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THEME :

Le streaming vidéo dans les réseaux véhiculaires ad-hoc

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Abstract

Recently, video streaming in vehicular ad hoc networks (VANETs) is considered as one of the most important challenges tackled by research community of vehicular networks. Defined as a continuous video transmission; video streaming in VANET helps to improve road safety and passengers comfort. However due to the highly dynamic of VANET topology, the video quality is often deteriorated where the communication suffers from a high packet loss rate and an increased transmission delay. This specificity makes it difficult to apply the conventional transport protocols such as UDP and TCP to video streaming over VANET. To deal with these limits, we propose in this thesis feasible solutions for video streaming in VANET. Based on VANET and video streaming particularities and challenges, three contributions are proposed and designed namely; an Enhanced Adaptive Sub-packet Forward Error Correction (EASP-FEC), an Enhanced User Datagram Protocol (EUDP), and a Hybrid Error Recovery Protocol (HERP). All these solutions aim at ensuring a high video quality at the end receiver in terms of the quality of service (QoS) and/or the quality of experience (QoE) metrics.

Based on a redundancy technique to recover uniform errors of the transmitted video and unlike existing Forward Error Correction (FEC) mechanism which generates redundant packets for each block of original packets, our first proposal (EASP-FEC) divides a packet into a set of original sub-packets, then it generates redundant sub-packets for each packet in order to enhance the error recovery rate and the video streaming quality. In addition and compared to the well-known Sub-packet Forward Error Correction (SPFEC) mechanism, EASP-FEC reduces the network congestion problem by adjusting the number of redundant sub-packets according to the network load. We propose to apply EASP-FEC at the sender and relay vehicles, where the calculation process of redundant sub-packets takes into account the traffic condition, the traffic load and the importance of video frame types (i.e. I, P, B). A set of simulations proved that EASP-FEC provides better error recovery rate than FEC scheme and avoids network congestion compared to SPFEC mechanism.

Contrary to User Datagram Protocol (UDP), which did not consider any recovery mechanism of erroneous packets, the second proposal (EUDP) uses SPFEC and adopts the unequal protection of video frame types (i.e. I, P, B) to improve the video streaming quality. EUDP is also based on a redundancy technique. This protocol was simulated on ns-2 simulator demonstrating that EUDP showed a significant improvement in terms of error recovery rate, Peak Signal-to-Noise Ratio (PSNR) and Mean Opinion Score (MOS) of transmitted video after a set of comparisons against UDP and EUDP protocols without unequal protection of video frame types (EUDP-E).

The last contribution (HERP) considers both redundancy and retransmission techniques to recover uniform and burst video errors. This protocol integrates the SPFEC mechanism to recover the uniform transmission errors and the retransmission technique to recover burst errors mainly due to the network congestion and route disconnection. Moreover, HERP adapts dynamically the redundancy rate and the retransmission limit according to the network condition measured by the Bit Error Rate (BER) to avoid the network overload and to reduce the transmission delay. HERP is based on the reporting technique, representing a dynamic feedback mechanism between the receiver and sender vehicles of the video to control the network condition and network load. To cope with the network congestion problem, HERP adapts the transmission rate in function to the network load indicated by the queue length of intermediate vehicles. To improve the video streaming quality, HERP suggests an unequal protection of video frames type (i.e. I, P, B), in which the protection degree of the video frames is given according to the frame types. After a set of ns-2 based simulations, the results obtained by HERP achieve significant improvements of transmitted video in terms of QoS and QoE metrics after comparisons against native UDP and SPFEC based UDP protocol.

Keywords: Vehicular ad hoc networks, video streaming, sub-packet forward error correction, redundancy, retransmission.

Résumé

Récemment, le streaming vidéo dans les réseaux véhiculaires ad hoc (VANETs) est considéré comme un défi très important visé par la communauté de recherche et les industriels dans le domaine des réseaux véhiculaires. Définit comme étant une transmission continue de la vidéo, le streaming vidéo dans un VANET aide à améliorer la sécurité de la route et le confort des voyageurs. En raison de la dynamique très élevée de la topologie des VANETs causée par la mobilité des véhicules, la qualité de la vidéo échangée est souvent détériorée en perdant un nombre important de paquets et en consommant un délai très élevé pour transmettre la vidéo. Cette spécificité rend difficile d'appliquer les protocoles de transport conventionnels tel que le protocole UDP ou TCP pour le streaming vidéo. Afin de surmonter cette limite, nous proposons dans cette thèse trois solutions pour le streaming vidéo dans un réseau VANET. Sur la base des particularités des VANETs et du streaming vidéo, nous avons proposé trois contributions nommées : Enhanced Adaptive Sub-packet Forward Error Correction (EASP-FEC), Enhanced User Datagram Protocol (EUDP) and Hybrid Error Recovery Protocol (HERP). Toutes ces solutions cherchent à assurer une haute qualité d'une vidéo reçue au niveau d'un récepteur en termes de qualité de service (QoS) et/ou de qualité d'expérience (QoE).

En se basant sur la technique de redondance pour la récupération des erreurs uniformes et à la différence du mécanisme de correction d'erreur sans voie de retour (Forward Error Correction –FEC-), notre première proposition (EASP-FEC) divise le paquet en un ensemble de sous paquets originaux et elle génère les sous paquets redondants pour chaque paquet dans l'objectif d'améliorer le taux de récupération des paquets et la qualité du streaming vidéo. Par ailleurs, EASP-FEC ajuste le nombre des sous paquets redondants en fonction de la surcharge du réseau pour réduire le problème de congestion du réseau connu surtout pour le mécanisme Sub-Packet Forward Error Correction (SPFEC). Nous proposons d'appliquer EASP-FEC au niveau du véhicule émetteur et au niveau des véhicules relais dont le processus du calcul des sous paquets redondants prendra en considération les conditions du trafic, la surcharge du réseau et le type des images vidéo (c.à.d. I, P, B). Cette contribution a été simulée en pouvant un meilleur taux de récupération des erreurs par rapport au mécanisme FEC et en évitant la congestion du réseau par rapport au mécanisme SPFEC.

La deuxième proposition (EUDP) utilise le mécanisme SPFEC et adopte la protection inégale des types des images vidéo (c.à.d. I, P, B) pour améliorer la qualité du streaming vidéo. EUDP est basé aussi sur la technique de redondance. La simulation de cette proposition par le simulateur ns-2 a montré que EUDP améliore considérablement le taux de récupération des erreurs, le rapport maximal Signal-Bruit (PSNR) et le score d'opinion moyen (MOS) de la vidéo transmise en comparant aux protocoles UDP et EUDP sans la protection inégale des images vidéo.

La dernière contribution (HERP) est basée sur la combinaison entre la technique de redondance pour la récupération des erreurs uniformes et la technique de retransmission pour la récupération des erreurs de transmission non uniformes survenues durant la transmission de la vidéo à cause de la congestion du réseau et les déconnexions des liens. Par ailleurs, HERP adapte de manière dynamique le taux de redondance et la limite de retransmission selon les conditions du réseau mesuré par le taux d'erreurs sur les bits (BER) pour éviter la surcharge du réseau et pour réduire le temps de transmission. De plus, HERP utilise la technique «reporting» qui représente un mécanisme dynamique de réaction entre les véhicules récepteur et émetteur de la vidéo pour contrôler les conditions et la surcharge du réseau. Pour faire face au problème de congestion du réseau, HERP adapte le taux de transmission en fonction de la surcharge du réseau indiquée par la taille de la file d'attente des paquets reçus au niveau des véhicules intermédiaires. Pour bien améliorer la qualité du streaming vidéo, HERP suggère aussi une protection inégale des images vidéo I, P, B en fonction de chaque type. Suite à une série des simulations en ns-2, les résultats obtenus montrent que HERP offre des améliorations significatives de la vidéo transmise en termes des métriques de QoS and de QoE après une comparaison avec le protocole UDP et le protocole UDP basé sur le mécanisme SPFEC.

Mots clés: réseau véhiculaire ad-hoc, streaming vidéo, SPFEC, redondance, retransmission.

ملخص

في الوقت الراهن، يعتبر بث الفيديو في شبكات السيارات (VANET) إحدى أٌهم التحديات المتداولة من طرف هيئات البحث في مجال شبكات السيارات.
بث الفيديو في شبكات السيارات هو عبارة عن إرسال مستمر للفيديو، يساعد بشكل كبير في زيادة سلامة الطرقات وكذا توفير راحة أكثر للمسافرين. لكن ونظرا لخاصية شبكات السيارات المتمثلة في الديناميكية العالية لبنيتها، تتأثر جودة الفيديو سلبيا بسبب إرتفاع معدل فقدان رزم الفيديو وكذا إرتفاع زمن الإرسال. هاته الخاصية لشبكات السيارات تجعل من الصعب تطبيق البروتوكولات التقليدية للإرسال مثل UDP و TCP على بث الفيديو في شبكات السيارات. لمعالجة هاته النقائص للبروتوكولات التقليدية، وإستنادا على خصائص و تحديات كلا من شبكات السيارات وبث الفيديو، نقترح في هاته الأطروحة ثلاث حلول ملائمة لإرسال الفيديو في شبكات السيارات، تمت تسميتها كما يلي: FEC-EASP، EUDP، HERP. هذه الحلول المقترحة تهدف جميعها لضمان جودة عالية للفيديوعلي مستوى المستقبل النهائي وفقا لمعايير الجودة QoS و/أو QoE.
بالإعتماد علي تقنية التكرار لتصحيح الأخطاء المنتظمة للفيديو المرسل و خلافا لآلية تصحيح الأخطاء FEC التي تضيف رزم مكررة لكل مجموعة من الرزم الأصلية، إقتراحنا الأول (FEC-EASP) يقوم بتقسيم كل رزمة فيديو إلي مجموعة من الرزم الفرعية الأصلية، ثم يضيف رزم فرعية مكررة لهاته المجموعة، وهذا من أجل زيادة معدل تصحيح الأخطاء و بالتالي زيادة جودة الفيديو المرسل. بالإضافة إلي ذالك، يقلص FEC-EASP من مشكلة إزدحام الشبكة مقارنة بالآلية SPFEC. نقترح تطبيق FEC-EASP علي مستوى السيارات المرسلة و الوسيطة، حيث أنه يتم الأخذ بعين الإعتبار في عملية حساب الرزم المكررة حالة و حمولة الشبكة و كذا أنواع إطارات الفيديو (أي B, P, I). بعد إجراء مجموعة من التجارب إعتمادا على المحاكاة، أثبتت النتائج المتحصل عليها أن FEC-EASP يوفر معدل إسترداد عالي للأخطاء مقارنة بالآلية FEC ، و كذا يقلص إزدحام الشبكة مقارنة بالآلية SPFEC.
خلافا للبروتوكول UDP، الذي لايملك أي آلية لتصحيح الأخطاء أثناء الإرسال، يطور إقتراحنا الثاني (EUDP) هذا البروتوكول بإدماج الآلية SPFEC و كذا إعتماد الحماية غير المتساوية لأنواع إطارات الفيديو (أي B, P, I)، و هذا لتحسين جودة الفيديو المرسل. يعتمد البروتوكول المقترح EUDP تقنية التكرار. أظهرت نتائج التجارب بإستخدام ns-2 أن EUDP أظهر تحسنا كبيرا لمعدل إسترداد الأخطاء و كذا PSNR و MOS المتعلقة بالفيديو المرسل و هذا بعد العديد من المقارنات ل EUDP مع UDP و EUDP دون الحماية غير المتساوية لأنواع إطارات الفيديو (EUDP-E).
أما عن إقتراحنا الأخير (HERP) فهو يعتمد على تقنية التكرار لتصحيح الأخطاء المنتظمة و كذا تقنية إعادة الإرسال لتصحيح الأخطاء الشديدة للفيديو الناتجة أساسا بسبب إزدحام الشبكة و كذا إنقطاع الطريق. بالإضافة لذالك، يقوم HERP بالتكييف الديناميكي لمعدل التكرار و حدود إعادة الإرسال حسب حالة الشبكة المقاسة ب REB و هذا لتجنب الحمولة الزائدة على الشبكة و كذا لتخفيض زمن الإرسال. يستند HERP إلي طريقة الإبلاغ لمراقبة حالة و حمولة الشبكة، الذي يمثل آلية رد فعل ديناميكية بين السيارة المرسلة و المستقبلة للفيديو. للحد من مشكلة ازدحام الشبكة، يكيف HERP معدل الإرسال وفقا لحمولة الشبكة التي تحدد بطول طابور الرزم على مستوى السيارات الوسيطة. لزيادة جودة الفيديو،يعتمد HERP على الحماية غير المتساوية لأنواع إطارات الفيديو (أي B, P, I). أثبتت نتائج المحاكاة باستخدام (ns-2) أن HERP يحقق تحسينات كبيرة علي جودة الفيديو المرسل وفقا لمعايير QoS و/أو QoE، وهذا بعد المقارنة مع UDP و البروتوكول UDP مدمج بالآلية SPFEC.

الكلمات المفتاحية: شبكات السيارات، بث الفيديو المتواصل، SPFEC، التكرار، اعادة الارسال.

List of Publications

The following listed are the publications related to this thesis.

Published Journal Papers

1. Sofiane Zaidi, Salim Bitam, Abdelhamid Mellouk. Hybrid error recovery protocol for video streaming in vehicle ad hoc networks. Vehicular Communications, vol. 12, pp. 110-126, 2018.

Published Conference Papers

1. Sofiane Zaidi, Salim Bitam, Abdelhamid Mellouk. Enhanced Adaptive Sub-Packet Forward Error Correction Mechanism for Video Streaming in VANET. IEEE Global Communications Conference (GLOBECOM), Washington, USA, pp. 1-6, 2016.

2. Sofiane Zaidi, Salim Bitam, Abdelhamid Mellouk. Enhanced user datagram protocol for video streaming in VANET. IEEE International Conference on Communications (ICC), Paris, France, pp. 1-6, 2017.

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Nomenclature

VANET	Vehicle Ad hoc NEtwork
FEC	Forward Error Correction
SPFEC	Sub-Packet Forward Error Correction
ITU	International Telecommunication Union
QoS	Quality of Service
QoE	Quality of Experience
PLR	Packets Loss Rate
MSE	Mean Squared Error
USP	Satisfaction Percentage
MDP	Mean Dissatisfaction Period
SSIM	Structural Similarity Index Measure
MOS	Mean Opinion Score
SVC	Scalable Video Coding
MDC	Multiple Description Coding
EC	Erasure Coding
FMO	Flexible Macroblock Ordering
MBs	Macro-Blocks
NC	Network Coding
PLNC	Packet Level Network Coding
SLNC	Symbol-Level Network Coding
MPEG	Motion Picture Expert Group
I-frame	Intra-coded frame
P-frame	Predictive frame

B-frame	Bi-directionally predictive-coded frame
GoPs	Groups of Pictures
AVC	Advanced Video Codec
HEVC	High Efficiency Video Coding
MAC	Media Access Control
UDP	User Datagram Protocol
TCP	Transmission Control Protocol
RTP	Real-time Transport Protocol
EC	Erasure Coding
CRC	Cylic Redundancy Check
RLC	Random Linear Coding
SRC	Scalable Reliable Channel
4G	Network of 4th generation
DSDV	Destination-Sequenced Distance-Vector
AODV	Ad hoc On Demand Distance Vector
GPSR	Greedy Perimeter Stateless Routing
DSR	Dynamic Source Routing
DYMOUM	Dynamic Manet On Demand
ZRP	Zone Routing Protocol
VADD	Vehicle-Assisted Data Delivery
HLAR	Hybrid Location-Based Ad hoc Routing
PDR	Packet Delivery Ratio
IP	Internet Protocol
SBF	Sender Based-Forwarding
RBF	Receiver Based-Forwarding
HPCT	High Preferred Content Table
RAP	Roadside Access Point

PSNR	Peak Signal-to-Noise Ratio
ACDB	Automatic Counter Distance Based
DECA	DEnsity-aware reliable broadCAsting
CH	Cluster Head
GPS	Global Positioning System
DP	Dynamic Programing
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
MWBM	Maximum Weighted Bipartite Matching
MUI	Maximum Utility Increment
RSUs	Road Side Units
EDR	Event Data Recorder
OBU	OnBoard Unit
MANET	Mobile Ad hoc NEtwork
XOR	Exclusive-OR
SUMO	Simulation of Urban Mobility
NS-2	Network Simulator 2
db	decibel
ITS	Intelligent Transportation System
MHz	MegaHertz
GHz	GigaHertz
FCC	Federal Communication Commission
DSRC	Dedicated Short Range Communications
CCH	Control CHannel
SCH	Service CHannel
WAVE	Wireless Access in Vehicular Environments
ASTM	American Society for Testing and Materials

IEEE	Institute of Electrical and Electronics Engineers
OSI	Open Systems Interconnection
RMA	Resource Management Application
RM	Resource Manager
RCP	Resource Command Processor
LLC	Logical Link Control
IPV6	Internet Protocol V 6
WSMP	WAVE Short Message Protocol
WSM	WAVE Short Message
WME	WAVE Management Entity
UTC	Universal Time Coordinated
WLAN	Wireless Local Area Network
PU	Processors Unit
ID	IDentification number
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance

Chapter 1

Introduction

Vehicular Ad hoc NETworks (VANET) is an emergent technology attracting currently the attention of industrial and research communities in different topics such as electronics, network, security, transportation, automotive, etc. VANET researches seek to make the vehicles more intelligent mainly in the aim to reduce road traffic accidents, which are increased dramatically at the present time due to the high number of vehicles on the road [1]. The world health organization reported based on the information from 180 countries that the number of road traffic deaths has reached 1.25 million per year [2]. In order to guarantee a road safety, traffic management and comfort of drivers and passengers, various applications are designed to be used in VANET, we mention traffic monitoring, driving assistance, sharing music and videos between passengers [3, 4].

VANET is composed of moving vehicles and fixed Road Side Units (RSUs) placed on the road edges to achieve specific services such as sending periodic messages about the traffic conditions to the vehicles, collecting and analyzing traffic data provided by vehicles, supporting seamless communication between the vehicles [5, 6]. A vehicle can communicate with other vehicles or with the RSUs in a single or multiple hop communication modes. This communication follows the Dedicated Short Range Communication (DSRC) standard specified by the U.S Federal Commission Communication where 75 MHz of spectrum in the 5.9 GHz band is allocated to be used for the three vehicular communication modes namely; Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and hybrid mode (V2X). Each vehicle is equipped with On-Board Unit (OBU), Global Positioning System (GPS), Event Data Recorder (EDR) and a set of sensors in order to detect and to communicate traffic status and data [7].

VANET is a special class of Mobile Ad hoc NETwork (MANET) [8]. Like MANET, in VANET the vehicles and RSUs use the wireless channels to exchange data between them. However, the vehicles high mobility, the wireless link volatility and rapid change of network topology lead to a high number of lost packets. Moreover, VANET suffers from the congestion problem, which forces the vehicles to drop its packets when the network is overloaded especially in high density environments like urban areas.

In vehicular networks, Intelligent Transportation Systems (ITS) were defined to provide mobile applications and services for the travelling public and to improve safety and security of VANET network [9]. VANET can support several applications, which can be classified into two categories: safety oriented applications and non-safety oriented applications [10]. The first category aims to avoid the risk of accidents in the road by generating and transmitting warning messages such as in the case of intersection collision and accidents. The second one ensures the traffic control and management like information given by a RSU about road congestion. Additionally, non-safety applications offer to passengers some conform and infotainment services such as the internet access and mobile e-commerce. In both safety and non-safety applications, development of techniques of transmitting real-time video (also known as the video streaming) attracts a great interest by academia and industries in reason of enhancing road safety and traffic efficiency in addition to response to drivers' and passengers' digital needs [11].

1.1 Motivation of video streaming in VANET

One of the most challenges tackled recently by VANET research community is the video streaming. The video streaming services and applications in VANET can satisfy requirements of car drivers and passengers by providing a clear vision on traffic or any digital data rather than textual messages.

For instance, each vehicle can use its embedded camera to capture some situations of the road traffic or any event occurred in the road like accidents, traffic congestion, parking availability, festival event. Therefore, vehicle digital system transmits the captured video in multi-hop mode to warn the other vehicles in the area. The camera can be also installed at the RSUs at road intersection to facilitate and accelerate the transmission of captured data to the concerned destinations (e.g. police cars or stations, hospital, emergency preparedness, etc.). Another example can be cited in this domain is the transmission in telemedicine, in fact, a video captured by a vehicle or a RSU about an accident can be forwarded toward the hospital or to the nearest ambulance to identify and diagnostic the injuries situation by distant doctors. Video streaming services are also requested by non-safety applications to serve and enhance passenger comfort like playing games between passengers, receiving nearest restaurant and hotel video information, ensuring video conference service between passengers, watching internet videos.

1.2 Problem Statement

This thesis was proposed to cope with video streaming improvement challenges over VANET, in the following aspects:

- **VANET features:** due to the high speed of vehicles leading to high dynamic of VANET topology, the fluctuation of vehicles density and environment obstacles are challenging for the video streaming, because they affect and rupture the communication path between the sender and the receiver when the video is transmitted. Consequently, these situations may produce network congestion and transmission errors, which decreases the video quality [12, 13].

- **Video streaming quality:** video data has strict Quality of Service (QoS) and Quality of Experience (QoE) requirements such as packet delivery ratio, transmission delay, Peak Signal to Noise Ratio (PSNR), Mean Opinion Score (MOS) and Structural Similarity Index Measure (SSIM). Two main issues can deteriorate the video streaming quality in

VANET are the packet loss and the transmission delay. In order to guaranteeing a good video streaming quality, CISCO has defined some video streaming requirements like the constraint of a transmission delay that not be higher than 4 to 5 seconds and a packet loss rate that don't exceed 5% [14]. A higher PSNR and MOS values of video streaming are able to provide higher video streaming quality. Table 1.1 shows a PSNR and MOS requirement values for video streaming and the mapping from PSNR to MOS [15].

Table 1.1: Mapping from PSNR to MOS

Video perception quality	**PNSR value (db)**	**MOS scale**
Excellent	> 37	5
Good	31 - 37	4
Fair	25 - 31	3
Poor	20 - 25	2
Bad	< 20	1

- **Video error recovery:** the main issue of video streaming in VANET is the recover of video errors. Efficient protocols of communication are needed to ensure the good reception of video streaming at the level of the end user. In this research domain, there are some proposed video streaming solutions based on traditional transport protocols such as User Datagram Protocol (UDP) or Transmission Control Protocol (TCP), which are designed originally for wired networks. However, the UDP based solutions did not adopt any error recovery mechanism then the video quality at the end user is affected [16]. Additionally, TCP based solutions are not suitable for video streaming applications because of its reliability mechanism to recover lost packets, which can increase enormously the video transmission delay [17, 18]. Also, most of error resiliency works for video streaming in VANET did not deal together with the three causes of lost packets: transmission errors, network congestion and route disconnection. It is worth noting that many of these works applied the Forward Error Correction (FEC) mechanism, which is based on the redundancy technique to overcome the erroneous packets. However, FEC mechanism suffers from the network overload problem due to the limited network resources. This issue can be solved by an adaptation and performance improvement of traditional error recovery mechanisms and transport protocols for video streaming in VANET.

Several studies have been recently proposed to tackle these issues, among them, we mention studies that applied different video coding and error resiliency techniques at the application and transport layers to improve the video streaming quality. Many other works select reliable paths to disseminate video packets at the network layer to deal with the VANET challenges such as vehicles mobility. In the literature, we can find other studies that adapt some video transmission parameters like the size of contention window to enhance the video quality. Many VANET video streaming works use the redundancy or the retransmission in order to recover the lost video packets. Nevertheless, on the one hand, the redundancy increases the network load and can recover only the uniform transmission errors, and on the other hand, the retransmission increases the end-to-end delay and recovers the burst errors. Therefore, an efficient error recovery protocol for video streaming in VANET is required in order to recover all types of video errors (uniform and burst) with a reduced network load and reduced transmission delay.

1.3 Contributions

In this Doctorate thesis, we propose three main contributions to overcome the aforementioned drawbacks related to the VANET video streaming;

- The first contribution is a new mechanism named: Enhanced Adaptive Sub-Packet Forward Error Correction mechanism (EASP-FEC), aiming at improving the conventional error resiliency approach for video streaming in VANET. EASP-FEC allows sender and relay vehicles to calculate the redundant sub-packets of each packet based on network conditions (i.e. effective packet error rate), network load (i.e. queue length) and frames types of the transmitted video. The objective of EASP-FEC is to increase the recovery efficiency in order to avoid network congestion and to guarantee a high quality of video streaming.

- The second contribution is a new protocol called the Enhanced User Datagram Protocol (EUDP), which integrates UDP with Sub-packet Forward Error Correction (SPFEC) as an error recovery mechanism and the unequal protection of video frame types (I, P, B) coded based on MPEG standard. The purpose of EUDP is to improve the video streaming quality at the level of the receiver vehicle in terms of QoS and QoE metrics.

- The third contribution is a new error recovery protocol named Hybrid Error Recovery Protocol (HERP), aimed at recovering the lost video packets due to the transmission errors, congestion and route disconnection with a reasonable transmission delay, then HERP can guarantee a high video quality at the end receiver in terms of QoS and QoE metrics. HERP combines the SPFEC mechanism with the retransmission technique. Considered as an error recovery mechanism based on the redundancy technique, SPFEC mechanism is applied to recover the lost packets due to transmission errors. On the one side, HERP applies the SPFEC mechanism aiming at providing more protection compared to the FEC mechanism then the network overload is reduced [19]. On the other side, the proposed HERP uses the retransmission technique in order to recover the lost packets caused by the congestion or by the transmission route disconnection. Furthermore, HERP applies the unequal protection of video frames (I, P and B) coded according to MPEG-4 standard, in which the protection degree of the video frames is given according to the frame types to improve the video quality. HERP adapts dynamically their parameters (i.e. redundancy rate, retransmission limit, transmission rate) according to the network condition and network load. HERP is also based on the reporting technique, which represents a dynamic feedback mechanism between the receiver and sender vehicles of the video to control the network condition and the network load.

1.4 Thesis Organization

The rest of this thesis is organized as follows:

- The second chapter backgrounds the thesis context, including the most important aspects of VANET, the video streaming based concepts and the different error recovery techniques that our proposed contributions are based on and inspired by. We describe in this chapter the video assessment metrics, video encoding techniques, and video compression standards

- The third chapter introduces, reviews, and discusses the VANET video streaming state-of-the art. This chapter presents the existing solutions, which suggested for video streaming in VANET. We classify, compare and study these solutions based on different features at each layer level.

- The forth chapter describes the design and development of our two first contributions tackling to improve the video streaming quality in VANET; it is the Enhanced Adaptive Sub-Packet Forward Error Correction mechanism (EASP-FEC), and the Enhanced User Datagram Protocol (EUDP). These proposed solutions are based on SPFEC mechanism and their performances have been evaluated comparing to the conventional error recovery mechanisms and protocols.

- Chapter five discusses our third video streaming solution over VANET proposed in this study; named Hybrid Error Recovery Protocol (HERP). This solution has been extensively evaluated and was compared with similar solutions, in terms of PDR, transmission delay, PSNR, MOS.

- Finally, chapter six summarizes this thesis, outlines the advancements toward video streaming in VANET and suggests some future research directions in this domain.

Chapter 2

Video streaming in VANET: an overview

Recently, the number of vehicles in the word has been rapidly growing, which creates many problems for the road traffic like road congestion, increasing number of accidents, air pollution. Several current research efforts from the automobile manufactures and academia are focus on the Vehicular ad-hoc networks (VANETs) domain in order to improve the vehicular traffic safety issues, traffic management and to provide some comfort to vehicle drivers and passengers.

VANET is a new technology consisting of a set of nodes such as vehicles and Roadside Units (RSUs). Each vehicle is equipped with an onboard unit (OBU) as a computer device helping to communicate the vehicle with other VANET nodes. The RSU is fixed at a specific location along the road to improve the communication between vehicles. There are three types of communication in VANET: the communication between the vehicles (V2V), the communication between the vehicle and RSU (V2I) and the hybrid communication. The Institute of Electrical and Electronics Engineers (IEEE) has defined a communication standard named IEEE 802.11 for Wireless Local Area Network (WLAN) in 1997. IEEE 802.11 adapts the PHY and MAC layers for OSI model to support the wireless communication. Many extensions of IEEE 802.11 have been proposed such as IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11h, IEEE 802.11p and IEEE 802.11e [20]. The standard IEEE 802.11p is one part in protocol stack called Wireless Access in Vehicular Environment (WAVE), which represents an enhanced IEEE 802.11 for V2V and V2I communications [21].

The video streaming in VANET is a crucial in the development of many services, with an installed camera at the vehicle or at a RSU, the road events such as an accident, traffic congestion, traffic conditions can be captured and saved in a video file, to be transmitted to different VANET nodes. However, the video transmission in VANET is an important issue in this domain due to VANET particularities such as the high mobility of vehicles, short links life-time and network overload and due to video streaming requirements such as a lower transmission delay and higher data reception ratio.

Therefore, one of the efficient solutions proposed in this area is the use of video error recovery techniques to protect video data against errors in the networks. These errors are produced and affected by several causes; we mention the transmission wireless support, congestion or network links disconnection.

Section 2.1 of this chapter introduces the basic definitions and concepts of VANET, including architecture, features, applications. Next, we outline in section 2.2 the video streaming concepts such as video streaming, Quality of Service (QoS) and Quality of Experience (QoE) metrics, video encoding techniques and video compression standards. In addition, this chapter presents in section 2.3 the error recovery techniques considered as a category in which our proposals is belong aiming at recovering different errors of video streaming in VANET. Finally, the section 2.4 summarizes this chapter.

2.1 Vehicular Ad Hoc Networks

Since our study is about enhancing video streaming quality in VANETs to improve the vehicles safety and traffic management in the road, we present in this section the basic concepts of VANETs.

2.1.1 Definition

VANET is defined as a subset of MANET where the mobile nodes are the vehicles, moving with a high speed compared to MANET nodes. Each vehicle is equipped with some electronic devices like calculator, sensors, radars, GPS, communication devices, etc. VANET inherits some MANET features such as: mobility, multi-hop and wireless communication, decentralized control, and it possesses some particular characteristics such as high dynamic topology, frequent link disconnection, predictability of the mobility pattern, sufficient storage capacity, high processing and battery power, unpredictability of vehicles density. Because of these particularities, VANET supports a fixed Roadside Units (RSUs) that provides some transmission and computing services, these RSUs are deployed at crucial locations like dangerous intersections, services stations [22]. Figure 2.1 shows an example of VANET network in urban environment.

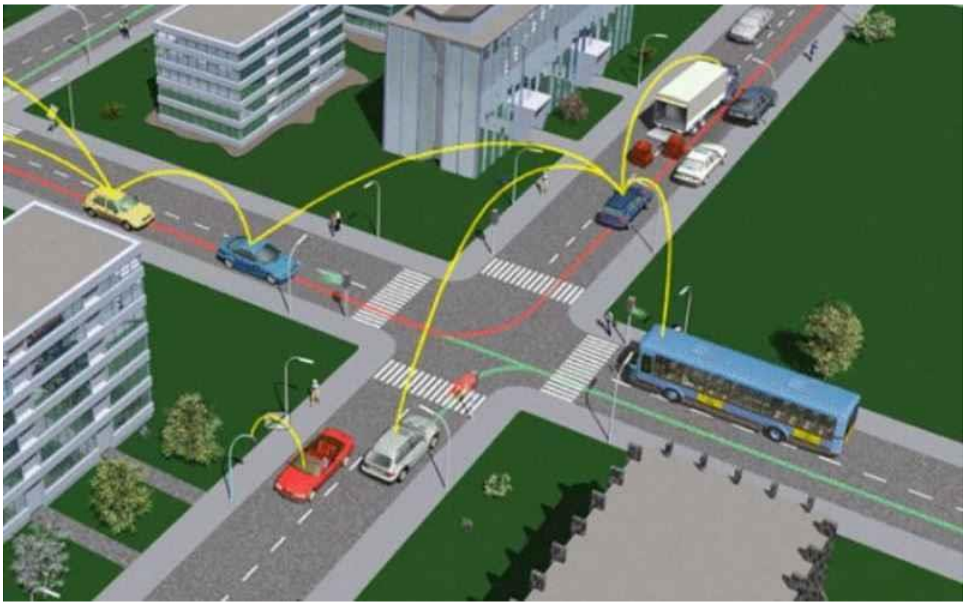


Figure 2.1: Vehicular Ad-hoc Network

2.1.2 VANET architecture

The main VANET components are the vehicles and RSUs, the crucial part of the vehicle, which allows the processing and the communication in the network is the OBU. Usually the RSU provides some services and the OBU uses these services in benefit of driver and/or passenger [23]. In the following, different VANET components are reviewed.

2.1.2.1 Vehicles On-Board Unit (OBU)

The OBU is a part of the vehicle responsible for making the vehicle smart and allowing the exchange of messages with other vehicles and with various RSUs. As shown in figure 2.2, OBU is formed by the following equipments:

- **Processors Units (PUs)**

  PU represents the computing platform of the OBU, which executes some functions to perform the communication with other OBUs or RSUs. For example, PU creates transmitted message, enforces transmission security and encrypts/decrypts communicated data [24].

- **Event Data Recorder (EDR)**

  EDR records the vehicle critical data, such as vehicle speed, vehicle engine overheating, received events, which can be helpful when a road event in the vehicle environment is occurred like in the case of an accident.

- **Tamper Proof Devices (TPD)**

  TPD saves the confidential information about the vehicles such as the vehicle IDentification number (ID), certificates, private keys. This information can be used by the authority or any other official order to ensure road security.

- **Global Position System (GPS)**

  GPS provides the geographic location of the vehicle, the speed, the direction at a specified time interval [25].

- **Radars and sensors**

  The vehicle uses the radars and sensors to detect the environment obstacles and events. The vehicle can be equipped with many types of radar such as forward radar, rear radar, and with different types of sensors like cameras, temperature sensor, or others.

- **Vehicle interfaces**

  There are two types of interfaces within the vehicle; the user interface and the interface with other OBUs. The first one allows the connection with the driver and the passenger of the vehicle. The second one permits the vehicle to connect with the other OBUs in the network.

- **Communication devices**

  The vehicle must be equipped with a communication device like Omni directional antennas, which allow a short-range wireless communication with other OBUs and/or RSUs based on IEEE 802.11p radio technology.

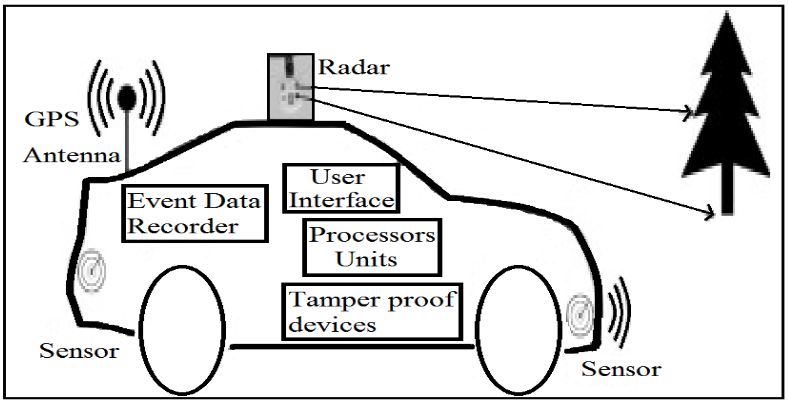


Figure 2.2: Vehicle On-Board Unit

2.1.2.2 Road side Units (RSUs)

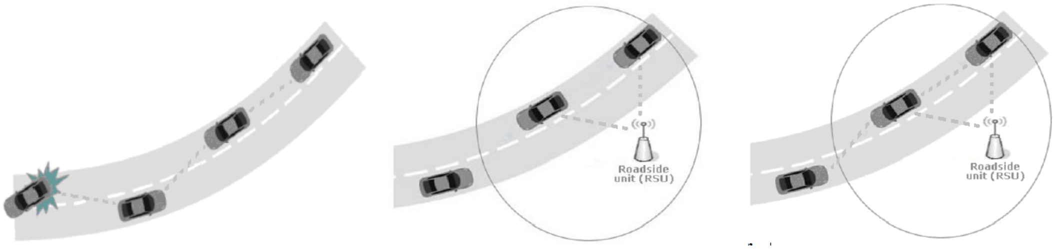
Roadside Units (RSUs) are fixed units, considered as stationary VANET nodes deployed along the road or in strategic locations like the intersections, near parking space. The RSU facilitates and extends the communication range between the OBUs by the forwarding of the collected data to other OBUs and RSUs. The RSU provides also several services to the vehicles such as accident warning and internet connectivity, which increase their safety and facilitate their movement. Based on IEEE 802.11p radio technology, the RSU sends and receives messages to and from the OBUs belonging to its transmission range.

2.1.3 VANET communication

The VANET architecture allows the communication between the vehicles and RSUs in the road following three possible configurations: V2V, V2I and hybrid communication.

- **Vehicle to Vehicle (V2V) communication**

  In this mode of communication (Figure 2.3 (a)), the vehicles inter-communicate with each other without any relation with the infrastructure or RSU. The V2V is a multi-hop wireless communication, in which the sender vehicle data pass through a set of vehicles to reach the receiver vehicle [26].



(a) V2V (b) V2I (c) Hybrid

Figure 2.3: VANET communication types

- **Vehicle to Infrastructure (V2I) communication**

  In this communication type (Figure 2.3 (b)), the vehicles exchange the messages with RSUs which are installed in surrounding infrastructure [27]. The RSU sends and receives messages in a signal hop with the vehicles appearing in its transmission range. V2I provides higher bandwidth link between vehicles and RSUs. Many applications can be supported by V2I communication, such as the broadcasting of periodic warning message containing the limit of maximum vehicle speed, which should be respected in the road.

- **Hybrid communication**

  It is a combination between V2V and V2I communications (Figure 2.3 (c)). In this communication type, if the vehicle can access directly to the RSU, it communicates with this latter in a single hop, otherwise the vehicle communicates with the other vehicles in a multi-hop fusion.

2.1.4 VANET applications

In the literature, many classifications of VANET applications have been proposed. We classify the VANET applications in three categories [28]: transportation safety based applications, transportation efficiency based applications and infotainment services. Notice that the safety and efficiency based applications are not completely separated from each other, for instance an accident in the road can lead to traffic jam [29]. Some examples of VANET applications are summarized in the table 2.1 [30].

- **Transportation safety applications**

  This category is the critical and the most important category for VANET services due to its impact in the road safety. It aims to decrease the number of accidents in the road [31]. The basic intention is to alert the drivers about the dangerous situations or some event in the road such as the accident, intersection and road congestion [32]. For instance, in the case of an accident, the approaching vehicles can use simple transportation safety application like sending emergency notifications to send a warner notification to nearby vehicles. When the vehicle drivers receive the notification, it stops or reduces the vehicle speed. The transportation safety applications are sensitive to the transmission delay and the warner messages must have a reduced length.

- **Transportation efficiency applications**

This category aims to optimize the road traffic management by means of the communication, to avoid the traffic congestion. For example, in the traffic jam situation, the cooperation between vehicles in the road facilitates the passage of an emergency vehicle. The road congestion application can provide the driver to choose the best routes and time to their destination. This applications category can control also the crossroads and intersections to decrease the possibility of collision, when the vehicles passing through these intersections [33].

- **Infotainment services applications**

This category provides to drivers and passengers some comfort services such as internet access, maps download, payment for parking, internet and mobile multiplayer gaming [34]. The infotainment applications have different communication requirements compared to safety and efficiency applications, in which no real-time constraint is required for some infotainment services.

Table 2.1: Some examples of VANET applications

Application category	**Application example**
Transportation safety	• Traffic signal violation warning • Left turn assistant • Stop sign movement assistant • Intersection Collision Warning • Curve speed warning • Emergency electronic brake light • Pre-crash sensing • Cooperative forward collision warning • Lane-change warning
Transportation efficiency	• Intelligent On-Ramp Metering • Intelligent Traffic Flow Control • Enhanced route guidance and navigation • Green light optimal speed advisory • Lane merging assistants • Free parking space
Infotainment services	• Music Downloads • Play videos. • Map Downloads and Updates

2.1.5 Communication standards and protocols in VANET

2.1.5.1 Dedicated Short Range Communications (DSRC)

The U.S. Federal Communication Commission (FCC) allocated a 75 MHz in the 5.850 GHz to 5.925 GHz of DSRC spectrum at 5.9 GHz in 1999 for V2V and V2I communications [35]. The DSRC band is structured into 7 channels of 10 MHz (Ch 172, Ch 174, Ch 176, Ch 178, Ch 180, Ch 182 and Ch 184). The Channel 178 is a control channel (CHH), which is reserved only for the safety applications. The Channels 172 and 184 are reserved for specific use (critical safety of life and high power public safety). The rest of channels (SCH) are served for safety and non-safety applications. Figure 2.4 shows DSRC spectrum band for VANET allocated by FCC.

Historically, American Society for Testing and Materials standardization company (ASTM) proposed the first ASTM-DSRC standard (published under the nomination ASTM E2213-03), which is based on IEEE 802.11a standard at the physical layer level, and IEEE 802.11 at MAC layer level, in accordance with DSRC technology. After that, IEEE defines a new family of protocols named IEEE 802.11p, which is based on IEEE 802.11 and ASTM E2213-03. In IEEE 802.11p, the physical layer and the MAC layer were modified in order to support the wireless communication in vehicular networks. Then, IEEE defines the Wireless Access in Vehicular Environments (WAVE), which defines the protocols at each layer level of the OSI model, to support the wireless vehicular communication.

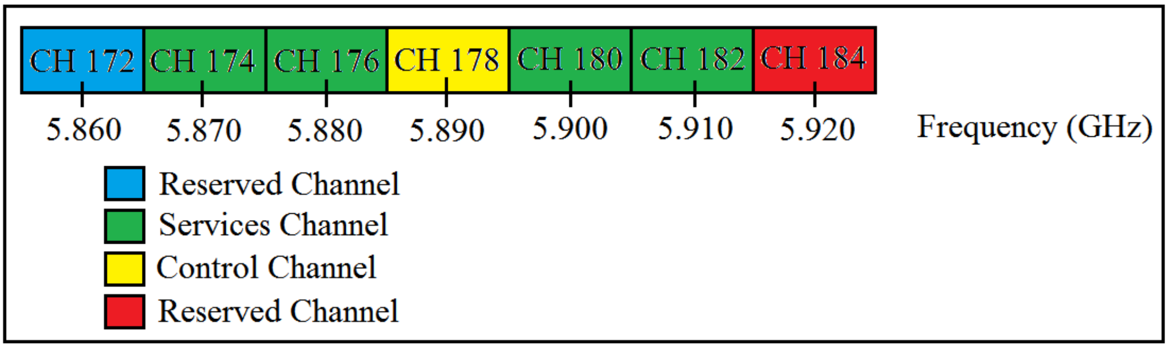


Figure 2.4: DSRC spectrum band for VANET allocated by FCC

2.1.5.2 Wireless Access in Vehicular Environments (WAVE)

WAVE is a VANET communication technology, which based on IEEE 802.11p and IEEE P1609 standards. The physique (PHY) and MAC layers of WAVE model employ IEEE 802.11p and the other layers of WAVE employ IEEE P1609. The MAC layer employs also IEEE P1609.4 standard. The WAVE architecture is given by figure 2.5.

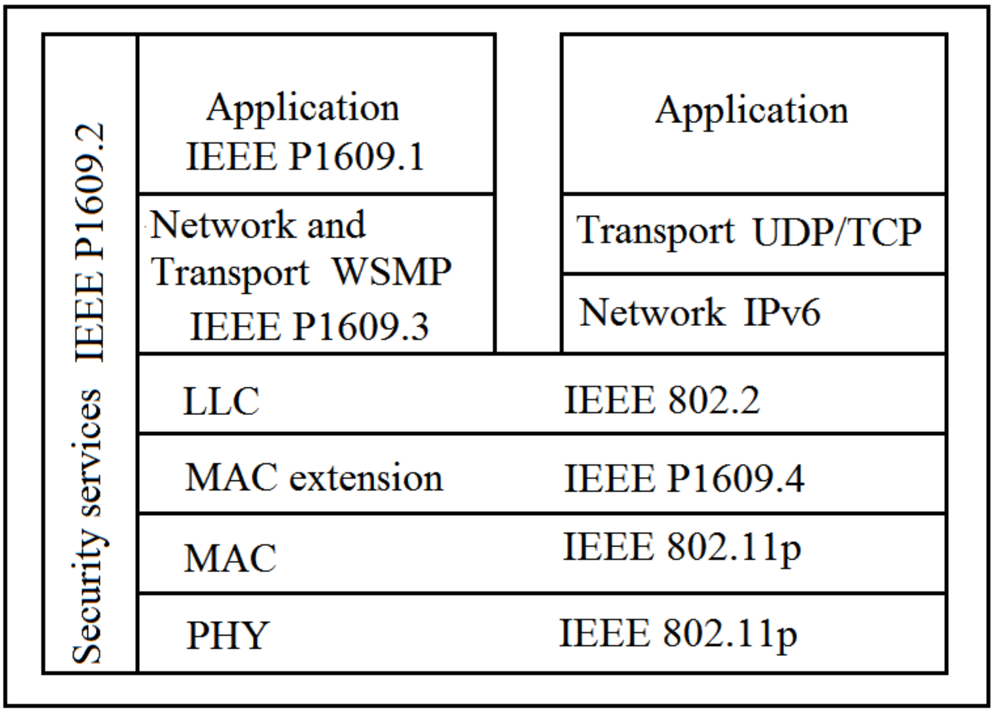


Figure 2.5: WAVE architecture

2.1.5.2.1 IEEE 802.11p

IEEE 802.11p is an extension standard of IEEE 802.11 for V2V and V2I communications in VANETs networks to support Intelligent Transportation Systems (ITS) applications. IEEE 802.11p is a modified version of IEEE 802.11a that uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as the basic medium access scheme at MAC layer level and DSRC technology at PHY layer level. The sending data rate in IEEE 802.11p is ranging from 3 to 27 Mbps over 10 MHz bandwidth, unlike IEEE 802.11a in which it operates with 20 MHz bandwidth [36].

2.1.5.2.2 IEEE P1609

IEEE P1609 is a set of standards (P1609.1, P1609.2, P1609.3 and P1609.4) used by the higher layers of WAVE.

- **IEEE P1609.1**

  IEEE P1609.1 standard [37] is responsible for the resource management including its services, interfaces, and protective mechanisms for security and privacy. According to this standard, OBU and RSU have three components: Resource Management Applications (RMAs), Resource Manager (RM) and Resource Command Processor (RCP). The first one represents the applications that run at the OBU computer and which requests the resources of other OBUs. The second one is the intermediate component considered as a broker between RMAs and RCP. The latter component executes the RMAs commands received via RM [38].

- **IEEE P1609.2**

  IEEE P1609.2 standard [39] provides the security services such as confidentiality, authenticity, integrity and anonymity for applications and management messages. This standard defines also the format of secure messages and their processing method.

- **IEEE P1609.3**

  IEEE P1609.3 standard [40] defines the protocols and functions mainly at network and transport layers. The WAVE network services can be divided into two parts: data-plan services and management-plan services [41]. The former supports the protocols IPv6 and WSMP in order to transmit a Wave Short Message (WSM). The latter is known as WAVE Management Entity (WME) and it responsible for the system configuration and maintenance.

- **IEEE P1609.4**

  IEEE P1609.4 standard [42] provides some functions to enhance the IEEE 802.11p at MAC layer level in order to increase the communication capacity of the vehicle and support the multi-channel operations. In IEEE P1609.4, a synchronized channel coordination scheme based on the Universal Time Coordinated (UTC) was developed to solve the multi-channel coordination problem [43]. UTC is based on the dividing of channel time into synchronized intervals with a fixed length, each interval time is used by an application service to the transmission of messages through this channel.

2.2 Video streaming

The video streaming is defined by [44] as follows: *'video streaming is a type of media streaming in which the data from a video file is continuously delivered via the internet to a remote user. It allows a video to be viewed online without being downloaded on a host computer or device'*.

We present in this section the basic concepts of the video streaming such as: video evaluation metrics, video encoding techniques and video compression standards.

2.2.1 Video streaming metrics

The assessment metrics of video streaming are classified into two main classes: objective assessment and subjective assessment. Objective assessment can be processed automatically using a set of information like network technical parameters to evaluate the video quality, while subjective assessment is based on human's perception and experience to process this evaluation. In subjective evaluation, a number of human observes are asked to watch and evaluate the video quality, the average of all human evaluations is given by Mean Opinion Score MOS [45]. International Telecommunication Union (ITU) defines in the recommendation ITU-R BT.500-11 [46] five categories of the images quality and image impairment, which help the human to classify perceived image. Table 2.2 shows ITU-R image quality and impairment scales.

Table 2.2: ITU-R quality and impairment scales [46]

Grade Scale	Image quality	Image impairment
5	Excellent	Imperceptible
4	Good	Perceptible, but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

The subjective assessment provides a most accurate evaluation due to the real human's perception than objective assessment, which is the better criterion used to evaluate the video quality. The limit of video streaming subjective assessment is the high cost and time of manpower inviting to evaluate the video quality, compared to objective assessment. We classify video streaming metrics in VANET into two essential classes: QoS and QoE.

2.2.1.1 QoS metrics of video streaming

Quality of Servise (QoS) is based on the objective assessment of video streaming, it has been defined in [47] in two contexts: the user (customer) context and the network provider context. In user context, QoS is defined by the attributes contributing essential in the use of service, whereas, in network provider context, QoS is defined by parameters contributing to end-to-end performance of service, where this end-to-end performance must reflect to user's requirements.

Many works uses QoS metrics to evaluate video streaming quality in VANET like Packets Loss Rate (PLR), PSNR, transmission delay, jitter and throughput, and others. We present in this subsection some QoS metrics used for video streaming evaluation in VANET, as summarized in table 2.3.

- **Rate distortion of video frames**

  According to [48], the rate distortion D*d* of video frames is calculated using the following equation:

$$Dd = De + Dv$$

  Where D*e* is the distortion caused by signal compression and D*v* is the distortion caused by residual errors and inter-frame error propagation. The authors of [49] proposed a reconstruction of this rate distortion equation for the video streaming in VANET, where the video is transmitted through a multi-hop communication, by the following equation:

$$Dd = De + Dn$$

Where *De* is the distortion caused by signal compression at the encoder and D*n* is the distortion caused by the network, Dn is calculated by the following equation:

$$Dn = Dparti + Dexpir + Derror$$

Where *Dparti* is the distortion caused by the partition of network, *Dexpir* represents the distortion caused by the video deadline expiration and *Derror* is the distortion caused by the transmission error due to wireless fading channel and interference.

- **Start-up delay**

In VANET, each vehicle has a buffer to stock the received packets, the process of video playback consists of two phases: charging phase and playback phase, when the buffer is empty the charging phase starts, it consists of charging the buffer by sufficient packets, when the buffer is charged by this packets (playback threshold) the playback phase is started. The time interval of charging phase is named start-up delay. According to [50] start-up delay *(Ds)* is given by the equation:

$$Ds = min\{t|X(0) = 0, X(t) = b, t > 0\}$$

Where $X(t)$ is the number of packets in the buffer at time t and b is the playback threshold. The average start-up delay is given by the equation:

$$E(Ds) = b/\lambda$$

Where λ is the arrival rate of the packets at the destination vehicle.

- **Frequency of streaming freezes**

When the effective arrival rate of video streaming at the receiver vehicle λ is smaller than playback rate μ of this vehicle, the playback phase will probably stop, which produces the interruptions (streaming freezes) of video streaming at the application layer. According to [50] the average number of streaming freezes after t seconds ($E(F)$) is given by the equation:

$$E(F) \approx -(\lambda(\lambda - \mu)/\mu b) * t$$

- **Packet Delivery Ratio (PDR)**

PDR represents the total number of received video packets over the total number of sent video packets. It is calculated as follows:

$$PDR = \frac{\sum ReceivedPackets}{\sum SendPackets}$$

- **Average transmission delay**

The transmission delay of a packet is the time interval between the sending moment of this packet at the sender and the complete reception time of this packet at the receiver level. The average transmission delay is the sum of all received packets delay divided by the number of the total number of the received packets. The average transmission delay is computed by the following formula:

$$Average\_transmission\_delay = \frac{\sum_{i=0}^{n}(RTimeOfPkt_i - STimeOfPkt_i)}{\sum ReceivedPackets}$$

Where, $RTimeOfPkt_i$ is the reception time of the $Packet_i$ and $STimeOfPkt_i$ is the sending time of the $Packet_i$.

- **Decodable Frame Rate (DFR)**

DFR is defined as the number of decodable video frames over the total number of sent video frames in a given *EPER* (Effective Packet Error Rate), it is calculated as follows:

$$DFR = \frac{NDF(I) + NDF(P) + NDF(B)}{\sum SendFrames}$$

Where, *NDF(I)* is the Number of Decodable Frames I, *NDF(P)* is the Number of Decodable Frames P and *NDF(B)* is the Number of Decodable Frames B.

- **Peak Signal to Noise Ratio (PSNR)**

[51] defined the PSNR as the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Mathematically, PSNR is defined via Mean Squared Error (MSE) [52], which measures the cumulative square error between original frame *'o'* and distortion frame *'d'*, as follows:

$$MSE = \frac{1}{M * N}\sum_{m=1}^{M}\sum_{n=1}^{N}|o(m,n) - d(m,n)|^2$$

Where *M.N* is the frame size in pixel, *o(m,n)* and *d(m,n)* are the luminance pixels in position *(m,n)* in the frame. In mathematical way, PSNR is the logarithmic ratio between the maximum value of a signal and MSE.

$$PSNR = 10 * \log\frac{255^2}{MSE}$$

Table 2.3: Some QoS metrics of video streaming in VANET

QoS metric	Signification
Throughput	Effective number of transmitted data per unit time (bits/s)
Transmission delay	Time interval between the send of data form the sender and the reception of this data at receiver
Jitter	Difference between the delays of the *i* th and the *(i+1)* th data units. (delay variation)
Packet Loss Rate (PLR)	Percentage of lost packets at receiver vehicle compared to the sent packets from the source
Packet Delivery Ratio	Total number of received packets per total number of sent packets
Receiving Data Rate	Total received video size divided by total transmission time
Start-up Delay	Time from the start of downloading the first segment to the time that the playback begins
End to End Delay	Time interval between the start of packets sending by the source and the end the complete reception of this packets by the receiver
Overhead, Cost	Total number of transmissions
PSNR	Ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation

2.2.1.2 QoE metrics of video streaming

ITU defines in the recommendation ITU-T P.10/G.100 [53] the Quality of Experience (QoE) as the overall acceptability of an application or service, as perceived subjectively by end-users. QoE includes a subjective assessment of video streaming, which provides a more accurate evaluation compared to QoS based only on an objective assessment. We present in this subsection some QoE metrics used for video streaming evaluation in VANET.

- **Mean Opinion Score (MOS)**

  MOS is widely chosen in the QoE as the result of subjective tests. MOS allows the quantification of subjective tests, during the subjective tests several users are invited to judge the quality of video and give a specific measured value for the video quality, at the end of subjective tests, MOS is calculated by averaging all video quality values. Figure 2.6 shows the process of obtaining MOS. In addition to MOS, the authors of [54]

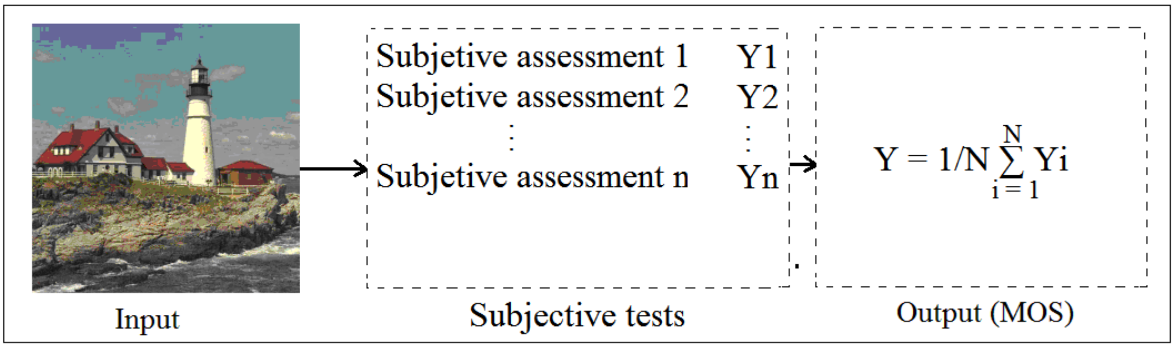


Figure 2.6: The process of obtaining MOS

proposed two other QoE metrics to evaluate the video streaming quality in VANET at the receiver level: the User Satisfaction Percentage (USP) and the Mean Dissatisfaction Period (MDP), explained as follows:

- **User Satisfaction Percentage (USP)**

  USP is the percentage of time that MOS keeping satisfaction of users over an acceptable threshold, higher value of USP mean that the higher number of good windows is received at the destination.

- **Mean Dissatisfaction Period (MDP)**

  Contrary to USP, MDP is proposed to measure the distribution of loss windows [54].

- **Structural Similarity Index Measure (SSIM)**

  SSIM is developed by [55] in order to measure similarity between two images according to Human Visual System perception, SSIM provides an assessment of video quality that separates the measurement of luminance, contrast and structural distortion. The authors in [56] analyzed and compared PSNR and SSIM to give a better understanding of similarity and difference between these two metrics. This study has revealed that values of PSNR can be predicted from the SSIM and vice-versa and PSNR and SSIM mainly differ on their degree of sensitivity to image degradations types.

In VANET video streaming, many recent researches have taken into consideration both PSNR and SSIM metrics to evaluate the video streaming assessment like [57], [58] and [59]. Table 2.4 summarizes basic QoE metrics of video streaming in VANET.

Table 2.4: Some QoE metrics of video streaming in VANET

QoE metric	**Signification**
MOS	Average of all video quality subjective assessments values
USP	Percentage of time that MOS is over the user satisfaction threshold
MDP	Measurement of distribution of loss windows
SSIM	Objective QoE metric measuring structural distortion of the video to obtain a better correlation with the user's subjective impression [59]

2.2.2 Video encoding techniques

This section presents some video streaming encoding techniques used in VANET.

2.2.2.1 Scalable Video Coding (SVC)

SVC is based on the layered coding. The video stream is encoded into two types of layers; the former is a based layer, which represents I-frames and P-frames, where the latter is introduced as an enhancement layer representing the B-frames. The basic layer guarantees a based video quality and the enhancement layer increases the video quality [60].

2.2.2.2 Multiple Description Coding (MDC)

MDC [61] encodes the video streaming as a set of descriptions; each of them is a sequence of frames. When a frame of any description is perturbed, the decoder can recuperate this frame from other description, based on the redundancy recuperation mechanism of MDC.

2.2.2.3 XOR based coding

The XOR based coding is very widely used in error resiliency mechanisms such as Forword Error Correction (FEC) and Erasure Coding (EC), because this coding is efficient and not complicate. FEC and EC are based on the idea of adding redundant packets to original packets to successfully recover these later at the end receiver.

When the XOR logical operation is applied on a set of packets (i.e. a, b,..., n) at the sender to produce one redundant packet, the presence of all these packets without one lost packet at the receiver allows the recovering of this lost packet.

2.2.2.4 Flexible Macroblock Ordering (FMO) coding

This encoding technique is based on the principal of dividing the frame into a set of slices; each slice consists of a set of Macro-Blocks (MBs). The Macro-Block is an elementary unit of slice. FMO is very powerful for the error resilience, for example if one slice is not available at the decoder, each lost macro-block of this slice may be surrounded by macro-blocks of other slices (above, bellow, right and left) [62]. Therefore, the lost macro-block can be recovered using the error concealment technique (explained in section 2.3.3).

2.2.2.5 Network Coding (NC)

NC is based on the idea that the intermediate nodes (re-encoder) mix the content of received units of data to produce new unit of data, which allows the reducing of the number of transmitted units of data, in order to increase the throughput of wireless network [63].

There are many variations of NC like the Packet Level Network Coding (PLNC) in which the unit of data is the packet and the Symbol-Level Network Coding (SLNC) where the unit of data is a group of consecutive bits.

2.2.3 Video encoding standards

We present in this section the most significant standards for video streaming encoding in VANET.

2.2.3.1 MPEG-4

MPEG (Motion Picture Expert Group) is a video coding standard used by many mobile networks for video streaming compression. Many versions of MPEG multimedia standard are introduced such as MPEG-2, MPEG-4, MPEG-7 and MPEG-21 [64]. We have chosen in our work to use the MPEG-4 for video streaming coding in VANET, because MPEG-4 is the MPEG version supported widely by the majority of multimedia applications, and it produces a good video quality in mobile networks [65].

Based on MPEG-4 standard, the video is encoded as *n* Groups of Pictures (abrevated *n* GoPs), where each GoP is composed of three kinds of frames: Intra-coded frame (I-frame), Predictive-coded frame (P-frame) and Bi-directionally predictive-coded frame (B-frame). In the same GoP, I-frame is the most important frame compared to P-frame, which is in its turn more important than B-frame. The encoding and decoding of P-frame require previous I-frames and/or P-frames of the same GoP. Also, the encoding and decoding of B-frame require previous and follows I-frames and/or P-frames of the same GoP [66]. Figure 2.7 shows the relation between frames of the GoP (ex. IBBPBBPBB).

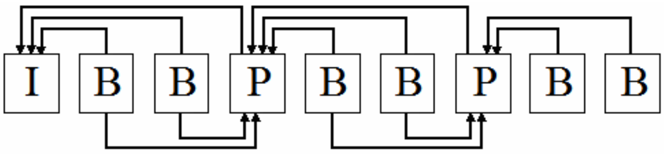


Figure 2.7: GoP structure of MPEG standard

2.2.3.2 H.264/AVC

H.264/AVC (Advanced Video Codec) is a video coding standard based on FMO coding techniques, in which each frame can be divided at most into eight (08) slices and there are six (06) types of assignment of MBs to slices [67]. The spatial and temporal concealment techniques allow the recovery of losses slices of any frame.

The study published in [68] proved that type 1 (checkerboard selection) of FMO coding of H.264/AVC standard provides a high PSNR of transmitted video in VANET than others FMO coding types, because type 1 is able to exploit wholly the error resiliency techniques of

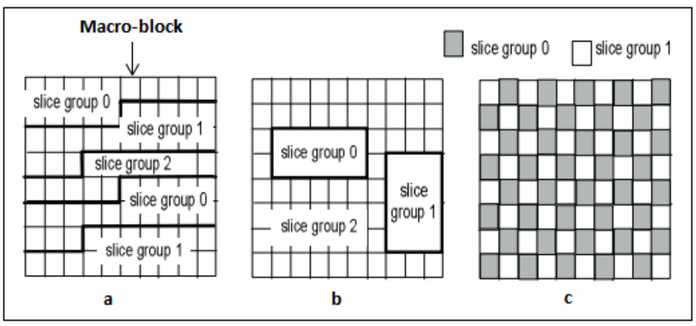


Figure 2.8: Three types of FMO coding of H.264/AVC standard

H.264/AVC. Figure 2.8 shows three types of assignment of MBs to slices of H.264/AVC standard, figure 2.8 (a) shows type 0 (Continuing row), figure 2.8 (b) shows type 2 (geometrical selection), and figure 2.8 (c) shows type 1 (checkerboard selection).

2.2.3.3 H.265/HEVC

H.265/HEVC (High Efficiency Video Coding) [69] is a new standard of video compression, tackling to reduce the bandwidth requirements by 50% compared to H.264/AVC standard with keeping the same PSNR video quality. Like H.264/AVC, H.265/HEVC is based on encoding the video frame into a set of slices and uses both the spatial and temporal concealment techniques to recover the lost slices. Among the differences between H.264/AVC and H.265/HEVC, making the last one more efficient than H.264/AVC is the use of elementary units of frame (i.e. Macro-Blocks) by H.264/AVC with the same and fixed size, however, H.265/HEVC uses elementary units of frame (called Coding Tree Units) with different sizes. Also, the number of spatial and temporal concealment techniques of H.265/HEVC are higher than those of H.264/AVC.

2.3 Error resiliency techniques

The main challenge of video streaming in VANET is the reliability [70], in which the packets data must be as possible received and without any errors at the destination. We can define the error resiliency technique as the basic strategy or mechanism available to recover the loss or corruption of data packet. Many VANET video streaming methods use error recovery mechanisms and techniques to overcome the erroneous packets caused by route disconnection, wireless nature of VANET or network congestion. We classify these video error recovery techniques over VANET into three classes: redundancy-based techniques, retransmission-based techniques and concealment-based techniques.

2.3.1 Redundancy-based techniques

In these techniques, the sender adds a duplicate data with the original data and transmits it to the receiver, when this latter receives all data, it can recover the lost data using its duplicate. There are some error resiliency techniques based on the redundancy like Forward Error Correction (FEC), interleaving, and Erasure Coding (EC). Redundancy-based techniques increase the packet delivery ratio, however it led to an increased network overload because of the high number of transmitted packets, especially when the network is dense or with high transmission rate.

2.3.1.1 Forward error correction (FEC)

FEC [71] is an error resiliency mechanism aiming at recovering lost packets at the receiver level based on the redundancy technique, without any interaction or feedback with the sender of these packets. FEC is based on the idea of encoding the video as a set of blocks of a fixed size *n*, where each block is composed of *k* source packets and (*n*-*k*) redundant packets. The decoding of k source packets of any block needs the good reception of k packets of this block.

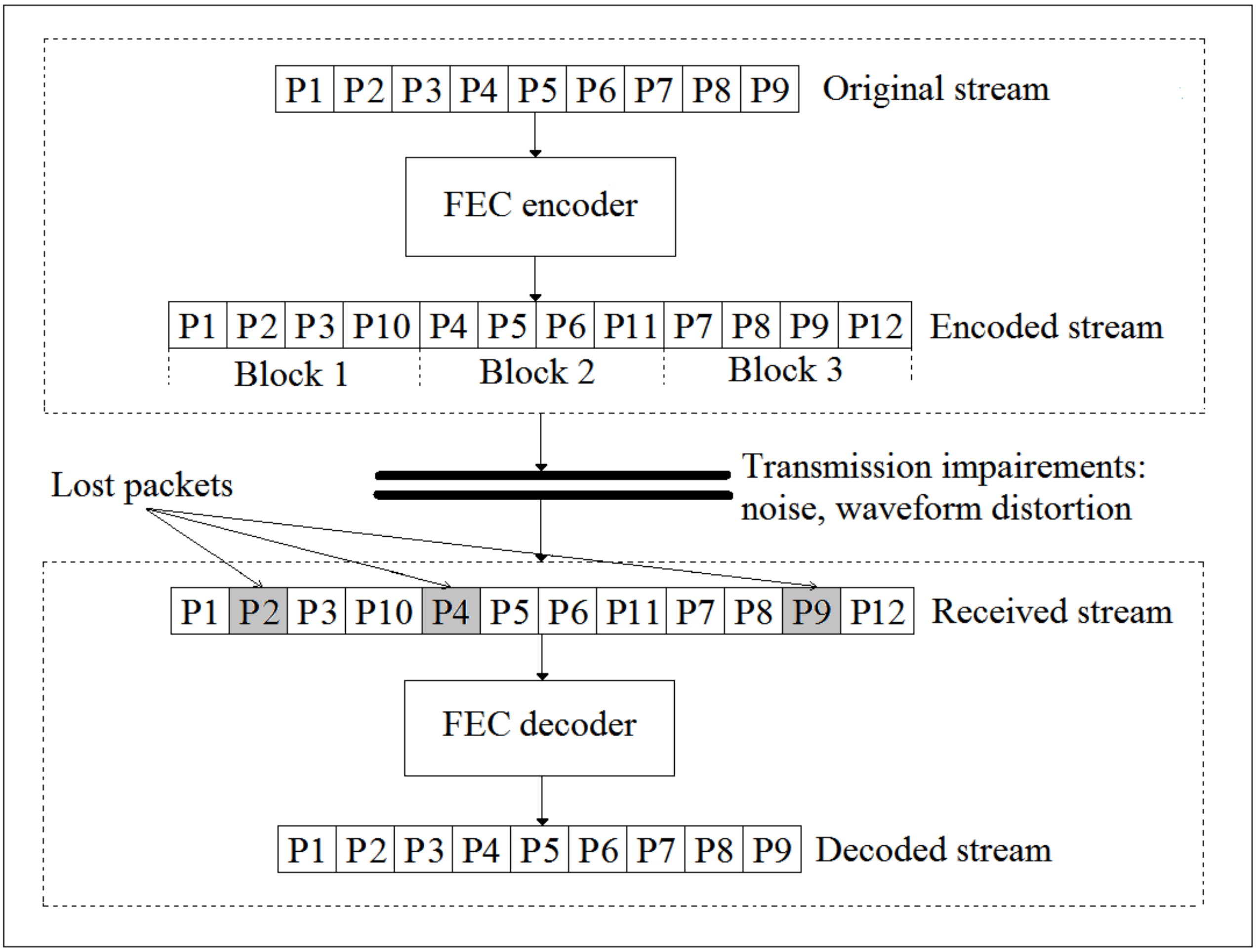


Figure 2.9: An example of Forward Error Correction mechanism

The network overload is considered as a limit of FEC due to the redundant packets. Moreover, this mechanism can recover only the uniform errors (i.e. errors occurring with uniform distribution independently in a sequence of packets), therefore FEC cannot recover the burst errors (i.e. consecutive lost packets). Sub-Packet Forward Error Correction (SPFEC) is a special case of FEC, in which the packet is a block of original sub-packets and redundant sub-packets. An example of FEC process is shown in figure 2.9.

2.3.1.2 Interleaving

Interleaving [72] is a recovery technique that transforms the burst frame errors into a set of uniform frame errors. These latter can be recovered easily by the redundancy technique. As shown in figure 2.10, the sender interleaves the original stream in which it changes the order of original frames (i.e. separate the original frames by a specific distance). After receiving the frames, the receiver returns the original frames in its original order. If consecutive frames are lost during the transmission in the interleaved stream, this burst error can be transformed into uniform errors when the frames are returned in their initial positions. The application of the redundancy can recover easily these uniform errors. Note that the original stream in the figure

2.10 is consisted of two GoPs (IBBPBBPBB), the first GoP consists of the first eight frames of the original stream (frame 1 to frame 9) and the second GoP consists of the second eight frames of the original stream (frame 10 to frame 18).

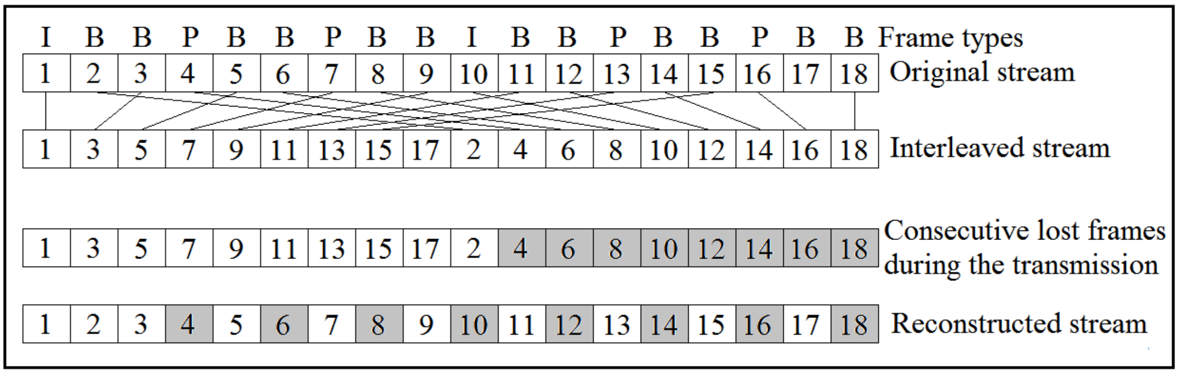


Figure 2.10: An example of interleaving technique with a distance of 2

2.3.1.3 Erasure Coding (EC)

Like FEC, Erasure Coding (EC) [73] is an error resiliency mechanism based on the redundancy technique. With EC, the sender adds a set of redundant packets, representing a combination of original packets. EC applies certain coding techniques to perform this combination like XOR and linear coding. The receiver can decode the original packet successfully, by means of the redundant packets.

2.3.2 Retransmission-based techniques

The retransmission of packets is an error resiliency technique based on the following principle; when a packet is lost at the receiver level, this latter sends an explicit negative acknowledgment to the sender requesting the retransmission of the lost packet. The retransmission reduces the bandwidth overload compared to the redundancy however; the transmission delay could be increased. Usually this technique uses Cyclic Redundancy Check (CRC) codes to detect the errors [74]. The receiver requires the retransmission of the received packet if it detects the errors in this packet after a verification based on CRC codes or if the expected packet is not received i.e. it is dropped in the network because of the congestion for example.

2.3.3 Error concealment-based techniques

The error concealment is another error resiliency technique conceived to recover lost regions of frame from other frames within the same video. This technique is applied at the decoder without any feedback with the video encoder. The error concealment decreases the bandwidth overload and the transmission delay because it recovers lost packets without any retransmission or redundancy of video packets, nevertheless the error concealment produces some artifacts in the displayed video. In order to recover the errors, the error concealment uses two approaches: spatial approach and temporal approach. The first one exploits the correlation between the adjacent pixels within the same frame to recover the errors; however, the second one is based on the temporal correlation between the adjacent frames to restore the missing area [75].

2.4 Conclusion

In this chapter, we have presented the context our study in the aim to improve the video streaming quality in VANET by recovering the video errors. In fact, this chapter includes the VANET network overview, video streaming concepts and error recovery techniques. Several concepts related to VANET have been presented such as VANET architecture, communication modes, applications, protocols and standards. Moreover, we have described the video evaluation metrics, video encoding techniques and video compression standards. To aid understanding our contributions to support video streaming in VANET and to guarantee a high QoS and QoE, we also explained in this chapter the errors recovery techniques namely the redundancy, retransmission and error concealment technique. The next chapter presents the related work of video streaming in VANET.

Chapter 3

Related work on video streaming in VANET

In this chapter, a taxonomy of the most important proposed video streaming works in VANET literature are reviewed and discussed. We classify VANET video streaming studies into three main categories: video streaming works at application and transport layers level, video streaming works at network layer level and video streaming works at MAC layer level. All these works aim at improving the video streaming quality at the end receiver in order to give an accurate information to drivers and passengers, as shown in figure 3.1.

Initially, in the section 3.1, we present the video streaming works of the first category i. e. at the application and transport layers. Specifically, we review the proposed schemes based on error recovery techniques and mechanisms for video streaming works at application and transport layers. A comparison between these works according to some features like video encoding, error recovery technique, evaluation metrics, forwarding type, routing protocol and environment, is also given. At the end of section 3.1, a discussion of the advantages and disadvantages of the video streaming works at application and transport layers is presented.

After that, section 3.2 surveys the various VANET video streaming works based on network layer; it is the second category. These different routing protocols for the uni-casting, multi-casting and broadcasting are listed and discussed in this section. Furthermore, we compare the surveyed protocols in function of several criteria such as video encoding, evaluation metrics, routing based approach and environment. The discussion of the second category works is presented at the last of this section.

In section 3.3, we present the video streaming works over VANET at MAC layer (third category). Like the previous sections, this section presents the contributions, limitations, comparison and discussion of these works.

Finally, section 3.4 concludes the chapter by a general discussion of the video streaming works of all categories. Additionally, this section reviews and discusses some cross layer VANET video streaming studies, which react at the three layers (application and transport layers, network layer, MAC layer).

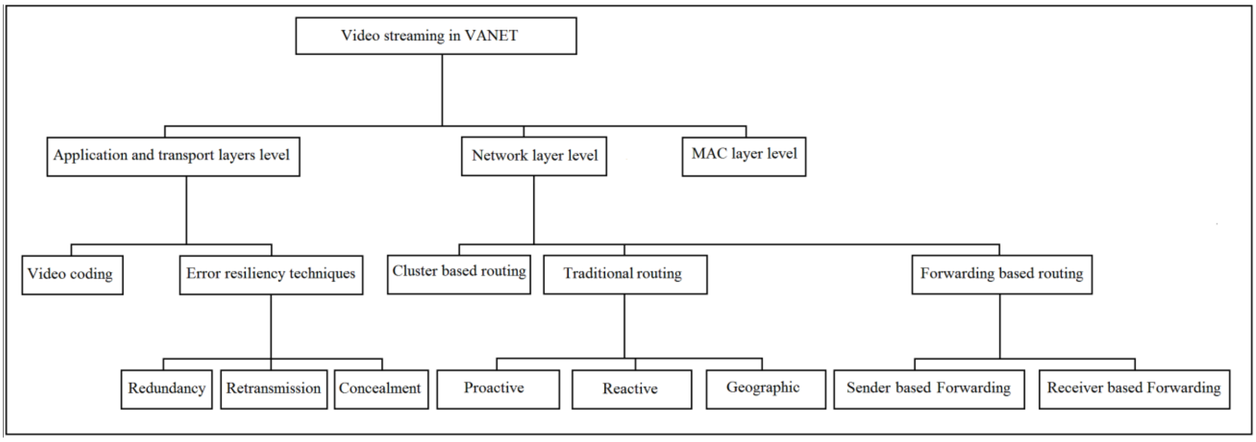


Figure 3.1: Taxonomy of video streaming works in VANET

3.1 VANET video steaming at application and transport layers

The schemes of this category apply different standards, mechanisms and techniques of video encoding and video streaming error resiliency to improve video streaming quality in VANET mainly at the application and transport layers.

3.1.1 Video encoding

In the literature of VANET video streaming, several works for video encoding using different standards and encoding techniques were proposed. Qadri et al. proposed in [76] an architecture of video transmission under VANET based on peer-to-peer paradigm and combined between MDC and slices for video encoding. This study combines also between redundancy recuperation mechanism of MDC and recuperation mechanism of FMO for compensation of slices. This work improves the quality of video streaming in terms of packet loss ratio, control overhead and video PSNR comparing to video transmission based on MDC strategy, however, this study did not consider the transmission delay factor to ensure that this is no deadline time constraints violation.

Many works have been proved the higher performance of H.265/HEVC standard for video encoding in VANET comparing to other standards. Torres et al. achieved in [77] an evaluation and comparison between H.264/AVC and H.265/HEVC video coding standards in highway VANET environment. This work demonstrated the effectiveness of H.265/HEVC comparing to H.264/AVC under VANET in terms of frame loss and PSNR of the transmitted video. Paredes et al. have evaluated in [78] the compression efficiency of the current video compression standards over urban VANET. The experimental results showed that 265/HEVC provides similar levels of video quality with reducing bit rate comparing to H.264/AVC and VP9 (a video coding format developed by Google), due to video efficiency encoding of 265/HEVC, which reduces the requirement of the bandwidth. Pinol et al. in [79] evaluated the video streaming that compressed with HEVC standard in VANET, with considering the problem of packets loss.

There are also some studies proposing to transmit the video in VANET using NC. Vineeth and Guruprasad analyzed in [80] the video transmission in VANET using NC while varying the mobility model, to prove the effectiveness of NC on the video transmission quality in terms of delay and jitter and to indicate the influence of mobility model and the density of vehicles on this transmission. Nevertheless, this study did not consider other QoS parameters of video steaming such as packet loss ratio. Moreover, [80] did not propose a method for selecting re-encoder vehicles to reduce delay and jitter. Razzaq and Mehaoua proposed in [81] a dissemination scheme of video packets in VANET based on multipath dissemination and NC. This work proposed a selection process of re-encoder vehicles according to the following factors: the selected re-encoder vehicle must have more free resources; this vehicle should be able to receive two adjacent sub-layers and should have a shorter distance to the destination. This work improves the transmission video quality in terms of received transmission rate and PSNR. However, this scheme led to paths coupling (i.e. the vehicles from neighboring paths access to the communication range of each other's which increases the collision) if the throughput increases or when the network is very dense. Additionally, Yang et al. in [82] proposed CodePlay scheme for live multimedia streaming in VANET, CodePlay is based on coordinated local push mechanism, which uses Symbol-Level Network Coding (SLNC). A simulation study proved that CodePlay based on SLNC outperforms CodePlay based on Packet Level Network Coding (PLNC), because SLNC improves the efficiency of bandwidth utilization by reducing the total number of transmissions compared to PLNC.

3.1.2 Error resiliency techniques

We classify the video error resiliency techniques in VANET into three classes: redundancy-based techniques, retransmission-based techniques and concealment-based techniques.

3.1.2.1 Redundancy-based techniques

In VANET literature, there are some video streaming works use the redundancy based mechanisms (Forward Error Correction –FEC-, Interleaving and Erasure Coding –EC-).

- **Forward Error Correction (FEC)**

  Despite the main limit of FEC based mechanisms related to high redundancy rate, several FEC based video streaming in wireless networks were proposed to overcome FEC limits such as network overloading and limited burst errors recovery; we cite Forward-Looking FEC (FL-FEC) [83], Enhanced Random Early Detection FEC (ERED-FEC) [84], Adaptive and Interleaving FEC (AIFEC) [85], FEC with Path Interleaving (FEC-PI) [86]. FL-FEC proposed that the lost packets can be recovered by packets of its block and by non-continuous packets of the previous block. By this way, the problem of burst packet loss must be solved. ERED-FEC is applied at the Access Point (AP) and it adapts dynamically the redundancy rate according to both wireless channel condition (indicated by packets loss rate) and network traffic load (indicated by the AP queue length). AIFEC adjusts dynamically the redundancy rate based on video priority levels, throughput, and wireless channel state. AIFEC is considered as an integration of FEC mechanism to recover uniform errors with the interleaving technique to recover the consecutive packet loss (burst errors). The based idea of FEC-PI is to apply the FEC mechanism at level of video sender where the video is streamed over multiple paths. Therefore, when the burst packet loss is produced at any path, the receiver could use received video from other paths to overcome this loss.

Tsai et al. in [19] proposed another FEC-based mechanism called Sub-Packet FEC (SPFEC) aiming to improve the video streaming quality over wireless network in terms of recovery performance and jitter compared with FEC.

Immich et al. proposed in [87] an adaptive QoE-driven COntent-awaRe VidEo Transmission optimisation mEchanism (CORVETTE) using FEC mechanism in VANET. The proposed mechanism is based on Hierarchical Fuzzy System (HFS) to adjust dynamically at the relay vehicles the video packets redundancy rate according to the network state and the video characteristics. The experimental results including the comparison of CORVETTE with and without adaptive mechanisms showed that CORVETTE enhances the QoE video quality in various rates of network density. When the density is high, CORVETTE decreases the overload of network, which increases the number of interferences and collisions. On the other side, when the density is low, CORVETTE increases the redundancy degree, which deals with the problem of link disconnections. Notice that CORVETTE could be tested while varying the mobility models.

- **Interleaving**

Bucciol et al. proposed in [88] an error recovery technique of video packet in VANET named FEC and Interleaving Real Time Optimization (FIRO). FIRO is based on three techniques: FEC to recover uniform errors, interleaving to recover burst errors and reporting technique to estimate the loss ratio of channel transmission (i.e. short term and long term estimations). The sender adapts dynamically the parameters of FEC and interleaving based on this estimation. FIRO enhances the video transmission quality compared to FEC and interleaving techniques. To obtain more convincing results, FIRO could be validated in urban environment when the network capacity is limited. Quadros et al. integrated in [89] the interleaving technique to their proposed QOE-aware and driven Receiver-based (QORE) mechanism, in order to handle the problem of burst losses at the application layer.

- **Erasure Coding (EC)**

In [90], Rezende et al. carried out a study and comparison between EC using RLC coding and EC using XOR based coding for the encoding of transmitted video in VANET. The work proved that EC using XOR based coding is more efficient than EC using RLC coding in terms of delivery ratio and end-to-end delay, because XOR based coding allows a more lost errors resiliency than RLC coding. It remains to prove the usefulness of EC compared with others video errors resiliency techniques in VANET. Rezende et al.

conducted in [91] an evaluation of the effect of redundancy of video packets on the broadcasting of the video in highway VANET, which uses gossiping broadcasting technique to broadcast the video, the authors carried out also an evaluation of using EC in this network. The result of simulation proved that the redundancy improves delivery ratio of video packets because the redundancy solves the problem of links dis-connection of VANET. The simulation study proved also that EC does not improve the redundancy efficiency especially for receivers' vehicles, which are far from video source vehicle. This is because when the number of received packets is not sufficient, the original packets cannot be decoded contrary to the simple redundancy which allows the decoding of a portion of original packets. This work considered only the highway scenario, in which the congestion and collision are not higher unlike in the case of urban scenario, the redundancy and EC in urban environment could be further evaluated to general conclusions of this study. Mammeri et al. proposed in [92] an Erasure Coding with Real-time Transport Protocol (EC-RTP) to handle the high packet loss rate problem of video streaming under VANET. In order to adapt RTP to VANET, this research activity implemented two converters; the first one converts the RTP packets to EC-RTP packets that are transmitted in the network, and the second one converts the EC-RTP packets to RTP packets redirected to RTP player. EC-RTP reduces the packet loss and provides higher PSNR video quality comparing to RTP. Due to the high cost of real experiments and that the authors not used the IEEE 802.11p technology, only a single hop was considered in this study, the IEEE 802.11p technology and a multi-hop scenario should be considered in future experiments of EC-RTP.

3.1.2.2 Retransmission-based techniques

Some video streaming researches in VANET use the retransmission technique as a basic mechanism. We mention Xie et al. that proposed in [57] a multi-path routing of video streaming in VANET. The proposed solution transmits the I-frames through a first path based on Transmission Control Protocol (TCP), this latter allows to errors recovery by retransmission strategy and transmits the P-frames and B-frames through a second path based on UDP. The proposed scheme achieves higher video transmission quality in terms of PSNR, SSIM, receiving data rate, comparing with FEC and UDP. The limit of this work is the high transmission delay due to the retransmission mechanism of TCP. Based in the same idea of [57], Xie at al. proposed in [93] a Multi-channel Error Recovery Video Streaming (MERVS). Moreover, the authors enhanced MERVS transmission delay by using the three techniques: Priority Queue, Quick Start and Scalable Reliable Channel (SRC). Priority Queue solves the disorder of both TCP and UDP channels in the waiting queue in the MAC layer. Quick Start maximizes the throughput of the TCP channel by eliminating the negative effect of the congestion control. The SRC avoids certain network performance degradation. The simulation results showed that MERVS with Priority Queue, Quick Start and SRC achieves a low transmission delay comparing with TCP, MERVS, MERVS with Priority Queue and Quick Start. Furthermore, the simulation proved that the proposed solution provides a good transmitted video quality. The reader can find in [94] a Mobility-Aware multimedia data transfer mechanism using MultiPath TCP (MA-MPTCP) proposed by Zhu et al. for vehicular network. MA-MPTCP is based on the dynamic distribution of data to different paths, based on the measured quality of these paths. MA-MPTCP handles the handover problem when the vehicle is out the RSU transmission range (non-connection scenario) by choosing another stable path (e.g. 4G found path). When the vehicle is connected to more than one RSU (multi-connection scenario), MA-MPTCP can trigger new path for the multipath data transmission. The simulation results demonstrated that MA-MPTCP improves the throughput and decreases the transmission delay in comparison with MPTCP. The higher performance of MA-MPTCP is due to the quality aware data distribution, which can reasonably utilize the network resource and due to the handover mechanism in non-connection scenario reducing the out-of-order data, also it is due to the multi-path data transmission in multi-connection scenario, which improves the transmission rate. This work can be ameliorated by a multi-hop communication between the vehicles in non-connection scenario. Comparing to the redundancy, the retransmission reduces the bandwidth overhead, but it increases the transmission delay.

3.1.2.3 Error concealment-based techniques

The error concealment-based techniques are used in some video streaming works in VANET. Pinol et al. implemented in [79] an error concealment method for video streaming transmission in VANET, based on the recovery of the missing frame at the decoder by the previous decoded frame. The error concealment reduces the bandwidth overhead and the transmission delay due to its recovery of lost packets without any retransmission or redundancy of video packets, but it produces some artifacts in the displayed video.

3.1.3 Comparison between different video streaming works in VANET at application and transport layers

The existing video streaming works in VANET suggested for application and transport layers and deal with the video encoding and error resiliency are summarized in table 3.1. This table shows that each work adopts some proprieties such as: video encoding technique, error resiliency technique, QoS and/or QoE metrics to evaluate the video streaming quality, forwarding type (unicast, multicast, or broadcast), appropriate routing protocol to the forwarding type and the VANET environment type.

We notice that each error resiliency technique supports an appropriate video encoding technique, for example the redundancy support the MDC, or SVC video encoding, the concealment support slices encoding. Most works take into consideration the loss ratio factor as an evaluation metric, because it has a direct impact on the visual video quality, but a few works does not consider the transmission delay factor, which is an important factor to guarantee that the application deadline constraint is respected. We observe in table 3.1 that the most works conceived within a highway environment use the redundancy allowing for far vehicles (from the source video) to receive efficiently the video in order to cope with the frequent link disconnections present in highways. However, the schemes introduced for an urban environment characterized by the collision and interferences because of lower link disconnection and obstacles, use the retransmission technique and not the redundancy to decrease the collisions. We mention here that [76] deals with this problem (i.e. the interferences and collisions) in urban environment by the multi-path routing leading to a reduced number of collisions. In Addition to the redundancy or the retransmission, the applied of the third error resiliency technique (error concealment), and particularly the use of spatial and temporal error concealment techniques of video standards allows more error recovery of video packet loss.

Table 3.1: Comparison between video streaming works in VANET at application and transport layers

Work	Video encoding	Error resiliency technique	Evaluation metrics	Forwarding type	Routing protocol	Environment
[76]	Combination between MDC and checkerboard slices	Redundancy of MDC and FMO concealment	Packet loss ratio, control overhead, PSNR	Unicast	Split Multi-Routing (SMR)	Urban
[68]	FMO coding of H.264/AVC	FMO error concealment	PSNR, Packet loss ratio, end-to-end delay	Multicast	AODV	Urban
[77]	H.264, H.265	H.264 and H.265 error concealment	Frame loss, PSNR	Broadcast	Distance-Based strategy	Highway
[79]	HEVC	Simple Error Concealment Method	Rate-Distortion, PSNR	N/A (Not/ Available)	N/A	Urban
[80]	Network Coding	N/A	Delay, jitter	N/A	AODV	Highway
[81]	SVC and Network Coding	N/A	Received rate, PSNR	N/A	GPSR	Urban
FIRO [88]	H.264/AVC	FEC, Interleaving	Packet Loss Rate, PSNR	N/A	N/A	Highway
[90]	H.264/MPEG-4 AVC	Erasure Coding	Delivery ratio, delay.	Unicast	VIRTUS [120]	Highway

[91]	MPEG	Erasure Coding	Correctness (received packets percentage), overhead	Broadcast	Gossiping	Highway
[57]	H.264/MPEG-4 AVC	Retransmission mechanism of TCP protocol	PSNR, SSIM, Receiving data rate, delay	Unicast	AODV	Urban
MERVS [93]	H.264/MPEG-4	Retransmission mechanism of TCP protocol	PSNR, SSIM, total time to transmit the video, jitter, receiving data rate.	N/A	AODV	Urban
CORVETTE [87]	H.264	Redundancy	SSIM, VQM, network overhead	Unicast	Cross-Layer, Weighted, Position-based Routing (CLWPR)	N/A
MA-MPTCP [94]	N/A	Retransmission mechanism of TCP protocol	Throughput, Delivery Delay	Unicast / Multicast	AODV	N/A
EC-RTP [92]	H.264	Erasure Coding	Packet loss rates, delay, PSNR, SSIM, bandwidth usage	N/A	N/A	N/A
QORE [89]	MPEG-4	Interleaving	Reachability, Ratio of forwarding nodes over receiving nodes, PDR, Average Delay, SSIM, MOS	Broadcast	N/A	Urban and Highway

[78]	H.265/HEVC, H.264/AVC and Google VP9	N/A	Frame Delivery Ratio, PSNR, MOS	N/A	N/A	Urban

For the redundancy error resiliency technique, many studies in wireless and VANET networks used the variations of FEC for video streaming error recovery. Table 3.2 shows a comparison between these works, we see in this table that all FEC variations in wireless and VANET networks consider the network condition (packet error rate) in the process calculation of redundant packets, some variations consider other factors like network overload and priorities of frames types to decrease the network overloading and to increase the video quality. We see also that in the most FEC mechanisms the redundant unit is the packet, although the sub-packet FEC provides more error resiliency than Packet FEC, we observe that some FEC mechanisms are applied at the sender of video stream when others are applied at the access point or relay vehicles. Note that in VANET, relay vehicle based FEC allows a reliable estimation of network condition and overload, contrary to sender based FEC, which cannot give an accurate estimation because of high dynamic of VANET topology.

Table 3.2: Comparison between FEC mechanisms for video streaming in wireless and VANET networks

FEC mechanism	**Network condition**	**Network load**	**Video frames type priorities**	**Redundant Unit**	**Network**	**Level of FEC application**
FL-FEC [83]	Considered	Not considered	Not considered	Packet	Wireless	Sender
AIFEC [85]	Considered	Considered	Considered	Packet	Wireless	Access Point
SPFEC [19]	Considered	Not considered	Not considered	Sub-Packet	Wireless	Sender
ERED-FEC [84]	Considered	Considered	Not considered	Packet	Wireless	Access Point
FEC-PI [86]	Considered	Not considered	Not considered	Packet	Wireless	Sender
FIRO [88]	Considered	Not considered	Not considered	Packet	VANET	Sender vehicle
CORVETTE [87]	Considered	Considered	Considered	Packet	VANET	Sender and relay vehicles

3.1.4 Video streaming works at application and transport layers discussion: Advantage and disadvantages

This category of studies is based on video encoding techniques and error resiliency approaches in order to improve the video streaming transmission quality. Here, many ways of video encoding were considered such as layer coding, MDC coding, FMO coding, etc. The objective of the encoding video is to facilitate the error recovery applied by the error resiliency techniques. The video encoding can also reduce the negative effects of error resiliency techniques, for example the use of Network Coding with the redundancy reduces the network overload and the transmission delay.

The redundancy, retransmission and error concealment are three main mechanisms used to recovery uniforms and burst errors of video packets in VANET. Table 3.3 summarizes a comparison between different error resiliency approaches in VANET in function of network overhead and transmission delay. In the case of redundancy mechanisms such as FEC, EC and interleaving and due to redundant packets, the network overload is high, whereas in the case of retransmission technique, the transmission delay is high because the duplicate video packets require a receiver request. The error concealment technique is applied at the receiver without any additional network overload or transmission delay.

Table 3.3: Comparison between error resiliency techniques for video streaming in VANET

Error resiliency technique	Network overload	Transmission delay	Artifacts in the displayed video
FEC	High	Low	Low
Retransmission	Low	High	Low
Erasure Coding	High	Low	Low
Interleaving	High	Low	Low
Error concealment	Low	Low	High

3.2 VANET video steaming at network layer

At network layer level, the vehicle relays selecting scheme for video streaming in VANET is responsible for finding the most reliable path(s) between the source and the destination nodes in order to improve a video streaming quality. We classify video streaming schemes in VANET at network layer into three classes: traditional based schemes, forwarding based schemes and cluster based schemes. In VANET, there are three strategies of video forwarding namely: unicast, multicast and broadcast mode. The unicast forwarding of video streaming is based on the idea that the video is triggered to one destination, while in multicast forwarding the video is triggered to many destinations, the broadcasting of video consists of dissemination the video to all vehicles in network.

3.2.1 Traditional schemes

Traditional schemes are the classical routing protocols namely topology-based schemes (proactive, reactive) and geographic-based schemes for the unicasting/multicasting of the video. Xu et al. proposed in [95] a framework named VANET-EvalVid composed of three integrated tools: ns-2 [96], Evalvid [97] and VanetMobiSim [98] to perform a comparison between the three routing protocols: Destination-Sequenced Distance-Vector Routing (DSDV) [99], Ad hoc On Demand Distance Vector (AODV) [100] and Greedy Perimeter Stateless Routing (GPSR) [101] for the video streaming in VANET according to different environment conditions. This framework proved that geographic routing protocol GPSR is more suitable for video transmission over VANET than the proactive routing protocol DSDV and the reactive routing protocol AODV, in terms of frame loss rate and video PSNR, because the control messages in GPSR are reduced. However, GPSR does not provide an exactly position of vehicles which can affect the video transmission in real VANET. For this reason, many works tend to combine the topology-based approaches and geographic-based approaches. Zaimi et al. evaluated in [102] and [103] various routing protocols for video streaming in VANET. The routing protocols were compared in terms of QoS and QoE metrics under the same environment and conditions, in order to give a quantitative and qualitative comparison between these protocols. The simulation results have been proved that the reactive routing protocols (AODV, DSR and DYMOUM) are the better than the proactive routing protocols (DSDV, OLSR and FSR) and better than hybrid routing protocols (ZRP). The results proved also that, the position-based routing protocols (GPSR, VADD and HLAR) provide lower delay and overload, but these routing protocols provide lower Packet Deliver Ratio (PDR) and lower throughput, which affect the PSNR, SSIM and MOS video quality, due to the location accuracy problem. This work can be improved by evaluating other enhanced geographic protocols for video streaming in VANET. Honda et al. proved in [104] that the transmission of video in urban VANET based on Optimized Link State *Routing* (OLSR) [105], which considered as a proactive routing protocol can be influenced in terms of throughput, delay and jitter by two factors: the number of video streams and the environment buildings. We mention that this study should prove the performance of OLSR comparing with other routing protocols such as: AODV, DSDV, GPSR. Additionally, this work does not consider the evaluation metric of video quality like PSNR or SSIM. Zaimi et al. presented in [106] a Greedy Perimeter Stateless Routing protocol with two Paths (GPSR-2P) for video transmission in urban VANET. To avoid the congestion, the GPSR protocol for video routing was applied through two paths. Note that in GPSR protocol, each sender vehicle forwards the video packets to its geographically closest neighbor to the destination, in order to choose the shorter path from the sender to the destination. The simulation results demonstrated that GPSR-2P provides higher packet delivery ratio and lower transmission delay comparing to GPSR. Moreover, this proposal enhances the user QoE. However, this study considered only two neighbors vehicles for each forwarding vehicle. To generalize the reached conclusion, GPSR-2P should be tested in various number of neighbors (K-neighbors).

Many enhancements of topology based routing protocol have been proposed to tackle the video streaming issue in VANET. Moussaoui et al. proposed in [107] an Enhanced version of AODV protocol (En-AODV) to handle the instability issues of the routes. En-AODV selects the most stable path by exploiting the cross layer information about the link quality, the estimating link lifetime and destination region information. Simulation results have proved that En-AODV achieves higher Packet Delivery Ratio (PDR), lower average end-to-end delay and reduces the network overhead, compared with AODV. Pham et al. proposed in [54] QoE-based routing protocol for video streaming over VANETs (QOV), which represents an adaptation of OLSR by balancing of transmissions across less loss paths. QOV improves OLSR in terms of QoE metrics: MOS, USP, MDP and in terms of packets loss rate, but it suffers from the same problem of OLSR of bandwidth overhead because of periodic exchange of control messages in VANET while the topology is very dynamic. Walker and Radenkovic improved in [108] the GPSR routing protocol by adding TArgeted Remote Surveillance module (TARS) to create the GPSR-TARS protocol. For multiple receivers, GPSR-TARS allows vehicles to request and receive video from vehicles within a specified geographic surveillance region. GPSR-TARS adopts also a congestion aware clustering scheme in order to handle the congestion problem by dynamic change of surveillance region size. The simulation results proved that GPSR-TARS outperforms the traditional routing protocols GPSR, AODV and DSDV due to their limits to detect and handle the congestion problem. However, GPSR-TARS can be improved by adding a multi-criteria selection process at the level of relay vehicles. As a traditional scheme, Mezher et al. proposed in [109] a new geographical routing protocol for the multimedia in realistic urban VANET called Multimedia Multimetric Map-aware Routing Protocol (3MRP). The proposed routing protocol adapted GPSR routing protocol by selecting the next forwarding vehicle from the neighbor vehicles based on five metrics: distance to destination, vehicle density, trajectory of the vehicles, available bandwidth and MAC layer losses. A weighted multimetric score for each neighbor vehicle is calculated based on these metrics. 3MRP proposes a calculation and dynamic adaptation process of metric weights according to the environment conditions. The simulations results showed that 3MRP+DSW (with Dynamic Weights) provides lower average packet loss and higher PSNR compared to 3MRP (with static and identical weights), VIRTUS and GPSR protocols. Nevertheless, the results reached showed that the multimetric selection and dynamic adaptation of metric weights increase the end-to-end delay compared to the other protocols.

In the literature of this category, we can find Quadros et al. that proposed in [58] a Multi-flow-driven VIdeo DElivery (MVIDE) for the dissemination of video packets in VANET through optimal paths. This work proposed also the integration of MVIDE with GPSR with Movement Awareness (GPSR-MA) [110] considering selected paths, vehicles mobility and application constraints, to improve transmitted video in terms of QoS and QoE metrics. Asefi et al. proposed in [111] an integrated scheme in VANET, which consists of two parts: geographic routing scheme of video packets and network mobility management scheme of vehicles IP address and handover prediction mechanism. The experiments proved that the proposed routing protocol improves the video quality in terms of start-up delay, frequency of the streaming freezes and frame distortion compared to greedy geographic routing protocol because the proposed protocol takes into account the distortion, delay and distance in the choice of relays vehicles contrary to greedy protocol, which considers only the distance factor.

3.2.2 Forwarding-based schemes

In VANET, there are two types of video streaming forwarding-based schemes: Sender Based Forwarding (SBF) and Receiver Based Forwarding (RBF). In SBF and RBF schemes, the dissemination is based on geographic information and they used to select the relays vehicles for a multi-hop transmission of video in VANET. Xie et al. performed in [112] a study and comparison between the two video forwarding schemes SBF and RBF through VANET in highway environment, the authors demonstrated that RBF provides a better video quality comparing to SBF in terms of PSNR, because the number of control messages in SBF is higher than those of RBF. The limitation of this study is the absence of transmission delay factor in the comparison between SBF and RBF.

3.2.2.1 Sender-Based Forwarding schemes (SBF)

In the SBF, each vehicle forwards the control messages to its neighbor vehicles periodically. The control message contains vehicle's information like location, speed, and direction. When a vehicle receives the control message, it updates its local neighbors list. Based in this latter, the forwarder selects the next forwarder vehicles from its neighbor vehicles. The selection is based on some factors such as the distance to the end receiver. The problem of SBF is that the control information is not always available especially in the disconnection case. Additionally, the exchange of this control message can increase the network overhead.

In this category, Bradai and Ahmed proposed in [113] a Selective Rebroadcast Mechanism for Video Streaming over VANET (ReViV) for the video streaming broadcasting in VANET. ReViV is built on top of IEEE 1609.4 protocol [114] by adding a module for the selection of video forwarding vehicles based on SBF according to its dissemination capacity aiming at reducing the interference rate. The simulation proved that ReViV improves the video streaming quality in terms of frame loss, delay and PSNR of received video compared to IEEE 1609.4. Also in this category, Wu and Ma proposed in [49] a formulation model of distortion rate for live video streaming in VANET. According to this model, a routing protocol was introduced on the basis of SBF to select a path between source video and destination based on a compromise between distortion and delay, this path maximizes the transmission video quality. Notice that [113] and [49] suffer from the interference and collision problems because of the periodic exchange of control messages.

Wang et al. in [115] proposed a Preference-aware Fast Interest Forwarding (PaFF) for video streaming in Information-Centric Networking (ICN) based VANETs. In PaFF, each vehicle selects a set of associate vehicles with similar mobility and video preference. At each vehicle, a High Preferred Content Table (HPCT) is created to save the status of associate vehicles. The vehicle uses its HPCT table to select the next hop for forwarding the interest packet. The simulations have been shown that the PaFF can achieve higher performances in terms of delay of finding data and cache hit ratio when comparing with the state-of-art solutions (i.e. social-tie based interest forwarding scheme (STCR) [116], Robust Forwarder Selection (RUFS) [117]). PaFF can be further enhanced by integrating new strategies of content centric mobile environment to for further improve the performance of sharing video streaming. Zhu et al. in [118] proposed an adaptive greedy forwarding scheme for video streaming under urban from a source vehicle to Roadside Access Point (RAP). The relay vehicles are selected not only based on the distance to the destination but also based on the stability factor. The experiments results proved that due to the stability factor, which avoids the link disconnections, the proposed scheme outperforms greedy forwarding scheme in terms of start-up delay, interruption ratio, PSNR, and application charge. This study could be improved by a future complement work providing a more precise prediction for the relay of vehicles, with the considerations of other factors such as buffer management, transmission rate and encouragement factor. Moreover, the problem of the routing loops and the relay in intersection mode should be solved.

3.2.2.2 Receiver-Based Forwarding schemes (RBF)

In RBF, the sender vehicle forwards its packets to its neighbor vehicles. Each neighbor vehicle calculates a waiting time according to some factors like the distance to destination. Among the neighboring vehicles, the highest priority vehicle selected as next hop (i.e. next forwarder) is that has a lowest waiting time. After the calculation of the waiting time, each neighbor vehicle starts decreasing its waiting time, at the same time, it listens the communication support. During the waiting time, if the neighbor vehicle detects a transmission of packets in the channel, it cancels its transmission. Otherwise, the neighbor vehicle forwards the received packets when its waiting time expired. So, the RBF approach is based on the idea that the selection of the next forwarding vehicle is taken by the neighbor vehicles, not by the sender vehicle. The limit of RBF is the additional transmission delay due to the waiting time added when selecting the forwarding vehicles.

Several works proposed video packets dissemination based on RBF in VANET for the unicasting or multicasting forwarding. We cite REceiver-based solution with video transmission DECoupled from relay node selection (REDEC) [119], which adapts RBF by adding the stability factor in the calculation of the waiting time and considering the idea of waiting window. This latter is proposed to reduce the additional transmission delay, produced when relay vehicles are selected according to their waiting times. The waiting window represents a period of time in which the node sends packets before starting relay vehicle selection. VIdeo Reactive Tracking-based UnicaSt protocol (VIRTUS) [120] is another RBF scheme based on the dissemination of video packets based on estimated location information. Belonging to this category, the reader can find [121], which is a VIRTUS with Density-Aware relay node selection Decoupled from Video Transmission (DADVT). In this study, the authors proposed a waiting time calculated in the basis of two factors: the distance to the destination and the network density in terms of vehicles. Another RBF based technique is a QOe-Driven and LInk-qualiTy rEceiver (QOALITE) [59], which calculates the waiting time in function of location information, link quality and QoE. The authors of [59] provide a most reliable path compared to those proposed in [119] and [120], due to the use of a multi-criteria selection of relays vehicles like QoE, which is essential in the human evaluation of video transmission. The main limit of the proposed schemes [119], [120], [121] and [59] studies is the interference and collision when the network density and transmission rate are high, because these schemes disseminate video packets through only one path. Other RBF schemes are proposed to deal with the interference and collision by conceiving multi-path solutions, we cite LocatIon-Aware multIpaTH videO streamiNg (LIAITHON) with two paths [122] and LIAITHON with three paths [123]. Note that these schemes (e.g. LIAITHON with two paths and LIAITHON with three paths) suffer from the paths coupling problem which often increases the collisions.

Some works proposed a video packets dissemination based on RBF in VANET for the broadcasting forwarding, like Reactive Density-Aware and Timely Dissemination protocol (REACT-DIS) [124], video dissemination protocol (VoV) [125]. Torres et al. in [126] performed a comparison between some flooding schemes introduced for video streaming in highways; we mention basic schemes (counter based, distance based) and adapted schemes (DECA [127] and Backfire [128]). The result of this study shows that Backfire outperforms the other flooding schemes in terms of the percentage of packets received and the end-to-end delay. The effectiveness of Backfire is due to the idea of selecting the rebroadcast nodes that provide more additional coverage area. After that, Torres et al. proposed in [129] Automatic Counter Distance Based (ACDB) flooding scheme for video broadcasting in highways. This proposal adapts the Distance Based flooding scheme by dynamic adjustment of the number of packet copies, which will be received from other vehicles. This is for the purpose to stop the broadcasting of this packet. In addition, ACDB proposed dynamic adjustment of the waiting time according to the environment density. The simulation study proved that ACDB outperforms many other flooding schemes such as Counter based, Distance based, Backfire, DECA in terms of packet arrival ratio and video PSNR. This outperformance is due to its ability to avoid widely the collision problem. Notice that ACDB, like other flooding schemes in highways, cannot provide a video streaming broadcasting for distant vehicles located far from video source under low dense VANETs.

3.2.3 Cluster-based schemes

Some other works in VANET literature have proposed the dissemination of video after forming network clusters. This idea is to facilitate the routing process and to improve the transmission quality. Tal and Muntean in [130] proposed a user-oriented and cluster-based multimedia delivery solution over VANET. Using the Quality Oriented Adaptive Scheme (QOAS) [131], the clusters are formed according to passengers and their profiles to deliver the multimedia content. The simulation was showed the effectiveness of this scheme in terms of mean cluster head lifetime, average throughput and loss compared with that of the most commonly used clustering algorithm in VANET, named Lowest-ID [132], this solution can choose the best Cluster Head (CH) with a life-time higher than Lowest-ID. Note that this work did not consider the transmission delay factor in the evaluation of its effectiveness. Chen et al. in [133] proposed a Cluster and Dynamic Overlay based video delivery over VANETs (CDOV) consisting of two parts; the former is the VANET clustering in which each cluster consists of cluster head vehicle and cluster members (i.e. vehicles) interested on the same video. The second part is a Dynamic Overlay-based Video Delivery Scheme responsible on providing and constructing of an overlay tree using the control messages facilitating video sharing between members of the same cluster. The simulation proved that CDOV provides better video transmission in terms of start-up delay and packet delivery rate, compared with the cases of non-cooperative communication and gossiping-based communication. Furthermore, CDOV provides an immediately video delivery using overlay tree to the requester vehicle, which minimizes the start-up delay. In addition, when a video is requested, CDOV selects the best vehicle that possesses video segments with increased packet delivery rate. CDOV presents a high control overhead generated by an important number of control messages to ensure the clustering and to construct the overlay tree.

3.2.4 Comparison between different video streaming works in VANET at network layer

Generally, VANET video streaming schemes at network layer select the cooperative relays (vehicles) aiming at disseminating video data with guaranteeing a high level of video transmission quality. Each scheme adopts a video encoding standard and some QoS and/or QoE metrics to evaluate the video quality. In addition, each work chooses a type of VANET environment (urban or highway) to perform its experiments. Furthermore, each work is based on a routing approach (traditional, SBF, RBF, cluster based) to forward video through one or many paths. Table 3.4 presents the works of this category for the unicast or multicast video streaming. We can see in this table that most of studies use the MPEG standard or its extensions to encode the video, which is based on the encoding of video frames into three (3) frames categories: I-frame, P-frame and B-frame. Moreover, it is clear that the multipath dissemination with this video encoding technique makes easy video frames repartition through different paths according to their importance. The major multipath based researches on video streaming dissemination chose the urban environment due to its restrictions like the presence of obstacles, high vehicles density and low speed of vehicles leading to increase the number of collisions and interferences. In fact, the multipath dissemination in such environment can help to decrease these collisions by a distributed forward of video streams through many paths. We note also that the most works consider the packet lost and transmission delay as a basic metrics to evaluate the each of these proposals. These two metrics affect directly the video quality, and can influence on other metrics.

Table 3.4: Comparison between the works at network layer for the uni-casting/multi-casting of video streaming in VANET

Work	Video encoding	Evaluation metrics	Single/ Multipath	Routing based approach	Environment
VANET-EvalVid [95]	MPEG-4	Frame loss rate, PSNR	Single	Traditional routing (DSDV, AODV, GPSR)	N/A
[104]	N/A	Throughput, delay, jitter	Single	Traditional routing (OLSR)	Urban

QOV [54]	N/A	USP, MOS, MDP, packet loss rate	Multi	Traditional routing (Adaptation of OLSR)	N/A
MVIDE [58]	MPEG	Packet delivery rate, average number of hops, end-to-end delay, SSIM	Multi	Traditional routing (geographic routing protocol GPSR-MA)	N/A
[111]	N/A	Start-up delay, number of freezes, frame distortion	Single	Traditional routing (Greedy geographic routing protocol)	Urban
[118]	MPEG4	Startup delay, interruption ratio, PSNR, application charge	Single	Traditional routing (Adaptation of Greedy geographic routing protocol)	Urban
[49]	N/A	Average delivery delay, PSNR, average numbers of hops	Single	SBF	Urban
[112]	MPEG4	PSNR	Single	SBF, RBF	Highway
REDEC [119]	H.264/MPEG-4 AVC	Delivery ratio, PSNR, video reception rate, end-to-end delay, number of transmissions, jitter.	Single	RBF	Urban
VIRTUS [120]	MPEG	Frame loss, delay, cost	Single	RBF	Highway
DADVT [121]	H.264/MPEG-4 AVC	Delivery ratio, PSNR, end-to-end delay, number of transmissions, video receiving rate	Single	RBF	N/A
QOALITE [59]	MPEG	Average packet delivery rate, average delay, SSIM, MOS	Single	RBF	Highway
LIAITHON with two paths [122]	MPEG	Frame loss, delay, cost	Multi (2 paths)	RBF	Urban
LIAITHON with three	MPEG	Frame loss, delay, cost	Multi (3	RBF	Urban

paths [123]			paths)		
3MRP [109]	MPEG-2	Average percentage of packet losses, Average end-to-end packet delay, PSNR	Single	Traditional routing (Geographic)	Urban
PaFF [115]	N/A	Delay in finding data, Cache hit ratio, Maintain overhead	Single	SBF	Urban
GPSR-TARS [108]	N/A	PDR, delay	Single	Traditional routing (GPSR)	Urban
GPSR-2P [106]	MPEG-4	PDR, delay, PSNR, VQM, SSIM	Multi (2 paths)	Traditional routing (GPSR)	Urban
En-AODV [107]	N/A	Packet Delivery Ratio, End-to-End (E2E) delay, number of RREQs broadcasted in the network	Single	Traditional routing (AODV)	Urban

We also conclude that few of existing video streaming works at network layer concentrate on cooperative relays selection for the broadcasting of video streaming in VANET. Table 3.5 depicts these works. The broadcasting of video streaming is efficient in highway environment, because this environment is characterized by the disconnection of links between vehicles due to the high speed of vehicles, therefore the high number of redundant packets providing by flooding mechanism allows to distant vehicles to receive the original video packets without errors. The existing works in VANET video streaming that use the broadcasting mode adapt the SBF or RBF schemes to support the video streaming in such networks by including some parameters in the selection of relay vehicles such as dissemination capacity of vehicle, density of vehicles, coverage area of vehicle.

Table 3.5: Comparison between existing works at network layer for the broad-casting of video streaming in VANET

Work	**Video encoding**	**Evaluation metrics**	**Routing based approach**	**Environment**
ReViV [113]	N/A	Frames loss, frames delay, PSNR	SBF	Urban
[126]	H.265	Packet delivery ratio, end-to-end delay	RBF	Highway
ACDB [129]	H.265	Packet arrival ratio, PSNR	RBF	Highway

VoV [125]	MPEG	frame loss, frame delay, total number of messages transmitted, PSNR	RBF	N/A
REACT-DIS [124]	MPEG	Delay, Delivery Ratio, Number of Packets Sent	RBF	N/A

3.2.5 Video streaming works at network layer, discussion: advantages and disadvantages

The video streaming works at network layer in VANET tend to improve the video streaming quality at the network level in terms of QoS and/or QoE metrics by selecting the best relays vehicles, which forward the received video packets in a multihop communication mode. We have classified the video dissemination schemes in three categories: traditional schemes, forwarding-based schemes (SBF and RBF) and cluster-based schemes. The traditional video dissemination schemes for VANET based on the video dissemination schemes conceived for MANET. However, contrary to this latter, VANET is characterized by high dynamic of its topology. Consequently, VANET requires a specific routing scheme. In SBF, the sender is the responsible of the selection of the next forwarder vehicles of the packets. However, SBF suffers from the high level of the bandwidth overhead and the collisions, due to high number of control messages exchanged between the vehicles. In RBF, the receiver is the responsible of forwarding video packets, this type of forwarding scheme suffers from the problem of high delay because of the waiting time of intermediate vehicles to become relays, but the network overhead in RBF is lower compared to SBF. In this category, there are some schemes based on video packets forwarding through a single path, in which the transmission suffers from the high level of congestion collisions. To handle the latter problem, many recent works proposed to forward video streams through a multiple paths, in order to provide more reliability of video packets transmission and to decrease the congestion of the communication. To facilitate the video dissemination, other schemes suggest a network clustering, however, the cluster-based schemes suffer from network overload due to many control messages generated to form the clusters.

3.3 VANET video steaming at MAC layer

The works of this category adapt some video transmission parameters at the MAC layer to enhance the video streaming quality in VANET such as the size of contention window and the resource allocation strategy. We can find Asefi et al. that proposed in [134] an adaptation of IEEE 802.11p [35] at MAC layer. The proposed adaptive scheme applied the multi-objective optimization to optimizing the limit of the number of video frame retransmission in VANET, and to minimize the probability of playback freezes and start-up the video at the destination vehicle. The authors proved that the proposed adaptation improves the video transmission quality at the receiver vehicle in terms of frequency of playback freezes with consideration of real constraints of transmission channel and the environment comparing to IEEE 802.11p. The additional transmission start-up delay can lead to exceed the deadline required by the user. Ruijian et al. in [135] solved the problem of playback freeze of video streaming over highways by proposing a new algorithm named Resource Allocation and Layer Selection with Base layer guarantee (RALSB). RALSB is composed of two phases: Base layer Guarantee (BG) phase and Resource allocation and SVC layer selection (RS) phase. In BG phase, a simple but effective method is proposed to solve the base layer guarantee problem in order to make sure that the video playback is smooth. In RS phase, the resource allocation problem at the MAC layer and SVC layer selection problem are solved with greedy and Dynamic Programing (DP) algorithms. The experiment results showed that RALSB can reduce the playback freeze but it cannot provide higher values of PSNR video quality. Belyaev et al. in [136] proved that the use of Skype application [137] for the transmission of the video from the vehicles to infrastructure (V2I) suffers from the high rate of packet losses, which decreases the visual video quality. The main cause of this problem is the lack of the coordination between vehicular users for channel resource allocation at MAC layer when they upload the video data simultaneously, which produces a congestion in the network. This work concluded that the basis coordination between users is necessary to improve the bandwidth allocation.

3.3.1 Comparison between different video streaming works at MAC layer

This category aims to improve the video transmission quality in VANET by the adaptation of some parameters of transmission in MAC layer. Table 3.6 shows the reviewed works. We see in this table that the adaptation can be performed to update the retransmission limit of video frames according to the network state or to enhance the resource allocation strategy, etc.

Table 3.6: Comparison between some video streaming works in VANET at MAC layer

Work	Video encoding	Evaluation metrics	Adaptive parameters	Environment	Routing protocol
[134]	N/A	Start-up delay, frequency of playback freezes	Retransmission limit	Urban	Greedy geographic routing
[135]	SVC	Average PSNR, freeze GOP number, SVC layer distributions	Resource allocation	Highway	N/A
[136]	H.264/AVC	Uplink bit rate, PSNR	Resource allocation	N/A	N/A

3.3.2 Video streaming works at MAC layer, discussion: advantages and disadvantages

This category improves the video streaming quality in function of some parameters such as size of contention window, resource allocation strategy. Few of works in the literature use intelligent systems and methods like heuristics of optimization, or neural network to perform this adaptation, these techniques provide optimal values of adaptive parameter.

3.4 Hybrid VANET video steaming studies

There are other works, which improve the video streaming quality in VANET in hybrid manner. Naeimipoor and Boukerche in [138] proposed a Hybrid Video Dissemination Protocol (HIVE), which is based on the combination of three techniques: congestion control at the MAC layer, relays vehicles selecting based on RBF at the network layer and EC at application layer. The simulations demonstrated that HIVE improves the video streaming quality in terms of packet loss and PSNR. In HIVE, The selection of the relay vehicles taken into account only the distance to the destination. HIVE should be improved by a multi-criteria selection to select the best relay vehicles. The problem of collision in urban environment increase when the redundancy is applied, many works proposed a multi-path routing of video streaming to solve this problem. We notice that the collision and interferences not influence on the video packets loss only but also on the transmission delay, because the packets loss decreases the receiving video rate which increase the transmission delay. Ruijian et al. in [139] formulated the SVC-based video streaming problem in VANET as an optimization problem. The authors decoupled this problem into two sub-problems: Relay Assignment (RA) sub-problem and Resource allocation and SVC layer selection (RS) sub-problem. The authors transformed the RA sub-problem to a Maximum Weighted Bipartite Matching (MWBM) problem, and they used Hungarian algorithm and Bellman-Ford algorithm to find the optimal relay assignment. The authors also proposed a Maximum Utility Increment (MUI) algorithm to solve the RS sub-problem, in which the algorithm can find an optimal assignment of resource segments to the users. The experiments results showed that the proposed scheme provides a high PSNR video quality, while varying the number of video users and the number of relay users.

3.5 General discussion of VANET video streaming studies

The existing works in video streaming over VANET improve the video transmission quality, each work chose a QoS and/or QoE evaluation metrics to assessment this transmission, the recent works use QoE because these metrics provide more accurate evaluation for the human perception.

The main problem of video streaming in VANET is the video packet loss and the transmission delay, which influences directly on the video quality and its deadline, hence, many works were proposed to decrease these two parameters. Many works neglect the transmission delay factor like [76, 77, 81, 88, 91, 95, 54, 112, 129, 87], which is considered (i.e. the transmission delay) as an important transmission metric to provide a real time video streaming, other works neglect the video packets loss factor affecting also the video quality by receiving non complete video.

The video streaming in VANET is also influenced by the environment type, vehicles density, mobility model and data rate. We have seen that each proposed research activities concentrates on the video transmission under a specific environment. For instance, the transmission under highway environment is different from that in the urban environment, due to various characteristics like the link availability, vehicle mobility, network loading, and the presence of obstacles.

Bucciol et al. in [140] proved that transmitting large size packets is preferred in highway environment, while the small size packets are more adequate to urban one. In this latter case, the collision and interference are high due to the high vehicles density increasing link availability, contrary to highway environment, which is characterized by the disconnection of links between the vehicles, because of the high speed of vehicles.

As mentioned in this chapter, we are classified the video streaming works in VANET into three classes according to the layer level, in which the works are concentrated to improve the video quality. The first category is the video streaming at transport and application layers level. The second category is the video streaming at network layer level. The last category includes the video streaming works at MAC layer level.

The video streaming works at transport and application layers level use the video encoding and error resiliency techniques to enhance the video streaming quality. The three error resiliency techniques (redundancy, retransmission and error concealment) aim to recover the erroneous video packets. The redundancy error resiliency techniques increase the network overhead, the retransmission increases the transmission delay and the error concealment produces the artifacts in the video.

The video streaming works at network layer improve the video streaming quality at network level, there are two types of video forwarding: unicast/multicast forwarding and broadcast forwarding, this two forwarding types are based on three approaches: traditional, forwarding-based approaches (SBF and RBF) and cluster-based approaches. The traditional routing uses or adapts the classical routing protocol conceived for wireless networks to support the video streaming in VANET, but this adaptation not always possible because a VANET has particular characteristics than other wireless networks like the high dynamic of its topology. The SBF based on the periodically exchange of beaconing messages between vehicles, it increases the interferences and collisions. In addition, the control messages in SBF do not always give a correct information about the vehicles such as vehicle identifier, vehicle geographical position and vehicle speed, due to the high dynamic topology of VANET. Since RBF did not exchange beacon messages, it is qualified as the better in terms of network overhead, however, RBF suffers from the increased transmission delay problem due to additional waiting time generated during the relay vehicle selection. The video streaming works at MAC layer improve the video streaming quality by the adaptation of some parameters or transmission strategy like the resource allocation method, this improvement could be enhanced by the use of different optimization techniques to calculate the optimum values of the adaptive transmission parameters at MAC layer level.

3.6 Conclusion

Video streaming in VANET becoming promising field due to the importance of video information for the route security, traffic monitoring and user comfort. A comprehensive state-of-art review of different video streaming works in VANET was presented in this chapter, including the classification, study and comparison of these different works in terms of different transmission metrics in order to guarantee a high video streaming quality.

In the next chapters, our contributions for VANET video streaming at application and transport layers will be presented. These proposed studies are based on the redundancy and retransmission techniques to recover the video errors.

Chapter 4

EASP-FEC and EUDP: redundancy-based video streaming mechanisms for VANET

In this chapter, we present our two first contributions based on the redundancy technique to recover the uniforms errors of video packets in VANET. We propose in the first contribution an enhancement of Sub-Packet Forward Error Correction mechanism (SPFEC) considered as a version of Forward Error Correction (FEC). The second contribution integrates the enhanced SPFEC with UDP protocol in order to support the network transmission of the video in VANET.

Initially, we review the basic concepts used in our contributions, including SPFEC mechanism and unequal protection of video frames in accordance with their types.

After that, the first proposed solution is described to improve error resiliency approaches for video streaming in VANET, we name this approach the Enhanced Adaptive Sub-Packet Forward Error Correction mechanism (EASP-FEC) [141]. EASP-FEC allows sender and relay vehicles to calculate the redundant sub-packets of each packet based on network conditions (effective packet error rate), network load (queue length) and frames types of the transmitted video. The objective of EASP-FEC is to increase the recovery efficiency, to avoid network congestion and to guarantee a high quality of video streaming.

To support the network transmission, we propose in this chapter a second protocol called the Enhanced User Datagram Protocol (EUDP) [142], which integrates UDP with SPFEC error recovery mechanism and the unequal protection of video frame types (I, P, B) coded based on MPEG standard. The purpose of EUDP is to improve the video streaming quality at the level of the receiver vehicle in terms of QoS and QoE metrics. Finally, our two contributions are discussed and then the chapter is concluded.

4.1 Basic concepts of the proposed contributions

4.1.1 Sub-Packet Forward Error Correction (SPFEC)

When the video sub-packets errors are uniform, the proposed contributions use the SPFEC to recover these errors without any retransmission mechanism. In fact, Sub-Packet FEC (SPFEC) was proposed by Tsai et al. in [19] to improve the video streaming recovery

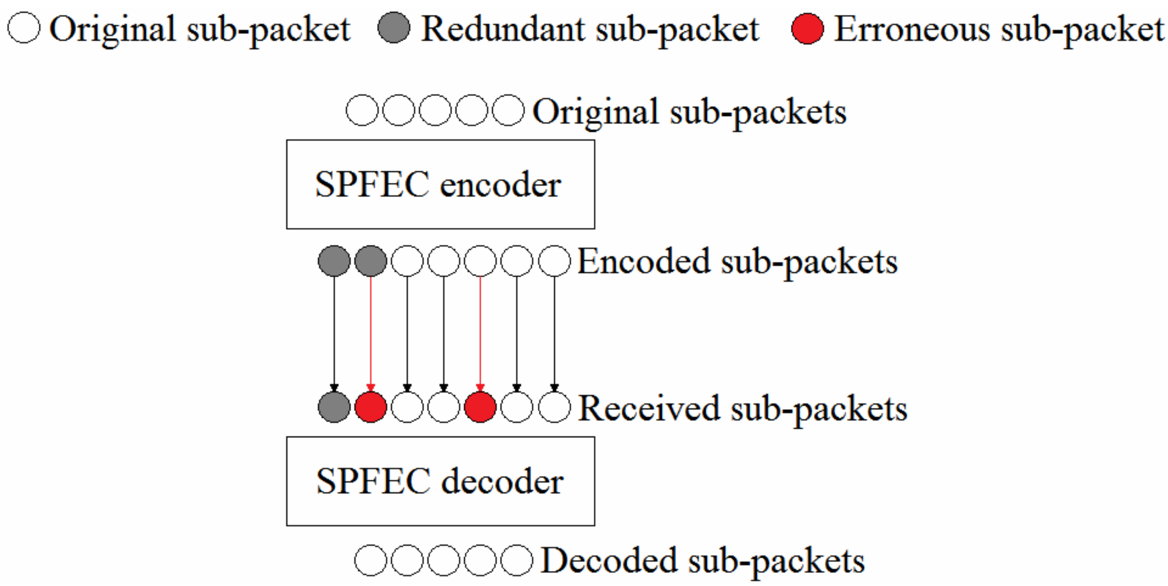


Figure 4.1: Sub-Packet Forward Error Correction mechanism

performance over wireless network. The video packet in SPFEC is composed of two parts: original sub-packets and redundant sub-packets. As shown in figure 4.1, SPFEC encoder adds ‘*n*’ redundant sub-packets into ‘*k*’ original sub-packets. When the decoder receives the video packet, it can recover the lost original sub-packets by means of redundant sub-packets. SPFEC reduces the Effective Packet Error Rate EPER) and the network overload compared with FEC, because the Sub-Packet Error Rate (SPER) is smaller than the Packet Error Rate (PER). SPFEC reduces also the transmission delay where the receiver decodes video packets without waiting other packets compared to FEC mechanism. SPFEC is based on the following equations to estimate BER and to calculate SPER and EPER.

1) Estimation of Bit Error Rate (BER): the *BER* at each interval of time *dt*, is estimated by the following formula:

$$BER(dt) = 1 - \left(1 - \frac{success(dt)}{Total(dt)}\right)^{\frac{1}{Total(dt)}} \qquad (1)$$

Where, *success(dt)* represents the number of successful received packets without applying SPFEC mechanism during the interval time *dt*, *Total(dt)* represents the total number of transmitted packets to receiver vehicle during the interval time *dt*.

2) Sub-Packet Error Rate (SPER): *SPER* represents the probability that a sub-packet video cannot be recovered at receiver vehicle, it is given by the formula:

$$SPER = 1 - (1 - BER)^{sub-pkt-size} \qquad (2)$$

3) Effective Packet Error Rate (EPER): *EPER* represents the probability that a video packet cannot be recovered at receiver vehicle, it is given by the formula:

$$EPER = 1 - (\sum_{i=k}^{k+h} C_i^{k+h} * (1 - SPER)^i * SPER^{k+h-i}) \qquad (3)$$

Where k is the number of original sub-packets and h is the number of redundant sub-packets in a packet.

4.1.2 Unequal protection of video frames

Our proposals are based on MPEG-4 standard as a video frames compression scheme. Within the GoP, if the I-frame is erroneous the other P-frames and B-frames cannot be decoded even there have been received correctly. This propagation of errors in the GoP is due to the relationship between the I-frames, P-frames and B-frames of the video stream. In order to minimize the error propagation on the quality degradation of reconstructed video, our proposals propose unequal protection of video frames in function of their types (I, P, B). According to video frames importance, the proposed contributions provide a higher redundancy rate for I-frames than the other video frames, this is proposed in order to guarantee more protection of I-frames which are the most important compared to the others.

The following sections present our first contributions which is based on SPFEC mechanism and unequal protection of video frames technique.

4.2 Enhanced Adaptive Sub-Packet Forward Error Correction mechanism (EASP-FEC) for video streaming in VANET

As aforementioned in subsection 4.1.1, the SPFEC divides the packet into a set of sub-packets and calculates the FEC sub-packets (redundant sub-packets) according to effective packet error rate in the network. Consequently, the network congestion appears and increases the packet error rate in the VANET, specifically when the density of vehicles is high. We firstly propose in this chapter an Enhanced Adaptive Sub-Packet Forward Error Correction mechanism for video streaming in VANET (called EASP-FEC) which improves SPFEC mechanism by adding traffic load factor to avoid the congestion problem. EASP-FEC adds the protection of sub-packets in accordance with their type (I, P, B) to increase the video streaming quality at the end receiver vehicle.

4.2.1 General architecture of EASP-FEC

EASP-FEC mechanism consists of three components (as presented in figure 4.2): (1) Traffic condition estimator, (2) FEC redundant sub-packets generator and, (3) a traffic load monitor. The vehicle sender encapsulates the video data in Real-time Transport Protocol (RTP) packets and the proposed mechanism is applied at the sender vehicle side and at the relay vehicles side. When the relay vehicle received the packet, the traffic condition estimator estimates current Bit Error Rate (*BER*) and Sub-Packet Error Rate (*SPER*). FEC redundant sub-packets generator generates the redundant sub-packets for received packet based on estimated *SPER*

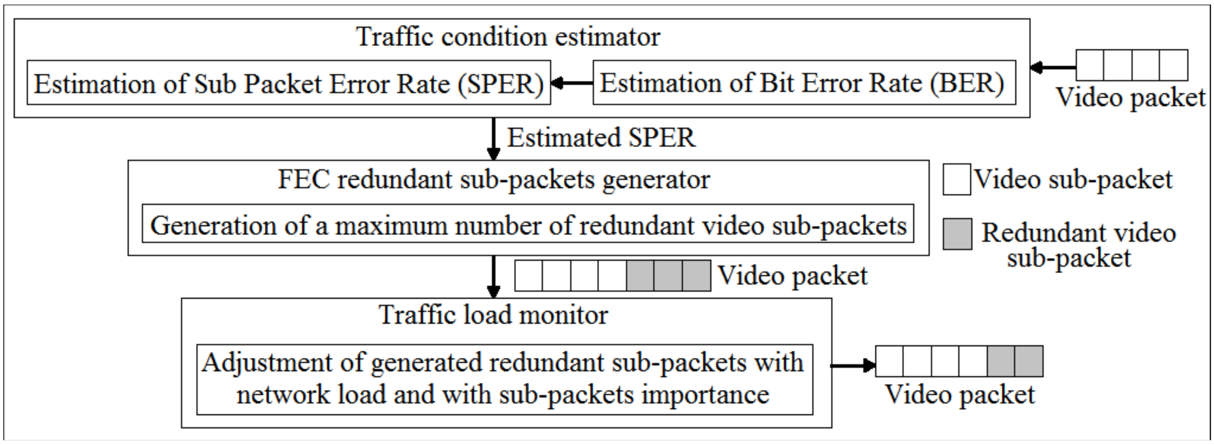


Figure 4.2: Architecture of EASP-FEC mechanism

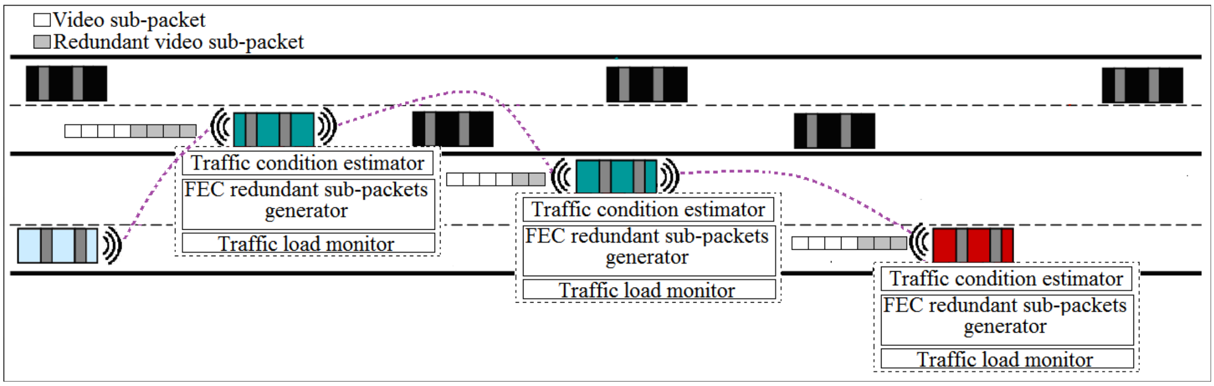


Figure 4.3: Video streaming transmission using EASP-FEC mechanism

which provides maximum video quality in terms of Decodable Frame Rate (*DFR*) at the next relay vehicle. Traffic load monitor adapts the number of generated redundant sub-packets according to network load (indicated by relay vehicle queue length) to avoid the congestion problem and also according to the importance of video sub-packets (I, P, B) to allow a high quality of video streaming for the vehicle in the next hop. In figure 4.3, the source vehicle (in red color) applies EASP-FEC mechanism and sends the packet to the relay vehicle in the next hop (i.e. green vehicle). When a relay vehicle received the packet, it recalculates the redundant sub-packets following EASP-FEC and transmits the packet to the next hop and so on, until arriving the packet to the destination vehicle (in blue color). It is worth noting that the redundant sub-packets of one packet are regenerated at each hop.

4.2.2 Analytical model of EASP-FEC

In our proposed mechanism, the Effective Packet Error Rate (*EPER*) is estimated based on *SPER* of video streaming in VANET and *SPER* is estimated based on *BER*. We assume that the video streaming composed of *N* video packets, the maximum size of video packet is *n* bit, also the number of sub-packets in a packet is fixed at *m*. EASP-FEC based on the following equations to estimate BER, SPER, EPER and the video streaming quality.

- **Estimation of BER, SPER and EPER:** EASP-FEC uses the equations (1), (2) and (3) of SPFEC mechanism to estimate and calculate BER, SPER and EPER.

- **Estimation of video streaming quality:** in order to estimate the quality of video streaming at the next hop according to the estimated *EPER* following EASP-FEC, we use a Decodable Frame Rate Model (*DFR*), *DFR* evaluates the quality of GoP at the application layer, it gives more accurate evaluation than *EPER*. *DFR* model calculates the number of decidable frames I, P and B in a given *EPER*. The value of *DFR* varies between zero and one, higher value of *DFR* indicates the best quality of video streaming. The number of decodable frames I is given by the formula:

$$NdecodeI = (1 - EPER)^{aI} * NGoP \qquad (4)$$

Where *NGoP* is the total number of GoPs in the video stream, *aI* is the average packets number in I frame.

The number of decodable frames P is given by the equation:

$$NdecodeP = (1 - EPER)^{aI} * \sum_{i=1}^{nP} (1 - EPER)^{i*aP} * NGoP \qquad (5)$$

Where *nP* is the total number of P frames in a GoP and *aP* is the average packets number in P frame.

The number of decodable frames B is given by the equation:

$$NdecodeB = [(1 - EPER)^{aI*nP*aP} + \sum_{j=1}^{nP} (1 - EPER)^{j*aP} * (1 - EPER)^{aB}] * (M - 1) * (1 - EPER)^{aI+aB} * NGoP \qquad (6)$$

Where *aB* is the average packets number in B frame and *M* is the distance between I frames and P frames in a GoP.

The percentage of total number of decodable video frames I, P and B at the next relay vehicle is given by the equation:

$$DFR = \frac{(NdecodeI + NdecodeP + NdecodeB)}{Ntotal} \qquad (7)$$

4.2.3 EASP-FEC algorithm

EASP-FEC algorithm is applied at the sender and relays vehicles side. This algorithm allows the generation of an appropriate number of redundant sub-packets, in order to recover the uniform errors and reduce the network overload. The pseudo-code of EASP-FEC algorithm is presented in figure 4.4. When a new packet arrived at the relay vehicle, the traffic condition estimator component of this vehicle estimates current *BER* and *SPER* by formulas (1) and (3)

Step 1. Estimation of current Bit Error Rate (BER) and current Sub-Packet Error Rate (SPER) in VANET network by equations (3) and (1)

Step 2. Determination of number of redundant sub-packets (h) in accordance with the network conditions

$h \leftarrow 0$
while $DFR < MaxDFR$ **do**
  1. Determination of Effective Packet Error Rate (EPER) by equation (2)
  2. Determination of number of decodable I-frames (NdecodeI) by equation (4)
  3. Determination of number of decodable P-frames (NdecodeP) by equation (5)
  4. Determination of number of decodable B-frames (NdecodeB) by equation (6)
  5. Determination of Decodable Frame Rate (DFR) by equation (7)
  $h \leftarrow h+1$
  $Max\_number\_generated\_redundant\_subpackets \leftarrow h$
end while

Step 3. Adjust the number of redundant sub-packets in accordance with the network load
if $Qlength < THL$ **then**
  $Number\_generated\_redundant\_subpackets \leftarrow Max\_number\_generated\_redundant\_subpackets$
else if $Qlength < THH$ **then**
  $Number\_generated\_redundant\_subpackets \leftarrow Max\_number\_generated\_redundant\_subpackets * (\frac{THH-Qlength}{THH-THL})$
else
  $Number\_generated\_redundant\_subpackets \leftarrow 0$
end if

Figure 4.4: EASP-FEC pseudo-code

(step 1 of EASP-FEC pseudo-code shows this estimation). After that, the FEC redundant sub-packets generator component recalculates for each packet the maximum number of redundant sub-packets (*h*) which provides a maximum quality of video streaming in terms of *DFR* (*MaxDFR*) at the next hop following equations (2), (4), (5), (6), (7) (step 2). Finally, traffic load monitor component of this vehicle adjusts the number of redundant sub-packets according to the current network load to avoid the congestion problem. This latter increases the packet error rate and the end-to-end delay especially when the density of vehicles is high. In our proposed mechanism the relay vehicle estimates the network load based on the length of its queue (step 3 of EASP-FEC pseudo-code presents this adjustment). We propose that the queue of current relay vehicle has two thresholds: THreshold High (*THH*) and THreshold

Low (*THL*). When Queue Length (*Qlength*) is lower than *THL*, it means that the current network load is lower, then the adjusted number of generated redundant sub-packets is set to the maximum number of generated redundant sub-packets. If the *Qlength* is high than *THH*, it means that the current network load is high, then the adjusted number of generated redundant sub-packets is set to zero. When *Qlength* is between *THL* and *THH*, the adjusted number of generated redundant sub-packets is calculated based on the following formula:

$$Number\_generated\_redundant\_subpackets = \\ Max\_number\_generated\_redundant\_subpackets * \frac{(THH - Qlength)}{(THH - THL)} \quad (8)$$

EASP-FEC uses MPEG standard based on the three types of frames: I, P and B following to its importance. Indeed, EASP-FEC is based on the idea of unequal protection of video sub-packets, the most important sub-packets must have high protection. Unequal protection is indicated by dynamic updating of *THH* and *THL* according to the type of current generated redundant sub-packets. The *THH* for the most important sub-packets is higher than lower important sub-packets, for instance, when the network is heavily congested, the generated redundant sub-packets B and P are set to 0 and only generated redundant sub-packets I are adjusted. Unlike *THH*, the *THL* for all sub-packets type is the same, in lightly congested network the maximum number of generated redundant sub-packets I, P and B must be transmitted to allow a high quality of video for the vehicle in the next hop.

4.2.4 Validation of EASP-FEC mechanism

To validate the effectiveness of the proposed EASP-FEC mechanism, a set of EASP-FEC simulations are performed using MATLAB. The confidence intervals are calculated with 95% of confidence level and Student's distribution function using Statistics Toolbox of MATLAB. The obtained results have been compared with the simulated PFEC and SPFEC mechanisms in terms of *EPER*, *DFR* and the number of redundant sub-packets. As cited above, EASP-FEC mechanism is applied at the sender and relay vehicles in a VANET. Moreover, in our simulations, we applied EASP-FEC, PFEC and SPFEC mechanisms to be compared at one relay vehicle where the video is encoding with MPEG-4 standard in a QCIF format with a GoP structure of IBBPBBPBB. Table 4.1 shows parameter settings of these simulations.

Table 4.1: Simulation parameters

Parameter	Value	Parameter	Value
Bit Error Rate	{0,..., 0.005}	Average packets number in P frames	10
Packet size	1000 bits	Average packets number in B frames	10
Number of sub-packets in a received packet	10	Total number of P frames in a GoP	2
Number of original sub-packets in a packet	8	The distance between I frames and P frames in a GoP	3
Number of GoPs in the video stream	10	*Qlength*	{0,..., 50 packets}
Average packets number in I frames	10	*THL*	10
Maximum desired DFR of video stream	1	*THH*	25

4.2.4.1 Validation of traffic condition estimation and effect of EPER on delivered video quality

The validation of EASP-FEC traffic condition estimation and the effect of *EPER* on delivered video quality is performed by comparing the *EPER* and *DFR* obtained by EASP-FEC and PFEC. The number of original sub-packets in one packet is assumed equal to 8 and the number of redundant sub-packets generated by the current relay vehicle is fixed at 4 in the case of EASP-FEC. The same parameters are assumed in the case of PFEC (number of

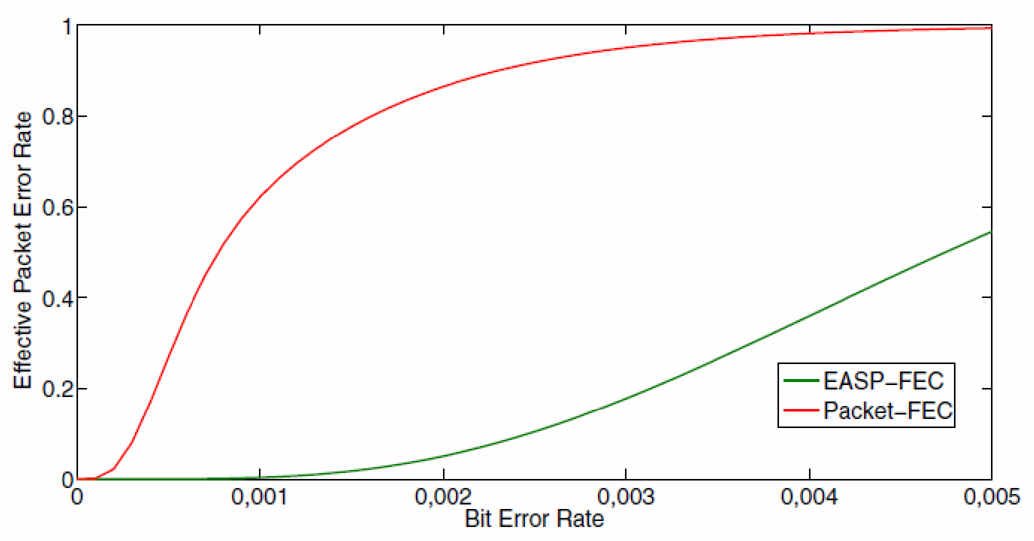


Figure 4.5: Variation of Effective Packet Error Rate with Bit Error Rate

original packet in a block is 8 and number of redundant packet in one block is 4). As shown in figure 4.5, with the same redundancy rate, the *EPER* of PFEC increases greatly than EASP-FEC with a varying *BER*, because in the same network condition the sub-packet is more susceptible to be recovered than the entire packet. Figure 4.6 shows the variation of *DFR* with *BER* for EASP-FEC and PFEC. When the *BER* increases and with the same redundancy rate, the *DFR* of PFEC decreases greatly than EASP-FEC, because the *EPER* of PFEC increases greatly than EASP-FEC.

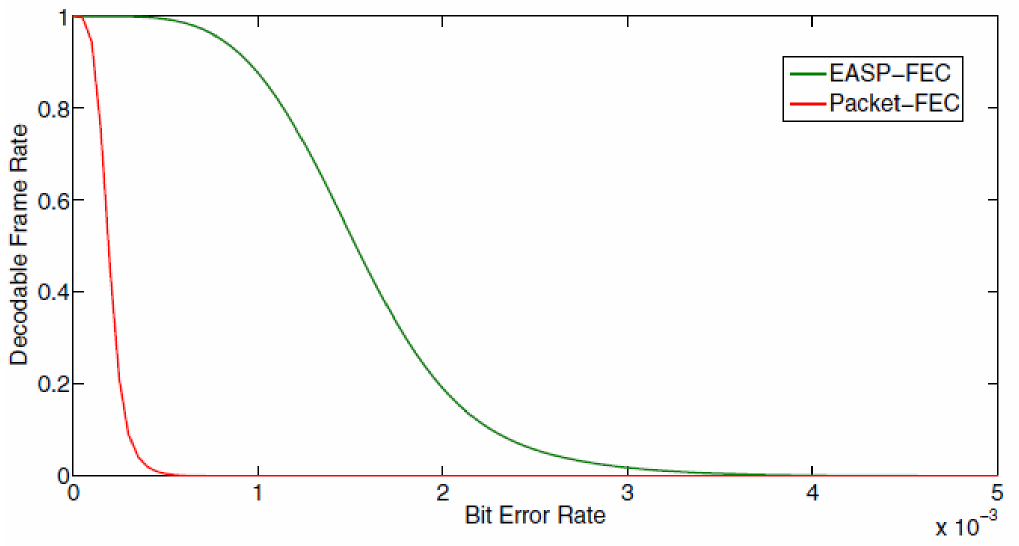


Figure 4.6: Variation of Decodable Frame Rate with Bit Error Rate

4.2.4.2 Validation of generation of redundant sub-packets and effect of redundancy rate on delivered video quality

To verify the effectiveness of redundant sub-packets generation used to recover the original sub-packets, the *EPER* is compared with the variation of redundancy rate in both EASP-FEC and PFEC. The redundancy rate represents the percentage of redundant sub-packets compared to original sub-packets in the case of EASP-FEC and the percentage of redundant packets compared to original packets in the case of PFEC. As shown in Figure 4.7, when the redundancy rate increases, the *EPER* of EASP-FEC decreases greatly than PFEC in three cases: *BER* = 0.005, 0.0005 and 0.00005, for example with 50% of redundancy rate (4 redundant sub-packets or packets) the *EPER* = 0.27 with EASP-FEC while with PFEC the *EPER* = 0.55, because in the case of PFEC the packet is dropped even if one part of this packet is erroneous, it is contrary to EASP-FEC in which only the sub-packet containing this part is dropped. Figure 4.7 shows also that when *BER* increases, the *EPER* increases in both EASP-FEC and PFEC, consequently the redundancy rate must be high to recover the erroneous bits. Figure 4.8 shows the variation of *DFR* of video stream with redundancy rate, as seen in this figure for both mechanisms EASP-FEC and PFEC that when redundancy rate increases, the *DFR* increases because the *EPER* decreases and when *BER* increases the *DFR* decreases because the *EPER* increases. This figure shows also that *DFR* of EASP-FEC is always higher than PFEC, because always the *EPER* of EASP-FEC is lower than PFEC.

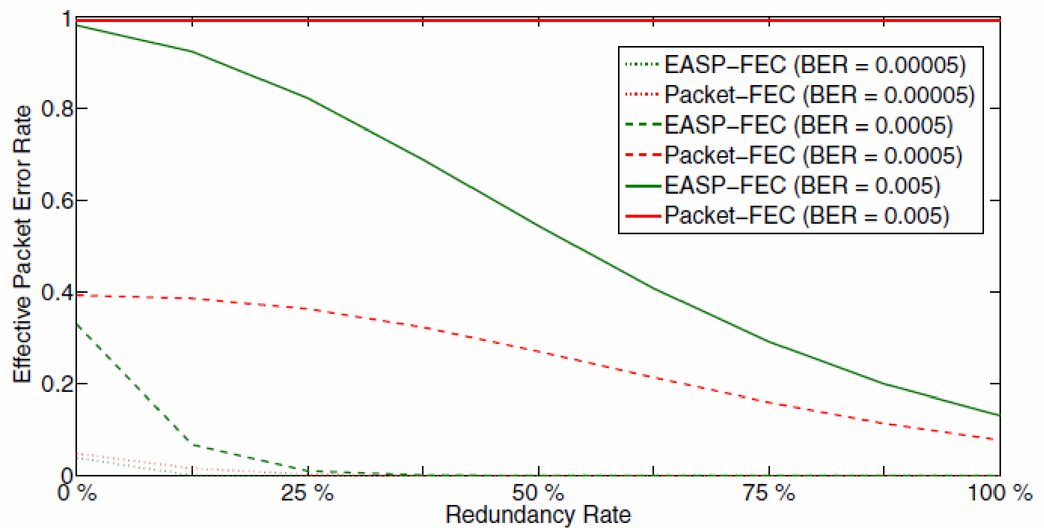


Figure 4.7: Variation of Effective Packet Error Rate with Redundancy Rate

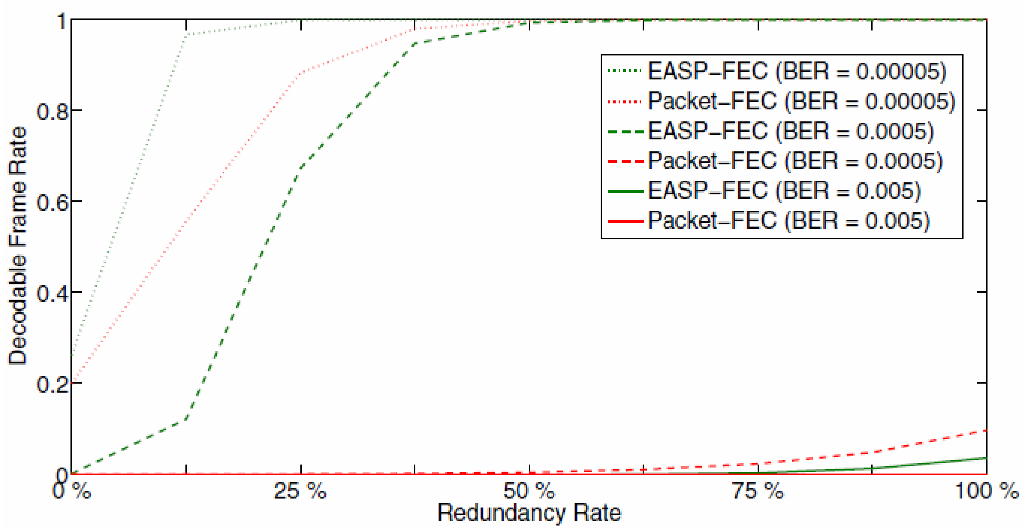


Figure 4.8: Variation of Decodable Frame Rate with Redundancy Rate

4.2.4.3 Validation of adjustment of redundant sub-packets number in accordance with the network load

In this subsection, the adjustment of generated redundant sub-packets number of the proposed EASP-FEC mechanism is evaluated as a VANET congestion metric. A comparison between EASP-FEC and SPFEC is performed. Figure 4.9 shows the variation of adjusted number of redundant sub-packets with queue length, we note that the number of redundant sub-packets before the adjustment is generated randomly. As seen in this figure, when queue length is lower than *THL* which means that the density of vehicles is low, the adjusted number of redundant sub-packets of EASP-FEC and SPFEC is the same. When queue length is between *THL* and *THH* which means that the density of vehicles is medium, the adjusted number of redundant sub-packets of SPFEC is higher than EASP-FEC, because SPFEC does not have a mechanism which controls the congestion problem. When the queue length is higher than *THH* which means that the density of vehicles is high, the adjusted number of redundant sub-packets of SPFEC is high. Contrary to EASP-FEC, in which *THH* is equal to zero, because the traffic load monitor of current relay vehicle detects that the network is heavy loaded, hence it stops the generation of redundant sub-packets. Consequently, EASP-FEC avoids the congestion contrary to SPFEC, which cannot prevent network collusion leading also to interferences.

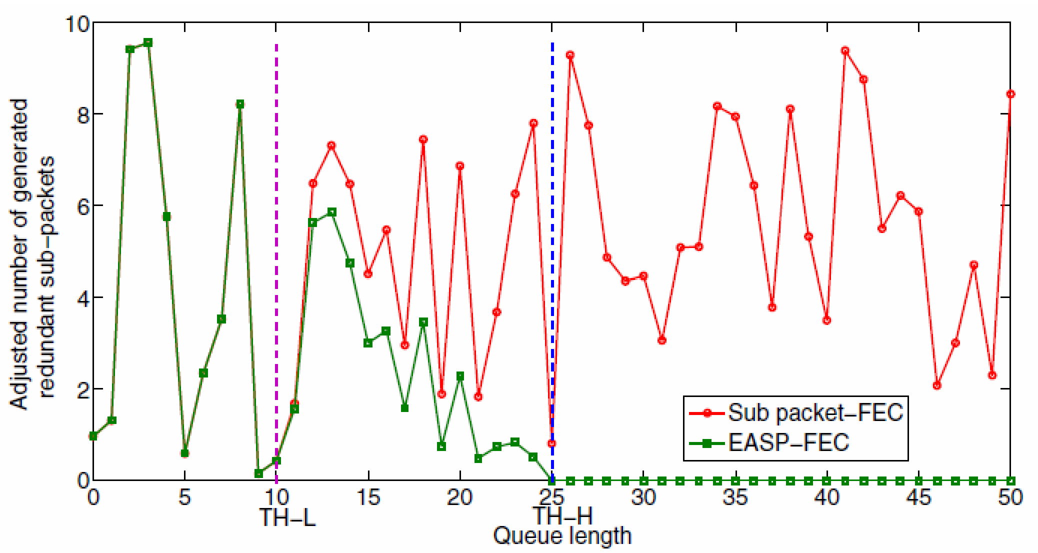


Figure 4.9: Variation of adjusted number of redundant sub-packets with Queue Length

4.2.4.4 Validation of unequal protection of video frames

Figure 4.10 depicts the variation of number of decodable frames with *BER*. This figure shows that when the *BER* increases, the number of decodable frames B decreases greatly than decodable frames P and this later decreases greatly than I frames. For example, when *BER* = 0.002, the number of decodable frames I = number of decodable frames P = number of decodable frames B = 5, because according to dependencies between frames of MPEG, an error of I frame influences on the P and B frames and the error of P frame influences on the B frames, for this reason, EASP-FEC proposes to distinguish values of *THL* and *THH* for different video frame types (I, P, B).

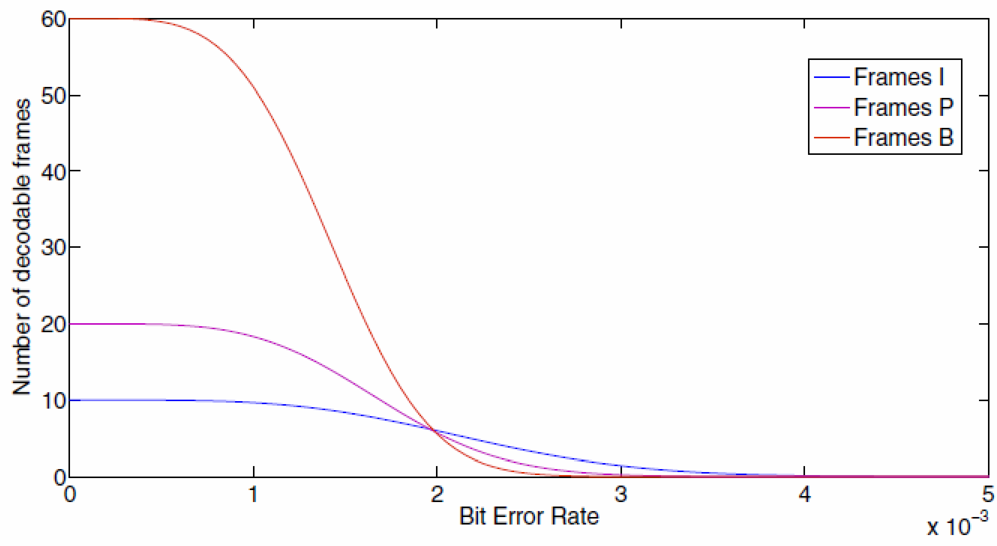


Figure 4.10: Variation of Number of decodable frames with Bit Error Rate

4.3 Enhanced User Datagram Protocol for video streaming in VANET

To enhance UDP protocol for video streaming in VANET network by adding the based concepts of proposed EASP-FEC, we have suggested our second contribution named Enhanced User Datagram Protocol (EUDP). Generally, many video streaming works in VANET use UDP and/or TCP control protocols at the transport layer. Unlike TCP protocol that uses retransmission mechanism to recover the erroneous packets, UDP did not use any resiliency mechanism. Therefore, in EUDP we introduce the idea of integrating UDP protocol with two error correctness techniques, namely SPFEC and unequal protection of video frame types (I, P, B). The first one allows the recovering of uniform errors of packets and reduces the Effective Packet Error Rate (*EPER*) as well as the redundancy overhead. Also, SPFEC reduces the end-to-end delay compared with PFEC. The second one reduces the overload of the network and increases the video quality. In the following subsections, EUDP is explained.

4.3.1 General architecture of video streaming using EUDP

Figure 4.11 illustrates the basic architecture of EUDP. This figure shows that the sender vehicle (in red color) generates video packets. Each video packet consists of originals sub-packets and redundant sub-packets. The sender vehicle calculates the number of redundant sub-packets based on the type of their video packet (I, P, B). The sub-packets of frames *I* and *P* must have higher protection level than frames *B*. The sender encapsulates the video data in Real-time Transport Protocol (RTP) packets and sends them toward the receiver (the destination) via a multi-hop transmission. When the receiver vehicle (in blue color) receives the video packet, it retrieves the packet information (header and data), estimates the Bit Error Rate (*BER*), calculates the Sub-Packet Error Rate (*SPER*) and *EPER* based on the estimated *BER* following SPFEC mechanism. According to the calculated *EPER*, the receiver accepts or rejects the received packet.

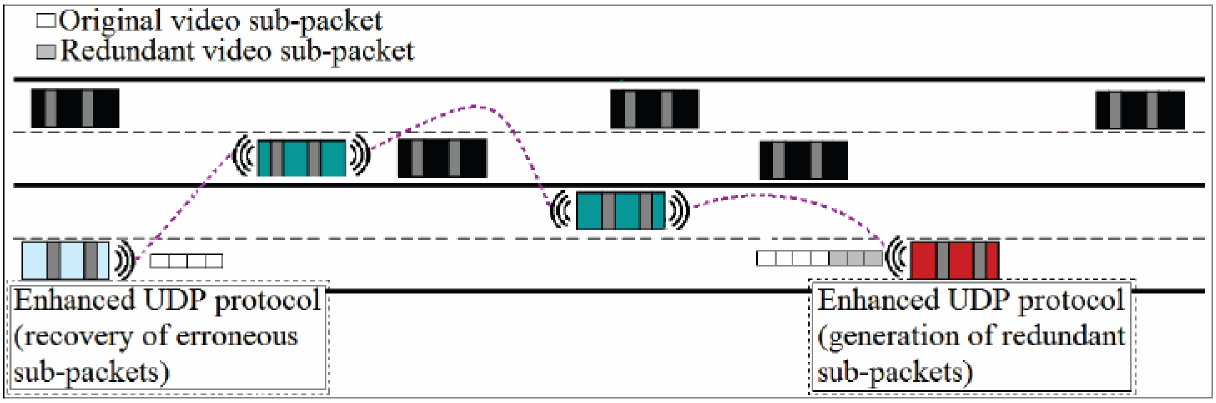


Figure 4.11: Video streaming using EUDP protocol

To allow receiver to calculate *SPER* and *EPER*, we propose to add a new header field called "eudp header" in the packet header. Figure 4.12 presents video packet format in proposed EUDP protocol. As shown in this figure, "eudp header" of the video packet consists of the following sub-fields:

- **video_pkt_id:** a sequence number of video packet.
- **video_pkt_type:** the type of video packet frame (I, P, B).
- **sub_pkt_size:** the length of one sub-packet of video packet.
- **nb_source_sub_pkts:** the number of original sub-packets '*k*' of video packet.
- **nb_redundant_sub_pkts:** the number of redundant sub-packets '*h*' of video packet.

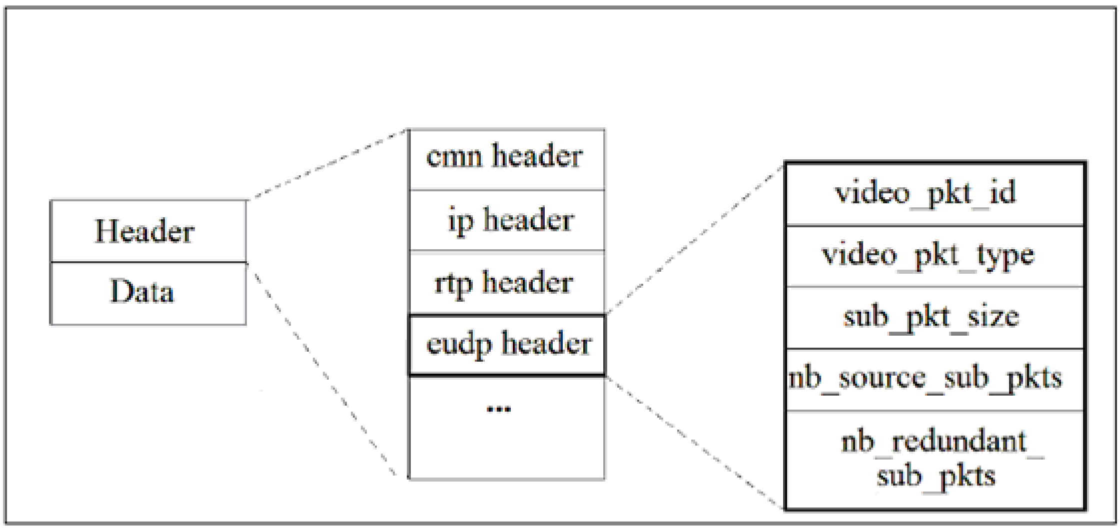


Figure 4.12: Video packet format in EUDP protocol

4.3.2 General algorithm of EUDP protocol

Figure 4.13 presents the pseudo-code of EUDP algorithm at the sender vehicle. When this vehicle needs to send a video packet to a receiver, it firstly applies Step 1 to calculate the number of redundant sub-packets (*nb_redundant_sub_pkts*) in function of frame type (I, P, B) of the video packet. The unequal protection of video frame types strategy is applied in EUDP protocol by unequal redundancy rate of frames types (*RR_I*, *RR_P*, *RR_B*). Then, the sender generates the video packet and sends it to the receiver (Step 2).

Figure 4.14 presents the pseudo-code of EUDP at the receiver level. When the destination vehicle receives the video packet, it retrieves packet header information (*sub_pkt_size*, *nb_redundant_sub_pkts*, *nb_source_sub_pkts*) (Step 1) used to calculate *EPER*. In EUDP, *EPER* is calculated based on *SPER*, which is calculated in its turn by the estimated *BER* (Step 2).

In this study, it is assumed that the total number of video packets is *N*. EUDP uses the equations (1), (2) and (3) of SPFEC mechanism to estimate and calculate BER, SPER and EPER. When the *EPER* is calculated, the receiver vehicle generates a uniform random number *r* varied in the interval [0, 1], and checks the probability of acceptation of video packet (Step 3). If the *r* value is higher than *EPER*, the receiver makes sure that the packet is recovered and then it accepts the packet, otherwise the receiver rejects the packet because it is not recovered.

```
Input: video_pkt_type, nb_source_sub_pkts, RR_I, RR_P, RR_B
Output: nb_redundant_sub_pkts
  Initialisation : nb_redundant_sub_pkts ← 0
  Step 1.
  if video_pkt_type = I then
    nb_redundant_sub_pkts ←(RR_I / 100) * nb_source_sub_pkts
  else if video_pkt_type = P then
    nb_redundant_sub_pkts ←(RR_P / 100) * nb_source_sub_pkts
  else
    nb_redundant_sub_pkts ←(RR_B / 100) * nb_source_sub_pkts
  end if
  video_pkt_id ←video_pkt_id + 1
  Step 2.
  Generation of video packet
  Send of generated video packet toward receiver vehicle
```

Figure 4.13: EUDP algorithm at sender vehicle

```
Input: Video packet, interval time dt
Output: Accept or reject decision of received video packet
  Initialisation : EPER ← 0, SPER ← 0
  if video packet is received then
    Step 1.
    Extract sub_pkt_size (n)
    Extract nb_redundant_sub_pkts (k)
    Extract nb_source_sub_pkts (h)
    Step 2.
    Estimate BER by equation (1)
    Calculate SPER by equation (2)
    Calculate EPER by equation (3)
    Step 3.
    Generate uniform random number r in the interval [0, 1]
    if r >EPER then
      Accept video packet (recovered packet)
    else
      Reject video packet (no recovered packet)
    end if
  end if
```

Figure 4.14: EUDP algorithm at receiver vehicle

4.3.3 Performance evaluation and results

4.3.3.1 Simulation setup

To validate the effectiveness of the proposed EUDP in VANET, we have performed many simulations using ns-2 network simulator version 2.35 [96]. In our simulations, three video streaming protocols are compared:

- **EUDP:** it is the proposed protocol, which integrates UDP with SPFEC and unequal protection of video frame types.
- **EUDP-E:** it is the integration of UDP with SPFEC, but without unequal protection of video frame types.
- **UDP:** it is the traditional UDP protocol without SPFEC and unequal protection of video frame types.

We assume that in the case of EUDP-E, there is an equal number of redundant sub-packets for all video packets (I, P, B). In addition, we assume that in EUDP, the number of redundant sub-packets of packet I and P is twice the number of redundant sub-packets of packet B, because the packets I and P are most important than packets B. Simulation settings are presented in Table 4.2.

Table 4.2: Simulation parameters

Parameter	**Value**	**Parameter**	**Value**
Number of vehicles	100	Scenario	V2V
Video file	Foreman.yuv	Routing protocol	AODV
Video packet size	1024 bits	Sub-packet size	100 bits
Communication range	300 m	Bit Error Rate	{0,, 0.005}
Propagation model	TowRayGround	Number of video frames	400
Evaluation metrics	EPER, delivery ratio, PSNR, MOS		

In these simulations, the Evalvid framework [97] was used to generate the trace of video stream at the sender and receiver vehicles. We have also used SUMO [143] to generate vehicles mobility pattern required by ns-2. Additionally, we have simulated the transmission of video stream in urban area, the generated mobility model is based on the downtown of Oum El Bouaghi city in Algeria, imported from Open Street Map [144] (see figure 4.15). We have chosen AODV as a routing protocol applied for V2V transmission mode, and we have used the following QoS metrics: *EPER*, delivery ratio, *PSNR* and *MOS* QoE metric, to evaluate the quality of video streaming. The chosen video benchmark is the MPEG-4 foreman.yuv, which consists of 400 frames, with GoP structure of IBBPBBPBB [145].

Figure 4.15: Studied urban area for video streaming in VANET

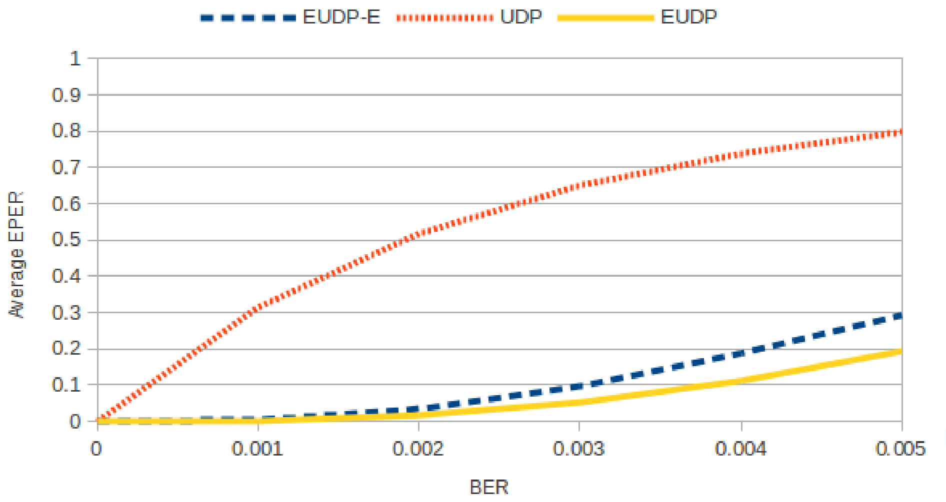


Figure 4.16: Variation of average EPER of video packets with BER

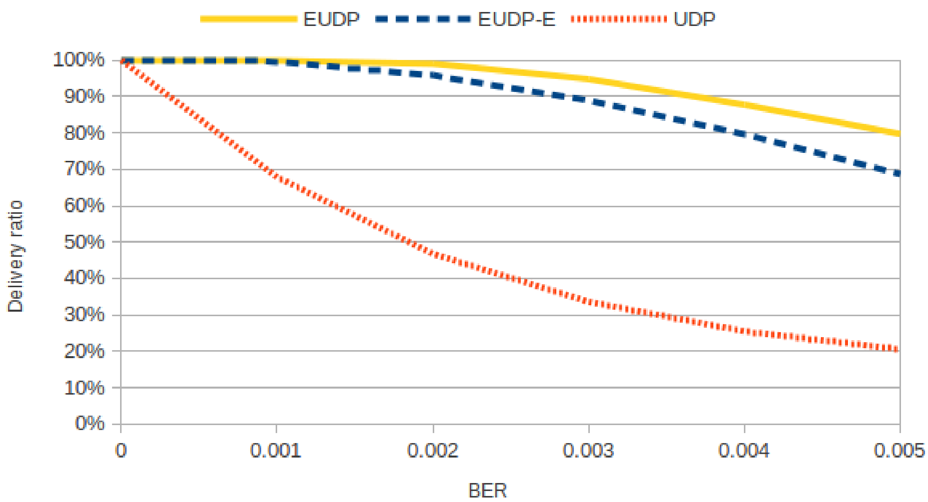


Figure 4.17: Variation of delivery ratio of video packets with BER

4.3.3.2 Results

In this section, we present the obtained results of simulations and discuss them. Figure 4.16 and figure 4.17 show the variation of the average *EPER* and the delivery ratio of video packets in function of the estimated *BER* following UDP, EUDP-E and EUDP protocols. It can be seen in figure 4.16 that when *BER* increases the average *EPER* following UDP increases greatly than EUDP-E and EUDP, because UDP has not a recovery mechanism of erroneous packets unlike EUDP-E and EUDP, which use the redundancy to recover the erroneous sub-packets. Figure 4.16 shows also that the average *EPER* of EUDP-E is higher than the average *EPER* given by EUDP, because in EUDP the redundancy rates of frames *I* and *P* are higher than the redundancy rate of frames *B* which guarantees more error resiliency contrary to EUDP-E, which did not distinguish between the types of frames. Figure 4.17 shows that the delivery ratio of EUDP is higher than those given by EUDP-E and UDP, because the average *EPER* following EUDP is lower than average *EPER* in the cases of EUDP-E and UDP.

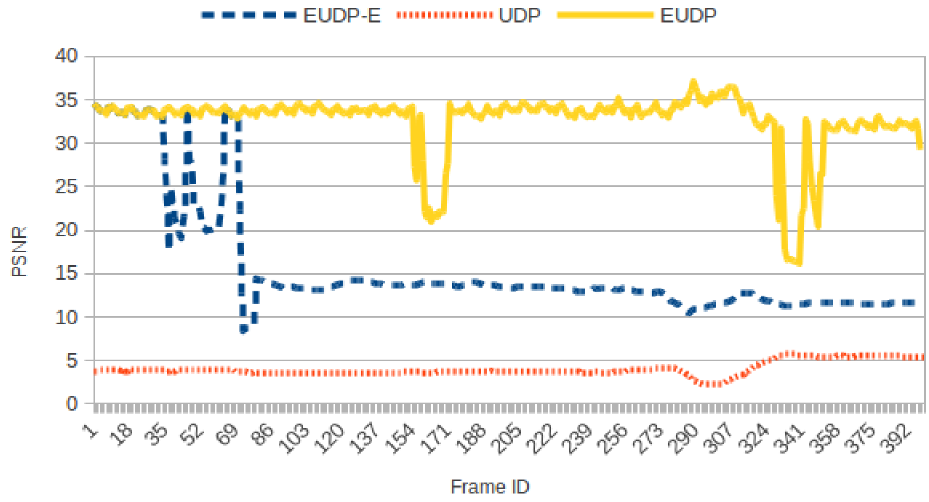


Figure 4.18: PSNR of video frames in the case of BER = 0.002

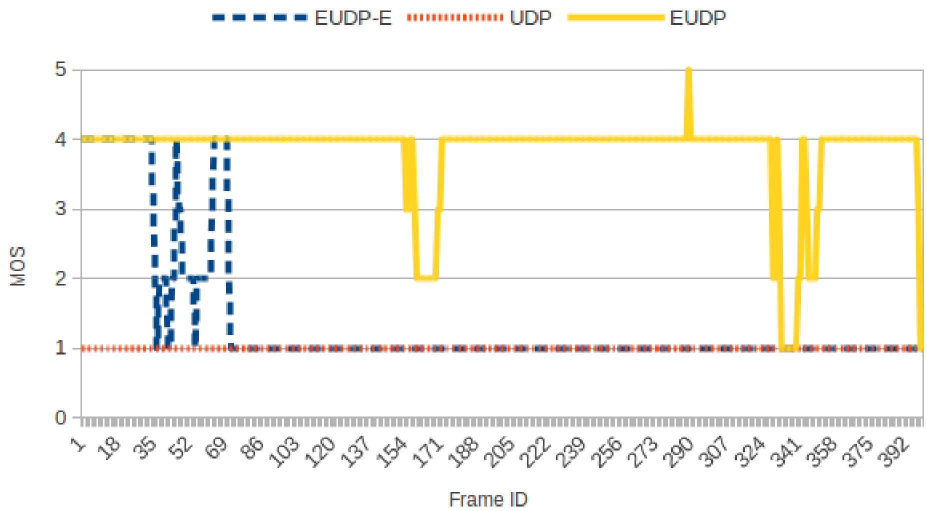
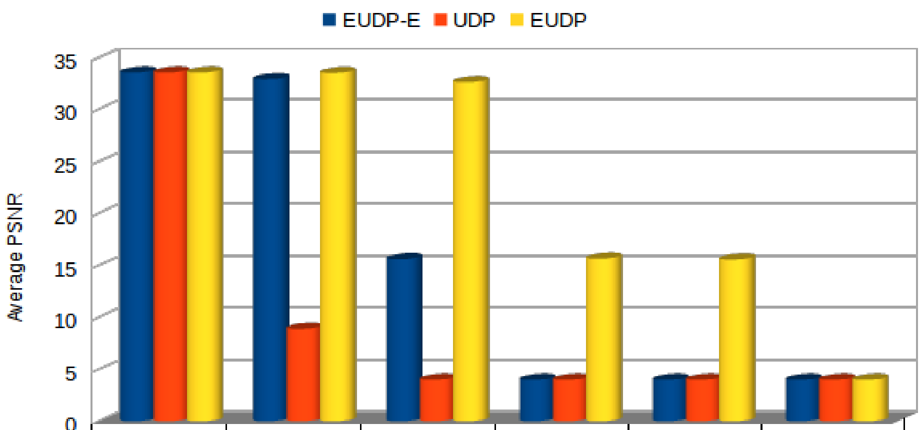


Figure 4.19: MOS of video frames in the case of BER = 0.002

Figure 4.18 depicts the *PSNR* of all video frames when the *BER* equal to 0.002. As shown in this figure, the *PSNR* values of video frames following EUDP are greater than EUDP-E PSNR values, because this latter does not allow an enhanced protection of video frames *I* and *P*, leading to decrease the video quality of others frames *B*. The figure 4.18 shows also that the

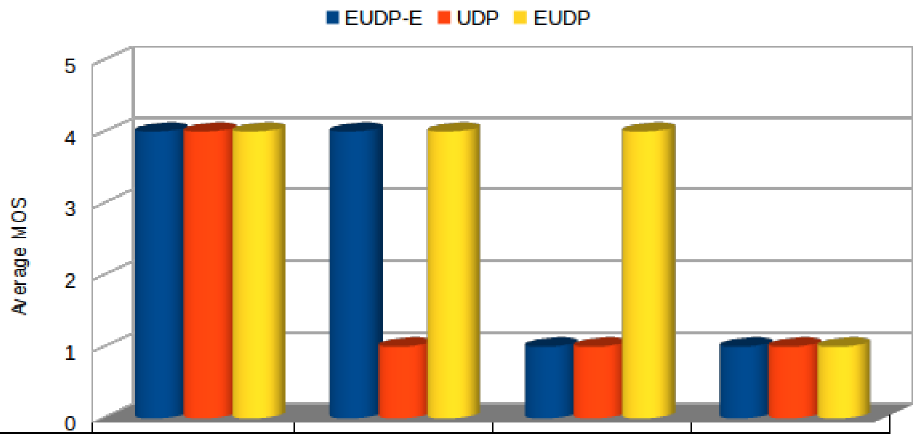
PSNR values of video frames following UDP are lower compared to EUDP and EUDP-E, because UDP cannot recover erroneous video packets, which increases its quality. Like figure 4.18, figure 4.19 presents the *MOS* values of 400 video frames when *BER* equal to 0.002. EUDP video quality of most video frames is the best one with (*MOS* = 4), contrary to EUDP-E and UDP, which is not preferred by the user (*MOS* = 1).

Figure 4.20 shows the variation of average *PSNR* of video packets with *BER*. We can see in this figure that regardless of *BER* the average *PSNR* of UDP is lower than EUDP and EUDP-E, because the delivery ratio of UDP is lower than EUDP and EUDP-E. It is seen also that the average *PSNR* of EUDP is higher than E-EUDP, because EUDP provides higher protection of *I* and *P* frames which allows the decoding of all frames contrary to EUDP-E. Figure 4.21 depicts the variation of the average *MOS* of video frames with *BER*, when *BER* is lower than 0.003, EUDP gives good quality of video streaming in terms of the average *MOS*, EUDP-E gives the good quality only when *BER* is lower than 0.002 and UDP gives the good quality when *BER* is lower than 0.001. The strong error recovery mechanism of EUDP, allows a higher average *MOS* value than EUDP-E and UDP.



BER	0	0.001	0.002	0.003	0.004	0.005
UDP	33.56	8.90	4.00	4.00	4.00	4.00
EUDP-E	33.56	32.92	15.61	4.00	4.00	4.00
EUDP	33.56	33.52	32.63	15.65	15.57	4.00

Figure 4.20: Variation of average PSNR of video frames with BER



BER	0	0.001	0.002	0.003
UDP	4	1	1	1
EUDP-E	4	4	1	1
EUDP	4	4	4	1

Figure 4.21: Variation of average MOS of video frames with BER

4.4 Conclusion

In this chapter, two new proposals for VANET video streaming were presented. The former is a new mechanism called an Enhanced Adaptive Sub-Packet Forward Error Correction (EASP-FEC). The main idea of EASP-FEC that it is capability to calculate the redundant sub-packets for each packet allowing more error resiliency, contrary to the well-known FEC which calculates the redundant packets for each block of packets. Moreover, EASP-FEC considers network load and the type of video frames (I, P, B) to avoid the congestion problem and to increase the video streaming quality, compared to Sub-Packet FEC which calculates the redundant sub-packets only in the basis of network condition. EASP-FEC is applied not only at the sender vehicle of video but also at the relay vehicles to guarantee an accurate estimation of network condition and network load. The experimental results have shown that EASP-FEC provides higher *DFR* of video stream than FEC with the same redundancy rate. Additionally, this proposed mechanism avoids the network congestion problem compared to SPFEC and improves the video streaming quality.

To support the network transmission, we also introduced the second proposal named the Enhanced User Datagram Protocol (EUDP) to improve video streaming over VANET. Contrary to UDP, which did not consider any recovery mechanism of errors, EUDP applies the Sub-Packet FEC to recover the erroneous sub-packets, and applies the unequal protection of video frame types to improve the video quality at the receiver vehicle. The experimental results showed that EUDP provides lower *EPER* and higher delivery ratio of video stream compared with UDP and EUDP without unequal protection of video frame types (EUDP-E), and also EUDP improves the video quality in terms of *PNSR* and *MOS*.

EASP-FEC and EUDP can recover only the uniform errors due to network transmission errors, but it cannot recover the burst errors due to route disconnection or network congestion. The next chapter presents an enhancement of EASP-FEC and EUDP by integrating the idea of detecting and revering the uniform and burst errors of video streaming in VANET lacked in the prior mechanisms.

Chapter 5

Hybrid Error Recovery Protocol (HERP) for video streaming in VANET

We introduce in this chapter our third contribution, which represents a new error recovery protocol for video streaming in VANET called Hybrid Error Recovery Protocol (HERP) [146]. HERP aims at improving the first and second contributions by detecting and recovering all types of video lost packets in VANET. As mentioned in the chapter 4, EASP-FEC and EUDP can recover only the uniform errors due to network transmission errors, but it cannot recover the burst errors due to route disconnection or network congestion.

HERP is based on the same basic mechanism as the EASP-FEC and EUDP, especially SPFEC (explained in section 4.1.1) and unequal protection of video frames (explained in section 4.1.2). Additionally, HERP considers the retransmission mechanism, reporting technique, dynamic update of its transmission parameters (i.e. redundancy rate, retransmission limit and transmission rate), congestion control, to recover all video packet loss and guaranteeing high video streaming quality with a reduced network overload and reduced transmission delay.

In the literature of error recovery mechanisms for VANET video streaming, many research activities adopted redundancy or packet retransmission for recovering lost video packets. On the one hand, the redundancy-based mechanism increases the network load and recovers only the uniform transmission errors, where, the retransmission increases the end-to-end delay and recovers the burst errors. Therefore, we suggest HERP protocol as a combination of redundancy and retransmission approaches to recover both uniform and burst errors. The main idea is the use of SPFEC mechanism to overcome the uniform errors and to reduce network overload as well as the transmission delay. HERP adopts also the unequal protection of video packets according to its frame types (I, P, B) in the aim of improving the video quality at the receiver vehicle. Using the reporting technique, HERP adapts dynamically the redundancy rate, retransmission limit and transmission rate according to network condition and network load. HERP proposes a detection mechanism of packet loss to distinguish between the lost video packets due to network condition and those due to the network overload, in order to react and cope differently with each packet loss type.

Firstly, section 5.1 presents some additional basic concepts of HERP such as reporting technique and different causes of video errors detected and handled by our proposed protocol. After that, we describe in sections 5.2, 5.3, and 5.4, our proposal including its architecture, packet head format, HERP algorithms at the sender, at the receiver and at relay vehicles. Section 5.5 presents the experimental study and discusses the reached results. Finally, we conclude this chapter in section 5.6.

5.1 Basic concepts of the proposed contribution

5.1.1 Reporting technique

Reporting technique is based on the periodic send of the report from the end receiver to the sender, in order to import an idea about the network state and to request the retransmission of lost packets. The HERP parameters adaptation and video packets retransmission are achieved by means of periodic receiver reports. The receiver vehicle maintains a trace of received and lost video packets. When the receiver vehicle cannot recover the burst errors of video packet by SPFEC mechanism, it sends a report to the sender vehicle. The report represents a request of unrecovered video packets retransmission, also it imports the network condition and network load information to allow the sender vehicle for adapting the redundancy rate, retransmission limit and transmission rate. Before the report sending, the receiver vehicle applies the proposed video packet loss detection of HERP to identify and differentiate between the causes of packet loss in order to better identify the network state.

5.1.2 Video packet loss detection mechanism of HERP

In VANET, the packets may be corrupted and lost due to several reasons such as congestion, transmission errors and route disconnection. Using HERP, the receiver vehicle can detect the lost video packets and distinguish between their types. HERP allows the sender vehicle to react with different types of these lost packets, by the retransmission of lost video packets and the adjustment the redundancy rates and retransmissions limits of video packets according to their types of frames (i.e. I, P, B). To cope with different causes of packet loss, HERP performs as follows:

- **Packet loss due to network congestion**

  In HERP, we propose to add a sub-field within the video packet header to control the congestion in the network. More specifically, when a relay vehicle forwards the video packet, it sets this sub-field by the dropped video packets identifications. Hence, the receiver can detect the congestion in the network, and the identification of dropped packets due to the network congestion by means of this sub-field and it informs the sender vehicle for the congestion production in the network.

- **Packet loss due to transmission errors**

  HERP suggests a periodic estimation to check the network condition at the receiver vehicle. If the receiver cannot recover the received erroneous video packets using SPFEC mechanism, then it considers the transmission errors as a cause of these lost packets.

- **Packet loss due to route disconnection**

  When successive video packets are not received before their waiting timeout and if these packets are not dropped because the congestion and transmission errors, HERP considers that the receiver has lost packets due to the network disconnection.

When the receiver vehicle detects and distinguishes between different types of lost video packets, it applies the reporting technique to inform the sender vehicle for the network state. Therefore, the sender vehicle retransmits the lost video packets, adjusts the transmission rate with network load and adapts the redundancy rate as well as the retransmission limit according to network condition.

5.2 General architecture of video transmission using HERP

As shown in figure 5.1 (the basic architecture of HERP), the HERP module at the sender vehicle (with red color) consists of five components: (1) SPFEC Generator (SPG), (2) Redundancy Rate Adaptor (RRA), (3) Retransmission Limit Adaptor (RLA), (4) Transmission Rate Adaptor (TRA), and (5) Packet Retransmission Monitor (PRM). Also, figure 5.1 presents HERP module of receiver vehicle (with blue color) consisting of two components: (6) Network Condition Estimator (NCE) and (7) Reporting Monitor (RM). In next subsections, all these components are explained.

(1) SPFEC Generator (SPG)

SPG component creates and generates video packets, each packet consists of original sub-packets and redundant sub-packets.

(2) Redundancy Rate Adaptor (RRA)

RRA adjusts dynamically the redundancy rate (amount of redundant sub-packets) in function of network condition and the frame type of this packet (I, P, B). If the error rate in the network is high, the RRA increases the number of redundant sub-packets in order to allow the receiver vehicle to recover the uniform erroneous sub-packets, otherwise (i.e. if the error rate is low), the RRA reduces the number of redundant sub-packets aiming at decreasing the network load.

(3) Retransmission Limit Adaptor (RLA)

RLA adapts dynamically the Retransmission Limit (RL) of each video packet, according to the network condition and the frame type of this packet (I, P, B). If the error rate in the network is low, the RLA increases the RL to recover the burst erroneous sub-packets. If the error rate in the network is high, RLA decreases the RL, to avoid the additional transmission delay because of the retransmission mechanism.

(4) Transmission Rate Adaptor (TRA)

TRA adjusts dynamically the Transmission Rate (TR) with the current network load. If the network is heavy loaded, the TRA reduces the TR to avoid the congestion, otherwise TRA increases the TR.

(5) Packet Retransmission Monitor (PRM)

PRM retransmits the requested video packet if the number of retransmissions of this packet does not exceed its retransmission limit, else, PRM does not send the request packet to avoid the additional retransmission delay.

(7) Network Condition Estimator (NCE)

NCE estimates the Bit Error Rate (*BER*), *SPER* and *EPER*. In function of the estimated *EPER*, the receiver vehicle accepts or rejects the received video packet.

(8) Reporting Monitor (RM)

RM detects lost packets of the video, distinguishes between their types and generates the reports. This latter will be sent to the sender vehicle to ask the retransmission of non-recovered packets and to adjust HERP parameters. Moreover, the report imports the network condition estimation (*BER*), and network load state.

As shown in figure 5.1, the sender vehicle communicates with the receiver via relay vehicles (with green color). The relay vehicle saves the identifications of lost packets of the video at its level, which are dropped because of the network congestion (i.e. received packets exceeding queue size of the relay vehicles). Also, when the video packet passes through the relay vehicle, this latter adds in the packet header the identifications of the dropped packets. Further, this exported information leads the receiver to detect lost packet of the video.

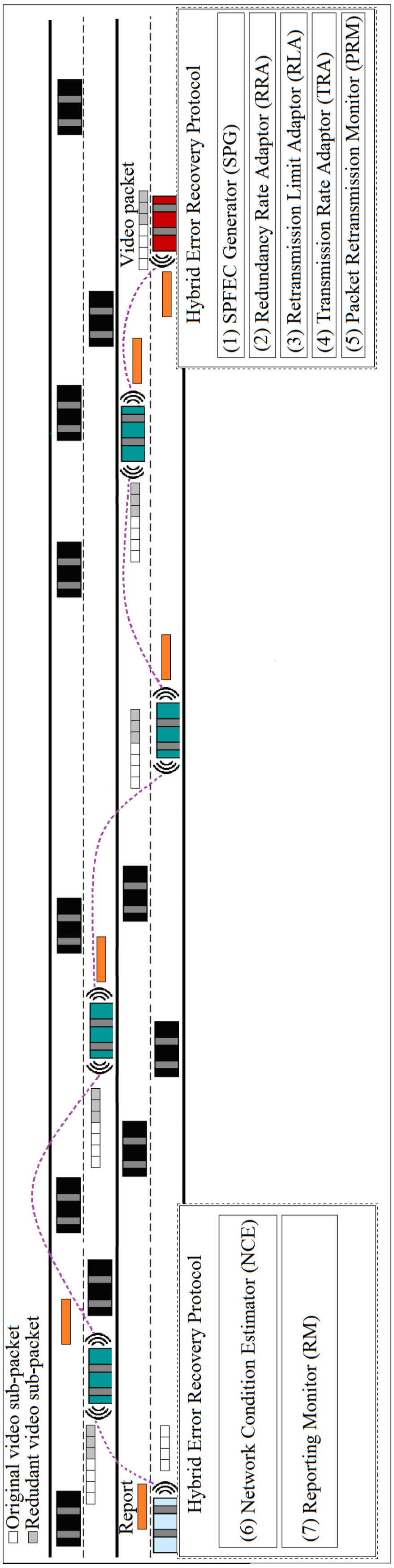


Figure 5.1: Video streaming using HERP protocol in VANET

5.3 HERP video packet and report

In our proposed HERP, the receiver vehicle calculates the *SPER* and *EPER* based on the essential information (cited below) imported by the received video packet header. The receiver uses this information to identify the network load state.

- **video_pkt_id:** is a sequence number identifying the video packet content.
- **video_pkt_type:** represents the type of video packet frame (I, P, B).
- **sub_pkt_size:** is the video sub-packet length measured in bits.
- **nb_source_sub_pkts:** is the number of source sub-packets ‘*k*’ within the video packet.
- **nb_redundant_sub_pkts:** is the number of redundant sub-packets ‘*h*’ within the video packet.
- **dropped_packets_id:** represents the identifications of lost video packets due to the network congestion.

The report generated by the receiver vehicle imports the following information (cited below) to identify the network condition and network load for the sender vehicle. The sender uses this information to adjust the HERP parameters (i.e. redundancy rates, retransmissions limits and transmission rate) and to retransmit the required video packets.

- **Bit Error Rate (BER):** measures the error probability of video packet bit in the network.
- **network_load_state:** is equal to 1, when the congestion is produced in the network, otherwise this variable takes the 0 value.
- **requested_video_packets_id:** are the identifiers of lost video packets due to the congestion, transmission errors and/or route disconnection.

5.4 HERP algorithm

5.4.1 HERP algorithm at the sender vehicle level

The general HERP algorithm at the sender vehicle level is presented in figures 5.2 and 5.3. The sender vehicle performs the pseudo-code shown in figure 5.2, when it wants to send a new video packet to a particular receiver vehicle. Before generating a video packet, SPG component of sender vehicle applies the SPFEC mechanism in step 1 to calculate the amount of redundant sub-packets (*nb_redundant_sub_pkts*) of this packet in function of three parameters namely the type of video packet (*video_pkt_type*), the redundancy rate (RR_I, RR_P and RR_B) and the amount of original sub-packets (*nb_source_sub_pkts*). Each video packet has a unique id according to its content. After this first step, the sender generates and sends in step 2 the video packet towards the receiver vehicle via a multi-hop communication.

Figure 5.3 shows the report reception algorithm at the sender. When the sender receives a report from the receiver vehicle, it extracts firstly the information exported by the report (i.e. *BER*, *network_load_state* and *requested_video_packets_id*) (step 1). Secondly (in step 2), the RRA and RLA components of this vehicle adapt the redundancy rates (RR_I, RR_P and RR_B) and retransmission limits (RL_I, RL_P and RL_B) of video packets in the basis of *BER* and HERP thresholds (i.e. *THL, THM* and *THH*). When the *BER* is lower than the THreshold Low (*THL*), RRA prohibits the generation of redundant sub-packets to avoid the overload of the network, which does not require a high protection of video packets against error transmission. The RLA activates the retransmission mechanism with the initials retransmission limits (RL_{Ii}, RL_{Pi}, RL_{Bi}) to recover the lost video packets due to the network congestion or the route disconnection. When the *BER* is higher than *THL* and lower than THreshold Medium (*THM*), RRA activates the redundancy mechanism, but it sets the redundancy rates to the half of initial redundancy rates values (RR_{Ii}, RR_{Pi}, RR_{Bi}) in order to guarantee a high protection of video packets against uniform errors and to avoid the network overload, which produces the congestion. In this error interval, RLA adapts the retransmission limits of video packets to the half of initial retransmission limits values in order to recover the burst errors and to reduce the additional transmission delay caused by the retransmission mechanism. When *BER* is higher than *THM* and lower than THreshold High (*THH*), RRA adapts the redundancy rates with the same value of initial redundancy rates to recover the high number of lost packets due to the transmission errors. RLA stops the retransmission of B-frames video packets to reduce the transmission delay. When *BER* is higher than *THH* due to the high number of burst errors,

```
Input: video_pkt_type, nb_source_sub_pkts, RR_I, RR_P, RR_B
Output: video_packet
  Initialisation : nb_redundant_sub_pkts ← 0
  Step 1.
  if (video_pkt_type =I) then
    nb_redundant_sub_pkts ←RR_I * nb_source_sub_pkts
  else if (video_pkt_type =P) then
    nb_redundant_sub_pkts ←RR_P * nb_source_sub_pkts
  else
    nb_redundant_sub_pkts ←RR_B * nb_source_sub_pkts
  end if
  video_pkt_id ←video_pkt_id + 1
  Step 2.
  Generation of video packet
  Send of generated video packet toward the receiver vehicle
```

Figure 5.2: HERP algorithm for video packet transmission at sender vehicle

which affects the delay constraint, RLA stops the retransmission of P-frames video packets. However, RRA keeps the initial redundancy rates to recover a maximum number of lost packets. In the third step, the TRA component adjusts the Transmission Rate (*RR*) according to the network load state (*network_load_state*). If the congestion is producing in the network (i.e. *network_load_state* = 1), the TRA decreases the *RR* to defeat the congestion problem. If the congestion was not produced (the case when *network_load_state* = 0), the TRA increases the *RR* to improve the transmission delay. The step 4 describes the retransmission process of proposed HERP. For each requested video packet, PRM compares the retransmissions number of this packet with its retransmission limit (RL_I, RL_P, RL_B). If the retransmission number is lower then retransmission limit, the PRM retransmits the required video packet. Otherwise, PRM prohibits the retransmission of required video packet to do not increase the transmission delay. After the retransmission of the requested video packet, PRM updates the table of sent packets (*sent_packets_table*) by the new value of the sent packet retransmission number (*packet_number_retranmission*), which will be checked in the next request of this packet.

Input: $Report$, THL, THM, THH, RR_{Ii}, RR_{Pi}, RR_{Bi}, RL_{Ii}, RL_{Pi}, RL_{Bi}, RR_i , $sent\_packets\_table$
Output: RR_I, RR_P, RR_B, RL_I, RL_P, RL_B, RR
 if ($report\ is\ received$) **then**
  Step 1.
  Extract $BitErrorRate$ (BER)
  Extract $network\_load\_state$
  Extract $requested\_video\_packets\_id$
  Step 2. Adaptation of RR_I, RR_P, RR_B and RL_I, RL_P, RL_B with BER
  if (BER<=THL) **then**
   $RR_I \leftarrow 0$ $RL_I \leftarrow RL_{Ii}$
   $RR_P \leftarrow 0$ $RL_P \leftarrow RL_{Pi}$
   $RR_B \leftarrow 0$ $RL_B \leftarrow RL_{Bi}$
  else if (BER<=THM) **then**
   $RR_I \leftarrow RR_{Ii}/2$ $RL_I \leftarrow RL_{Ii}/2$
   $RR_P \leftarrow RR_{Pi}/2$ $RL_P \leftarrow RL_{Pi}/2$
   $RR_B \leftarrow RR_{Bi}/2$ $RL_B \leftarrow RL_{Bi}/2$
  else if (BER<=THH) **then**
   $RR_I \leftarrow RR_{Ii}$ $RL_I \leftarrow RL_{Ii}/2$
   $RR_P \leftarrow RR_{Pi}$ $RL_P \leftarrow RL_{Pi}/2$
   $RR_B \leftarrow RR_{Bi}$ $RL_B \leftarrow 0$
  else
   $RR_I \leftarrow RR_{Ii}$ $RL_I \leftarrow RL_{Ii}/2$
   $RR_P \leftarrow RR_{Pi}$ $RL_P \leftarrow 0$
   $RR_B \leftarrow RR_{Bi}$ $RL_B \leftarrow 0$
  end if
  Step 3. Adaptation of Transmission Rate with $Network\_Load\_State$
  if ($network\_load\_state$ =1) **then**
   $RR \leftarrow RR_i$ / 2
  else
   $RR \leftarrow RR_i$
  end if
  Step 4. Retransmition of each requested video packet
  Search the packet in the $sent\_packets\_table$ by its id
  if ($video\_pkt\_type = I$) **then**
   if ($packet\_number\_retranmission <= RL_I$) **then**
    Send the requested video packet I toward reciever vehicle
    $packet\_number\_retranmission \leftarrow packet\_number\_retranmission + 1$
   end if
  else if ($video\_pkt\_type = P$) **then**
   if ($packet\_number\_retranmission <= RL_P$) **then**
    Send the requested video packet P toward reciever vehicle
    $packet\_number\_retranmission \leftarrow packet\_number\_retranmission + 1$
   end if
  else
   if ($packet\_number\_retranmission <= RL_B$) **then**
    Send the requested video packet B toward reciever vehicle
    $packet\_number\_retranmission \leftarrow packet\_number\_retranmission + 1$
   end if
  end if
  Update the $sent\_packets\_table$
 end if

Figure 5.3: HERP algorithm for report reception at sender vehicle

5.4.2 HERP algorithm at the receiver vehicle level

Figure 5.4 shows the pseudo-code of HERP module at the receiver vehicle. When this latter receives a video packet, it extracts firstly (in step 1 of the algorithm) the information exported by the packet header: *video_pkt_id*, *sub_pkt_size(n)*, *nb_redundant_sub_pkts(k)*, *nb_source_sub_pkts(h)* and *dropped_packets_id*. Secondly, the NCE component of the receiver estimates *BER*, *SPER* and *EPER* (step 2). In the step 3, RM component generates a uniform random variable *r* to check the recovery probability of received video packet. If RM can recover the errors of video sub-packets using SPFEC mechanism (*EPER* is lower than *r*), the RM accepts the received video packet and calculates the number of dropped video packets (*number(dropped_packets_id)*), which are packets lost during the network congestion. If some video packets were dropped, RM adds the identifiers of dropped packets (*dropped_packets_id*) into the requested video packets identifiers (*requested_video_packets_id*), updates the *network_load_state* variable, creates a report, adds the currents information into the report (*BER*, *network_load_state* and *requested_video_packets_id*) and sends this report to the sender vehicle. If *EPER* is higher than *r*, which means that RM cannot recover the burst errors (i.e. packet lost due to transmission errors) of video sub-packets using SPFEC mechanism, the RM adds the unrecovered video packet identifier (*packet_id*) into *requested_video_packets_id*, rejects the unrecovered video packet, creates a video report, adds the currents information into the report (*BER*, *network_load_state* and *requested_video_packets_id*) and sends the report to the sender. The receiver vehicle sends the report towards the sender vehicle, in order to require the retransmission of the burst lost video packets and to adjust the HERP parameters at the sender vehicle. If the received packet sequence number (*video_pkt_id*) is higher than the expected packet sequence number (*expected_pkt_id*), meaning that there are not received some video packets (their *id* is between *expected_pkt_id* and *video_pkt_id*). For each *packet_i* of these packets, RM starts a waiting time, to make sure that these packets are lost because the route disconnection. After the expiration of video *packet_i* waiting time (step 4), and if this *packet_i* is not received, the RM considers this loss is due to the route disconnection, then RM requires the retransmission of this packet by sending a new report to the sender vehicle.

NCE uses the equations (1), (2) and (3) of SPFEC mechanism (chapter 4, subsection 4.1.1) to estimate and calculate *BER*, *SPER* and *EPER*.

```
Input: Video packet, expected_pkt_id
Output: Report
  Initialisation : EPER ← 0, SPER ← 0, network_load_state ← 0
  if (Video packet is received) then
    Step 1.
    Extract video_pkt_id
    Extract sub_pkt_size(n)
    Extract nb_redundant_sub_pkts(k)
    Extract nb_source_sub_pkts(h)
    Extract dropped_packets_id
    Step 2.
    Estimate BER by equation 1
    Calculate SPER by equation 2
    Calculate EPER by equation 3
    Step 3.
    Generate uniform random number r in the interval [0, 1]
    if (r >EPER ) then
      Accept video packet (recovered packet)
      if (number(dropped_packets_id) > 0) then
        /** Detect the packet loss due to network congestion **/
        network_load_state←1
        Add dropped_packets_id to requested_video_packets_id
        Create and send a report toward sender vehicle
      else
        /** Detect the packet loss due to to wireless errors **/
        Add video_pkt_id to requested_video_packets_id
        Reject video packet (no recovered packet)
        Create and send a report toward sender vehicle
      end if
    end if
    if (video_pkt_id > expected_pkt_id) then
      For each video_packet_i / i >= expected_pkt_id and i < video_pkt_id
      Start waiting time of video video_packet_i
    end if
  end if
  Step 4.
  if (waiting time of any video_packet_i is expired) then
    if (video_packet_i not received) then
      /** Detect the packet loss due to route disconnexion **/
      Add id of video_packet_i to requested_video_packets_id
      Create and send a report toward sender vehicle
    end if
  end if
```

Figure 5.4: HERP algorithm at receiver vehicle

5.4.3 HERP algorithm at the relay vehicle level

We present the HERP algorithm at the relay vehicle in figure 5.5 and we explain it as follows. When the relay vehicle receives the video packet (case 1), it checks its queue length (*queue_length*), which is compared with maximum size of queue length (*max_queue_length*). When *queue_length* is equal to *max_queue_length* (it means that the vehicle buffer is full), the relay vehicle adds *video_packet_id* of received packet to its local table, which saves the *video_packet_id* of dropped video packets (*dropped_packets_id_table*), then the relay vehicle drops the received video packet due to the network congestion. If *queue_length* is lower than *max_queue_length* (it means that the vehicle buffer is not full), the relay vehicle inserts the video packets in its queue and increases the *queue_length*. The relay vehicle applies the step 1.2 when it wants to forward the received video packet. If its *dropped_packets_id_table* contains at least one *video_packet_id*, the relay vehicle adds the elements of *dropped_packets_id_table* to *dropped_packets_id* field of the received video packet. Then, the relay vehicle sends this received packet towards the receiver vehicle and decreases the length of its queue. In the case of the reception of a report (case 2) and if the relay vehicle buffer is full (*queue_length* equals to *max_queue_length*), the relay vehicle drops the received report. Otherwise, it extracts the *requested_video_packets_id*, removes it from its *dropped_packets_id_table*, because the receiver vehicle has been informed that these video

```
Input: video_packet, report
Output: video_packet, report
  Case 1.Reception of a video packet
  if (video_packet_is_received) then
    Step 1.1.
    if (queue_length = max_queue_length) then
      Add video_packet_id to dropped_packets_id_table
      Drop the video_packet
    else
      Add video_packet_id to queue
      queue_length ← queue_length + 1
      Step 1.2.
      if (length(dropped_packets_id_table) > 0) then
        Add (dropped_packets_id_table) to (dropped_packets_id of received video packet)
        Send a received video packet toward receiver vehicle
        queue_length ← queue_length − 1
      end if
    end if
  end if
  Case 2.Reception of a report
  if (report_is_received) then
    Step 2.1.
    if (queue_length = max_queue_length) then
      Drop the report
    else
      Extract requested_video_packets_id
      Remove all requested_video_packets_id from dropped_packets_id_table
      Add report to queue
      queue_length ← queue_length + 1
    end if
    Step 2.2.
    Send a received report toward sender vehicle
    queue_length ← queue_length − 1
  end if
```

Figure 5.5: HERP algorithm at relay vehicle

packets were dropped. Next, the relay vehicle inserts the report in its queue and increases the queue length. The relay vehicle applies the step 2.2 when it desires to send the report to the sender vehicle, consequently it decrements the length of its queue.

5.5 Performance evaluation and results

In order to evaluate HERP protocol, we have performed an experimental analysis of its performance. We have divided these experiments into two groups: primary evaluation and performance comparison. The first group aims to fix the HERP parameters (*THL*, *THM* and *THH*) with varying the network condition. The second group represents a series of comparisons between HERP based on chosen thresholds values with two other protocols: UDP and UDP with SPFEC under real scenarios and through different levels of network condition and network load.

5.5.1 Simulation and parameter settings

In order to measure the performance of HERP in VANET, we have conducted a set of simulations performed on network simulator ns-2 [96] version 2.35. We have compared the following protocols for VANET video streaming:

- **HERP:** is the proposed protocol, which integrates SPFEC with the retransmission and the unequal protection of video frame types.
- **UDP:** is the traditional UDP protocol without SPFEC mechanism.
- **UDP-SPFEC:** is the traditional UDP protocol with SPFEC.

Table 5.1: Simulation parameters

Parameter	Value	Parameter	Value
Number of vehicles	100	Scenario	V2V
Routing protocol	AODV	Communication range	300 m
Propagation model	TowRayGround	Bit Error Rate	{0,, 0.005}
Video file	Foreman.yuv	Frame rate (fps)	30
Video packet size	1024 bits	Sub-packet size	100 bits
RR_{Ii}	75%	RL_{Ii}	7
RR_{Pi}	50%	RL_{Pi}	5
RR_{Bi}	25%	RL_{Bi}	3
Evaluation metrics	PDR, average delay, DFR, PSNR, MOS	Number of video frames	400

The simulation parameters are presented in table 5.1. We have applied EvalVid framework [97] to generate the video streaming trace at the sender and receiver vehicles. We have also used SUMO [143] for road traffic simulation based on downtown area of Oum El Bouaghi city (Algeria), imported from Open Street Map [144] and showed in figure 5.6. SUMO takes into consideration several VANET particularities like street capacity, traffic light and vehicles movement, in order to generate the urban mobility model required by ns-2. All the results are represented at a confidence interval of 95%. The AODV routing protocol is chosen in our

Figure 5.6: Studied urban area for video streaming in VANET

simulations under V2V scenarios. The metrics used for the primary evaluation and for the comparison between the studied protocols are Packet Delivery Ratio (*PDR*), average transmission delay, Decodable Frame Rate (*DFR*), Peak Signal-to-Noise Ratio (*PSNR*) and Mean Opinion Score (*MOS*). We have used packets with a maximum size of 1024 bits. The video transmitted in our simulations is the well-known video benchmark named the foreman.yuv. It is composed of 400 frames that are encoded with MPEG-4, using GoP structure of IBBPBBPBB and temporal resolution of 30 frames per second. For the proposed HERP, we have assumed that the initial values of RR_I, RR_P and RR_B are 75%, 50% and 25%, respectively, and the initial values of RL_I, RL_P and RL_B are 7, 5, 3, respectively. We assume that (RR_I, RL_I) are greater than (RR_P, RL_P) and these latter are greater than (RR_B, RL_B), because the I-frames are more important than P-frames, and P-frames are more important than B-frames. In addition, it is assumed that the UDP-SPFEC is submitted to the same redundancy rates of video frame types, as for HERP.

5.5.2 Evaluation metrics

To evaluate the effectiveness of HERP, we analyze the (*PDR*), average transmission delay, Decodable Frame Rate (*DFR*) and Peak Signal to Noise Ratio (*PSNR*) as QoS metrics. We also take into account the Mean Opinion Score (*MOS*) as a QoE metric. These QoS and QoE metrics were explained in chapter 2, section 2.2.1. In our simulations, a mapping of *PSNR* values to *MOS* values is performed to estimate the human quality perception for video streaming.

5.5.3 Preliminary evaluation

The HERP performance is dictated by *THL, THM* and *THH* parameters. *THL* is used to start the redundancy to recover the packet loss due to the transmission errors. *THM* is used to stop the retransmission of B-frame video packets and *THH* is called to stop the retransmission of P-frame video packets. HERP employs *THM* and *THH* in order to reduce the retransmission effect on the transmission delay of video packets. Our goal by this preliminary evaluation is to analyze the behavior of HERP to choose values of *THL*, *THM* and *THH*. For this initial evaluation, we have chosen to observe the performance of HERP under the Decodable Frame Rate (*DFR*) metric.

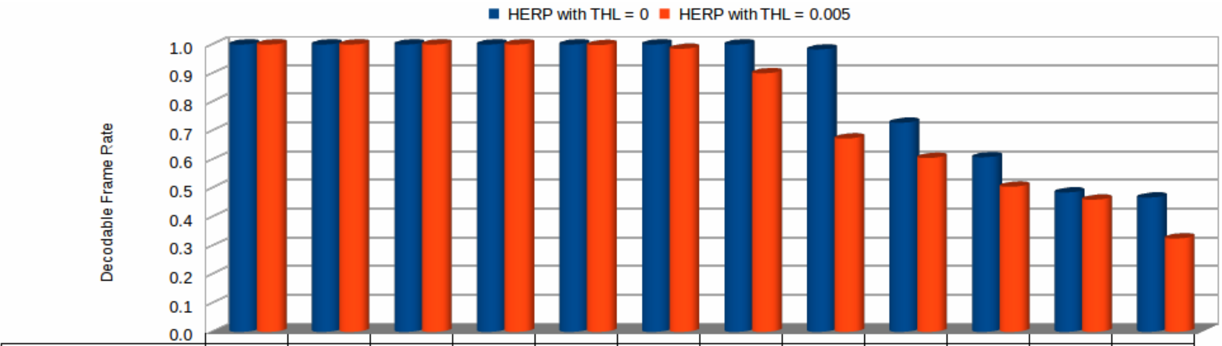
To choose the *THL* value, we have set the *THM* and *THH* primary values at the maximum *BER* value considered in our simulation (fixed at 0.005) and we have performed many simulations of two HERP variants:

- **HERP with *THL* = 0:** in this scenario, the HERP starts the redundancy with the retransmission when the *BER* is higher than 0.
- **HERP with *THL* = 0.005:** in this scenario, the HERP starts the redundancy with the retransmission when the *BER* is higher than 0.005, but when *BER* is lower than 0.005, HERP uses only the retransmission without the redundancy.

Figure 5.7 shows the *DFR* of the two HERP scenarios, while varying the *BER*. On the one hand, we see in this figure that when *BER* is lower than 0.00001, the two HERP variants provide the same *DFR*, which means that the redundancy has not any utility on the HERP protection performance at this error level. On the other hand, when *BER* is higher than 0.00001, HERP with *THL* = 0 provides better *DFR* than HERP with *THL* = 0.005, which means that the use of the redundancy with the retransmission at this error level guarantees more protection of video frames than the use of the retransmission only. In order to reduce the network overload and according to these results, we fix the *THL* value of the proposed HERP at 0.00001. When *BER* is lower than 0.00001, HERP applies only the retransmission scheme, and when *BER* is higher than 0.00001 HERP applies both retransmission and redundancy processes.

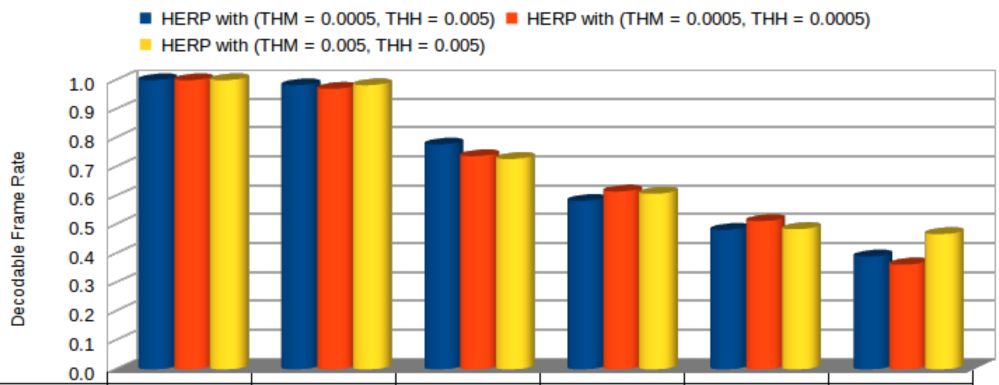
We remark in figure 5.7 that when *BER* is higher than 0.0005, the *DFR* of HERP with *THL* = 0 begins to decreasing, because at this error level the retransmission starts to avoid the transmission delay which effects the *DFR* of video stream. Based on this remark, the *THH* and *THM* values must be higher than 0.0005, in order to reduce the retransmission of video packets in function of their frame types (I, P, B).

We have analyzed the following HERP variants to choose the *THM* and *THH* values. As mentioned above, the *THL* value is fixed at 0.00001.



Bit Error Rate	0	0.000001	0.000005	0.00001	0.00005	0.0001	0.0005	0.001	0.002	0.003	0.004	0.005
HERP with THL = 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.73	0.61	0.49	0.47
HERP with THL = 0.005	1.00	1.00	1.00	1.00	1.00	0.99	0.90	0.67	0.61	0.51	0.46	0.33

Figure 5.7: Variation of Decodable Frame Rate with BER between HERP with THL = 0 and HERP with THL = 0.005



Bit Error Rate	0.0005	0.001	0.002	0.003	0.004	0.005
HERP with (THM = 0.0005, THH = 0.005)	1.00	0.98	0.78	0.58	0.48	0.39
HERP with (THM = 0.0005, THH = 0.0005)	1.00	0.97	0.74	0.62	0.51	0.36
HERP with (THM = 0.005, THH = 0.005)	1.00	0.98	0.73	0.61	0.49	0.47

Figure 5.8: Variation of Decodable Frame Rate with BER between HERP with (*THM* = 0.0005, *THH* = 0.005), HERP with (*THM* = 0.0005, *THH* = 0.0005) and HERP with (*THM* = 0.005, *THH* = 0.005)

- **HERP with (*THM* = 0.0005, *THH* = 0.005):** in this scenario, HERP stops to retransmit B-frame video packets when *BER* is higher than 0.0005 and it stops retransmitting P-frame video packets when *BER* is higher than 0.005.
- **HERP with (THM = 0.0005, THH = 0.0005):** in this case, HERP stops the retransmission of B-frame and P-frame video packets when *BER* is higher than 0.0005.
- **HERP with (THM = 0.005, THH = 0.005):** HERP stops retransmitting both B-frame and P-frame video packets if *BER* is higher than 0.005.

Figure 5.8 depicts *DFR* of the three HERP variants according to *BER*. As shown in this figure, when *BER* is between 0.0005 and 0.002, HERP with (*THM* = 0.0005, *THH* = 0.005) provides a higher *DFR* than the other HERP variants. At this error interval, the HERP must avoid only the retransmission of video packets of B-frame to reduce the transmission delay and at the same time it allows the retransmission of the other I and P video frame packets to guarantee a high protection of video stream. When the *BER* is higher than 0.002, HERP with (*THM* = 0.005 and *THH* = 0.005) provides a best *DFR* value because it allows only the retransmission of I-frame video packets and it stops the retransmission of P-frame and B-frame video packets which improves the transmission delay and keep the HERP protection performance. According to these results, we have fixed *THM* value at 0.0005 and *THH* value at 0.002. When the *BER* is between 0.0005 and 0.002, HERP stops the retransmission of B-frame video packets, and when the *BER* is higher than 0.002, HERP ends the retransmission of P-frame video packets. We have also remarked that when *BER* = 0.005, the HERP with (*THM* = 0.005 and *THH* = 0.005) gives a higher *DFR* than the other HERP variants. In this case, HERP must stop the retransmission of all video packet types.

5.5.4 Performance comparison

In this part, we compare HERP performance with UDP-SPFEC and UDP protocols and we discuss the obtained results. Figure 5.9 displays the result of Packet Delivery Ratio (*PDR*) on the y-axis, while the x-axis represents the *BER* varying from 0 to 0.005. As depicted in this figure, when the *BER* increases, the *PDR* decreases due to the lost video packets produced in the network due to transmission errors. When *BER* is lower than 0.002, HERP achieves higher *PDR* than UDP-SPFEC and UDP, because by means of the hybrid error recovery between the redundancy and retransmission, HERP can recover all types of lost packets in reason of network congestion, transmission errors and route disconnection, contrary to UDP-SPFEC which can only recover the uniform packet errors due to the transmission errors, and UDP that cannot recover any kind of lost packets. When *BER* is higher than 0.002, HERP and UDP-SPFEC provide the same *PDR*, because at this interval, HERP deactivates the retransmission of P-frame and B-frame video packets and it uses the same redundancy rate like UDP-SPFEC. Also, as shown in figure 5.9, UDP does not define any error recovery mechanism but it achieves higher *PDR* than UDP-SPFEC when *BER* is lower than 0.0005, because at this interval error, UDP-SPFEC suffers form the congestion problem due to the transmitted redundant video sub-packets which increase the number of dropped packets.

Figure 5.10 shows the average transmission delay achieved by each solution. When *BER* is lower than 0.002, HERP achieves lower average delay compared to UDP-SPFEC. The reason of the UDP-SPFEC limited performance at this interval error is that it suffers from the network overload, which affects the transmission delay. Contrary, HERP achieves lower transmission delay because it does not use the maximum rate of the redundancy in order to avoid the network overload and does not reduce the transmission rate at the same interval error. On the other hand, when the *BER* is higher than 0.002, UDP-SPFEC provides lower average delay than HERP, due to the adaptive mechanism of HERP, which decreases the

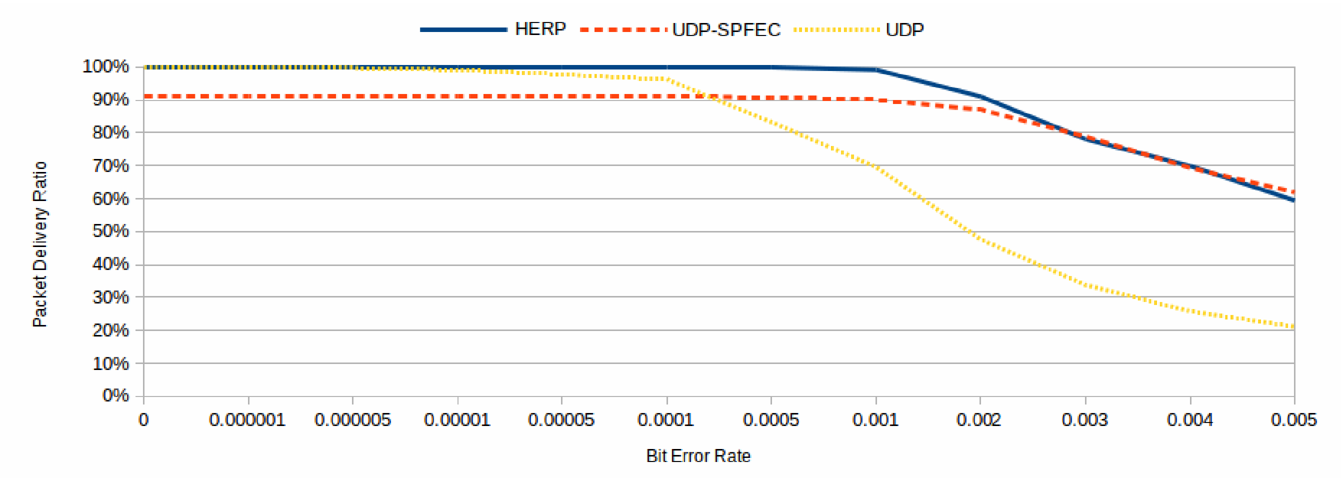


Figure 5.9: Variation of Packet Delivery Ratio with BER

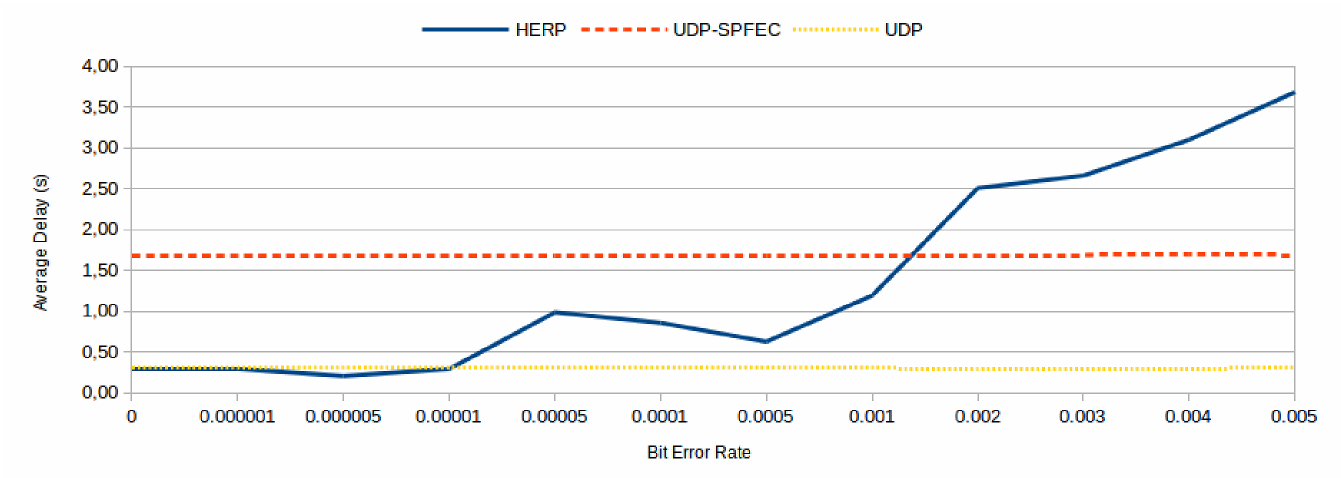


Figure 5.10: Variation of Average delay with BER

transmission rate to avoid the congestion problem and due to the high number of I-frame video packets retransmissions. We note that HERP average delay does not exceed the time requirements defined by CISCO for video streaming [14], in which the delay should not be higher than 4 to 5 seconds. The figure 5.10 shows also that UDP achieves lower average delay than HERP and UDP-SPFEC while varying *BER*, because UDP does not suffer from the congestion problem like UDP-SPFEC and does not reduce the transmission rate like HERP.

The *PSNR* of video frames achieved by each protocol is shown in the figure 5.11 when the *BER* is equal to 0.001. We can see that for all video frames, HERP provides higher *PSNR* against the other protocols due to its strength error protection. UDP provides lower *PSNR*, it does not adopt any error recovery technique. We remark that UDP-SPFEC provides lower *PSNR* values for the last video frames (from 287 to 400), because many video packets of these frames were lost due to the congestion or the route disconnection which are not tackled by UDP-SPFEC. Figure 5.12 illustrates the average *PSNR* of all video frames for the simulated

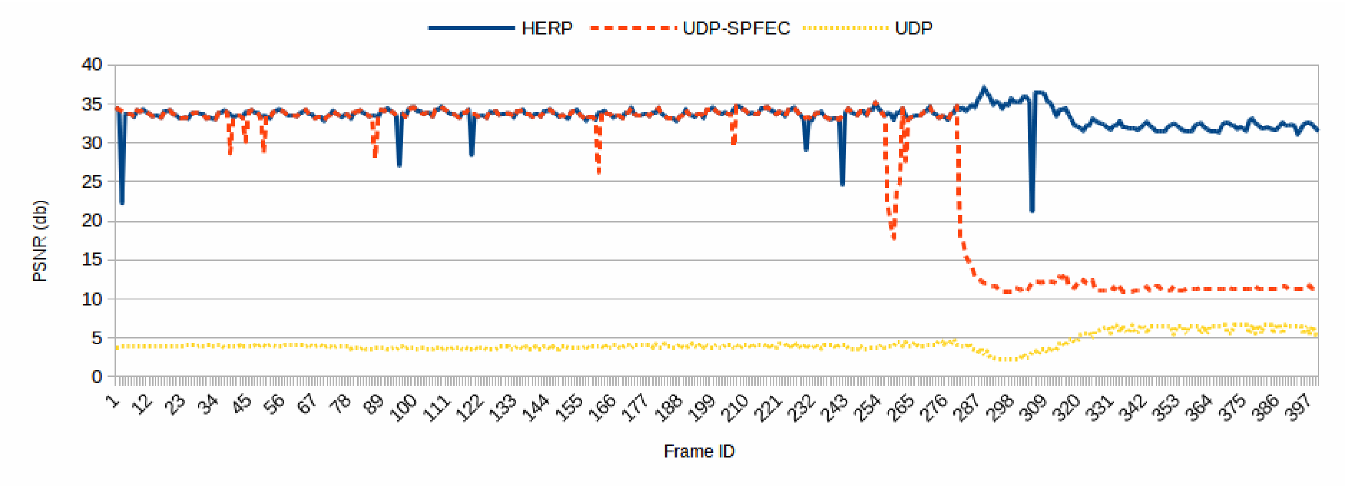


Figure 5.11: PSNR of video frames in the case of BER = 0.001

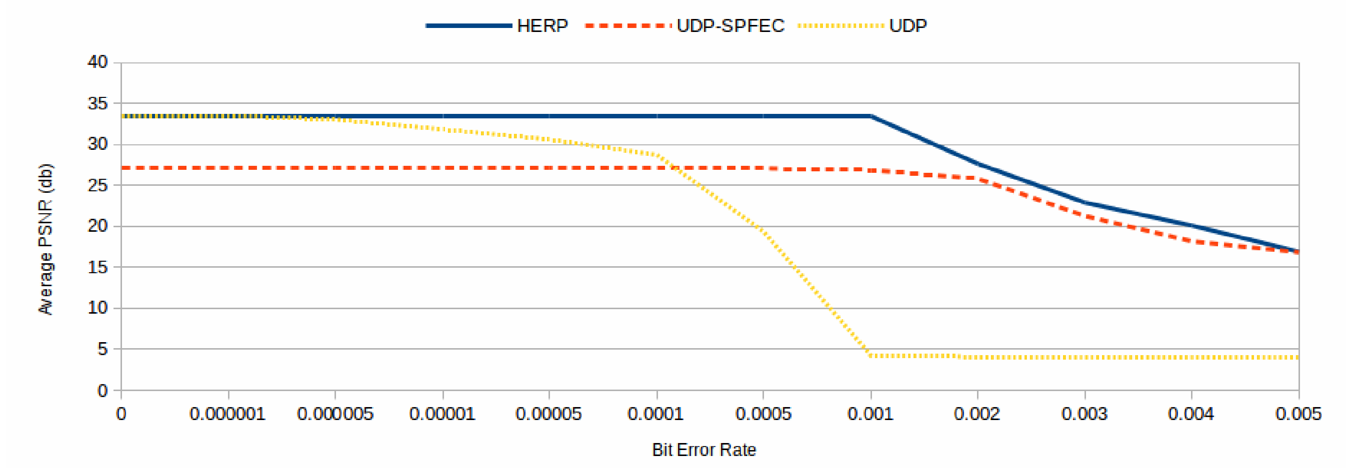
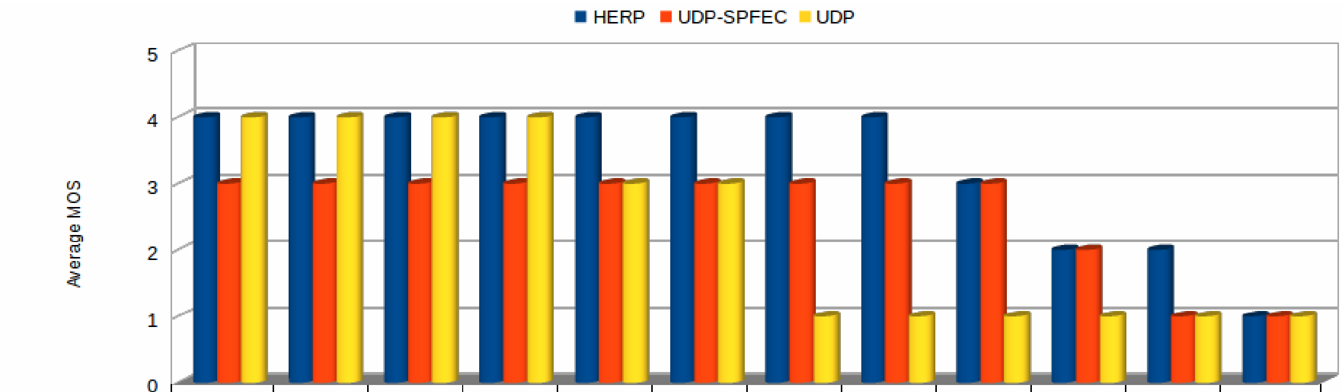


Figure 5.12: Variation of average PSNR of video frames with BER

protocols. When the *BER* is lower than 0.002, HERP achieves higher *PSNR* than UDP-SPFEC and UDP, because the *PDR* of HERP is higher than the other protocols, which provides higher *DFR*. When *BER* is higher than 0.002, HERP and UDP-SPFEC achieve almost the same *PSNR* because these two protocols provide the same *PDR* at this interval time which make the *DFR* almost the same. UDP provides the highest *PSNR* when *BER* is low, because it does not suffer from the network congestion like UDP-SPFEC, but it achieves lower *PSNR* when *BER* is high because it cannot recover the lost video packets like HERP and UDP-SPFEC.

The *MOS* QoE metric is presented in figure 5.13. In the case of *BER* lower than 0.0005, HERP and UDP provide a good video quality in terms of *MOS*, contrary to UDP-SPFEC, which achieves fair *MOS* video quality, due to the weakness of UDP-SPFEC to deal the dropped packets problem. When *BER* value is chosen between 0.0005 and 0.002, HERP achieves a good *MOS* video quality than the other protocols, because it can recover uniform and burst video packets errors affecting the video quality of experience. When *BER* value is



Bit Error Rate	0	0.000001	0.000005	0.00001	0.00005	0.0001	0.0005	0.001	0.002	0.003	0.004	0.005
HERP	4	4	4	4	4	4	4	4	3	2	2	1
UDP-SPFEC	3	3	3	3	3	3	3	3	3	2	1	1
UDP	4	4	4	4	3	3	1	1	1	1	1	1

Figure 5.13: Variation of average MOS of video frames with BER

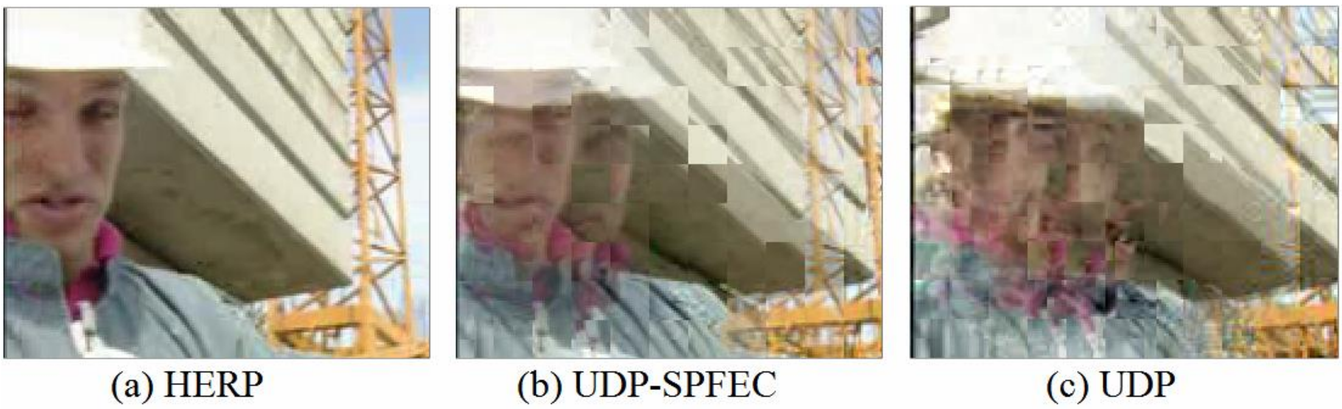


Figure 5.14: Comparison between different simulated protocols at the frame #281

between 0.002 and 0.005, HERP achieves a poor *MOS* video quality, but better than the other two protocols (i.e. UDP and UDP-SPFEC). In the case of *BER* higher than 0.005, all protocols achieve bad *MOS* video quality due to the frequent loss of video packets.

In figure 5.14, we have selected the transmitted video frame #281 when the *BER* equal to 0.001, aiming to give an idea of the user's point-of-view when he evaluates the video. Due to the robust protection mechanism of HERP that conceived to reach a higher protection for the video I-frames against the other frames, the transmitted video frame #281 is exposed to a lower distortion under a bad network condition. On the other hand, the same frame is highly distorted with UDP-SPFEC and UDP protocols, which cannot recover all kind of lost packets like HERP under the same network condition.

5.6 Conclusion

In this chapter, we have introduced and explained our last contribution named a Hybrid Error Recovery Protocol (HERP) to achieve a high quality and real-time of video streaming over VANET. HERP performs SPFEC mechanism to overcome the packet loss caused by the uniform transmission errors. In this proposal, SPFEC is combined with the retransmission technique to recover the lost packets mainly due to the network congestion, route disconnection or due to successive packet transmission errors. HERP limits the number of packet retransmissions to respect the transmission delay constraint and it adapts dynamically at the sender level the redundancy rates and the limited number of retransmitted frames (I, P, B) based on the reports received periodically from the receiver vehicle. HERP offers high protection to the most important frames using the unequal protection of video packets according to the frame types (I, P and B). Simulation results showed that HERP provides better video streaming quality in terms of QoS and QoE metrics than UDP with SPFEC (UDP-SPFEC) and the conventional UDP protocol. We specify that HERP can recover all lost packet types unlike UDP-SPFEC, which can only recover lost packets due to the uniform transmission errors and unlike UDP, which does not apply any error recovery mechanism.

Chapter 6

Conclusion and future research directions

This chapter gives a general conclusion of this thesis and some future research directions.

6.1 Conclusion

Video streaming in Vehicular Ad Hoc Networks (VANETs) is an important issue talked by current research due to many applications in VANET that are based on video transmission to improve the road safety, traffic management, and passengers comfort. Most of existing video streaming works in VANET focus on the routing of video packets and the resources managements, in order to reduce the rate of packet loss and transmission delay. However, a few of them are based on the error resiliency techniques considered as efficient approach to recover erroneous video packets and then to enhance video streaming in such networks.

This doctorate thesis focuses on providing error recovery solutions for video streaming in VANETs. To this end, we have firstly used and enhanced a redundancy based mechanism named SPFEC for video streaming in VANET. Based on this mechanism, Enhanced Adaptive Sub-packet Forward Error Correction (EASP-FEC) and Enhanced User Datagram Protocol (EUDP) solutions are proposed in order to recover uniform video errors. However, in VANET many causes of errors can be occurred like errors transmission, network congestion and route disconnection. To deal with these causes, we have conceived our third contribution called Hybrid Error Recovery Protocol (HERP) protocol, which can recover the uniform errors and burst errors produced due to aforementioned causes in VANET. Notice that HERP is a combination of the redundancy and retransmission correction technique.

To validate our proposals, various simulations were performed using Matlab and ns-2 simulator proving that EASP-FEC, EUDP and HERP can recover the video errors in VANET and achieve high video streaming quality in terms of QoS and/or QoE metrics. More specifically, the experimental results have shown that with the same redundancy rate, EASP-FEC outperforms FEC and SPFEC in terms of EPER, DFR and network overload. In addition, the simulation of EUDP has showed an improvement of UDP to cope with video streaming in VANET to achieve high video streaming quality in terms of QoS and QoE metrics. Furthermore, the HERP have been also validated in terms of QoS and QoE metrics comparing to UDP and UDP with SPFEC (UDP-SPFEC).

Some futures research directions and perspectives for video streaming in VANET are highlighted as follows.

6.2 Future works

To guarantee a high video streaming quality in VANET, some perspectives could be considered as a future development in VANET video streaming research:

- **Realistic vehicular testbeds:** due to the high cost of realistic vehicular testbeds (number of vehicles, communication technologies…etc), most of video streaming works in VANET are based on the simulation tools such as ns2, Omnet++ etc., in order to evaluate their performance [147]. However, these simulation tools cannot simulate exactly the real network conditions, which affect the results reliability when they are compared with real world experiments [148]. In realistic VANET and based on the simulation, it is difficult to modelling accurately the traffic mobility, radio propagation and network interference, which represent the main challenges of VANET network. As a future perspective, the researchers can use the different open-source platform, such as Arduino [149], Raspberry Pi [150], to perform a realistic vehicular testbeds of video streaming in VANET, with a lower cost and risk.

- **Localization system accuracy:** to forward video packets in VANET, the vehicles can get the information on the environment in the basis of GPS. However, GPS is not very accurate to localize network nodes. Therefore, a future video streaming investigation should improve the idea of considering vehicle localization accuracy when transmitting video packets.

- **Congestion control:** the state-of-the-art of VANET video streaming deals with various problems such as link disconnection, error recovery, routing, with the purpose of enhancing the video quality at destination vehicle side. We can mention a limit of these video streaming works, which is the generation of an immense number of packets leading to the network congestion phenomenon. Specifically, the network congestion could be produced due to high video data quantity transmitted in the network, bandwidth limitation, fast change of the network topology and vehicles density, CSMA/CA protocol of IEEE 802.11p standard [151]. We suggest as a future work to analyze and enhance the traditional congestion control algorithms or to propose new ones for VANET video streaming.

- **Internet of Vehicles (IoV) for video streaming:** Internet of Thing (IoT) is a new area of research in heterogeneous vehicular networks, in which vehicles can communicate with sensors, pedestrians, vehicles, RSUs, base stations. In IoV, vehicles are intelligent and can apply artificial intelligence techniques like the deep learning, cognitive computing, swarm computing, to improve road safety and to serve road users. Based on the collaboration between IoV nodes, the video streaming quality can be enhanced in such network. Some studies in this direction could be conducted.

- **New video coding standards:** it is suggested that the future video streaming works in VANET consider the efficiency of new generation of video streaming standards such as VP10 [152] instead of the traditional standards such as MPEG, HEVC, VP9, or others, to apply the most adequate standard for video coding in VANET.

- **Optimization and bio-inspired techniques:** few of VANET video streaming research activities use the optimization and bio-inspired techniques such as Ant colony, Particle Swarm, Fuzzy Logic, Genetic Algorithm etc, in order to guarantee a lower packets loss ratio and lower transmission delay. Future works may be proposed in the basis of this kind of techniques to achieve a high level of QoS and QoE in this context. For instance, the adaptive mechanism of our proposed protocol HERP can be improved by using the meta-heuristic methods to calculate the optimum values of the redundancy rate and the retransmission limit, in order to enhance further the video quality over VANET.

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