protocol with selfishness detection mechanism under sparse infrastructure-based deployment in VANET. In: *2011 IEEE 7th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob.* Wuhan, pp.498-504. doi: 10.1109/WiMOB.2011.6085347

Sullivan, G. J., Ohm, J., Han, W.-J. and Wiegand, T., 2012. Overview of the high efficiency video coding (HEVC) standard. *IEEE Transactions on Circuits and Systems for Video Technology,* 22(6), pp.1649-1668.

Takai, M., Martin, J. and Bagrodia, R., 2001. Effects of wireless physical layer modeling in mobile ad hoc networks. In: *MobiHoc '01: Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing*

Tal, I. and Muntean, G., 2012. User-oriented cluster-based solution for multimedia content delivery over VANETs. In: *IEEE international Symposium on Broadband Multimedia Systems and Broadcasting*, Seoul, 2012, pp.1-5. doi: 10.1109/BMSB.2012.6264290

Toledo-Moreo, R., Santa, J. and Zamora-Izquierdo, M., 2009. *A Cooperative Overtaking Assistance System.* pp.50-56.

Tonguz, O. K. and Boban, M., 2010. Multiplayer games over vehicular ad hoc networks: A new application. *Ad Hoc Networks.* Elsevier, 8(5), pp.531-543.

Tripp-Barba, C., Urquiza-Aguiar, L., Igartua, M.A., Rebollo-Monedero, D., de la Cruz Llopis, L.J., Mezher, A.M. and Aguilar-Calderón , J.A., 2014. A Multimetric, Map-Aware Routing Protocol for VANETs in Urban Areas. *Sensors,* 14(2), pp.2199-2224.

VANETMobiSim, 2014. *Mobility Model.*

Venkataraman, H., D'Ussel, A., Corre, T., Muntean, C.H. and Muntean, G.-M.,, 2010. Performance analysis of real-time multimedia transmission in 802.11 p based multihop hybrid vehicular networks. In: *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference.* ACM, New York, pp. 1151-1155. doi: 10.1145/1815396.1815660

Vinel, A., Belyaev, E., Egiazarian, K. and Koucheryavy, Y., 2012. An overtaking assistance system based on joint beaconing and real-time video transmission. *IEEE Transactions on Vehicular Technology,* 61(5), pp.2319-2329.

Wang, Y., Reibman, A. R. and Lin, S., 2005. Multiple description coding for video delivery. *Proc. of IEEE,* 93(1), pp.57-70.

Whaiduzzaman, M., Sookhak, M., Gani, A. and Buyya, R., 2014. A survey on vehicular cloud computing. *Journal of Network and Computer Applications,* Elsevier, 40(2), pp.325-344..

Wired, 2014. *Feds Will Require All New Vehicles to Talk to Each Other.* [Online] Available at <https://www.wired.com/2014/02/feds-v2v/>

Wu, H. and Ma, H., 2013. CAVD: A Traffic-Camera Assisted Live Video Streaming Delivery Strategy in Vehicular Ad Hoc Networks. In: *2013 IEEE 10th International Conference on Mobile Ad-Hoc and Sensor Systems*. Hangzhou, 2013, pp.379-383. doi: 10.1109/MASS.2013.55

Xie, F., Hua, K.A., Wang, W. and Ho, Y.H., 2007. Performance study of live video streaming over highway vehicular ad hoc networks. In: 2007 IEEE 66th Vehicular Technology Conference, Baltimore, MD, 2007, pp. 2121-2125. doi: 10.1109/VETECF.2007.445

Xing, M. and Cai, L., 2012. Adaptive video streaming with inter-vehicle relay for highway VANET scenario.In: *The 2012 IEEE International Conference on Communications (ICC).* Ottawa, ON, 10-15 June, pp. 5168-5172. doi: 10.1109/ICC.2012.6364143

Xu, C., Zhao, F. Guan, J, Zhang, H. and Muntean, G.M.., 2013. QoE-driven user-centric VoD services in urban multihomed P2P-based vehicular networks. *IEEE Transactions on Vehicular Technology,* 62(5), pp.2273-2289.

Xu, S., Zhou, H., Yu, Z. and Zhang, S., 2012. Simulated study on video communication over VANET. In: *Word Automation Congress (2012).* Puerto Vallarta, Mex*ico*, 24-28 June, pp.221-225,

Yasmeen, F. et al., 2015. A Message Transfer Framework for Enhanced Reliability in Delay-Tolerant Networks. *Network Protocols and Algorithms,* 7(3), pp.52-88.

Zeadally, S., Hunt, R., Chen, Y.-S, Irwin, A. and Hassan, A., 2012. Vehicular ad hoc networks (VANETS): status, results, and challenges. *Telecommunication Systems.* Springer, 50, pp.217-241.

Zeng, X., Bagrodia, R. and Gerla, M., 1998. GloMoSim: a library for parallel simulation of large-scale wireless networks. In: *Twelfth Workshop on Parallel and Distributed Simulation, 1998. PADS 98. Proceedings.* Banff, Alta., 1998, pp.154-161.