

Video Streaming and Multimedia Broadcasting over Vehicular Ad Hoc Networks

by

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Abstract

Video dissemination capabilities are crucial for the deployment of many services over VANETs. These services range from enhancing safety via the dissemination of video from the scene of an accident, to advertisement of local services or businesses. This work considers the infrastructure-less scenario of VANETs and dissemination of video content over this network environment, which is extremely challenging mainly due to its dynamic topology and stringent requirements for video streaming.

This study discusses issues and challenges that need to be tackled for disseminating high-quality video over VANETs. Furthermore it surveys and analyzes the suitability of different existing solutions aimed towards effective and efficient techniques for video dissemination in vehicular networks. As a result, a set of the most promising techniques are selected, described in detail and evaluated based on standard terms in quality of service. This thesis also discusses efficiency and suitability of these techniques for video dissemination and compares their performance over the same network condition. In addition, a detailed study on the effect of network coding on video dissemination protocols has been conducted to guide how to employ this technique properly for video streaming over VANETs. From this study, a summary of the observations was obtained and used to design a new hybrid solution by deploying robust and efficient techniques in number of existing protocols in an optimal manner. The proposed hybrid video dissemination protocol outperforms other protocols in term of delivery ratio and complies with other quality-of-service requirements for video broadcasting over vehicular environments.

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Dedication

To my
Mother, Father, and Sister
for their love, endless support and encouragement

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Chapter 1

Introduction

1.1 Research Framework

In the past decades, mobile devices such as laptops, personal digital assistants (PDAs), notebooks and smartphones have become popular due to their ability to provide wireless communication to their users. Wireless technologies like Bluetooth, 802.11/WiFi and WiMAX [30] enable exchanging of information between these mobile devices with different radio transmission ranges. Networks that consist of moving devices have to consider the scenario where no infrastructure is deployed to support wireless communication. Therefore, a new field of mobile communication has surfaced to provide self-configuring infrastructure-less networks, namely Mobile Ad Hoc Networks (MANETs), which are networks where mobile nodes may act as clients, servers and routers [4].

1.1.1 Vehicular Ad Hoc Networks

Due to the recent development of computing devices and wireless communication technologies, another network infrastructure has been formed where moving vehicles, such as cars, buses, trucks and motorcycles can communicate without any deployed fixed infrastructure [45]. These types of networks, known as Vehicular Ad Hoc Networks (VANETs),

have recently become a very attractive field for academic research and have also received quite a bit attention from the industry [47]. VANETs are an important technology that supports Intelligent Transportation Systems (ITS) along with driver assistance and safe navigation as well as business and infotainment applications [22]. Many studies introduce VANETs as a subset of MANETs where vehicles act as high speed mobile nodes [54]. In comparison with MANETs, VANETs have a more dynamic environment that leads generally to high error rates due to the high numbers of connection losses and topology changes. On the positive side however, vehicles have an unlimited power source and their computational resources, including CPU, memory and other storage capacities, are as good as the best existing options in the market. [36]

VANETs consist of several entities that should interact in proper ways to provide services for driving vehicles. These entities include On-Board Units (OBUs) such as sensors, GPS and any other necessary equipment installed in vehicles, Road Side Units (RSUs) such as access points and base stations which are deployed on the road side [35]. RSUs can facilitate Vehicle to Vehicle (V2V) communication by offering a medium to exchange messages between vehicles or by acting as relay nodes. These units are also essential entities to provide Vehicle to Infrastructure (V2I) communication [22]. Figure 1.1 illustrates the performance framework for

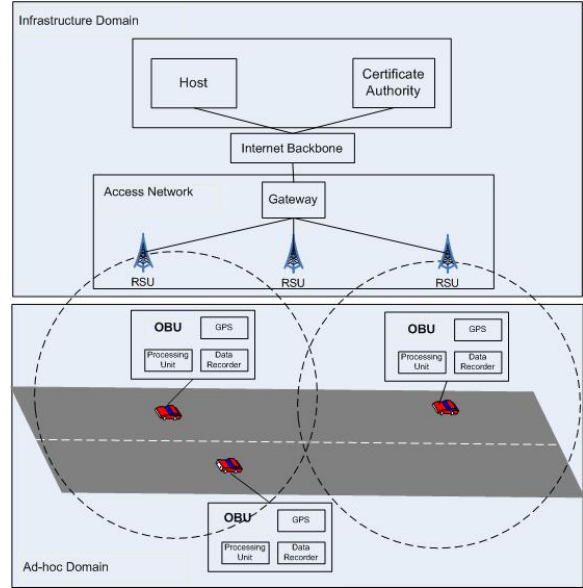


Figure 1.1: Performance Framework in VANETs

vehicular networks and shows how participant entities collaborate with one another. VANETs also have to abide by specific standards and regulations to provide vehicular

network communication.

Disseminating video content is possible via both infrastructure-based (V2I) and infrastructure-less (V2V) vehicular communication systems. However, the V2V approach is more suitable for peer-to-peer applications such as traffic accident warning dissemination whereas V2I communication is usually better suited for infotainment services such as news broadcasting and advertising [9]. Furthermore, video transmission can be divided into two major categories; these are interactive video which supports two-way communication, and video streaming which refers to the transmission of video packets from one source to one or multiple receivers [59]. Considering this classification, infrastructure-less network is proper approach for providing interactive video services, while in video streaming, it is more suitable to gain benefit from RSUs as sources or relay nodes for the video to be transmitted. However, it has to take into consideration that deploying infrastructure is costly due to the need of a wide range hardware devices and manpower. Therefore, there is also a need of streaming videos over V2V approach.

1.2 Motivation for Video dissemination over VANETs

The services and applications that provide by video streaming over VANETs have recently become very attractive to technology users. Therefore there is a need to have efficient and effective protocol to support dissemination of video that can satisfy the Quality of Service (QoS) metrics in terms of packet delivery ratio, delay, transmission cost, jitter and bandwidth usage.

The provision of multimedia support to vehicles on the road introduces a new range of services such as video conferencing [26] and online gaming [63]. Video broadcasting over VANETs also enhances existing services to provide safe navigation news and advertisement delivery along with other business, military and scientific applications. In general, audio and video services improve the communication approach by providing more precise information than plain text messages. In order to make use of this type of data, provid-

ing support for video dissemination to deliver sound and video with reasonable quality is essential. For this reason, it should be taken into consideration the fact that multimedia data is naturally larger than text, and high density video broadcasting that can cause many packet collisions. Therefore, a reliable data dissemination approach is needed to prevent packet loss in video streaming and guarantee an acceptable packet delay and overhead [59].

1.3 Problem statement

Vehicular ad hoc networks pose intrinsic challenges due to their specific characteristics such as high dynamic topology and fluctuation of vehicles density in the roads. In spite of the fact that VANETs are a particular type of MANETs and both are organised in an ad hoc manner, they are very different from each other in terms of network architecture, mobility pattern, energy construction and application setup [9]. Maintaining optimal routes between high speed vehicles, reducing the likelihood of link breakage and handling disconnected end-to-end path have to be provided in an ideal manner. In addition, deploying a wireless access standard that provides communication in vehicular environments and dealing with network congestion in parallel to meet stringent set of QoS requirements at both ends of communication are considered as major challenges that need to be addressed in vehicular networks.

To the author's best knowledge, only a few number of works [70], [25], [44] have evaluated the performance of video streaming approaches over VANETs. Therefore there is a need of more systematic comparisons and performance evaluation studies to analyze the functionality of video dissemination protocols.

Another main issue that is encountered with video applications is lack of video quality due to packet delay, loss and overhead [59] especially in high data rate networks. A video content differs significantly from other data types such as alert messages, vehicles information (e.g. speed, position, etc.) or services description (e.g. closest gas station).

Parameter	Video-streaming	Interactive video
Delivery Ratio	< 5%	< 1%
Delay	< 5 seconds	< 150 ms
Jitter	N/A	< 30 ms

Table 1.1: Quality-of-Service Requirements of Video [59]

Video is constructed using large amounts of data and has stringent requirements in terms of delivery ratio and delay. Cisco which is the worldwide leader in networking has defined some of these requirements [59] for the exchange of video content. In the case of video-streaming, a delay should not be higher than 4 to 5 seconds, while packet loss should not exceed 5 percent. Bandwidth requirements depend on applications and jitter imposes no significant requirements. Table 1.1 summarizes the QoS requirements for streaming of video content over vehicular networks. The transmission of video over VANETs is expected to require the use of high amounts of network resources, but it cannot be too excessive. Therefore, video streaming solutions for VANETs have to fulfil all of these basic requirements while being limited to a reasonable occupation of the wireless medium.

Hence, there is a need of video streaming protocol that is capable of providing an integrated solution while dealing with different challenges simultaneously.

1.4 Thesis Objective

This thesis has two main objectives. In the first stage, this study aims to analyze performance of current video streaming protocols which adapt different techniques to cope with dissemination challenges in VANETs. The second stage of this thesis intends to propose a robust hybrid dissemination protocol for video streaming to respond to aforementioned challenges in vehicular networks by providing high delivery ratio with low latency. This protocol designs to support emergency and delay sensitive video content addition to delay tolerance video applications. In order to achieve these objectives, this

thesis addresses the following relevant works:

- ***Highlight different types of current video streaming protocols over VANETs:*** The related works are studied in terms of different QoS metrics to analyze their specific features and characteristics. These protocols concentrate on different protocol stack layers to improve video broadcasting techniques. Advantage and disadvantages of these approaches are presented and summarized in an appropriate way. In addition, a number of efficient and effective protocols have been selected to implement over altered network scenarios to form an impressive performance analysis of existing solutions.
- ***Providing a guideline for use of Network Coding in video dissemination over VANETs:*** A detailed study of Network Coding (NC) technique is conducted to evaluate the effect of this technique on video quality in receiving vehicles. This study distinguishes how network coding techniques at the source of video or at intermediate receiver vehicles affect video quality in terms of delivery ratio, delay and transmission overhead. Network throughput varies by employing different parameters and schemes to adapt best solution under specific vehicular environment. This study indicates a direction for adopting NC technique in most appropriate way to improve QoS.
- ***Proposing an efficient hybrid solution:*** In this protocol high-performance techniques collaborate to enhance QoS in video streaming over VANETs. This proposed approach is able to detect video frames at the receivers end from limited sources using video coding, control network delay and overhead by selecting a subset of vehicles as a relay in an optimal manner and improve delivery ratio in congested networks by adopting a Media Access Control (MAC) channel congestion control mechanism.
- ***Performance evaluation:*** A performance evaluation is conducted for all selected approaches, enhanced form of existing protocols and proposed cross-layer

hybrid protocol. Different network scenarios are used and the results are compared and discussed in details. The observation of this evaluation gives a clear insight to enhance existing video broadcasting solutions by touching on the different aspects that have not been considered before.

1.5 Contribution

A comparative study in section 2 introduces and discusses a number of approaches and solutions that could be involved in different network layers to improve the video quality at receiver vehicles. This thesis conducts a performance evaluation on a number of selected video streaming protocols as its first contribution. These protocols have been evaluated based on standard metrics and their techniques and suitability have been discussed to indicate the direction for the design of new solutions.

In addition, this thesis proposes a hybrid broadcasting protocol that combines mentioned video streaming protocols while taking advantage of the best features of their involved approaches. The proposed protocol is based on V2V infrastructure and uses a specific error resilience ,congestion detection and routing technique to fulfil the video streaming requirements to the best. The main contributions are the combination of a MAC congestion control mechanism [27], Reactive, Density-aware and Timely Dissemination Protocol (REACT-DIS) and Network Coding based Data Dissemination (NCDD) protocol [40] and injecting the redundant packets in the optimal manner to reduced number of lost packets and control the transmission delay and overhead. Throughout this thesis, the Hybrid Video Dissemination Protocol (HVDP) refers to this proposed protocol. This protocol has been tested over twenty different network scenarios to analyze its performance compares to current existing approaches. This study discusses the set of experiments that have been carried out to evaluate the performance of HVDP, and report on the obtained results.

It has also discovered the most appropriate way of employing these features to apply

it on the proposed hybrid protocol and provide a clear insight on the impact of these solutions on the network performance.

1.6 Thesis Organisation

The reminder of this thesis is organized as follow:

- Chapter 2 elaborates a background study of existing solutions for streaming video over vehicular networks based on different architectures. These presented approaches are classified based on different standards and features that they deploy on top of each layer of a stack protocol.
- Chapter 3 outlines the framework for this research, expresses the research model and defines the methodology used for this thesis study. The simulation software, video evaluation method, mobility model, and the different scenarios are explained along with the different metrics used to evaluate all introduced protocols.
- Chapter 4 introduces a number of selected reliable and efficient broadcasting protocols based on findings in literature review followed by a detailed explanation of their functionality and performance to compare the distinct features of these protocols.
- Chapter 5 describes the design and implementation of a hybrid video dissemination protocol that has been proposed in this study. This chapter also discusses the performance evaluation results in details and exhibits the results thus obtained. The performance of HVDP protocol has been illustrated in term of packet loss ratio, packet arrival time and transmission overhead to evaluate its performance compare to existing reliable solution over different network layer.
- Chapter 6 concludes the thesis and outline the potential and future direction of this work.

Chapter 2

Background and Related Work

This chapter first explains the basic definitions, concepts and measurement criteria that impact QoS parameters in video streaming over VANETs. Then, it highlights different decent techniques that have been proposed to provide high quality video in receiver vehicles driving on the roads. In addition, this chapter discusses existing related work on video streaming in VANETs which are focused on different protocol stack layers. As the results, this chapter identifies advantages and disadvantages of these deployed techniques.

2.1 Introduction

Video streaming refers to a type of multimedia transport for distributing real-time video content through a network. In order to enable streaming data or broadcasting multimedia, different layers in the protocol stack must work in tangent to provide content delivery to the end receivers in a network environment. OSI and Transmission Control Protocol/Internet Protocol (TCP/IP) models [6] are both representative of network models where TCP/IP is closer to reality in the world and OSI is an ideal model for protocol stack. In case of video streaming over VANETs, this study elaborates a protocol stack with four layers involved in data transmission process as shown in figure 2.1.

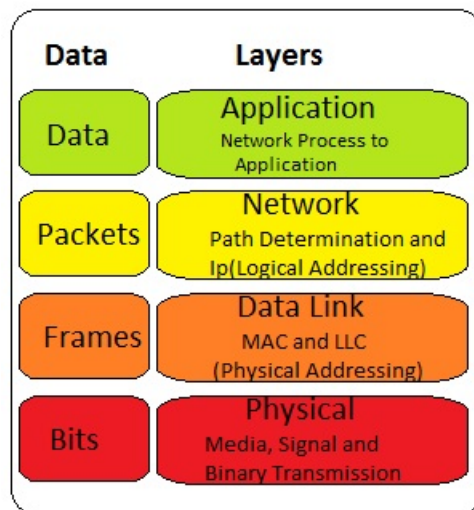


Figure 2.1: Protocol Stack Layers

To provide high-quality video in acceptable time, different techniques can be applied over these layers to improve the QoS parameters. Traditional video streaming protocols without any enhancement are not enough to meet QoS requirements for distribution of video content and, performance of these broadcasting protocols can degrade quickly over ad hoc networks [36]. Currently, many video streaming techniques that have been used in vehicular networks are extensions of techniques in MANETs [29], [67] while the important point is the way of deploying these solutions and techniques to fit vehicular environments for delivering large video files to all qualified vehicles, within a distance.

2.1.1 Definition

Broadcasting is being chosen more often to support video streaming to a large number of receivers simultaneously [40], [33], [20]. In general broadcasting is a method to disseminate data from one source to all other nodes within the same radio range. In this study we use the term dissemination as a synonym for broadcasting. Different definitions of broadcasting have being given in literatures.

In Reliable Broadcasting in VANET [31], Pat Jangyodsuk refers to broadcasting as

follows:

” Broadcasting in VANET is the situation where a vehicle needs to propagate the report to other vehicles. The broadcast initiator starts by broadcasting the report to its neighbours.”

Sandhaya Kohli et al. [50] defined broadcasting as follows and referred to two major problems in this approach:

” Broadcast sends a packet to all nodes in the network, typically using flooding. This ensures the delivery of the packet but bandwidth is wasted and nodes receive duplicates.”

Broadcasting storms are one of the major challenges that should be addressed in broadcasting, especially for a large volume of data such as video. A broadcasting storm [5] can be defined as:

” A situation in which messages broadcast on a network cause multiple hosts/nodes to respond simultaneously by broadcasting their own messages, which, in turn, prompts further messages to be broadcast, and so on.”

In broadcasting in VANETs [62], Zan Tonguz et al. refer to a broadcasting storm as:

” Because of shared wireless medium, blindly broadcasting the packet may lead to frequent contention and collision in transmission among neighbour nodes. This problem sometimes refers to as broadcasting storm problem.”

In still other literature [64], Sze-Yao Ni et al. defines a broadcasting storm as:

” First, because the radio propagation is omni-directional and a physical location may be covered by the transmission ranges of several hosts, many rebroadcasts are considered to be redundant. Second, heavy contention could

exist because rebroadcasting hosts are probably close to each other. Third, collisions are more likely to occur because the Request To Send/ Clear To Send (RTS/CTS) dialogue is inapplicable and the timing of rebroadcasts is highly correlated. Collectively, they refer to these problems associated with flooding as the broadcast storm problem.”

This definition explains three reasons that cause a broadcasting storm through data communication. Type of broadcast data also needs to take into consideration, while video and multimedia files carry significant number of data packets which can intensify these conditions. Therefore, a robust video streaming technique should address broadcasting storms for large amounts of data in a network environment that has specific characteristics.

2.1.2 Measurement Criteria

After introducing the major challenges for video broadcasting and discussing the characteristics of vehicular environments, it is important to define operational concepts related to the main construct of this research, which is providing QoS at the receivers. Specifying properties of operational concepts, their criteria and scale for measuring these criteria is necessary to evaluate robustness, efficiency and effectiveness of proposed video streaming protocols both quantitatively and qualitatively. The following table sums up findings based on author’s studies on related work. It also summarizes concepts and criteria that have major impact on QoS parameters in video broadcasting over VANETs.

The impact of delivery ratio, effect of packet latency and impact of transmission overhead are three major operational concepts that are tightly related to main construct in this research, which aims to provide high-quality videos to vehicles driving on the roads. There are a number of properties that have a direct effect on the named operational concepts. In order to enable video streaming to vehicles while driving, existence of a wireless access technology, infrastructure, routing protocol, recorded video etc. is

necessary. Each of these properties defines more involved factors such as video coding techniques or radio range of each vehicles that can also consider as network properties, which have an effect on involved operational concepts.

Construct/ Concept	Operational Concept	Properties	Criteria	Scale
Video quality at the receiver' vehicles	Impact of delivery ratio	Wireless access technology	Technologies available	suitability to network scenario
		Data Transfer Rate	Transmitted Packets	Number of transmitted bit per second
		Video Coding Technique	How well does the application layer technique work	Tracking packet delivery ratio,delay ,and video quality (PSNR)
		Vehicle Radio Range	OBU characteristics	Area that vehicle can cover and transmit data
		Involved MAC Protocol	How well does the link layer technique work	Synchronise back off time
	Effect of latency on responding to emergency and video quality	Routing Protocol	How well does the network layer techniques	End-to-end connection
		Transmission Power	OBU characteristics	Power of transmitting video packets
		Infrastructure approach	Involved elements in network	Existence of off-road and on-road units/ infrastructure based or infrastructure-less
	Impact of transmission overhead on network scalability	Collaborating nodes	transmission range, node locations, routing technique, environment element	Number of travelled hops
		Distance from video source	Source and receivers location	X and Y position of mobile nodes
		Involved vehicles	Traffic condition, supported area	Number of vehicles in network area
		Network congestion	Traffic condition, type of application, available bandwidth	Number of transmitter vehicles, size of data
		Original video packets	Quality and type of original video	Number of original video packets

Table 2.1: Measurement Criteria

These properties are not particularly for one of the aforementioned operational concepts while all of them have a different impact on delivery ratio, delay and transmission overhead.

Each of these properties has its own criteria and these criteria can be measured using

specific scales that are listed in the following table. In general, this table summarizes measurement criteria and metrics that should be considered in order to evaluate video streaming techniques over VANETs.

2.2 Video Streaming Techniques

Several protocols [22], [53], [70] have been proposed for video dissemination over VANETs. These research works have applied different network adaptive techniques to support media streaming and improve video quality in unreliable and dynamic vehicular network environments. To support video streaming, large amounts of data should be exchanged between vehicles which may cause more overhead and bandwidth consumption in the network [21]. Video quality at the receivers is affected by distortion due to packet loss and delay. As mentioned before, this may happen for different reasons such as VANETs dynamic topology, limited shared bandwidth and disconnected platoons leading to link breakage. In addition, collision among hidden nodes is a reason for packet loss which has been addressed in a number of studies [61], [57], [33]. As for the delay, its effect on video quality is highly related to the type of video application. In fact, delay requirements are less challenging in stored playback videos and video streaming compared to interactive and safety-related video applications.

In this thesis, video streaming techniques in VANETs are studied based on the different protocol stack layers they have been applied to. The findings in those aforementioned studies show that most of the proposed applications have been designed in cross-layer fashion. This research focuses more on the centric layer that has been involved in proposed techniques. Classification of these solutions is very important to compare their performance and reliability. This layer-wise classification supports a clear vision to understand which protocol stack layer is engaged in different type of applications. Therefore, a promising technique can take advantage of layer-centric solutions that are more suitable in providing high-quality video recovery at receivers end in a vehicular network.

2.2.1 Link Layer Techniques

Link layer techniques are the essential elements of all network solutions. This layer mainly manages the interaction of devices with the shared wired or wireless medium using the Media Access Control (MAC) sub-layer. Proposed protocols for video broadcasting in VANETs at the link layer are extensions of IEEE 802.11 that have been introduced to provide wireless access in a vehicular environment. According to previous research works [72], [61], [58] pioneer MAC layer approaches are not suitable to provide reliable and robust video broadcasting techniques. The major challenge is the acknowledgment (ACK) explosion that would happen due to the transmission of numerous ACK control frames via all receivers of a broadcasted message. In addition, another challenge surfaces from the hidden terminal problem, which is a severe issue in broadcasting scenarios since the RTS/CTS (Request To Send/Clear To Send) handshaking process cannot be treated in the same manner as in unicasting scenarios. There are a number of works in the literature about the topic at hand that have proposed reliable MAC approaches [61], [57] to provide acceptable QoS in ad-hoc networks by reducing collision among the hidden nodes using control frames. However, deploying the proposed techniques for ad-hoc networks is not suitable in VANETs due to their specific characteristics. Therefore, a standard is developed for vehicular communication, known as IEEE802.11p, which improves the proposed approaches over VANETs in terms of packet loss, average end-to-end delay, and throughput [28]. The 802.11p Wireless Access in Vehicular Environment (WAVE) is an amendment to the IEEE 802.11 standard to enable wireless access for V2I and V2V communication. The 802.11p standard has the same core mechanism as 802.11e, which integrates the QoS into its MAC layer. IEEE 802.11e defines a new medium access procedure based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme called the Hybrid Coordination Function (HCF). The 802.11p follows an Enhanced Distributed Channel Access (EDCA) scheme as one of the provided medium access methods by HCF. In addition to EDCA, another scheme called HCF Controlled Channel Access (HCCA) scheme is also available under the HCF, but is not utilized by

802.11p as a medium access method. [60] The EDCA takes advantage of the Listen Before Talk (LBT) and back-off time that are defined based on random wait times and a channel access parameter known as the Arbitration Inter-frame Space (AIFS). The channel access parameter, AIFS, in addition to the contention window size (CW_{min}, CW_{max}), is assigned to traffic of the access categories to provide distributed channel access. CW_{min} here is the minimum Contention Window size and the CW_{max} is the maximum Contention Window size. This scheme prioritizes packet queues from the same source according to a virtual resolution function and retransmitting lowest priority packets to increase packet delivery probability. The WAVE architecture distinguishes two types of channels: six Service Channels (SCH) that are used to exchange non-safety and long stream data as well as one Control Channel (CCH) that is reserved for communication coordination and safety message delivery [8]. Vehicles adapt to this approach by periodically switching to the control channel for monitoring emergency and warning messages when all communication via SCH are suspended. Once the emergency presented by the safety message is resolved, vehicles switch to the SCH and data transmission over the CCH stop until the next channel switch. In order to achieve multi-channel accessibility in WAVE, two separated EDCA functions should be deployed for SCH and CCH, which handle different sets of queues for packets [8].

An enhancement and higher layer of 802.11p is the IEEE 1609 family, which has developed a set of standards to provide resource management via multi-channel operation and also deal with communication coordination and security issues. The following table summarizes each standard in the 1609 family.

Standard	Year	Function	Description
IEEE 1609.1	2006	Resource Management	Facilitate communication between remote applications and vehicles
IEEE 1609.2	2006	Security Services	Provide security services for applications and management Messages
IEEE 1609.3	2007	Networking Services	Addresses network layer issues
IEEE 1609.4	2006	Multi-channel Operation	Deals with communications through multiple channels

Table 2.2: IEEE 1609.X Family [23]

With all the 802.11p mentioned standard improvements for data transmission over

vehicular networks, there are still some issues such as large end-to-end delays due to switching between different channels and lack of guaranteed bandwidth in high congestion networks that makes it unsuitable to be used as-is for video broadcasting applications. Therefore, a number of techniques have been introduced to enhance the functionality of IEEE 802.11 standards and MAC layer for broadcasting over VANETs.

2.2.1.1 Relay node selection in MAC Layer

Flooding data in the network without adopting a reliable broadcasting approach can simply result in a highly congested network leading to broadcast storm problems and a high percentage of packet loss. Therefore, data dissemination protocols have to be designed in a robust manner for coordinating nodes to deliver data packets to large numbers of the nodes within the shortest possible delivery time. These facts increase the importance of redesigning the MAC layer approaches to overcome multi-hop broadcasting issues. According to the research findings, assigning the duty of forwarding and acknowledging the broadcast of packets to one or a subset of vehicles is one of the most adopted solutions. The Urban Multi-hop Broadcast (UMB) protocol [33] engages in a similar RTS/CTS handshake process using Request to Broadcast (RTB) and Clear to Broadcast (CTB) to decrease the effect of hidden nodes. In this approach, the source sends an RTB request with its geographic location to all the nodes in its segmented transmission range. Nodes that receive the RTB in each segment send a black-burst signal in the shortest possible time where the length of this signal is proportional to their distance from RTB transmitter. At the end of the black-burst period, nodes switch to the channel sensing mode when the node in the furthest segment detects idleness in the channel. If there is more than one node in the furthest segment, all the procedures are repeated to divide the segment into further sub-segments used to choose only one node as the furthest one. This node has to respond to the RTB by sending a CTB message using its unique identifier or ID and then is responsible for forwarding incoming broadcasts. The UMB approach does not need any prior topology information to select relay nodes and this makes it appro-

appropriate to adapt to any traffic volume. In contrast, using the longest black-burst signal that causes high latency makes it useless for delay sensitive applications. In the Smart Broadcast (SB) protocol, Fasolo, et al. [19] state a robust broadcast mechanism used to deliver alert messages to large numbers of vehicles within acceptable delivery time. This approach makes use of a different method than UMB to select appropriate relay nodes. However, similar to the UMB, SB divides the transmission area to different segments called sectors. When a node receives a RTB, it determines its segment and randomly picks up a back-off time, as well as contention window size associated to this segment. The back-off time for each node is determined based on the non-overlapping contention windows ordered from the outermost to the innermost segments. As a result of this process, nodes in the furthest segments pick a random back-off time of smaller time slots. The back-off counter is decremented by one during idle time slots and the node sends a CTB response whenever the counter becomes zero. The transmitter of this CTB is also responsible for broadcasting data and sending ACK messages to confirm data reception. Other nodes that receive a CTB message before the timeout of their back-off timer exit from the contention phase and wait to receive broadcasted data. This procedure guarantees selection of the furthest node in transmission range as a forwarding relay node. The SB method for choosing the furthest node is dependent on the minimum waiting time that enhances the UMB functionality in terms of packet delivery time. However, this approach is not capable of determining optimal contention window sizes based on vehicle congestion. Therefore, it is not suitable for any vehicular scenario.

2.2.1.2 Network Congestion Control

As discussed earlier, network congestion is one of the challenges that must be addressed in vehicular networks especially when large a number of bits should transfer per second. IEEE 802.11 technologies may offer more adaptive solutions to guarantee fair sharing of bandwidth which significantly reduces the impact of network congestion. Adjusting the frame rate and controlling the back-off time and contention window size are reliable

solutions for network congestion control that can be addressed in different ways, described below.

- Selective Frame Rate:** Maurizio A. Bonucceli, et al. in [12] propose a solution that applies frame skipping and transcoding together with a rate reduction technique over IEEE 802.11 to improve the video quality of real time services in highly congested vehicular scenarios. Frame skipping can occur when the sender monitors the channel access delay for a video frame transmission. If the sender detects a real time frame loss, it avoids wasting the bandwidth by dropping this frame F . In this case, temporal transcoding applies and the decoding process at the receivers end relies on the previously received frame (i.e., $F - 1$). If the frame is transmitted over the network, it delivers after an acceptable delay and will not be displayed at the receivers side. However, this frame participates in the decoding of the next arriving frame (i.e. $F + 1$). In the case two consecutive frames are skipped, the sender assumes that the network is congested and consequently reduces the frame rate.
- Back-off time and Contention Window Control:** Several proposed protocols [56], [27] suggest a modification on the back-off time for controlling congestion in networks. Most of these approaches rely on a dynamic adjustment of CW_{min} to determine an optimal back-off time. In some proposed schemes, obtaining an optimal back-off time depends solely on the duration of the collision in the channel. This is not suitable in many cases where packet drops can occur for reasons other than collisions, and therefore should not be the only factor used to achieve an ideal CW_{min} . Applying Adoptive Offset Slot (AOS) [27] is a mechanism that has proposed to modify back-off time in IEEE 802.11p and is developed based on different solutions. Similarly, this approach suggests that the MAC channel mechanism should control the back-off time based on the modified minimal value of CW. In this proposed approach, the CW_{min} value is altered depending on the po-

tential number of neighbour vehicles that are defined in the congestion estimation function. The number of neighbours is calculated by considering the broadcasted hello-messages by those neighbours as it listens to the control channel during the listening interval. In the next step, an expected offset calculation function picks offset slot values depending on the number of neighbouring vehicles. The number of offset slots add to the minimum value of the old contention window size to get a new CW_{min} depending in this instance on the vehicular traffic volume. As a result, the packet collision is reduced and higher packet delivery ratio is achieved. However, increasing the minimum value of the contention window is not always a practical solution especially for safety applications where vehicles exchange Co-operative Awareness Messages (CAMs) periodically and bigger values of CW_{min} increase the beacon waiting time at the MAC layer. The longer waiting time may result in transmission of expired CAMs that transfer outdated information to the vehicles and waste shared bandwidth. To handle CAM expiration, R. Stanica, et al. in [56] have suggested a method for back-off time modification to guarantee a balance between collisions and expiring beacons. According this approach, the CW value is set to the maximum size as a default and is divided by two after any CAM expiration. Whenever a beacon transmits successfully, the contention window size resets to its maximum value. This method has been used to address the hidden nodes problem by giving transmission priority to the vehicles that have experienced higher numbers of expired CAMs and reduced collision by decreasing the probability of back-off timers expiration at the same time.

2.2.1.3 QoS-based Solutions

As discussed, the WAVE spectrum is composed of seven channels of 10 MHz [60] each, including six SCHs and a single CCH channel. According to the original idea of 80.11p, messages over VANETs are divided into safety and non-safety and are prioritized based

on this classification. To improve QoS over 802.11p, further classification of applications can enhance services provided in terms of delay and shared bandwidth.

Several video applications have been developed to provide infotainment services. However, 802.11p is more suitable for safety applications. Since the main goal of this study is on video dissemination approaches, investigating on proposed protocols for infotainment video services provide a more in-depth focus towards this goal. The W-HCF (WAVE-based Hybrid Coordination Function) is a MAC protocol [8] that has been proposed by Marica Amadeo, et al. to provide infotainment applications by enhancing IEEE 802.11p standards. This protocol distinguishes between QoS-sensitive and non-QoS sensitive applications in non-safety services. The W-HCF treats QoS-sensitive services in a different way than 802.11p while keeping the bandwidth available for non QoS-sensitive services. This method relies on resource reservation by using extra signalling which does not have a negative effect on the safety services delivered over the CCH. However, QoS-sensitive service providers (Q-Prs) keep track of the vehicles on their coverage by adapting a polling technique to avoid unnecessary resource reservation for out of range QoS-sensitive service users.

2.2.2 Network layer techniques

A significant number of video streaming protocols in VANETs are tightly dependent on routing approaches [16], [34]. Most of these protocols are extensions of proposed routing schemes for video data dissemination in MANETs that are redesigned based on the nature of VANETs [13]. Involved techniques in the routing protocols can be classified as network-layer-centric techniques, since the main task of the network layer is forwarding data packets as well as providing routing for these packets. Generally, routing protocols can be divided into four major categories: broadcasting, multicasting, unicasting, and geo-casting. In this study, the main focus is on broadcasting approaches as enablers for video dissemination over vehicular networks. Several applications including safety and emergency related applications should deliver messages to all vehicles in the network with

high delivery ratio and minimum packet arrival time. As mentioned before, multimedia data is naturally large and packet collisions are a very common issue in high density video broadcasting. Moreover, broadcast storms problem can happen easily when large number of vehicles in the same vicinity rebroadcast the packets at the same time. Therefore, a reliable broadcasting approach is needed to avoid high number of packet collision and the broadcast storm problem in video dissemination. This study surveys different routing techniques that have improved video broadcasting functionality to achieve acceptable QoS over VANETs.

2.2.2.1 Topology Aware

Nowadays, significant numbers of vehicles on the roads are equipped with OBUs. As a result, each vehicle has adequate information about its geographical location and its position relative to other vehicles in the same region. Adapting wireless communication capabilities allows vehicles to share their topology information with others to facilitate service and application delivery on the roads.

- **Intersection-based:** Vehicles are able to detect road intersections using preloaded digital maps and GPS information. Several proposed approaches [33], [16] have deployed these technologies to improve broadcasting performance by handling the network in a different manner in the case where an intersection appears in the packet dissemination path. Jinyoun Ch, et al. in [16] has proposed an intersection-based approach to reduce the end-to-end delay of a suggested Reliable Data Pouring (RDP) method [74]. This approach suggests broadcasting packets to the listed multiple relay vehicles in all direction simultaneously and wait before rebroadcasting the packet for only one back-off slot. Urban Multi-hop Broadcast [33] is another intersection-based technique that has suggested the installation of repeaters in road intersections. In this approach, if the source node is inside the transmission range of a repeater, the node sends the packet to the repeater using the point-to-point

IEEE 802.11 protocol and the repeater forwards this packet to all road directions except in the direction where it has received the packet from.

- **Density-Aware:** In VANETs, the distribution of vehicles through the network is not homogeneous, as vehicles density varies significantly depending on route popularity, traffic seasonality, traffic lights, accidents and other unexpected events. Solutions that consider a uniform distribution of vehicles may suffer from either communication disruption through low density regions or excessive overhead and congestion in dense areas. For this reason, some works [11], [38] have designed ways of estimating local density and based on such information take different measures.
- **Movement similarity:** Next hop relay selection is a critical issue to ensure acceptable reliability and efficiency in multi-hop broadcasting over VANETs. Road maps and topology information, such as vehicles position, direction and velocity, make vehicles movement more predictable and this mobility forecasting can be exploited to improve routing features. In addition to these factors, a Reliable Broadcasting routing scheme based on Mobility Prediction (RB-MP) [34], has considered the delay of position updating also known as Prediction Holding Time of the connection (PHT) to ensure the reliability in broadcast routing. RB-MP divides the neighbors into several sets according to the movement direction and then utilizes the position and velocity to predict the maintain time of all neighbors. In this approach, movement information and node direction are calculated based on the node movement history and its current situation.

2.2.2.2 Node selection

As discussed previously, intermediate relay nodes can be used as an appropriate solution in data broadcasting if selected in an optimal manner to minimize packet redundancy as well as collision and packet latency. Since, in this method, only a subset of receiver nodes participate in the rebroadcasting, it is important to choose nodes as relays appropriately

in such a way that optimizes the network throughput. In this section, we study relay node selection techniques based on the participant nodes nature, which can fall into one of the following two categories: (1) sender-based selection or (2) receiver-based selection.

- Sender-based:** Generally, in the sender-based selection techniques, the source node is responsible for assigning forwarding duty to the one or more potential relay nodes. In order to evaluate forwarding capability of these potential relay nodes, data sources need to keep track of their neighbours local information such as their position, direction and speed. Therefore, all nodes should distribute their local information via a broadcasting message. After being aware of all potential relay nodes local information, different criteria could be used to select the optimal relay node to that sender. Some approaches make their decision based on the movement direction of the packet to be forwarded compared to the movement direction of the potential relay nodes [70], the maximum transmission range of the potential relay nodes compared to other nodes [55], and the velocity of those potential relay nodes traveling in the same direction as the packet being forwarded. These factors may vary depending on the application type in order to optimize QoS in video disseminations accordingly.
- Receiver-based:** The receiver-based techniques are dependent on each receiver nodes decision to either broadcast a received message further or to drop it. In contrast to the source-based methods, receiver-based techniques are mostly reactive and do not rely on topology information. To satisfy optimal relay selection requirements, potential relay nodes employ other techniques such as using a re-broadcasting timer, which is set based on their distance from the original source and/or final receiver [38], [49], calculating inter-arrival time between consecutive duplicate packets [11] or sending an acknowledgment message from the first receiver to stop rebroadcasting the same message by other potential relay nodes in the same hop level [70]. According to the study in [70], the receiver-based forwarding scheme

outperforms the sender-based forwarding scheme in the terms of packet delay, collisions, and overhead, and is therefore more suitable to provide video dissemination services over vehicular networks.

2.2.3 Application layer techniques

A video stream consists of a sequence of pictures and images known as frames. Each frame consists of smaller elements called pixels [9]. As discussed in the previous section, one of the main challenges in video broadcasting is detecting video frames at the receivers end from limited sources, while considering high-corruption probability in VANETs [36]. Video coding is a key solution to meet this challenge. Reduction in the streams bitrate and detection of video streams from limited received frames while preserving acceptable quality is possible by employing video coding techniques at the application layer.

The Moving Pictures Experts Group (MPEG), an international standards committee, and H.26x, a family of advanced video coding standards, have defined a set of non-scalable video coding standards. The main principle of these standards is to deploy redundancy in inter-frames as well as intra-frames. In the intra-frame scheme, video streams divide to macroblocks of pixels using Discrete Cosine Transform (DCTs). On the other hand, inter-frame coding divides frames into three types: I-frames (intra-coded), P-frames (inter-coded) and B-frames (bidirectional coded) which are organized into a group called Group of Pictured (GOP). I-frames are coded independently and receiving a higher number of I-frames is directly proportional to the video quality, whereas P- and B- frames can be predicted from previous I-frames. Furthermore, an enhanced version of these standards, MPEG-2 and MPEG-4 / H.264/AVC has been introduced and have had a rich impact on coding efficiency. [9]

All of the aforementioned works do not allow for scenarios where scalability is significant. This work surveys other techniques that are deployed for scalable video coding and error resilience to enhance QoS and tackles video transmission errors apparent in VANETs.

2.2.3.1 Scalable Video Coding

Traditional video coding techniques are used to encode video streams several times to generate coded video with different bit rates and serve all receivers with a variety of available bandwidth. These coding techniques are not practical in VANETs since multiples encoding increases delay and packet overhead in the network [18]. Therefore, a number of techniques are introduced to provide efficient multistream coding. Layered and multi-description coding are two existing forms of scalable video coding and are explained in details below.

- **Layered Coding:** In this approach, video is encoded to a base layer and two or more enhanced layers. After decoding the base layer, basic video quality is achieved, and in order to further improve the quality, decoding of the enhanced layers is essential. Protection of the base layer and the retrieval of maximum numbers of enhanced layers is a major challenge for video dissemination [36]. This challenge is addressed by transferring the base layer across the best path and by deploying the optimal amount of network resources for delivering the base layer. This technique guarantees video delivery even with minimum quality (e.g., QCIF). Scalable Video Coding (SVC) is the most well-known example of layered coding. Razzaq et al. [46] use SVC as a solution to the high levels of packet loss in VANETs.
- **Multi Description Coding (MDC):** The main difference between MDC and layered coding is dependency. In layered coding each layer is dependent on the preceding layer with strict dependency between the base and enhanced layers. MDC is a form of scalable video coding where the main purpose is creating several independent layers, known as descriptions [65]. Based on the MDC approach, balanced or unbalanced, descriptions can have similar or different importance. The corruption of any of these descriptions can adversely impact the decoded video quality [67]. Qadri et al. [41] use MDC for a Peer to Peer (P2P) exchange of multimedia data over VANETs to take advantage of path diversity inherent to vehicular networks.

In [42], they discuss the advantages of MDC's layer independence when compared to layered coding such as SVC.

2.2.3.2 Error Resilience Techniques

Video coding using non scalable and layered coding create substreams of video data that are extremely sensitive to packet corruption. A small error in one block of this compressed video data can have a huge impact on video quality at the receivers end. Retransmission of redundant packets to compensate for packet loss is a way to provide error recovery in the application layer, but it is not always a suitable solution. Therefore, keeping some redundancy in video streams among coding processes can reduce inter-dependency between video blocks [18]. Packet Redundancy, MDC, Erasure Coding (EC) and Network Coding (NC) are techniques that consider error resilience and are explained briefly below.

- **Packet Redundancy:** A reliable protocol should guarantee that transmitted data by sender is delivered to the intended receivers. Retransmission of data packets is one of the traditional way to recover lost packets in the network. For unicast transmission is easier to satisfy protocol reliability using this technique, but for broadcasting it is not always the case, while broadcasting storms could easily happen. Moreover, packet redundancy could affect on protocol reliability by providing duplicated packets in the receiver's vehicles.
- **MDC:** This scalable video coding technique provides a certain redundancy between the descriptions which provides it with the capability to tackle transmission errors [18].
- **Erasure Coding:** Erasure coding provides redundancy in video streams without a tangible effect on the total overhead in the network. In order to distribute video content using this technique, the video stream must initially be divided into n number of blocks which are then encoded to generate a larger set of m blocks. Optimal erasure coding recovers the original video by receiving at least n blocks,

ensuring that at least one of the original initially divided n blocks is included [68]. Reed-solomon [69] and Tornardo [37] coding are the most well-known algorithms that are used in case of erasure coding to encode and decode video blocks. Sardari et al. in [51], [52] show the use of erasure coding for VANETs. In their scheme, RSUs work together with vehicular nodes trying to improve delivery ratio and decrease delay in the dissemination of multimedia data in the vicinity of available RSUs.

- Network Coding:** The idea of network coding, proposed by Ahlswede et al. [7], showed that the combination of video data packets using a linear function is a robust solution for saving in bandwidth and improving network throughput. Traditionally, source nodes send simple video data packets while intermediate nodes only replicate and relay the received original packets. In this approach, if a node receives more than one packet (e.g. packet A, B), it can encode them using a linear function f and forward a packet $f(A, B)$ with a size equal to the size of the original packets [29]. To achieve better results, the linear function can be designed randomly to generate new packets by different combinations of buffered packets [24]. A. Chou et al., [17] improved the network coding concept by proposing a practical solution for wireless networks with link failures, variable capacity nodes, packet loss, and delay where the actual broadcast capacity is unknown. They introduce a buffering model and a packet format that removes the need for any centralized knowledge of graph topology or encoding and decoding functions. This work attempts to focus on the network coding techniques to study the impact of network coding on video quality where video packets are transmitted over vehicular networks. In this technique, video data may be encoded only at the source node, while intermediate nodes simply forward the coded packets. Furthermore, some proposed approaches [40], [39], [73] apply network coding at both source and intermediate nodes, where the intermediate nodes re-encode recovered packets and then forward these newly re-encoded packets to all vehicles in their radio transmission range.

2.3 Comparison of Video Streaming Protocols

This section summarizes the qualitative performance evaluation of proposed techniques for video streaming in terms of QoS parameters. The following table can be used as an insight for quantitative comparison in next stage of this study.

Protocol Stack Layer	Category	Technique	Delivery Ratio	Latency	Overhead
Link Layer	Network Congestion Control	Selective Frame Rate	Medium	Medium	Low
		Back-off time and CW Control	Medium	Medium	Low
	QoS Aware		Adaptive	Adaptive	Medium
	Node Selection		Medium	High	Low
Layer Network	Topology Aware	Intersection-based	High	Low	Low
		Density-aware	Medium	Low	Low
		Movement similarity	Medium	Medium	Medium
	Node Selection	Sender-based	Low	Medium	Low
		Receiver-based	High	High	High
Application Layer	Multiple Video Layers	Layered Coding	Medium	Medium	Medium
		Multi Description Coding	High	Medium	High
	Error Resilience Techniques	Erasure Coding	Medium	Low	High
		Network Coding	High	Medium	Medium

Table 2.3: Qualitative Comparison

As has been highlighted in table 2.3 following techniques provide high delivery ratio: Topology aware intersection-based approach, Receiver-based node selection technique, Multi Description Coding and network coding.

The selective frame rate, Back-off time and CW Control, and node selection techniques are solutions that provide medium delivery ratio over link layer. Since node selection techniques in link layer cause high latency and can deploy on the network layer, this study is not going to discuss it in further detail. The other two techniques seem to have similar conditions, in terms of QoS parameters that have been shown in this table. However, a selective frame rate technique delivers lower quality video, specifically in the case of a high data rate, namely because of frame dropping. As a result, this research is more interested in Back-off time and CW Control technique as a solution over link layer.

In terms of network layer techniques, intersection-based technique is a practical solution in the context of urban scenarios while the focus of this study is on highway scenarios. Therefore, a receiver-based node selection technique could be a considerable solution to enhance QoS for broadcasting video among vehicles in highways.

In the application layer, NC technique get more attention in this study because it has the advantage of less packet overhead, compared to MDC.

2.4 Summary

There are a number of outstanding services envisioned for vehicular networks that require the provision of video streaming and multimedia dissemination support. Due to stringent requirements for video streaming and the highly dynamic topology of vehicular networks, the design of an efficient protocol for the dissemination high quality video over VANETs becomes extremely challenging. This chapter presented related background by introducing basic definitions, concepts and measurement criteria related to video streaming processes on vehicular environment. This chapter will be followed by a profound literature review that categorizes video streaming techniques based on their involved protocol stack layer. This layer-wise classification provided a broad view of the current existing video streaming techniques and protocols for VANETs. It also gives a clear vision to state advantages and disadvantages of each technique and examines solutions that can improve performance of a video streaming protocol in terms of QoS parameters. The study concludes with a qualitative comparison of existing techniques which is provided and summarized results of all findings in this chapter.

Chapter 3

Methodology

This chapter describes the methodology that is used to gather and summarize data for this research. This methodology aims at designing a rich structure to investigate the challenges of video streaming in VANETs and analyzes its enabling solutions and techniques. The organization of this chapter is as follows:

A research model for investigating video streaming over VANETs is defined based on the analyses of prior studies in VANETs. The research model that illustrated in figure 3.1 outlines relation between different stages of this study to meet the final objectives that are listed in chapter 1.

The use of an experimental approach is one of the best ways to do a research in video streaming protocols over VANETs. The fundamental reason for choosing this approach is to validate the advantages of the rationale behind the design of protocols for VANETs. Therefore, this study tests a number of experimental hypothesis by doing simulation.

The final section describes all simulation software, support measurement tools and mobility models used to perform experimental analysis of video streaming techniques. These software and tools have been selected based on preferred software in similar studies and experience of PARADISE Laboratory members.

3.1 Research Model

The survey on a number of studies, as discussed in chapter 2, defines that there still is some lack of reliability and consistency for supporting QoS parameters in proposed video streaming techniques. As a result, it is important to investigate the strength and weakness of these techniques and enhance their performance to fulfil QoS requirements. The diversity of existing video streaming solutions, and the specific category that they belong to, is susceptible to have an influence on QoS parameters in received video at the involved vehicles. This research model is described in this chapter, after taking into account the relation between different video streaming categories and its QoS parameters.

The methodology of this research work is a combination of the qualitative and quantitative comparisons between different video dissemination approaches over VANETs. The qualitative comparison surveys different approaches in a theoretical fashion, whereas the quantitative comparison provides some insight on the impact of these approaches on the network performance. These comparisons offer a strong guideline as well as solutions for video streaming over vehicular networks.

3.1.1 Prior Studies and Literature Review

To initiate the leading phase of this research study, a well-performed analysis of the proposed protocols for video dissemination over ad hoc networks has to be conducted. In order to achieve this purpose, a thorough literature review has been performed to form a strong basis for framing and refining the research objectives. These existing works have proposed protocols that applied different techniques in vehicular environment to enhance video streaming capabilities. A number of these protocols use similar techniques in various ways, or enhance the video streaming performance by deploying a robust technique in correlation with other approaches in an optimal manner. An investigation into all details, aspects and nuances of these protocols, and defining weaknesses and strengths of their solutions, lends a broad view to the author for defining other stages

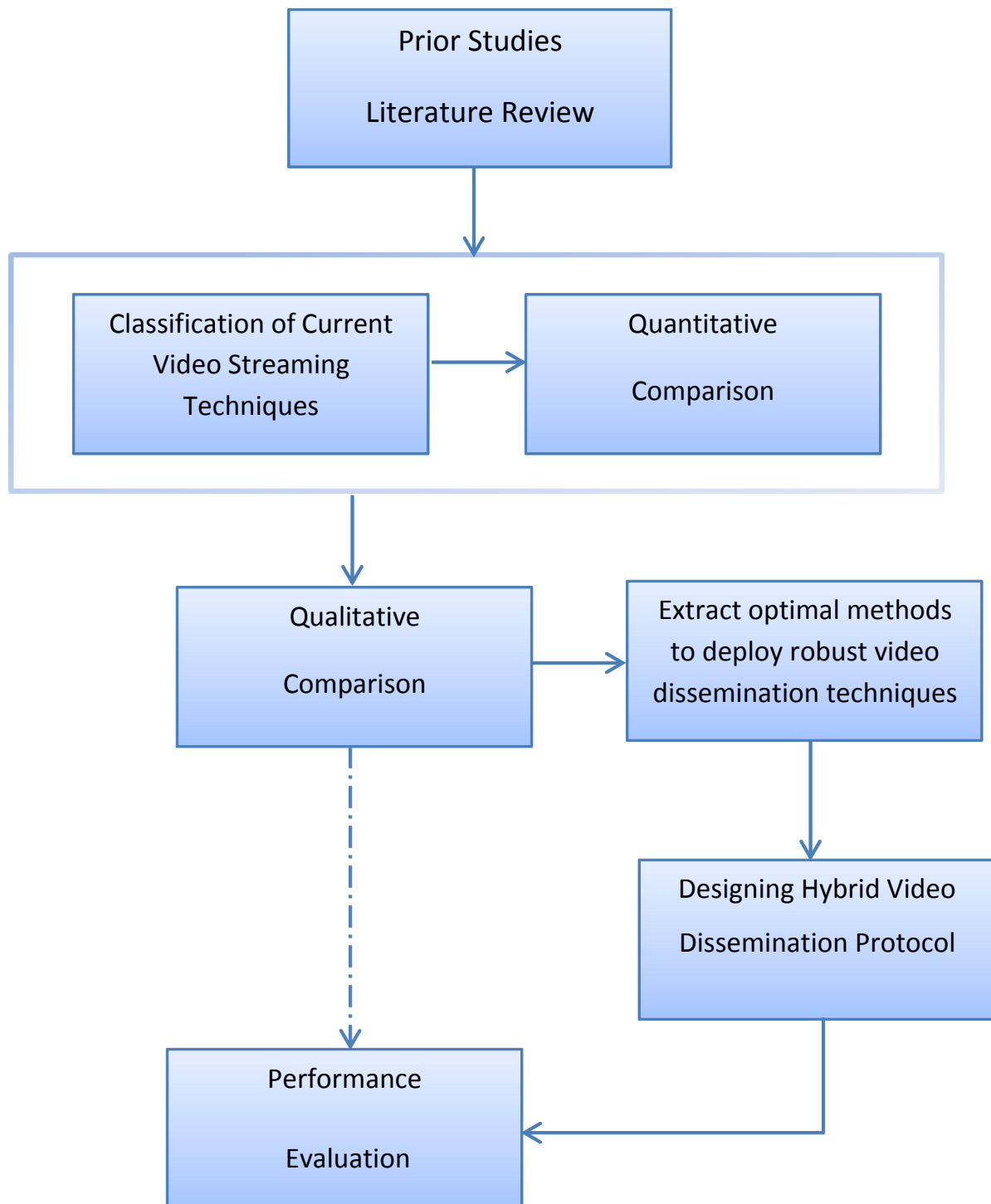


Figure 3.1: Model of Research for Video Streaming over VANETs

of this research. It is important to mention that this study has covered a majority of the proposed solutions for video streaming over VANETs in the last decade. However, it highlights more relevant studies and techniques to this research work.

3.1.2 Classification of Current Video Streaming Techniques

The classification of any technique should be based on the properties that can be attributed to that specific technique and distinguishes it from the others. The result of an effective classification leads to a determination of major aspects of video streaming techniques which characterize them. Consequently, this research has looked at a major aspect that can distinguish video streaming techniques and justify the performance of proposed solutions for broadcasting video over VANETs. As a result, a layer-centric classification has been selected to categorize existing video streaming techniques in vehicular environment. A number of proposed solutions in the literature are cross-layered but the important point is that they still focus more on specific protocol stack layer that is described before. Therefore, this research has fitted all discussed protocols in three major categories: (1) Link Layer techniques (2) Network layer techniques and (3) Application Layer techniques that are discussed in detail in previous chapter.

3.1.3 Qualitative Comparison

A strong and clear literature review led this thesis to perform a qualitative comparison between proposed techniques for video dissemination over VANETs. On the first stage, all parameters that have to be considered for a complete comparison should be defined. These parameters are known as QoS metrics, that have been defined in chapter 1 and chapter 2, where their selection process is discussed in more detail. However, it is important to know how to evaluate video streaming techniques using these parameters. The performance of all these techniques have been evaluated by some experimental analysis to prove their robustness compare to similar proposed techniques. This study takes advan-

tage of these experimental studies for each technique to perform a qualitative comparison between all discussed video streaming techniques in the vehicular environment. On the other hand, the accuracy of this comparison could not be very high due to some differences between the QoS parameters, networking scenarios and other involved parameters in simulation such as different transmission ranges, number of vehicles in the network and other criteria that are listed in table 2.1. Therefore, relying on this comparison is not enough to evaluate and define the most efficient techniques for video broadcasting but it is an initial step for a quantitative comparison to pick those techniques that are more promising under different network scenarios based on involved QoS metrics.

3.1.4 Quantitative Comparison

As mentioned earlier, applying a comparison based on achieved results in different networking scenarios with different parameters is not strong enough to make a theory on video streaming protocols in vehicular environments. This stage of study deals with the shortage of the qualitative comparison to obtain accurate data by doing further analysis on functionality and performance of selected techniques, using an experimental approach. A first step, the metrics that have an effect on protocol performance should be defined. In order to achieve this requirement, an approved study with experts [59] has been selected as a reference, which is provided by Cisco to specify the quality of service parameters for video streaming in high dynamic environments such as VANETs. As listed in table 1.1, this article defines these parameters as (1) Delay and (2) Delivery ratio with a specific threshold. In addition to these two metrics, the cost of the network is another critical parameter that could not be ignored in a case of evaluation of networking protocols. This metric can be measured by determining the number of packets that are sent and received by involved nodes in the network, known as transmission overhead.

3.1.5 Hybrid Video Dissemination Protocol

Since the number of video streaming applications for VANETs is growing, the design of an efficient protocol has become a necessity. In order to reach this goal, a hybrid solution has been chosen. This protocol is a combination of all protocols presented in the qualitative study and takes advantages of the best characteristics of these protocols in an optimal manner. Moreover, some other techniques that are found effective for video streaming, and tested by performing simulation analysis, are combined to improve performance of this hybrid protocol.

3.1.6 Performance Evaluation

This study performs a qualitative comparison as discussed in previous section. Further, on a count of the evaluation performance of selected protocols compare to the hybrid protocol, number of simulations should run under the same condition with the same network scenario. All networking protocols can be simulated using existing simulation software and their performance can be evaluated by measuring the QoS parameters using sufficient measurement tools. The detailed description and reasons for selecting specific software and tools for quantitative study are discussed in the simulation set-up section. There are some metrics that are not the same for all nodes in the network. The distance from the source of the video is one of these parameter that has been considered in this study. The effect of data rate is another parameter that has impact on other variables in the network. In order to analyse the impact of data rate, other parameters should remain unaltered in network and simulations run under different data rates.

The detailed steps of protocols' evaluation has been elaborated in following sections.

3.1.7 Optimal Method for Deploying Video Streaming Solutions

Existing solutions that have been chosen in this study are considered efficient and robust solutions for video streaming over VANETs based on qualitative comparison results. Moreover, this study proves this assertion by completing an experimental analysis on these techniques. The important question that attracts an author's attention in this point is that "Is there any other way for deploying these techniques to enhance the quality of video in end receivers ? ". In order to answer this question two techniques in the application layer have been selected for further analysis. The achieved results of this analysis are discussed in the next chapter to provide a guideline for deploying selected techniques. The focus of this section is more on application layer solutions, while it can extend to reliable techniques in other protocol stack layers.

3.2 Experimental Approach

As mentioned previously, this study includes a number of evaluations, analyses and implementations of the proposed video streaming approaches. Therefore, choosing a reliable technique to conduct an accurate experiment study by enabling a thorough performance evaluation is important in this research. In order to collect data and control variables, this study relies on observational and experimental methods. The defined hypothesis for video streaming over VANETs could test and evaluate quantitatively in an applicable research environment, which can be an actual condition experience or imitation of real world networking scenarios using specific software and tools. In general, performance of any network solution, including the proposed protocols for video dissemination over VANETs, can be evaluated in three different ways: (1) Mathematical analysis, (2) Network simulation or (3) Conduction of real world experiments [36]. Mathematical analysis is mostly practical for the deterministic schemes where their performance can be sufficiently modelled and parametrized by mathematical formula. On the other hand, the

real world experiments are time consuming and costly due to the need of a wide range hardware devices and manpower. Moreover, this way of network solution evaluation faces difficulties according some existing regulations in Canada. Therefore, in case of this study a network modelling using simulators is the best method to evaluate video dissemination techniques over VANETs.

3.3 Research Hypothesis

This thesis has studied number of video streaming techniques and solutions over VANETs on different layers in the protocol stack. All these techniques have been evaluated using existing tested hypothesis in literatures and based on achieved results in this qualitative state, number of reliable solutions that have better performance in term of QoS requirements have been chosen for further analysis.

In addition, this study intends to evaluate video streaming solutions based on the packet delivery ratio, delay and transmission overhead by means of major parameters that affect video quality [59]. Furthermore, videos are excessively demanding in terms of data rate [41] and, the distance between video source and receivers may also have a huge impact on these parameters depending on other involved factors and the type of application. Therefore, this study attempts to measure how each solution performs through different data rates and how QoS parameters alter in further receivers.

As the result, some hypothesises related to a number of discussed techniques in section 2 have been developed which are listed as follow:

Ha₁: *Deploying Network coding technique at only source node or at both source and intermediate nodes has a different impact on QoS parameters.*

This hypothesis tests the performance of two different types of network coding technique on application layer to define how these approaches affect on video quality at the end receivers.

Ha₂ : *Network coding technique has more impact on delivery ratio on further nodes*

in the network environment.

This hypothesis test whether the distance between source and receivers is susceptible to influence the performance of network coding technique.

Ha₃ : *Number of optimum redundant packets that can improve protocol performance is different depend on the other involved factors in the network.*

This hypothesis tests the role that defining factors in the network such as application type, radio range, distance and routing techniques plays on specifying the ideal number of redundant packets to optimize protocol performance.

The last hypothesis that has been developed by this research study is the main motivation for proposing the hybrid protocol (HVDP).

Ha₄ : *A cross-layer technique outperforms layer centric solutions for video broadcasting over VANETs.*

To estimate the extent to which these hypotheses are supported, various simulation were developed using methodological software and scenarios.

3.4 Experiments Setup

This section describes in detail the vehicle movement scenarios and software that are used for simulating vehicular environments and routing, as well as the measurement tools that are deployed to analyze QoS parameters.

3.4.1 Mobility Model

Mobility in vehicular networks has specific characteristics where vehicles move with high speed in specific roads and streets. In general, VANETs can be divided into two different categories based on their moving scenario. The first category consists of the vehicles that are moving in a city environment, where they usually are limited to lower speed because of more junctions, intersections and traffic lights on their way. In addition, there are more buildings and obstacles in this network environment. This type of movement

is known as the urban mobility scenario. The second category is the highway scenario, where vehicles moving on the freeway, usually with higher speed and in more disconnected platoons. Consequently, these two categories have distinct movement behaviours that lead to different topology scenarios.

This research study attempts to deal with the video streaming challenges in highway scenarios, therefore implementing a movement pattern for the highway is required. The deploying Freeway [10] model is the most common way for implementing a highway scenario. However, this model is not considered as a realistic model in some aspects because fast vehicles that reach vehicles with lower speed do not cross the vehicles and just slow down their speed within a certain range from this vehicle. Therefore, an enhanced model known as Freeway⁺, has been proposed by Rezende et al. in [14] in order to overcome this issue. This model provides a more accurate and dynamic network by not synchronising vehicles' speed in the same lane. The highway in this experimental study has two directions with the same number of straight lanes that cover whole 30 meter highway' width. The speed of vehicles vary between minimum and maximum threshold and change randomly in each S_c second. Moreover, the location of vehicles reset when they reach an edge of the highway which is 12 km long this case. This happens by calling a reset function that replaces vehicles in opposite edge of highway length. The detailed parameters for mobility scenario in this work is provided in table 3.1.

Cold start is a common issue that affect the results of simulations [14] where the nodes are not at stable state in the beginning of networking scenarios. In order to avoid this issue, a waiting time is recommended before distributing video packets. As mentioned in table 3.1, the simulation time is 20 minutes while 10 minutes of this time spend just for reaching a stable state in vehicles' mobility. Another solution for this aforementioned issue is ignoring any exchange of messages that occur in first and last kilometre of the simulated road. This study also has been applied this condition in some simulation scenarios to avoid the effect of cold start. In addition, in the hybrid protocol, null packets start to transmit 1 second before beginning of video packet exchange and

Parameter	Value
Radio Propagation Model	TwoRayGround
MAC Layer	IEEE 802.11/IEEE 802.11P
RXThresh_(Radio Range)	
Antenna	OmniAntenna
Simulation Time	20 mins
Number of Nodes	601
Highway Length	12km
Lanes per Direction	3 - 5m wide each
Speed Limit(m/s)	5-15;10-25;20-40
S_c	60s 10%

Table 3.1: Simulation Parameters

are not evaluated in the final results. All these criteria guarantee simulation results free of cold start effect in analyses that have been provided by this research.

3.4.2 Network Simulator

After dealing with issues of mobility patterns and generating a realistic mobility model, we need to implement a networking scenario with routing protocols and agents working on the vehicles. In order to achieve this objective, a network simulation software is required. OMNet++ [2], Simured [3] and Network Simulator (NS) [1] are number of C++ based software and moulders, respectively, that can be used for implementing networking scenarios.

This study chose the Network Simulator version 2 (NS-2) that had been tested with expertise in PARADISE laboratory and it is known as a standard experiment environment in the research community [1]. Therefore, there is a guarantee that it provides the full functionalities needed in this experimental study. Network simulator is discrete event network simulators that have introduced different series such as NS-1, NS -2 and

NS-3. NS supports modelling for routing schemes, broadcasting protocols and multi hop communication between the RSUs and vehicles. It also facilitates simulation of network scenarios by providing implemented functions and components/modules for well-known protocols and approaches. Implementing a simulation scenario using NS-2 is comprised of two programming language, as shown in figure 3.2. In order to define parameters and initiate configuration of networking scenarios such as number of nodes, nodes' radio range, stop and start time of simulation, and etc, the Tcl language is used. In addition to support detailed protocol simulation, such as packet processing and algorithm implementation, a system programming language is required. NS-2 uses C++ language to fulfil this requirement [66].

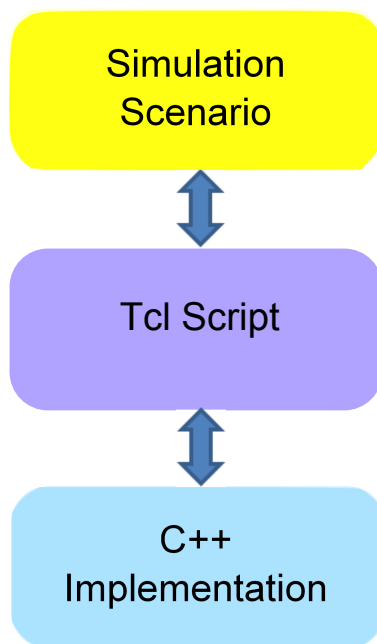


Figure 3.2: NS-2 Environment

3.4.3 Evaluation

In the next stage of the experimental set up, it is important to deal with the data type. The focus of this study is on video content and NS-2 works at the packet level. Therefore,

raw video should convert to data packet to enable transmission of video content via the simulated network scenarios. This work has used EvalVid [32] *A Complete Framework and Tool-set for Video Transmission and Quality Evaluation* to convert the raw video to standard video packets and get results relevant to video streaming.

As discussed in chapter 2, a video file encoded with MPEG consist of I, P and B frames. Using supported codecs in EvalVid video frames are fragmented into 1000 bytes for transmission. In this case, if a frame capacity is more than 1000 bytes, it divides to two or more packets and the overload bytes count as a separate packet. For instance, if an I frame has a capacity of 4350 bytes , it is divided to 5 packets which capacity of four of them is 1000 bytes addition to a packet of 350 bytes. A simple modification is completed in the fragmentation process where the overload byte of any frame integrates with the next frame to provide a lower number of fix size of packets. This conversation process happens in the video encoder stage. The video transmitted in this study is from a well-known benchmark and it is widely available online (akiyo_cif) [71]. This video is in MPEG format with resolution of 360x486 composed of 300 frames, divided into the payload of 1,000 bytes that could fit in 353 different packets. Table 3.2 summarizes all these specification for transmitted video in this experimental study.

Parameter	Value
Video Name	Akiyo_cif
Compression	MPEG
Resolution	360x486
Number of Frames	300
Number of Packets (1000 bytes Payloads)	353

Table 3.2: Video Parameters

It is assumed that video content is distributed by only one camera source and the case of multi sources have not been considered. However, the scalability of each solution was measured by the number of packets transmitted by them and this allows us to estimate

the impact of multi sources.

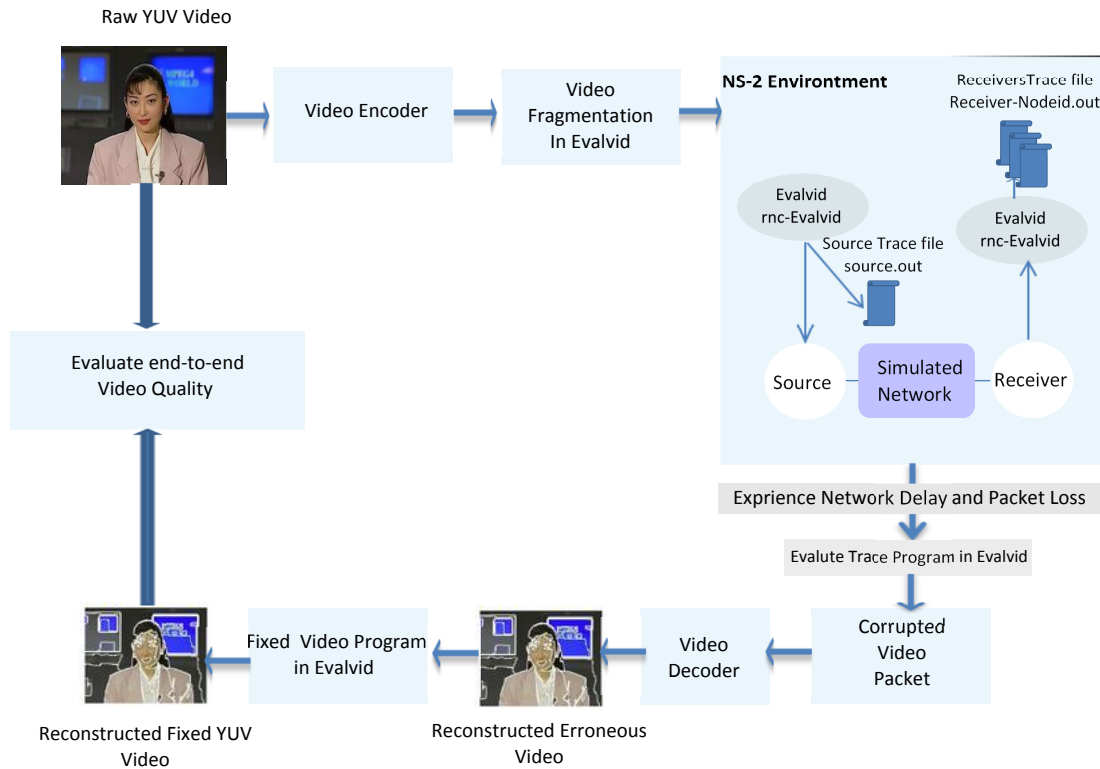


Figure 3.3: Interfaces between EvalVid and NS2 [15]

The EvalVid framework provides some tools to evaluate the quality of video by determining packet and frame loss, in addition to other metrics such as delay, jitter, PSNR and MOS (Mean Opinion Score). In order to measure these parameters, video packets should be traced by generating summary files (Frame Type, Packet ID, Sent Time, Received Time and Number of Bytes) of sent video packets by source and received packets by each node. When the simulation ends, each receiver file assembles what would be the received videos at that specific node/vehicle. EvalVid uses these received files to compare with original video trace file then provides delay, packet loss, PSNR and etc for each receiver' node. This calculation process is extremely time consuming, since it should be repeated for the number of receiver nodes (600 times) for each simulation. In this study delay and packet loss are obtained with the assist of the EvalVid framework. To summarize total

delay and packet loss a script is needed to sum up the achieved results of EvalVid in an appropriate way.

In general, to provide a QoS framework for video streaming over a network scenario an enhancement of EvalVid is required to combine EvalVid with NS-2. As illustrated in figure 3.3 two agents, namely Evalvid and rnc-EvalVid, have been implemented to support the connection interface between these two tool sets. These agents are designed to handle different functions such as reading the video file, receiving the video packets, and the conversion of packet ID and packet type.

3.4.4 Statical Computation

In order to conduct a statistical analysis, a plot of the observed results R [43] has been used. Each plotted point is an average of 15 to 20 runs and confidence intervals are calculated using Student's t-distribution at a confidence level of 95%. Videos are excessively demanding in terms of data rate. Therefore, this study attempts to measure how each solution performs through different data rates. The data rate used here is the network data rate so it is the frequency by which packets are sent by nodes in the network.

Chapter 4

Video Dissemination Protocols

The aim of this chapter is to provide a detailed description of the main solutions that are evaluated in this research study. As a result of a qualitative comparison, the most effective and efficient layer-centric solutions for video dissemination over VANETs have been revised to investigate how these solutions tackle video dissemination challenges and how they perform based on video streaming requirements. The next few paragraphs provide a short introduction of the video dissemination protocols that will be discussed in this chapter.

A Media Access Control (MAC) congestion control mechanism over Wireless Access in Vehicular Environment (WAVE) [27] has been selected as a reliable approach on top of the link layer. This solution adopts a parameter known as Adoptive Offset Slots (AOS), which is used to determine an optimal back-off time based on the network congestion level.

The Reactive, Density-aware and Timely Dissemination (REACT-DIS) protocol is another selected solution that has been implemented over the network layer. REACT-DIS is a receiving-based routing approach that avoids high packet delay and transmission overhead, especially in denser areas.

The Network Coding based Data Dissemination (NCDD) [40] approach has been chosen as one of the best solutions to be used over the application layer. This approach

takes advantage of network coding techniques in the intermediate nodes to improve packet delivery ratio by broadcasting a lesser number of video packets.

Moreover, this study highlights how the network coding technique at the source or intermediate nodes affect video quality in terms of delivery ratio, delay, and transmission overhead. The achieved results in this section provide a clear insight into how to deploy network coding for video streaming over VANETs.

4.1 Description of Protocols

In this section each protocol will be explained in details and a performance evaluation results for different video streaming techniques and protocols over VANETs will also be provided.

4.1.1 MAC Channel Congestion Control Mechanism in IEEE 802.11p/WAVE Vehicle Networks

This study has opted for a link layer-centric solution to evaluate the affect of MAC sub-layer, which is responsible for managing the interaction of devices with the shared wireless medium.

Due to the nature of broadcasting applications, a lot of data traffic in vehicular networks are generated by this type of service. As discussed before, lack of acknowledgement and RTS/CTS control frames in broadcasting scenarios causes problems for the transmitter of messages in choosing an adaptive contention window size to avoid collisions in the network. Consequently, and in most cases, there is no channel reservation and participant nodes access the channel with a fixed constant back-off time. Absence of control frames and failure to allow adaptability in the contention window size can waste the time slots and cause congestion in a shared channel between transmitters of broadcast messages. The channel congestion leads to a high percentage of packet collision and, as a result, causes the network throughput to reduce, especially in the case where the num-

ber of messages transmitted change. As mentioned earlier, the 802.11p uses the EDCA scheme to access channels. EDCA takes advantage of Listen Before Talk and back-off time to enhance its performance and reduce packet collision over a transmission. The channel access parameter ,AIFS gives a number of slots with a duration of 8 s to define a fixed waiting time as the back-off time. The back-off time also consists of a random waiting time which depends on a contention window size where its initial value is given by the factor CW_{min} and doubles when a transmission fails. This number of slots can not exceed CW_{max} , and after each successful transmission, it resets to the value of CW_{min} . As a result, EDCA provides differentiated and distributed channel access by prioritizing packets based on different channel access parameters. In this scheme, whenever a frame is received, the MAC layer maps it to an appropriate Access Category (ACs) including the AIFS and contention window size (CW_{min}, CW_{max}). The set of these parameters used in EDCA/802.11p is shown in table 4.1.

Traffic Type	Message Type	AIFS	CW_{min}	CW_{max}
Voice	Accident	2	3	7
Video	Possibility of Accident	3	3	7
Best-effort	Warning	6	7	15
Background	General	9	15	1023

Table 4.1: EDCA Parameters Set used in CCH [27]

The probability of packet collision can be unexpectedly high in 802.11p, especially immediately after channel switching between SCH and CCH occurs. It is possible that neighbouring vehicles queue data units (in the case of high data rate, for instance) by picking same back-off lengths to access the CCH channel. Consequently, after the SCH and guard interval periods elapse, vehicles wait for the same back-off time and start transmitting buffered packets for CCH transmission. This causes channel congestion and results in a high rate of packet collision. According to the study in [27], the likelihood of collision is higher for smaller CW_{min} , particularly when a higher number of vehicles are involved in the network. The employed mechanism for controlling the contention window size in 802.11p may perform well when there are fewer vehicles competing for

the channel, but it is not an ideal solution when a large number of vehicles need to use the same channel for broadcasting data packets. Therefore, the optimal setting of CW_{min} has a direct affect on controlling back-off time, which can enhance the performance of this scheme and reduce packet collision through the network.

The MAC channel congestion control mechanism in [27] introduces a new parameter called AOS to control the back-off time based on the modified minimal value of CW. In this approach, the CW_{min} value is altered depending on the potential number of vehicles neighbours that have been defined in the congestion estimation function. The number of neighbours is calculated by considering the broadcasted "hello" messages by those neighbours, as it listens to the control channel during the listening time interval.

Each "hello" message contains MAC-id and position information of its transmitter. Therefore, receiver nodes can keep track of their neighbouring nodes by having their MAC-id, GPS position and the quiet duration information, which is the difference between the finished interval time and the timestamp of the last received "hello" message. Each receiver has a neighbouring table that it updates when it receives a new "hello" message or a message with the same MAC-id in a different position. This solution also provides a threshold value that should ideally be more than the "hello" message repetition interval. This allows a node to be removed from the neighbouring table when the quiet duration is larger than that predefined threshold. Since this threshold is larger than the "hello" message repetition interval (in this case is it's twice), a single message loss does not cause node removal from the neighbouring list. MAC channel congestion control mechanism in the contestant estimation function uses the updated information in vehicles' neighbours table to pick the maximum number of vehicles in the last interval or average of neighbouring vehicles in all previous intervals using to the following formula:

$$EST[N] = \max \left(Pre[N_{K-1}], \left[\frac{\sum_{i=1}^k N_i}{k} \right] \right), \quad (4.1)$$

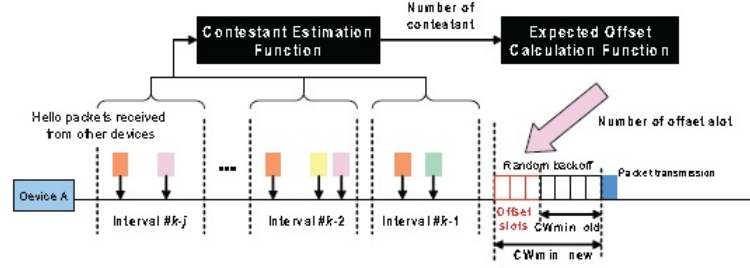


Figure 4.1: The WAVE-AOS Mechanism [27]

In the next step, the number of ideal offset slots is calculated using an estimated constant (N). The expected offset time is the mean of possibilities, which have been derived from the number of neighbouring vehicles of each packet transmitter.

$$EO[N] = \left[\frac{1}{N+1} \sum_{i=0}^N i \right], \quad (4.2)$$

In order to get the new CW_{min} , which controls back-off time in an optimal manner compared to the original 802.11p/WAVE, the calculated number of offset slots should be added to the minimum value of the old contention window size. The new CW_{min} depends on the vehicular traffic volume and logically should outperform WAVE, especially in highly congested networks.

$$CW_{min_{new}} = EO[N] + CW_{min_{old}} \quad (4.3)$$

Figure 4.1 graphically illustrates how contention estimation and expected offset calculation function is performed.

4.1.1.1 Performance Evaluation of WAVE-AOS Mechanism

This work attempts to evaluate the performance of selected reliable protocols in the same networking condition to provide a fair comparison between robust video streaming solutions in the literature. Therefore, in this stage, a simulation scenario has been built

to evaluate the performance of 802.11p/WAVE and MAC channel congestion control mechanism using AOS (WAVE-AOS). In order to implement IEEE 802.11p/WAVE, some modifications have been applied on the MAC 802.11EXT protocol, which is supported by NS-2. The scenario that has been chosen for this experiment is the same as the highway scenario described in Chapter 3.

Both approaches implemented over gossiping, which is a well-known basis scheme for the data dissemination. In the employed gossiping approach, only a predefined percentage of intermediate nodes contribute in broadcasting packets further. This approach is a type of flooding where the source node starts the dissemination by broadcasting packets, and every node that receives a packet retransmits it. The difference with gossiping is that the retransmission of a packet by intermediary nodes is subjected to a random test of probability γ (flooding happens when $\gamma = 100\%$). These are the most simple dissemination protocols but they serve as baselines for delivery ratio, latency and overhead. The protocol followed by gossiping when packets are received is shown in Algorithm 1.

Algorithm 1 Gossiping/Flooding - Receiving packet p

if p has not been received before **then**

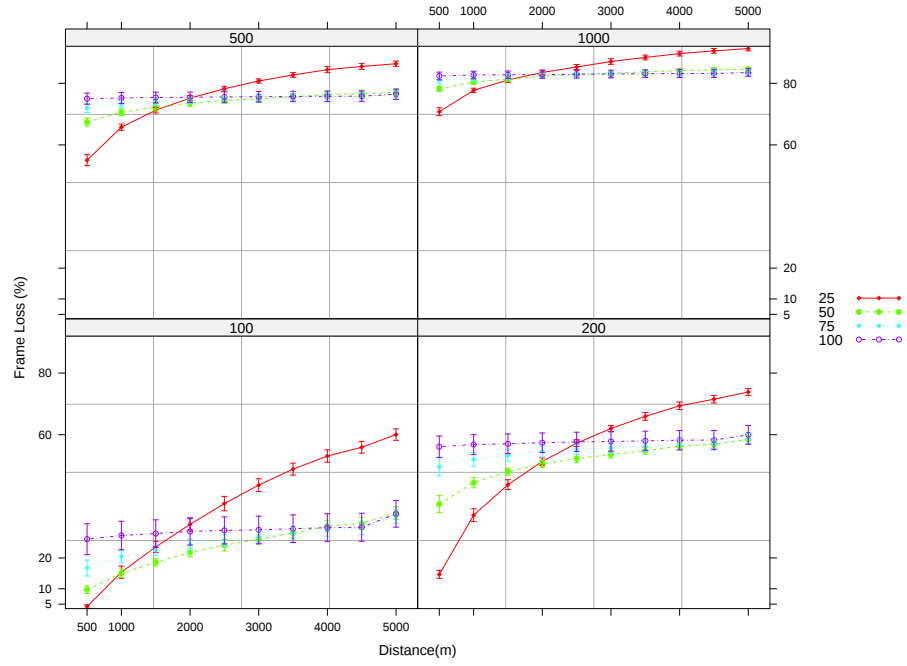
forward packet p with probability γ

$\{Flooding \text{ at } \gamma = 100\%\}$

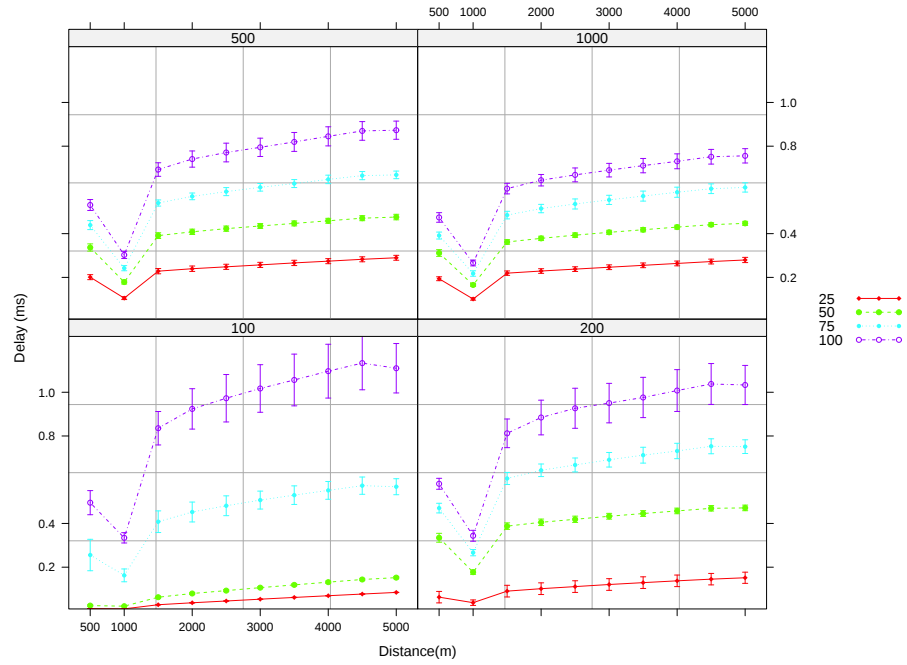
end if

It is important to find the broadcasting percentage γ that will optimize quality of service parameters. In order to find the best condition for deploying flooding/gossiping, a simulation has been implemented with the same scenario and different broadcasting probability. The results of this simulation are shown in the Figure 4.2.

As illustrated in Figure 4.2(a), gossiping with a probability of 50% performs better in terms of packet loss, where its average delay is also lower than flooding and gossiping by 75%. In terms of packet delivery ratio gossiping with a probability of 25% performs well for closer nodes, but it is not an appropriate solution for delivering packets to further nodes in the network.



(a) Packet Loss



(b) Latency

Figure 4.2: Experimental Results of flooding and gossiping approach

It is obvious that rebroadcasting a lower percentage of received packets reduces network cost. Therefore, gossiping with a probability of 25% is the optimum solution in terms of transmission overhead and rebroadcasting half the received packets reduces network cost compared to gossiping by 75% and flooding. However, gossiping with a probability of 50% has nearly the same delivery ratio to the gossiping with higher probability.

In general, based on the achieved results, gossiping with a probability of $\gamma = 50\%$ is the best solution (compared to flooding and gossiping with a probability of 25% and 75%) to enhance and balance video QoS parameters. For this reason, we employ rebroadcasting of half of the received packets by relay nodes to improve performance of the proposed solutions.

In the following section, the performance of WAVE and WAVE-AOS approaches are evaluated on top of gossiping.

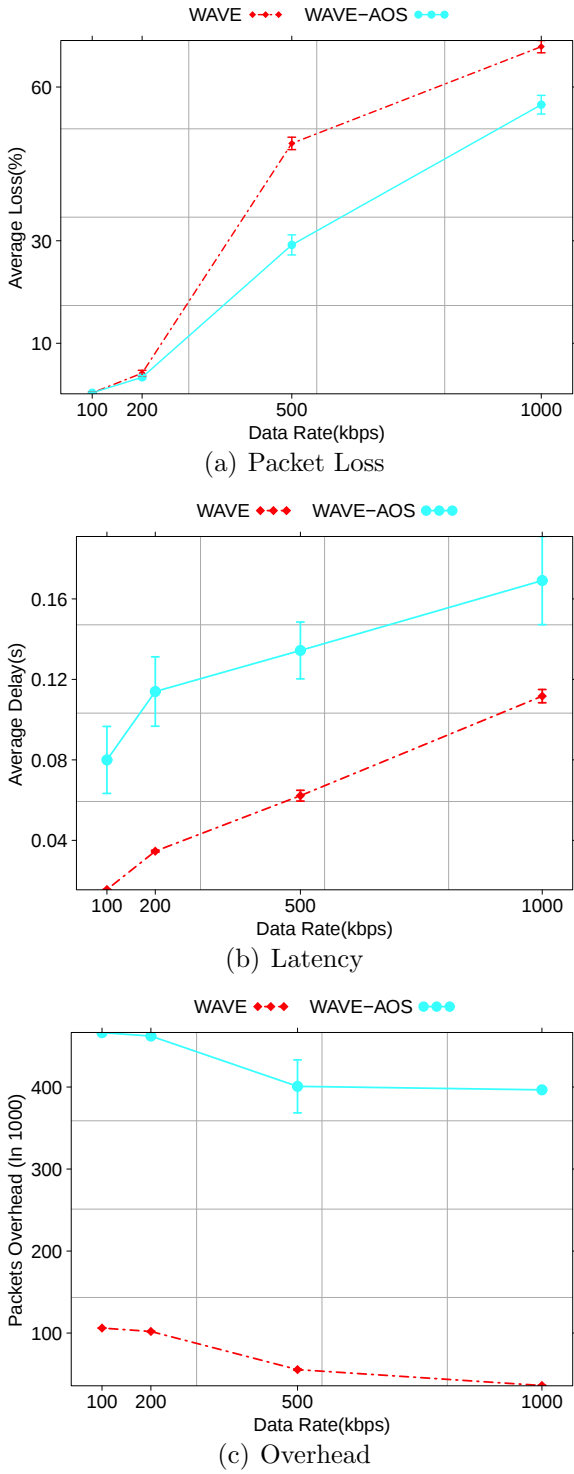


Figure 4.3: Experimental Results of WAVE-AOS vs. WAVE approach

As discussed previously, data rate is a factor that has a huge impact on delivery ratio and packet delay. In other words, delivery ratio and delay are dependent variables that are altered based on data rate in the network. In the case of video streaming, it is important that the network supports high data rates. Therefore, we study the performance of video streaming protocols by forcing different data transmission rates.

Figure 4.3 shows that the frequently of packet collision is reduced by using the AOS mechanism and higher packet delivery ratio is achieved. The gap between plots in 4.3(a) get bigger in higher data rate (500 kbps, 1000 kbps), which shows the WAVE-AOS mechanism performs much better than WAVE when data transmission range is high. In order to increase back-off time in a highly-congested network, the WAVE-AOS approach causes more delay, which is not more than 1 second and still complies with the video-streaming requirements. The number of transmission in WAVE-AOS solution is much higher than the original WAVE due to propagation of "hello" messages. However, that is not considered as a problem while "hello" messages are much smaller than video packets and gathering this information can be used by other layers and approaches. As is shown in 4.3(c), overheads of both applications increase in the same trend, which is clearly impacted by distributing control messages.

4.1.2 Reactive, Density-aware and Timely Dissemination Protocol

Selecting a subset of intermediate nodes as relay nodes in optimal manner can be used as an appropriate solution in data broadcasting to minimize packet redundancy as well as collision and packet latency.

Reactive, Density-aware and Timely Dissemination (REACT-DIS) is a protocol that has been designed to fulfil mentioned requirements for high-quality video streaming in VANETs. This protocol has a reactive approach that employs a specific receiving-based technique in choosing relay nodes to respond to constant topology changes in vehicular environments. Through the receiving-based technique, selection of relay or forwarding nodes is done on the receiver nodes instead of the sender of transmitted messages. As mentioned earlier, according to the study in [70], the receiving-based forwarding scheme outperforms the sender-based scheme in the terms of packet delay, collisions, and overhead. The REACT-DIS takes advantage of this forwarding scheme where the nodes within sender's radio range trigger a mechanism to decide which nodes are going to forward the message further. In this mechanism all the nodes which receive the message schedule themselves to make forwarding decision in t time. The value of waiting time has been chosen from a range $[\alpha, \beta]$ that determines the node suitability to act as a relay node. This waiting time chooses based on the distance of receiver node and sender of disseminated message and it is shorter for the receivers that have more potential to be ideal forwarding node. The minimum value of this range is equal to θ , which is a maximum random delay time between forwarding packets with the selected relay node. As simultaneous transmission, especially in the case of broadcasting, leads to large numbers of collisions, forcing a minimum delay between forwarding packets can have huge impact in reducing packet collision. Based on the study that has been done by C. Rezende in [48], 10 ms is the optimum maximum delay time in this case. Before t expires all the scheduled nodes sense the channel to keep track of overheard duplicate packets to

be aware of local density and to make their decision for forwarding the message based on the overhead broadcasts after the time out. In most of the receiving-base solutions and in case of unicast, t value is inversely proportional to the distance of relay node and destination node but as it is defined in following equation, REACT-DIS has considered distance between last hop node and potential relay nodes divided by sender' radio range.

$$t = \left[\left(1 - \frac{d(n_s, n_r)}{R} \right) (\beta - \alpha) \right] + \alpha \quad (4.4)$$

One of the main purposes of this study and much of the proposed solutions for data dissemination in any networking scenario is saving the cost of transmission by optimizing the trade-off of overhead. This become complicated when you want to achieve high delivery ratio in the wide density variety environments. As discussed before, many factors such as road intersections, traffic lights, constructions or even accidents make density of vehicular environment fluctuate and make it non-uniform and dynamic. REACT-DIS overcomes this issue by choosing a variable number of relay nodes dependent on the density of each region since any receiver keeps track of number of duplicated packets during its t time and a node forward the packet with probability of ρ which is inversely proportional to the number of overheard copies of the same message c . This probability is given by the following equation.

$$\rho = \frac{1}{r^c} \quad (4.5)$$

The r variable, known as forwarding probability reducer, has been tested by picking different constant numbers. As the result the ideal number for r is 10 while it alters the forwarding probability to optimal percentage that saves cost of transmission and at the same time delivers acceptable percentage of broadcast packets.

By this manner, the relay node selection method is dependent on the receiver' suitability based on the node distance from last sender and the density and congestion of vehicles on its vicinity. Consequently, nodes in regions with high density have a lower percentage to forward the broadcast message further while in sparse regions, nodes have

higher chance to act as a relay node. In other words, the chance of a node to become a relay node starts at 100% if no retransmission of the packet is observed and it decreases exponentially with the number of overheard retransmissions. This selection mechanism make REACT-DIS a density-aware receiving-based protocol.

Another common issue in receiving-based solutions is the end-to-end delay caused by the waiting time for choosing the optimal relay nodes to rebroadcast the messages. The REACT-DIS tackles this issue by extending the decision of a node to become a relay node from a single transmission to predefined amount of time ϕ . Therefore, there is no need to repeat competition between receiver nodes and wait for new relay nodes in this specific time window. Selected nodes continuously forward sequential receiving packets and in order to prevent another node to forward the message in place of previous relay node the waiting time should be larger than maximum additional random delay. Consequently α picks same value as maximum delay between packets forward θ which is 10 ms. This solution does not impact the ability of REACT-DIS to act in response to the link breakage while eligible neighbours of an unreachable relay node can compete in the same way to replace its role.

There is the possibility that excessive number of nodes consider themselves as a suitable node for forwarding packets further and cause unnecessary packet transmission over the network. In order to avoid this issue, the density aware principle should adapt by relay nodes with the help of a probability δ to decide if specific packets should be forwarded. This probability alter using following formula:

$$\delta = \begin{cases} 1.0 & \text{if } c \leq k \\ 1.0 - [(c - k) \times \Lambda] & \text{if } c > k \end{cases} \quad (4.6)$$

Where the k is the maximum ideal number of relay nodes in a same vicinity that are required to optimize packet delivery by saving transmission cost. In case of REACT-DIS, authors [48] consider if more than four nodes rebroadcast message in same broadcasting zone of another relay node, its transmission is probably unnecessary ($k=4$). In this

equation, Λ is a constant variable which is known as relay node forwarding probability reducing factor. The Λ value addition to value of three more involved variable (β, r and ϕ) has huge influence on REACT-DIS performance.

Algorithm 2 shows the detail steps of this protocol to deal by receiving packets.

Algorithm 2 REACT-DIS - Receiving packet p

```

if  $p$  has not been received before then
  if node is a relay node then
    forward packet  $p$  with probability depending on the number  $c$  of duplicates
    reset counter  $c$ 
  else
    if node is scheduled to try to broadcast then
      insert  $p$  into buffer of packets to send
    else {Node is idle}
      Schedule to try to become a relay node; store  $p$ 
    end if
  end if
else { $p$  has been received before}
  increment counter  $c$ 
end if

```

As mentioned in this algorithm, when a packet has not been received before by a receiver node, three possibility should consider. The receiver node can be a relay node then it immediately forwards the packet further with the probability δ and reduce the counter c . However if the node has scheduled to attempt to broadcast, it keeps the packet into a buffer and waits for the next stage of transmission. Packet may also receive by an idle nodes and these nodes only schedule themselves to try to broadcast the packet after t time. The process of buffering packets is essential because the transmission data rate usually is large enough to receive more than one packet before expiration of t . Whenever the t expires, each node should calculate its forwarding probability using the following

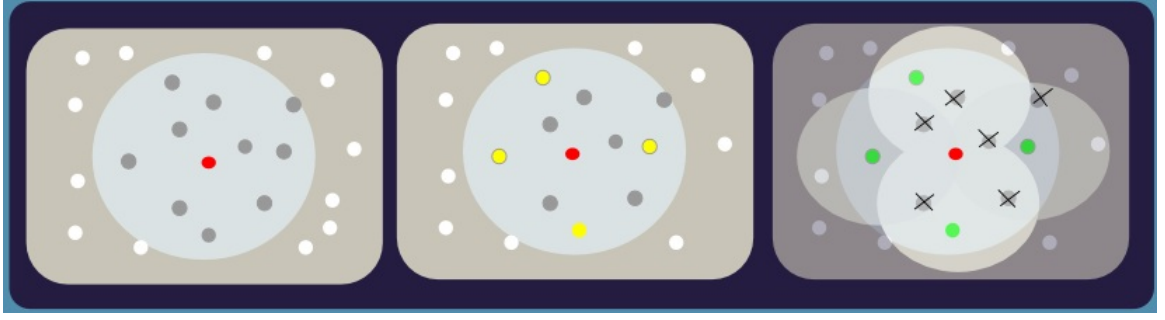


Figure 4.4: Dissemination of video content in REACT-DIS approach

formula where the s is the number of buffered packets and the node that has more buffered packets has more chance to forward the packet.

$$\rho = \frac{1}{r^{c/s}} \quad (4.7)$$

In the case that packet has been received before, broadcasting the packet with high probability increases the transmission cost then REACT-DIS handles this situation by incrementing c when both relay nodes and nodes that are scheduled to try to broadcast receive a duplicate packet. As it's shown in equation 4.6, when the counter c increases the probability of broadcasting the same packet at the relay nodes decrease proportionally.

Figure 4.4 illustrates the process of video content dissemination in REACT-DIS and graphically shows the steps taken by this approach to select optimal relay nodes.

4.1.3 Network Coding based Data Dissemination

As mentioned in chapter 2, the network coding technique provides a way to combine packets in an efficient manner. Furthermore, sending an encoded packet instead of original packets could save lots of bandwidth and network cost while enhance network throughput.

Network Coding based Data Dissemination [40] is a robust protocol that uses the network coding technique to take advantage of shared medium to achieve high delivery ratio. This approach proposes a reliable video packet delivery within contiguous platoon and delayed delivery using "data muling" technique in case of disconnected platoon through the network area. NCDD guarantees high delivery ratio and low transmission overhead. This section describes this protocol in details and arranges a deep study on different types of network coding technique to provide a clear insight for employing NC in optimal manner.

NCDD employs a block coding scheme to provide encoding and forwarding under random linear coding framework. As a result, in this protocol the original stream of generated video at the source node divides into n number of blocks $b = b[i]$ with fixed number of segments $P_1, P_2, P_3, \dots$ as a primary step in using network *Block* coding technique. Each block is distinguished by a unique ID that is equal to the first segment' number belonging to the same block. A coded packet $C_{(B_{id}, \eta)}$ is a linear combination of the segments in $(blockid, blocksize)$.

$$C_{(B_{id}, \eta)} = \sum_{k=1}^{\eta} e_k P_{(k-1+B_{id})} \quad (4.8)$$

When intermediate nodes receive a first packet of a new encoded block, they schedule themselves to handle received packets at a time proportional to η divided by the data rate, which is the expected time to receive η packets from a block. In expiration of timers, receivers check that they have received enough packets to recover the original video frames and re-encode the coded packets to disseminate them further or they need

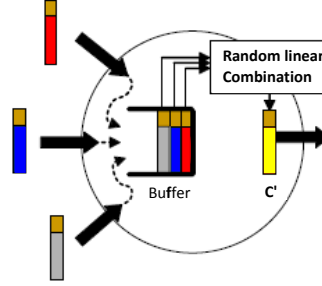


Figure 4.5: Re-encoding at intermediate nodes [40]

more segments of same block for frame recovery and re-encoding. A coefficient e_k , which is randomly chosen from a finite field F , is embedded in each received block in order to generate a matrix used to decode the original block by multiplying the inverted coefficient matrix with the coded block.

$$P = E^{-1}C \quad (4.9)$$

In case of receiving *blocksize* of encoded packet, intermediate nodes broadcast η newly encoded packets, which are produced using same random linear combination at the source. Otherwise, they broadcast a help message with the number of missed frame is known as *rank*, with a specific block ID requesting neighbouring nodes to pass them further packets. The neighbour nodes that have received the same block before, respond to help message by sending *rank* number of encoded packets to the source of the message. Re-encoding process at intermediate nodes has been shown in Figure 4.5.

In general, NCDD aims to take advantage of the network coding capability of permitting intermediary nodes to generate new encoded packets by re-encoding received packets, thus, they can efficiently use the shared wireless medium. Algorithm 3 shows how nodes handle incoming packets.

As mentioned before this study also evaluates the impact of network coding by itself. For this purpose, we have expanded gossiping to use network coding where there are two ways of using NC in this circumstance. The first is using it through intermediary nodes

Algorithm 3 NCDD - Receiving packet p

```

if  $p$  has not been received before then
    if  $p$  first packet from  $p$ 's block then
        Schedule to try to broadcast newly encoded packets in  $\frac{\eta}{data\ rate}$  seconds.
    else
        store  $p$ 
    end if
end if

```

with a similar perspective to NCDD. For clarity reasons, the remainder of this paper refers to this approach as Network Coding at Intermediary nodes (NC-Intermediate).

4.1.3.1 Network Coding at Intermediary Nodes

Results from previous works [39], [40], [73] showed that deploying a random linear function to encode received packets at the intermediate nodes improves the overall delivery ratio in VANETs. As mentioned in NCDD section 4.1.3, intermediate nodes usually set up a timer to wait for a specific time before receiving the whole block of coded packets from the source or its neighbours. In this scheme, only an intermediate node that receives *blocksize* number of frames forwards re-encoded packets, otherwise it is not able to contribute to the broadcasting. Obviously, waiting to collect the whole block of coded packets before forwarding the video frames increases the packet delay and have an effect on the quality of service.

Differently from NCDD, NC-Intermediate does not use help messages, so it does not require a timer and the broadcast of newly encoded packets is performed once a block can be decoded upon the reception of a new packet. The η newly encoded packets are all broadcast following the same dissemination strategy of flooding based on a probabilistic approach. Algorithm 4 describes the behaviour of a node using NC-Intermediate when it receives a packet.

The second method is coding solely in the source node itself, which is known as

Algorithm 4 NC-Intermediate - Receiving packet p

```

if  $p$  has not been received before then
    if  $p$ 's block can now be decoded then
        forward  $\eta$  newly encoded packets with probability  $\gamma$ 
    end if
end if

```

Network Coding at Source nodes (NC-Source).

4.1.3.2 Network Coding at Source

NC-Source follows the exact same approach as flooding with predefined probability for forwarding packets (gossiping) in intermediate nodes. The difference is that, instead of non-encoded packets, the source node broadcasts encoded packets. This solution does not require intermediary nodes to wait for the reception of η packets to continue the dissemination process, however, they do not fully take advantage of an efficient use of the available bandwidth.

4.1.3.3 Performance Study of Network Coding Techniques

In this section a qualitative comparison has been completed to give an overview to number of protocols that employs network coding techniques at source and intermediate nodes in different manner. After that the results of a quantitative comparison between NC-Intermediate and NC-Source have been illustrated to prove assertions about NC in this study.

Table 4.2 compares a number of video broadcasting approaches that use network coding technique. CodeCast [39] is a specific version of NCDD . This scheme is a network coding based multicast protocol which applies random network coding technique to provide localized loss recovery and path diversity with very low overhead. CodeCast employs same technique as NCDD to encode and decode video frames and use sub graph

Video Broadcasting Protocols	Video Coding Technique	Packet Delivery Ratio	Delay	Overhead
NCDD	Network Coding At source and intermediate nodes	High Acceptable	High Not Acceptable	Medium
CodeCast	Network Coding At source and subset of intermediate nodes	High Acceptable	Medium Not Acceptable	Low
CodePlay	Symbol-level Network Coding At source and subset of intermediate nodes	High Acceptable	Medium Not Acceptable	Low
SVC	MCD & Network Coding At source and subset of intermediate nodes	High Acceptable	Medium Not Acceptable	Low

Table 4.2: Comparison of Existing Protocols for Network Coding

selection to find optimal set of relay nodes and frequency of injection packets. Another presented approach in this table, CodePlay [73], is a live multimedia streaming scheme in VANETs that takes advantage of symbol-level network coding (SLNC) to improve performance of video streaming delivery rate, delay and bandwidth efficiency. SLNC performs network coding on smaller symbols which refers to group of consecutive bits within a packet to get benefit from network coding as well as symbol-level diversity in wireless transmission. In addition, it provides a Coordinated Local Push (CLP) based on SLNC to select distributed relay nodes and coordinate transmission of relays. Scalable Video Coding (SVC) [46] is another protocol that provides a robust video coding scheme over an urban VANET with path diversity and network coding. This approach classifies video bit-stream to a base layer and one or more enhanced layers. SVC calculates the robustness and quality of all available path using Grey Relational Analysis (GRA) and then assigns path to different layers according to their importance. In addition, in order to receive higher quality video using enhancement layers, this technique selects nearby nodes to the receiver along the transmission path to be used for network coding. Selected nodes XOR specific combination of sub-stream packets to maximize throughput. All of these protocols operate well in term of packet delivery and overhead but they can not guaranty acceptable packet delivery time by using network coding at both source and intermediate nodes.

In order to simulate two different network coding techniques which are described in this section, same highway scenario in chapter 3 is used. We also used this opportunity to study impact of packet redundancy in video streaming using network coding. In all the solutions, the $\eta = 8$ and $\kappa = 12, 16$ which means for the cases that used forced additional redundancy, there was an increase of 50% and 100% in the number of packets sent.

As a result, optimum percentage of redundant packet that enhance wireless network performance is obtained by analysing below results.

As both Figures 4.6 and 4.7 show, the effect of application layer solutions can be extended by employing hybrid approaches that consider additional redundancy in network coding where source or intermediate nodes forward κ newly encoded packets.

Figure 4.6(a) shows packet loss for two NC techniques with a different percentage of redundant packet in nodes within different distance from source. Deployment of NC-Source without injecting redundant packets in the network has the worse result in packet loss for different data rate. It happens because losing a packet can cause losing all of the received packet in the same block while receivers are not able to decode encoded packets. However, in case of lower data rate, NC-source with increase of 50% and 100% perform better than NC-Intermediate with same number of redundant packets. The interesting point is the trend of plots in high data rate networks, which increase smoothly for NC-Intermediate while for NC at source node, packet loss increase sharply. This means, NC-Intermediate is better solution to guarantee higher delivery ratio in further nodes in the network.

NC-intermediate with 50% and 100% increase in redundant packets, result in close delivery ratio and cause almost same amount of delay in different data rates. Therefore, by considering higher transmission overhead for NC-Intermediate with 100% increase, we can conclude that generally NC-Intermediate with 50% performs better. This case is different for NC at source while NC-Source with 100% always outperform NC-Source with 50% redundancy in terms of packet delivery ratio. However, having two times more

packets, increases cost of network highly that in some cases is not tolerable.

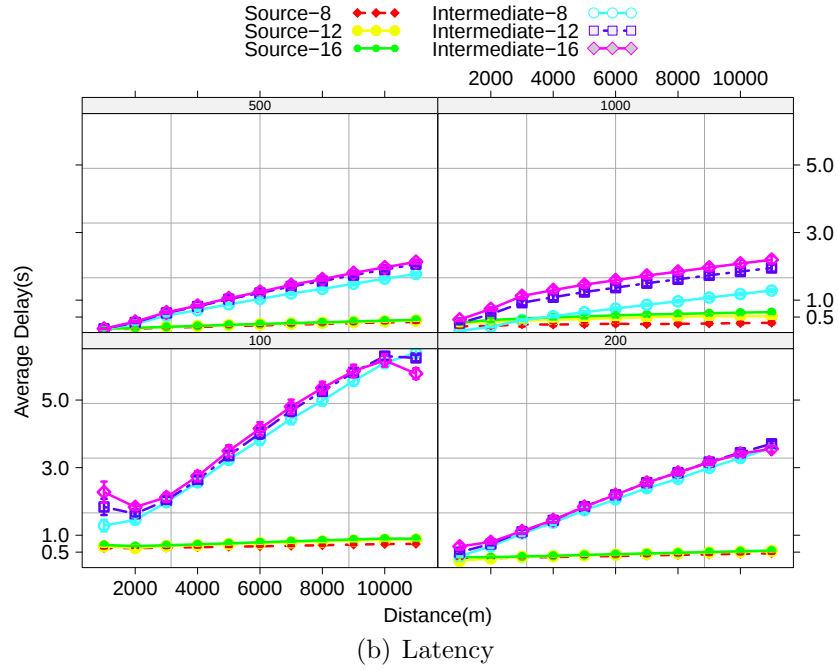
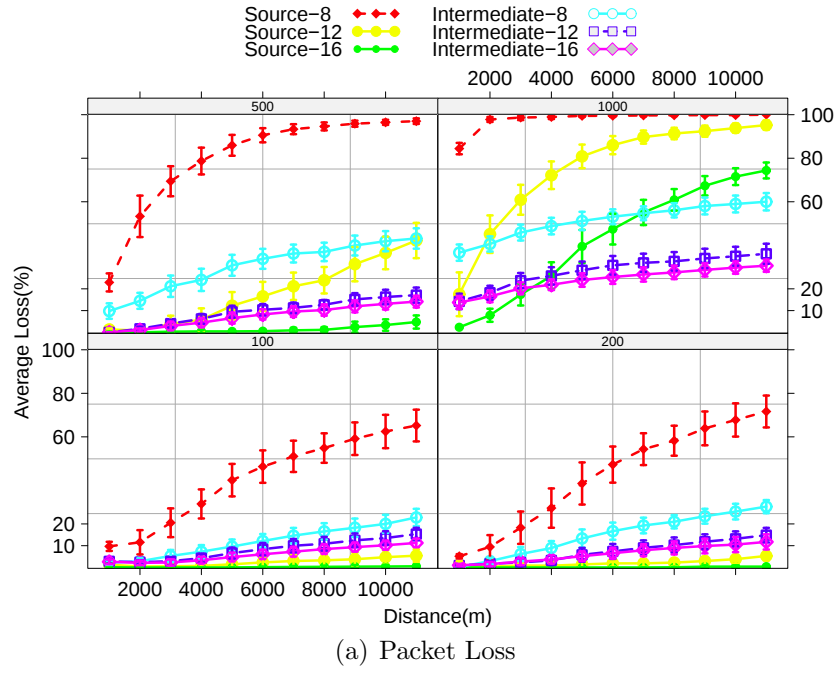


Figure 4.6: Experimental Results of NC-Intermediate and NC-Source with additional redundancy on nodes within Different Distance from Video Source

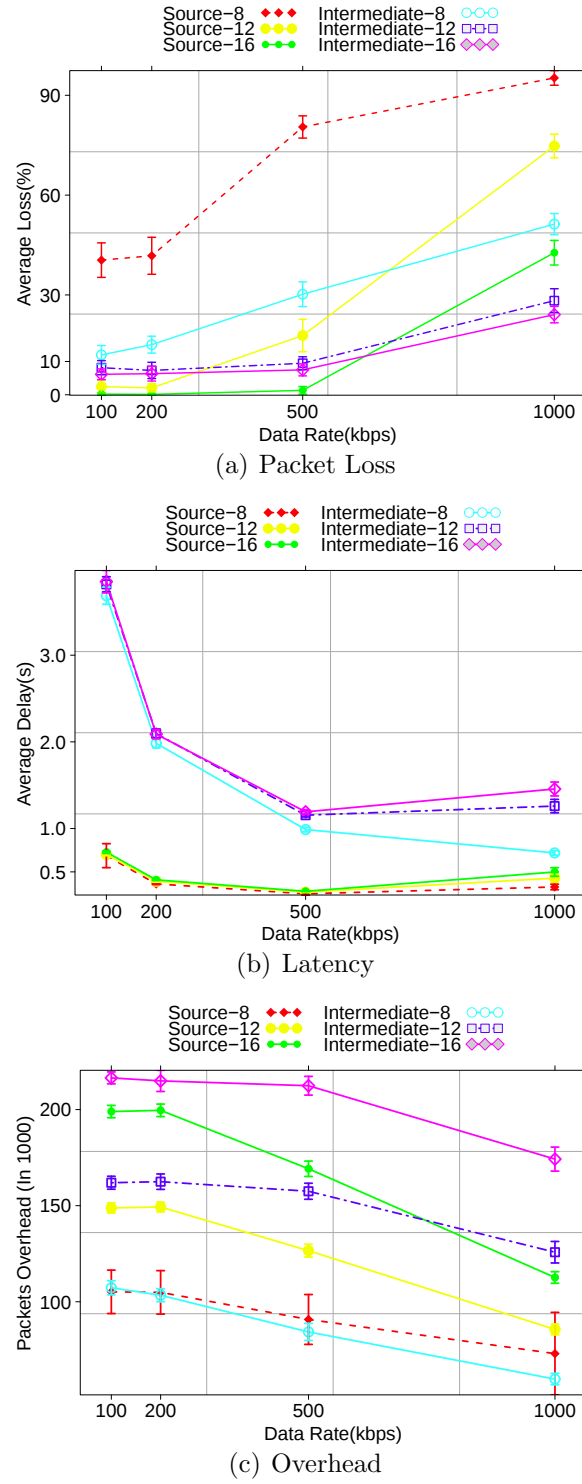


Figure 4.7: Experimental Results of NC-Int and NC-Source with additional redundancy

In conclusion, the use of network coding is definitely an effective measure to reduce frame loss as it is shown by the observed results of NC-Intermediate and NC-Source. In this case, it happens because these approaches exploit network coding as both an error correction technique in forcing additional redundancy and in using efficiently the available bandwidth. Delay is a big concern in NC-Intermediate because of waiting time in intermediate nodes to receive enough packets for re-encoding while it achieved acceptable delay in higher data rates because of receiving packets faster. In addition, by comparing the overhead of NC-Intermediate and NC-Source, it becomes clear how requesting intermediary nodes to stall the dissemination process until they are able to encode new packets with new sets of coefficients is an efficient way of using transmissions to achieve higher delivery ratios. However, as results demonstrate in general, forcing additional encoded packets at the source have a better impact on network throughput in terms of delay, delivery ratio and cost of the network, especially in lower data rates scenarios.

4.2 Summary

This chapter discusses and evaluates performance of three different layer-centric video dissemination protocols. Based on our findings in chapter 2, each of these protocols employs a robust and promising technique to provide high-quality video to end receivers.

As the first efficient protocol, a link layer-centric approach has been chosen. The WAVE-AOS uses a neighbour discovery method to adjust back-off time based on the traffic congestion in the network environment. This protocol has been compared with the original 802.11p to ensure its efficiency and robustness.

REACT-DIS is another discussed protocol in this chapter. This protocol is designed over network layer and improves performance of video streaming on vehicular networks by an optimum selection of relay nodes.

The last promising protocol has focused on video content by sending encoded packets

instead of original video packet. This application layer-centric protocol outperforms existing video dissemination techniques without network coding. In conclusion, simulation results show single layer centric protocols have low resource utilization and do not guarantee QoS based on defined metrics in [59]. Consequently, we anticipate that multi-layer protocols over MAC, network and application layers can be deployed in VANETs with infrastructure support for providing satisfactory QoS performance for video streaming applications.

Chapter 5

Hybrid Video Dissemination

Protocol:Design and Implementation

This chapter presents a new proposed hybrid video dissemination protocol, which is referred to HVDP. This protocol is a combination of three presented protocols, WAVE-AOS, REACT-DIS and NCDD with integration of an error resilience technique and non deterministic filtering scheme. This protocol takes advantage of the best characteristics of each of these robust video dissemination protocols and tries to employ these characteristics in their optimal manners. This chapter is structured as follows:

Initially the design of the Hybrid Video Dissemination Protocol is described by illustrating its architecture and techniques applied to ensure satisfactory QoS as well as reliability and scalability factors. The second section presents the implementation of proposed hybrid protocol and compares its evaluation results to other three mentioned robust protocols.

5.1 Design of Hybrid Video Dissemination Protocol

As presented before, several protocols have been designed in order to find an efficient scheme that can satisfy all QoS parameters for video streaming over vehicular networks.

However, many of these protocols concentrate on one aspect of QoS parameters and fail to meet other requirements that are essential to provide video quality in vehicular environments. In addition, they mostly focus on single layer techniques to tackle video streaming challenges, limits their performance, and, affects their efficiency.

As implementation results in chapter 4 show, each presented protocol in this chapter fails to meet specific requirement for delivering high-quality video to other vehicles in the intended network area. WAVE-AOS cannot guaranty high delivery ratio by just considering network congestion and changing back-off time in MAC layer. Therefore, as it is shown in Figure 4.3, MAC channel congestion control mechanism alone is not a reliable solution to meet QoS requirements. REACT-DIS performance evaluation result is illustrated later in this chapter and it also proves that this technique alone is not efficient enough to provide satisfactory delivery ratio with network at high data rate. The other described protocol, NCDD, performs well in terms of packet delivery for low data rate but because of deploying network coding techniques in all participant nodes it fails in meeting acceptable packet delay in the network. Moreover, its high delivery ratio is not sustainable in network at higher data rate. For that reasons, we thought having a hybrid solution that take advantage of robust techniques in these protocols can improve performance results for broadcasting high quality video in vehicular networks.

HVDP deploys two error resilience techniques, packet redundancy and network coding. Both these techniques have been tested under different condition in chapter 4. In order to avoid delivering high percentage of duplicated packets and causing high cost in network, redundancy with 50% is used to guarantee that transmitted data by sender is delivered to the receivers nodes and lost packets can be recovered by retransmitting same packets.

In addition, as a primary step in designing this approach, network coding at source is picked because of lower delay and its high delivery ratio in network at low data rate.

According to previous study in this thesis, redundant packets can easily cause broadcasting storm and result more packet loss in the network. To prevent this issue and based

on summarized information in table 4.2, selecting a subset of nodes as relays enhance protocol reliability. In order to fulfil this condition, this work relies on achieved results in [70] and deploy receiver-based selection technique that is suggested in REACT-DIS protocol.

It is observed that the combination of mentioned techniques can satisfy QoS requirements in some vehicular network scenarios. Network congestion is one of the major challenges that is likely to occur when transmitted data is huge and, traffic congestion is also common in case of an emergency. Therefore, HVDP sets up the MAC congestion control mechanism that is suggested in WAVE-AOS to adapt itself with different congestion conditions. As a result, relay nodes' back-off time change based on new calculated contention window size which is tightly dependent on number of their surrounded vehicles within range.

5.1.1 Reliability and Scalability

According to achieved results in the qualitative comparison, we found HVDP as a reliable and scalable protocol that has error recovery ability. The following describes reliability and scalability and how they apply to the video dissemination hybrid protocol.

- **Reliability:** A protocol is said reliable if it guarantees that data transmitted by the sender is delivered to the intended receivers (all participant nodes in the network) in order and without duplication. The reliability is easy to satisfy in a unicast transmission, since there is only one receiver that either receives or does not receive all the transmitted data by the sender. However, for a multicast transmission, it is not always the case, and protocols need strong reliability properties, to be able to deliver data to the intended receivers.

The reliability of this proposed protocol is applied by injecting redundant and encoded packets in the network which is similar to the technique that is used in NCDD protocol. In this technique, packet loss detection is not necessary while

redundant packets are there to recover probable packet loss. Encoded packets also enhances reliability of HVDP where a lost video frames can recover by decoding received packets in the node.

- **Scalability:** An application said to be scalable if it is able to handle growing number of users in a graceful manner. In case of video broadcasting, a scalable approach should handle the network and keep QoS in the same level if new vehicles join the network, then there is no need to redesign this approach every time. HVDP satisfies this condition while its flexible to changes in number of vehicles by modifying back-off time depends on number of neighbouring cars. Joining new vehicles to the network does not have important effect on number of relay nodes in a specific region because HVDP uses selection node mechanism same as REACT-DIS which prevents the exceed number of nodes to forward packets further in each radio range. Therefore, network throughput expects to stay high by growing number of vehicles that are serving in this network.

5.2 Implementation Of Hybrid Video Dissemination Protocol

The hybrid video dissemination protocol is implemented in this thesis study to illustrate its reliability and efficiency in comparison to other proposed protocols for video streaming over vehicular networks. In this protocol recorded video on the source convert to blocks of I,B and P frames with the size of 1000 byte. Each block includes $\eta = 8$ segments, which combine using the following random linear function to produce random coded packets known as rnc-packets.

$$C_{(B_{id},\eta)} = \sum_{k=1}^{\eta} e_k P_{(k-1+B_{id})} \quad (5.1)$$

The rnc-packets carry their block info and η random coefficient number e_k which use

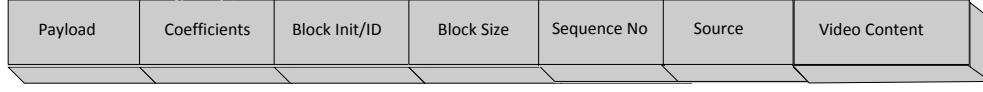


Figure 5.1: Random Network Coded Packet Format of video message in HVDP

to encode and decode same packets. Figure 5.1 shows random network encoded packet that is used in HVDP protocol.

Following algorithm illustrate the role of the source node in proposed hybrid protocol.

Algorithm 5 HVDP - Sending Packet p at Source

encode packet p

forward packet p at time = $blockSize$ divided by the data rate

After distributing video packets by source node, other participant nodes in the same radio range receive encoded packets. In this time, receivers should schedule themselves to make forwarding decision in t time. Before expiring t each node keeps track of received duplicated packets to forward the packet further with probability ρ :

$$\rho = \frac{1}{r^c} \quad (5.2)$$

The selected relay nodes forward received packets immediately with $\kappa = 12$ redundant packets. Behaviour of receiver nodes is described using algorithm 6 while it follows the same steps in REACT-DIS algorithm that were explained in detail in the previous chapter.

In order to control network congestion in HVDP, participant nodes in the network send hello messages to their neighbouring nodes in each one second. These hello messages are used to update neighbour table in participant vehicles after each two seconds. This data is used to pick the maximum numbers among vehicles in the last interval or average of neighbouring vehicles in all the previous intervals as a constant N . The adaptive offset slots calculates using N value by applying following formula:

Algorithm 6 HVDP - Receiving packet p

```

if  $p$  has not been received before then
  if node is a relay node then
    forward half of received packets  $p$  with probability depending on the number  $c$ 
    of duplicates after defined back-off time
    reset counter  $c$ 
  else
    if node is scheduled to try to broadcast then
      insert  $p$  into buffer of packets to send
    else  $\{Node\ is\ idle\}$ 
      Schedule to try to become a relay node; store  $p$ 
    end if
  end if
else  $\{p\ has\ been\ received\ before\}$ 
  increment counter  $c$ 
end if

```

$$EO[N] = \left[\frac{1}{N+1} \sum_{i=0}^N i \right], \quad (5.3)$$

The estimated AOS value in this function is added to the constant value of minimum contention window size to get new value for CW_{min} that alters dependent on vehicles congestion.

In order to avoid high delay in the network, relay nodes continue forwarding packets for predefined amount of time ϕ before entering next stage of competition for being a forwarder. All the other steps in selecting sufficient relay nodes in REACT-DIS are kept in HVDP and receiver nodes uses the same formula in NCDD to recover original packets.

5.2.1 Discussion and Results

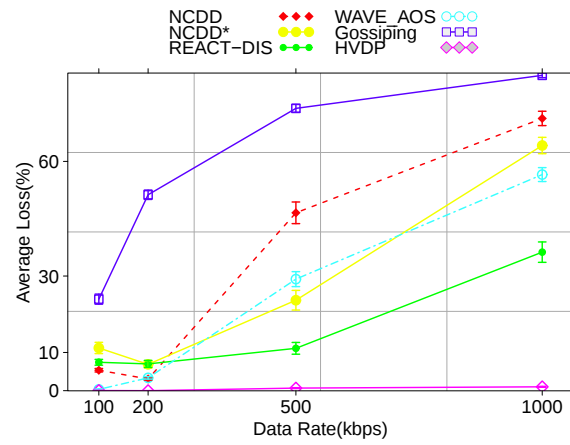
The experiment setup section in chapter 3 explains every detail of simulated network in this study. As discussed before, all described protocols in this study are implemented under the same conditions as well as the mobility model and evaluation software used to have a fair comparison between these protocols and the proposed hybrid protocol.

The mobility simulation parameters are summarized in table 3.1, while the MAC Layer in HVDP sets as IEEE 802.11P to follow the AOS mechanism in MAC congestion control.

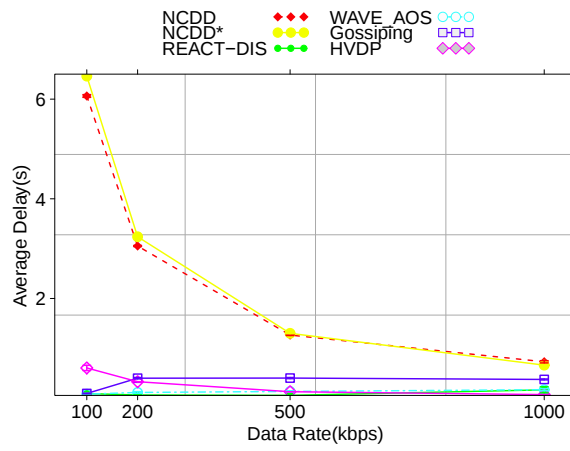
NS-2 has been used to simulate routing protocols and agent sitting in the mobile nodes. To evaluate sent and received video files, EvalVid tool set has been deployed and R is used to handle statical computation and plot of the observed results.

In this section, the protocols that are described in chapter 4 have been compared with HVDP and gossiping which is a well-known basis approach for data dissemination.

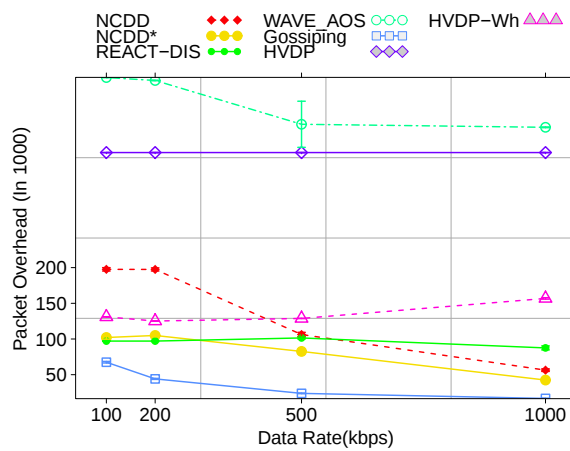
The first observation in figure 5.2(a) is that higher data rates are exceedingly more challenging than scenarios with lower rates, for all solutions there are steep hikes on frame loss as data rates increase. Therefore, it is crucial that solutions aimed at the dissemination of content that requires the delivery of large amount data over short periods of time, be evaluated under scenarios with demanding data rates. The high ratios of frame loss by gossiping is expected as they do not have any mechanism to prevent or handle packet loss due to congestion. Although NCDD could achieve low frame loss at low data rates, this was not sustained at higher data rates. A minor modification has been applied on NCDD to form NCDD* where only half of intermediate nodes broadcast received packets and 80% of neighbouring nodes respond to the help message. This solution improved the ratio of frame loss in NCDD for scenarios with high data rate. REACT-DIS had a similar performance to NCDD but it handles much better in the high data rates networks. As illustrated in the 5.2(a), the WAVE approach with use of AOS performs better than NCDD and REACT-DIS in term of frame loss in lower data rate but it is not as efficient as REACT-DIS in high data rate scenarios. The proposed



(a) Packet Loss



(b) Latency



(c) Overhead

Figure 5.2: Performance comparison of HVDP

hybrid protocol tackles all challenges that other surveyed protocols are facing in terms of frame loss since it delivers almost 100% of the broadcast packets to participant nodes in all scenarios with different data rate. WAVE-AOS reduces packet loss in high congested spots and REACT-DIS is used to select the most suitable nodes to relay packets. As a result, these two techniques make packet loss very low and in this case NC could be very useful solution to make the packet loss close to zero.

In Figure 5.2(b), in terms of the end-to-end delay, solutions that make use of Network Coding with re-encoding at intermediary nodes (both NCDD and NCDD*) are highly influenced by the data rate used. This is the outcome of the necessary wait at each hop for nodes to receive at least η unique packets from each block before they can decode and encode new packets to be further forwarded. Although this delay is prohibitively at low data ratios, it decreases significantly at higher data rates, as the time for the reception of a whole block is inversely proportional to the data rate. HVDP and all the other solutions have an average end-to-end delay inferior to 1 second which complies with the video-streaming requirements.

HVDP has also been compared to other implemented protocols in terms of the overhead they incur into by measuring the total number of transmissions through the simulations. Gossiping' low number of transmissions is due to the high frame loss that these approaches are subjected to. NCDD flooding characteristics associated with the use of help messages causes it to be the solution that requires the high amount of transmissions. In compare to NCDD, NCDD* saves cost of the network in terms of overhead by reducing numbers of redundant packets in the network.

HVDP has a large number of data transmission because of neighbour detecting mechanism that is deployed for its control congestion mechanism. However its transmission overhead is less than WAVE-AOS itself because of its relay node selection technique for broadcasting video packets. Control messages for detecting nodes' neighbours only carry the source identifications. These messages are much lighter than video packets or help messages in the NCDD and don't consume network resources as much as involved pack-

ets in other protocols. For that reason, we have included result of packet overhead in HVDP without considering hello message (HVDP-Wh) and as it is illustrated in 5.2(c), the number of transferred packets is affected by its neighbour detecting method. The transmission cost in HVDP-Wh is reasonable while is delivering almost all packets to participants nodes.

REACT-DIS also could sustain reasonable levels of frame loss while not incurring into an excessive number of transmissions because of node selection techniques that is dependent on number of overheard packets in the network.

5.3 Summary

In this chapter, the features of our proposed protocol, known as HVDP, have been discussed. This scheme is based on a combination of a number of protocols and techniques, which were discussed earlier (WAVE-AOS, REACT-DIS, NCDD, gossiping and redundancy). The hybrid video dissemination protocol takes advantage of these protocols and techniques in an optimal manner to satisfy the QoS requirement.

HVDP is a reactive and congestion aware protocol that uses filtering and error recovery techniques to overcome existing challenges in vehicular networks. This scheme attempts to optimize resource utilization and make sure to deliver high quality video to all participant vehicles in the network, while keeping the networking cost as low as possible.

This designed hybrid protocol outperforms other protocols that have been considered as robust approaches for video dissemination in vehicular networks. The main advantage of HVDP is its multi-layer design, which has consider different aspects for QoS satisfaction.

Chapter 6

Conclusion and Future Work

Video dissemination over VANETs is necessary for the deployment of useful and crucial services over vehicular networks. However, there are many challenges that need to be overcome in order to fulfil all video streaming requirements.

6.1 Conclusion

This study has discussed and compared a number of selected approaches for video broadcasting. Both qualitative and quantitative comparisons have been performed on different video dissemination protocols. The qualitative comparison was divided based on the protocol stack layer that each solution is related to categories of the techniques used. Findings of this comparison have been summarized in Table 2.3 with an emphasis on what aspect each solution is tackling.

From these approaches, the most reliable and suitable technique has been highlighted for each specific protocol stack layer. These solutions have been compared through simulation and their performances have been analyzed in terms of frame loss, delay and communication overhead.

This work also evaluates the impact of network coding in video dissemination over VANETs. A number of experiments and simulations were designed to study the effect of

different types of network coding schemes, and the lack thereof, on video streaming, keeping into consideration altered gossiping probability conditions and different percentages of redundant packets in the network for the same highway scenarios.

Results show that network coding at both source and intermediate nodes is an effective solution for reliable and low overhead packet delivery to vehicles with limited distance from the source in low data rate network. Based on our findings, the network coding alone is not adequate to achieve quality of service requirements for dissemination of video in high-density networks with high data rates. However, it is an efficient solution to combine with other stack layer techniques to provide satisfactory QoS.

Generally, the implementation results showed that all of these highlighted approaches have improved the performance of the gossiping as a basis for data dissemination and are equipped with enough capabilities to enhance existing video broadcasting solutions by touching on the different aspects that have not been considered before.

Therefore, this study has combined these techniques to form a reliable cross-layer hybrid approach to tackle the different video streaming challenges across different stack layers.

6.2 Future Work

Even though this thesis provides a comprehensive study and evaluation from different perspectives, there are still some open issues and several research directions that can be pursued to improve the performance of our quantitative comparison and proposed hybrid protocol. The following are some points that can be taken into consideration when deciding to further the work done in this thesis:

- This study evaluates performance of video dissemination protocols in highway scenarios. However, in urban scenarios, there are many more factors such as lower speed limits, intersections, traffic lights, etc..., that can affect the protocol performance in vehicular networks. Therefore, the qualitative comparison study can be

extended to include urban scenarios, especially for the WAVE-AOS solution where its performance tightly depends on network congestion.

- The HVDP performs very well in terms of delivery ratio and delay for networking scenario at specific data rates that are evaluated in this work. However, video content is large and this solution has the potential to extend for 3D videos and games, which may need to deliver more data per second. For that reason, considering networks at higher data rates can make this protocol more efficient. According to the study on network coding in chapter 4, NC-Intermediate is a better solution for network scenarios at high data rate. NC-Intermediate can be applied on a subset of selected relay nodes in HVDP to improve data delivery for higher data rates in the network. To avoid high end-to-end delay, re-encoding can be employed after forwarding encoded packets for a specific number of hops in the network.
- The HVDP protocol has enough potential to extend for delay sensitive applications, such as video conferencing and online gaming. Therefore, as a future work, some minor modifications can apply on this protocol to test on these types of applications.

Appendix A

Bibliography

Bibliography

- [1] *The Network Simulator - ns-2*. <http://www.isi.edu/nsnam/ns/>.
- [2] *The Optical Micro-Networks - OMNeT++*. <http://www.omnetpp.org/>.
- [3] *Simured - Multicomputer Network Simulator*. <http://simured.uv.es/index-en.php>.
- [4] *Handbook of Wireless Networks and Mobile Computing*, chapter Mobile Ad Hoc Networks. DISCA, IIMAS, Universidad Nacional Autonoma de Mexico, Mexico D.F., Mexico, 2002.
- [5] The linux information project. Technical report, November 2005. <http://www.linfo.org/index.html>.
- [6] *Cisco Networking All-in-One For Dummies*. John Wiley and sons, Inc., 2011.
- [7] R. Ahlswede, Ning Cai, S.-Y.R. Li, and R.W. Yeung. Network information flow. *Information Theory, IEEE Transactions on*, 46(4):1204–1216, jul 2000.
- [8] Marica Amadeo, Claudia Campolo, and Antonella Molinaro. Enhancing ieee 802.11p/wave to provide infotainment applications in vanets. *Ad Hoc Networks*, 10(2):253–269, 2012. Recent Advances in Analysis and Deployment of IEEE 802.11e and IEEE 802.11p Protocol Families.
- [9] Mahdi Asefi. Quality-driven cross-layer protocols for video streaming over vehicular ad-hoc networks. Phd Thesis, University of Waterloo, 2011.

- [10] Fan Bai. Important: A framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks. In *IEEE INFOCOM*, pages 825–835, 2003.
- [11] M. Bakhouya, J. Gaber, and P. Lorenz. An adaptive approach for information dissemination in vehicular ad hoc networks. *J. Netw. Comput. Appl.*, 34(6):1971–1978, November 2011.
- [12] M.A. Bonuccelli, G. Giunta, F. Lonetti, and F. Martelli. Real-time video transmission in vehicular networks. In *2007 Mobile Networking for Vehicular Environments*, pages 115 –120, may 2007.
- [13] A. Boukerche. *Algorithms and Protocols for Wireless and Mobile Ad Hoc Networks*. Wiley & Sons, 2008.
- [14] A. Boukerche, C. Rezende, and R.W. Pazzi. Improving neighbor localization in vehicular ad hoc networks to avoid overhead from periodic messages. *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, pages 1 –6, nov. 2009.
- [15] WEN-SHYANG HWANG CHIH-HENG KE, CE-KUEN SHIEH and ARTUR ZIVIANI. An evaluation framework for more realistic simulations of mpeg video transmission. *JOURNAL OF INFORMATION SCIENCE AND ENGINEERING*, 2008.
- [16] Jinyoun Cho, Seokjoo Shin, and J. Copeland. Fast broadcast at the intersection in vanet. In *Consumer Communications and Networking Conference (CCNC), 2011 IEEE*, pages 65 –69, jan. 2011.
- [17] Philip A. Chou, Yunnan Wu, and Kamal Jain. Practical network coding, 2003.
- [18] cyril soldani. Resilient video transmission: Application layer versus transportation layer approaches. Technical report, University of Lige, 2006.

- [19] E. Fasolo, A. Zanella, and M. Zorzi. An effective broadcast scheme for alert message propagation in vehicular ad hoc networks. In *Communications, 2006. ICC '06. IEEE International Conference on*, volume 9, pages 3960 –3965, june 2006.
- [20] Victor Gau, Chih-Wei Huang, and Jenq-Neng Hwang. Reliable multimedia broadcasting over dense wireless ad-hoc networks (invited paper). *Journal of Communications*, 4(9), 2009.
- [21] K. Ghafoor and K. Abu Bakar. Inter-vehicle communication protocols for multimedia transmission. In *International MultiConference of Engineering and Computer Scientists*.
- [22] Meng Guo, M.H. Ammar, and E.W. Zegura. V3: a vehicle-to-vehicle live video streaming architecture. In *Pervasive Computing and Communications, 2005. PerCom 2005. Third IEEE International Conference on*, pages 171 – 180, march 2005.
- [23] Farzad Hassanzadeh. Reliable broadcast of safety messages in vehicular ad hoc networks. Master’s thesis, University of Toronto, 2008.
- [24] T. Ho, R. Koetter, M. Medard, D.R. Karger, and M. Effros. The benefits of coding over routing in a randomized setting. In *Information Theory, 2003. Proceedings. IEEE International Symposium on*, page 442, june-4 july 2003.
- [25] Yao H. Ho, Ai H. Ho, and Kien A. Hua. Routing protocols for inter-vehicular networks: A comparative study in high-mobility and large obstacles environments. *Computer Communications*, 31(12):2767 – 2780, 2008.
- [26] T. Hossain, Yi Cui, and Yuan Xue. Vanets: Case study of a peer-to-peer video conferencing system. pages 1 –2, jan. 2009.
- [27] Chih-Wei Hsu, Chung-Hsien Hsu, and Huei-Ru Tseng. Mac channel congestion control mechanism in iee 802.11p/wave vehicle networks. In *Vehicular Technology Conference (VTC Fall), 2011 IEEE*, pages 1 –5, sept. 2011.

- [28] A.G. Ibanez, C. Flores, P.D. Reyes, A. Barba, and A. Reyes. A performance study of the 802.11p standard for vehicular applications. In *Intelligent Environments (IE), 2011 7th International Conference on*, pages 165–170, july 2011.
- [29] Kamal Jain, László Lovász, and Philip A. Chou. Building scalable and robust peer-to-peer overlay networks for broadcasting using network coding. In *Proceedings of the twenty-fourth annual ACM symposium on Principles of distributed computing*, PODC '05, pages 51–59, New York, NY, USA, 2005. ACM.
- [30] J. Jakubiak and Y. Koucheryavy. State of the art and research challenges for vanets. pages 912–916, jan. 2008.
- [31] Pat Jangyodsuk. Reliable broadcasting in vanet. Master’s thesis, San Jose State University, 2010.
- [32] Jirka Klaue, Berthold Rathke, and Adam Wolisz. Evalvid - a framework for video transmission and quality evaluation. In *In Proc. of the 13th International Conference on Modelling Techniques and Tools for Computer Performance Evaluation*, pages 255–272, 2003.
- [33] Gökhan Korkmaz, Eylem Ekici, Füsun Özgüner, and Ümit Özgüner. Urban multi-hop broadcast protocol for inter-vehicle communication systems. In *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, VANET '04, pages 76–85, New York, NY, USA, 2004. ACM.
- [34] Peiyuan Lai, Xinhong Wang, Ning Lu, and Fuqiang Liu. A reliable broadcast routing scheme based on mobility prediction for vanet. In *Intelligent Vehicles Symposium, 2009 IEEE*, pages 1083–1087, june 2009.
- [35] Xiaodong Lin, Xiaoting Sun, Pin-Han Ho, and Xuemin Shen. Gsis: A secure and privacy-preserving protocol for vehicular communications. *Vehicular Technology, IEEE Transactions on*, 56(6):3442–3456, nov. 2007.

- [36] Morten Lindeberg, Stein Kristiansen, Thomas Plagemann, and Vera Goebel. Challenges and techniques for video streaming over mobile ad hoc networks. *Multimedia Systems*, 17:51–82, 2011. 10.1007/s00530-010-0187-8.
- [37] Michael Luby. Tornado codes: Practical erasure codes based on random irregular graphs. In Michael Luby, Jos Rolim, and Maria Serna, editors, *Randomization and Approximation Techniques in Computer Science*, volume 1518 of *Lecture Notes in Computer Science*, pages 171–171. Springer Berlin / Heidelberg, 1998.
- [38] M. Nekovee and B.B. Bogason. Reliable and efficient information dissemination in intermittently connected vehicular adhoc networks. In *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th*, pages 2486 –2490, april 2007.
- [39] Joon-Sang Park, M. Gerla, D.S. Lun, Yunjung Yi, and M. Medard. Codecast: a network-coding-based ad hoc multicast protocol. *Wireless Communications, IEEE*, 13(5):76 –81, october 2006.
- [40] Joon-Sang Park, Uichin Lee, Soon Y. Oh, Mario Gerla, and Desmond S. Lun. Emergency related video streaming in vanet using network coding. In *Proceedings of the 3rd international workshop on Vehicular ad hoc networks, VANET '06*, pages 102–103, New York, NY, USA, 2006. ACM.
- [41] N. Qadri, M. Fleury, M. Altaf, B.R. Rofoee, and M. Ghanbari. Resilient p2p multimedia exchange in a vanet. In *Wireless Days (WD), 2009 2nd IFIP*, pages 1 –6, dec. 2009.
- [42] N.N. Qadri, M. Fleury, M. Altaf, and M. Ghanbari. Multi-source video streaming in a wireless vehicular ad hoc network. *Communications, IET*, 4(11):1300 –1311, 23 2010.

- [43] R Development Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2008. ISBN 3-900051-07-0 , <http://www.R-project.org>.
- [44] Aneel Rahim, Zeeshan Shafi Khan, and Fahad bin Muhaya. Performance evaluation of video streaming in vehicular adhoc network. In Samir Kumar Bandyopadhyay, Wael Adi, Tai-hoon Kim, and Yang Xiao, editors, *Information Security and Assurance*, volume 76 of *Communications in Computer and Information Science*, pages 220–224. Springer Berlin Heidelberg, 2010.
- [45] Maxim Raya and Jean-Pierre Hubaux. The security of vehicular ad hoc networks. In *Proceedings of the 3rd ACM workshop on Security of ad hoc and sensor networks*, SASN '05, pages 11–21, New York, NY, USA, 2005. ACM.
- [46] A. Razzaq and A. Mehaoua. Video transport over vanets: Multi-stream coding with multi-path and network coding. In *Local Computer Networks (LCN), 2010 IEEE 35th Conference on*, pages 32 –39, oct. 2010.
- [47] Giovanni Resta, Paolo Santi, and Janos Simon. Analysis of multi-hop emergency message propagation in vehicular ad hoc networks. In *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing*, MobiHoc '07, pages 140–149, New York, NY, USA, 2007. ACM.
- [48] Cristiano Rezende, Azzedine Boukerche, and Richard W. Pazzi. A reactive solution with a redundancy-based error correction mechanism for video dissemination over vehicular ad hoc networks. In *The 15th ACM International Conference on Modeling, Analysis and Simulation on Wireless and Mobile Systems*, Paphos, Cyprus, 2012. (to appear).
- [49] F.J. Ros, P.M. Ruiz, and I. Stojmenovic. Reliable and efficient broadcasting in vehicular ad hoc networks. In *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, pages 1 –5, april 2009.

- [50] S. Bindra S. Kohli, B. Kaur. A comparative study of routing protocols in vanet. Technical report, Dept. of CSE, RIMT-IMT, Dept. of CSE, RIMT-IET, 2010.
- [51] M. Sardari, F. Hendessi, and F. Fekri. Dmrc: Dissemination of multimedia in vehicular networks using rateless codes. In *INFOCOM Workshops 2009, IEEE*, pages 1 –6, april 2009.
- [52] Mohsen Sardari, Faramarz Hendessi, and Faramarz Fekri. Ddrc: Data dissemination in vehicular networks using rateless codes. *J. Inf. Sci. Eng.*, 26(3):867–881, 2010.
- [53] Hulya Seferoglu and Athina Markopoulou. Opportunistic network coding for video streaming over wireless. In *Packet Video 2007*, pages 191 –200, nov. 2007.
- [54] Pranav Kumar Singh, Kapang Lego, and Dr. Themrichon Tuithung. Simulation based analysis of adhoc routing protocol in urban and highway scenario of vanet. *International Journal of Computer Applications*, 12(10):42–49, January 2011. Published by Foundation of Computer Science.
- [55] F. Soldo, C. Casetti, C.-F. Chiasserini, and P. Chaparro. Streaming media distribution in vanets. In *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*, pages 1 –6, 30 2008-dec. 4 2008.
- [56] R. Stanica, E. Chaput, and A.-L. Beylot. Enhancements of ieee 802.11p protocol for access control on a vanet control channel. In *Communications (ICC), 2011 IEEE International Conference on*, pages 1 –5, june 2011.
- [57] Min-Te Sun, Lifei Huang, A. Arora, and Ten-Hwang Lai. Reliable mac layer multicast in ieee 802.11 wireless networks. In *Parallel Processing, 2002. Proceedings. International Conference on*, pages 527 – 536, aug. 2002.
- [58] Min-te Sun, Lifei Huang, Shaoyong Wang, Anish Arora, and Ten-Hwang Lai. Reliable mac layer multicast in ieee 802.11 wireless networks. *Wireless Communications and Mobile Computing*, 3(4):439–453, 2003.

- [59] Tim Szigeti and Christina Hattingh. *End-to-End QoS Network Design: Quality of Service in LANs, WANs, and VPNs (Networking Technology)*. Cisco Press, 2004.
- [60] Mostafa M. I. Taha. Broadcasting protocols in vehicular ad-hoc networks (vanets). Master's thesis, Assiut University, 2004.
- [61] K. Tang and M. Gerla. Mac reliable broadcast in ad hoc networks. In *Military Communications Conference, 2001. MILCOM 2001. Communications for Network-Centric Operations: Creating the Information Force. IEEE*, volume 2, pages 1008 – 1013 vol.2, 2001.
- [62] O. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, and V. Sadekar. Broadcasting in vanet. In *2007 Mobile Networking for Vehicular Environments*, pages 7 –12, may 2007.
- [63] Ozan K. Tonguz and Mate Boban. Multiplayer games over vehicular ad hoc networks: A new application. *Ad Hoc Netw.*, 8(5):531–543, July 2010.
- [64] Yu-Chee Tseng, Sze-Yao Ni, Yuh-Shyan Chen, and Jang-Ping Sheu. The broadcast storm problem in a mobile ad hoc network. *Wireless Networks*, 8:153–167, 2002. 10.1023/A:1013763825347.
- [65] Andrea Vitali. Multiple description coding - a new technology for video streaming over the internet. Technical report, STMicroelectronics, 2007.
- [66] Jianping Wang. *NS-2 Tutorial*. Multimedia Networking Group, The Department of Computer Science, UVA, 2004. <http://www.cs.virginia.edu/cs757/slidespdf/cs757-ns2-tutorial1.pdf>.
- [67] Y. Wang, A.R. Reibman, and S. Lin. Multiple description coding for video delivery. *Proceedings of the IEEE*, 93(1):57 –70, jan. 2005.

- [68] Hakim Weatherspoon and John Kubiatowicz. Erasure coding vs. replication: A quantitative comparison. In Peter Druschel, Frans Kaashoek, and Antony Rowstron, editors, *Peer-to-Peer Systems*, volume 2429 of *Lecture Notes in Computer Science*, pages 328–337. Springer Berlin / Heidelberg, 2002.
- [69] Stephen B. Wicker and Vijay K. Bhargava, editors. *Reed-Solomon Codes and Their Applications*. John Wiley & Sons, Inc., New York, NY, USA, 1999.
- [70] Fei Xie, K.A. Hua, Wenjing Wang, and Y.H. Ho. Performance study of live video streaming over highway vehicular ad hoc networks. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 2121–2125, 30 2007-oct. 3 2007.
- [71] Xoph. Video test media. <http://media.xiph.org/video/derf/>.
- [72] Qiong Yang and Lianfeng Shen. A multi-hop broadcast scheme for propagation of emergency messages in vanet. In *Communication Technology (ICCT), 2010 12th IEEE International Conference on*, pages 1072–1075, nov. 2010.
- [73] Zhenyu Yang, Ming Li, and Wenjing Lou. Codeplay: Live multimedia streaming in vanets using symbol-level network coding. In *Network Protocols (ICNP), 2010 18th IEEE International Conference on*, pages 223–232, oct. 2010.
- [74] Jing Zhao. Data pouring and buffering on the road: A new data dissemination paradigm for vehicular ad hoc networks. *Vehicular Technology, IEEE Transactions*, 2007.