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Survey on QoE/QoS Correlation Models for Video Streaming over Vehicular Ad-hoc Networks

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Vehicular Ad-hoc Networks (VANETs) are a new emerging technology which has attracted enormous interest over the last few years. It enables vehicles to communicate with each other and with roadside infrastructures for many applications. One of the promising applications is multimedia services for traffic safety or infotainment. The video service requires a good quality to satisfy the end-user known as the Quality of Experience (QoE). Several models have been suggested in the literature to measure or predict this metric. In this paper, we present an overview of interesting researches, which propose QoE models for video streaming over VANETs. The limits and deficiencies of these models are identified, which shed light on the challenges and real problems to overcome in the future.

ACM CCS (2012) Classification: Networks → Network properties → Network manageability
Networks → Network performance evaluation → Network simulations

Keywords: vehicular ad-hoc networks (VANETs), multimedia services, quality of service (QoS), quality of experience (QoE), quality metrics

1. Introduction

Vehicular Ad-hoc Networks (VANETs) represent a rapidly emerging and a particularly challenging class of Mobile Ad Hoc Networks (MANETs) where vehicles communicate [1]. It has a significant interest by car manufacturing industries, academia and government agencies. They have put much joint efforts together towards realizing the concept of vehicular communications in a wide scale. These efforts have led to numerous vehicular communications researches with their associated standardization projects in many countries across the world [2].

VANETs are characterized by:

a) trajectory-based movements with location prediction and time-varying topology,
b) varying number of vehicles with independent or correlated speeds,
c) fast time-varying channel (*e.g.*, signal transmissions can be blocked by buildings),
d) frequent network disconnection due to the movement of vehicles at high speed, and
e) battery power and storage is unlimited [3], [4].

They are self-organizing and self-governing communication networks without any central coordinator [5]. Vehicles can communicate with each other (V2V) or with the Road Side Units (RSU) which are a fixed infrastructure along the roadside (V2I) [6] as shown in Figure 1 [7]. To ensure communication, vehicles use wireless communication equipment which is either short-range or medium-range [8], [9]. For instance, VANETs currently use the Dedicated Short Range Communication technology (DSRC) which is the IEEE 802.11p standard [10], [11], [12]. A VANET architecture is presented in Figure 1.

The main objective of VANET is achieving safe and comfortable driving. It can provide a very wide variety of applications in the field of transportation. Typically, applications are categorized as road safety, traffic coordination, and infotainment applications [13], [14], [15], [16]. These applications of VANET mostly need to send multimedia data for communication, which still remains a great challenge on Quality of Services (QoS) and Quality of Experiences (QoE) issues due to the nature of VANET.

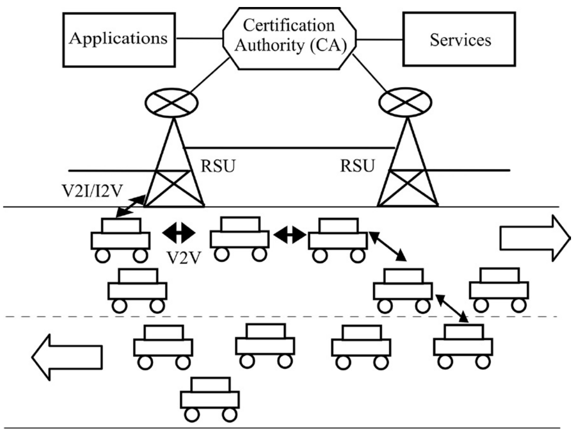

Figure 1. VANET architecture [7].

The QoS is only focused on service requirements that need to be met by the network [17]. It does not include the user and context factors for quality evaluation. The QoE puts emphasis on the degree of satisfaction of users by the offered service [18], [19]. Several researches have been conducted in QoE modeling, monitoring and management. The QoS is objective but the QoE is subjective. Even though QoS and QoE measurements are quite different, they have a high degree of correlation. In the literature, a number of studies have focused on identifying the relationships between QoS and QoE for multimedia services.

This paper presents a comprehensive review and a thorough analysis of recent and pertinent research related to QoS and QoE correlation models for video transmission over VANET. The rest of the paper is organized as follows. In Section 2, video streaming over vehicular networks is highlighted. In Section 3, QoE applications in video streaming are presented. Section 4 introduces the influence factors of QoE in video streaming. Section 5 is a literature review of QoE models for video streaming over Wireless Network, Mobile Network, MANET and VANET. In Section 6, limits and deficiencies of QoE models for video streaming over VANET are identified and discussed, which opens wide doors of challenges and issues to deal with in the future. Finally, conclusions and perspectives are given in Section 7.

2. Video Streaming Over Vehicular Networks

The video streaming is a client-server paradigm where interactive media data of streaming applications such as video on demand, IP Television (IPTV), video conferencing, e-learning and videogames are exchanged, shared and consumed [20]. Video streaming over vehicular networks is a need for many applications. These applications can generally be grouped into two categories: safety applications and non-safety applications as shown in Figure 2. We summarize the main applications of these categories in the next paragraphs [21], [22], [23], [24].

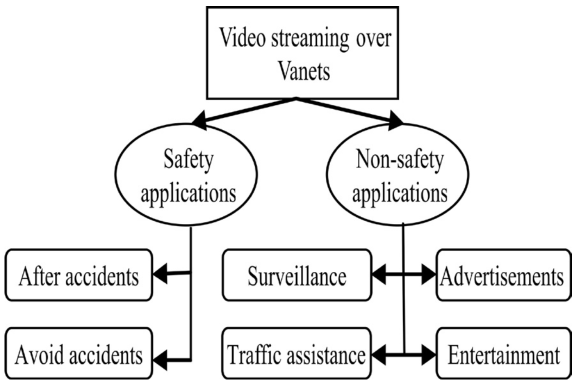

Figure 2. Video streaming applications over vehicular network.

2.1. Video in Safety Applications

The aim of safety applications is saving the life of drivers and passengers. The video can play an important role to avoid accidents by showing dangerous situations such as collision risk, vehicle lane change, overtaking vehicle, stopped vehicle, work zone, pedestrian crossing and low bridge. It can also be helpful even after accidents when offering collision recording, notifications for other vehicles, telemedicine, medication identification, help in guiding emergency rescuers and authorities, investigation support for accident liability.

2.2. Video in Non-safety Applications

The aim of non-safety applications is traffic assistance, surveillance, entertainment and advertisements. In traffic assistance, the video can assist driver decisions and give a clear overview of the road traffic conditions to better trajectory planning by avoiding congestions and closed roads. It can show him dangers on the road and weather information. The video can be also used to prevent anti-social behaviour such as crimes, robbery, irritating people inside/outside vehicles. It can also help authorities to identify vehicles or pedestrians they are searching for. Besides all these, video can be used in comfort and entertainment. Vehicles can exchange video information like multi-player games for entertainment, live video stream of both sides, video conferencing and video changing. Roadside commerce can use video in advertisements of services like nearest parking lots, gas stations, shopping malls, hotels and fast food restaurants.

Video streaming is considered as one of the challenging issues in VANET due to highly dynamic network topology, high mobility, frequent connectivity interruption and requirements of Quality of Experience (QoE) and Quality of Service (QoS), typical for multimedia applications. The most challenging points are achieving high rates of delivery ratio with less delay in available bandwidth and offering a good quality [21], [22], [23], [24].

3. QoE Applications in Video Streaming

The theory of quality of experience (QoE) has been widely used to represent user perception. For network service evaluation, a number of models and tools have been proposed in QoE modeling, monitoring (assessment) and management with the exploration of many influencing factors.

In the QoE monitoring, we measure or estimate the QoE of video streaming using dedicated tools with the consideration of the influencing factors. To monitor QoE, two schemes were developed which are subjective test and objective QoE monitoring. In the QoE management, videos are prepared and encoded with proper quality levels in order to maximize the user's QoE. In the QoE modeling, models are developed to measure or predict the QoE as closely as possible to the QoE perceived by the end users. It aims to model the relationship between different QoE influencing factors. These models can be adopted in QoE monitoring [25].

In this paper, we focus on the pertinent proposed QoE models of video streaming in VANETs found in the literature. In the next section, we present the main QoE factors of video streaming and review the corresponding proposed models.

4. Influence Factors of QoE in Video Streaming

Quality of Experience (QoE) is a set of human-centric metrics that captures the overall acceptability or unacceptability of the service or application by end users, which includes the end-to-end factors [26]. The QoE is affected by various factors of experience that are grouped in three main categories: human, system, and context influence factors [26], [27]. The influence factors of QoE in video streaming are summarized in Figure 3.

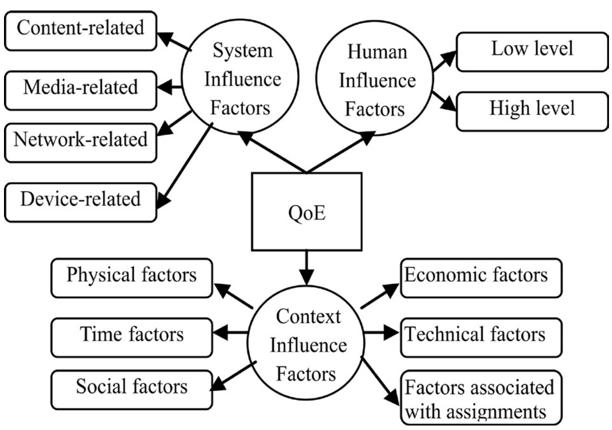

Figure 3. Influence factors of QoE in video streaming.

4.1. Human Influence Factors (H.I.Fs)

Human Influence Factors are any property or characteristic of a human. They could be divided into two subgroups. The first is the low-level influence factors such as age, gender, personality and mood. The second is the high-level influence factors such as socio-economic conditions, educational background, needs, previous experience and life stage [27].

They are poorly understood and are taken into account in a very limited set of studies [28] [29]. We outline in Table 1, some interesting research projects that studied the influence of human factors on QoE in different domains.

4.2. System Influence Factors (S.I.Fs)

System Influence Factors refer to properties and characteristics that determine the technically produced quality of an application or service. They could be classified into content-related, media-related, network-related and device-related factors.

- The content-related S.I.Fs consider the content of the video itself like high-motion or low motion, 2D or 3D.
- The media-related S.I.Fs refer to media configuration factors, such as encoding, resolution, sampling rate, frame rate, and media synchronization.
- Network-related S.I.Fs refer to data transmission over a network. The main network characteristics are bandwidth, delay, jitter, loss and error rates and distributions, and throughput.
- Device-related S.I.Fs refer to the visual interface that displays the video to the user.

A summary of research efforts devoted to the study of the influence of system factors on QoE in diverse domains is given in Table 2.

4.3. Context Influence Factors (C.I.Fs)

They consider the environmental factors associated with the user. Their classification includes six sub-groups [27]:

- physical factors,
- time factors,
- social factors,
- economic factors,
- factors associated with assignments, and
- technical factors.

Table 3 presents some research papers which studied the influence of context factors on QoE in different domains.

Table 1. Human influence factors.

Author	Human Influence Factors	Level	Domain
Kara [30]	Subject's prior knowledge	High-level	Auto stereoscopic glasses-free 3D video
Hyder [31]	Gender (male/female)	Low-level	Virtual acoustic environments
Mccoll [32]	Facial expressions and gender	Low-level	Web-video sales
Msakni [33]	Male/female, age	Low-level	Lab-based videos
Murray [34]	Gender, age	Low-level	Videos sequences
Rodriguez [35]	Personal and cultural traits	High-level	Lab-based videos
Guntuku [36]	Preference	High-level	Video streaming services
Zhu [37]	Gender and age	Low-level	Lab-based videos
Chen [38]	User's emotions	High-level	Streaming video
Scott [29]	Gender, age	Low-level	Lab-based videos
Scott [29]	Personality, culture, nationality	High-level	Lab-based videos
Oche [39]	Gender	Low-level	VANET multimedia service

Table 2. System influence factors.

Author	System Influence Factors				Domain
	Network-related	Media-related	Content-related	Device-related	
Han [40]	Throughput, bitrates	No	No	User equipment	Wireless network
Xing [41]		Start-up latency, interruption ratio, average playback quality	No	No	VANET
Msakni [33]	Bitrates	No	Video type (soccer and documentary), Video cotenant	Video display resolution, video display equipment	Lab-based videos
Msakni [42]	No	No	Video type, video length	No	Lab-based videos
Pokhrel [43]	Packet loss rate, packet loss, burstiness, jitter	No	No	No	IPTV
De Felice [44]	Node densities, end-to-end distances, Packet Delivery Ratio (PDR)	No	No	No	Live video streams in VANET
Quan [45]		Start-up delay, Playback freezing	No	No	VANET
Song [46]	Bitrates	Encoding parameters	Video content characteristics	Device display resolution	Mobile video service
Lina Zhu [47]	Nodes speed, nodes number	No	No	No	VANET video streaming
Mocanu [48]	No	Bit rate, percentage of I-frames lost, percentage of I,P,B frames lost, sad (sum of absolute differences), number of bursts	No	No	Digital terrestrial television
Zhu [37]	No	Compression bitrates	Video genre	No	Lab-based videos
Chen [38]	No	Buffer ratio, average bitrates	No	No	Streaming video

Table 3. Context influence factors.

Author	Context Influence Factors	Domain
Pyykko [49]	Physical factors and time factors	Mobile (3D) television
Han [40]	Environment factors	Wireless Network
Msakni [42]	Day time	Lab-based videos
Zhu [37]	Social context, technical factors	Lab-based videos
Seufert [50]	Technical factors	Web video streaming

Other factors emerge and are related to the nature of the VANET itself such as large-scale sizes, frequent link disconnections, rapid topology changes and the impact of density and driving environments. These factors are connectivity probability, reliability, availability, link duration, hop count, end to end delay and stability [51], [52], [53].

5. QoE Models for Video Streaming over VANET

In QoE studies, several models have been proposed in both wired and wireless networks, some of them were presented and evaluated in [54], [55], [56] and [57]. These models are not well adapted to VANETs since they do not take into account their specificities.

In this section, we present QoE models for video streaming over VANETs. In the literature, to the authors' best knowledge, only few studies propose QoE models for video streaming in VANET. This pushes us to extend the studied models designed for Wireless Networks, Mobile Networks and MANETs to include specificities of VANETs, which is itself a sub class of MANETs [58] and can be formed in pure cellular or mobile network [59].

We begin by presenting some QoE models for video streaming over Wireless Networks, Mobile Networks and MANETs, and then discussing QoE models for video streaming in VANET. In this paper we evaluate only QoE models for video streaming in VANETs. Models designed for other networks will be only presented to enlarge the reader's view.

5.1. QoE Models for Video Streaming over Wireless Network, Mobile Network and MANETs

We present some QoE models for video streaming over Wireless Networks, Mobile Networks and MANETs, which could be extended to VANETs by considering their characteristics such as high speed of vehicles on predefined roads that makes the topology highly dynamic. The highly dynamic topology generates frequent network disconnection [58].

5.1.1. Cerqueira – Wireless Mesh Networks

Cerqueira *et al.* in [60], propose an on-the-fly parametric QoE video quality estimator for real-time video streaming applications over Wireless Networks. The model was built to assess the QoE of the video perceived by end-users. It takes as input values a set of parameters related to the video characteristics of an encoder, which correspondingly quantify the video quality. The model is based on statistical learning using Multiple Artificial Neural Networks (MANNs). It is designed to evaluate videos coded in standard MPEG.

To estimate the QoE, the model takes into account the current network conditions and different video parameters (loss rate in I, P and B frames, total loss rate, GoP length, and motion and complexity levels).

Four successive stages were required to implement the Multi QoE approach in a networking system, including Wireless Mesh Networks (WMNs):

- Quality-affecting factors,
- Distorted video database generation,
- Subjective Quality Assessment, and
- Learning the quality of the behaviour with MANNs.

5.1.2. Fung – MANET

Fung *et al*. propose a QoE model based on QoS parameters for web-TV streaming service over Peer-to-peer (P2P) in MANETs [61]. Their MANET system uses the Landmark-based routing model, which provides a free-scale and highly dynamic routing functionality. They define three levels of user experience for qualitative measurement:

- QoS Packet Loss level,
- QoS Packet Delivery level, and
- Resource QoS Contribution level.

They use these parameters in exponential and logarithmic models.

A simulation study using OMNeT++ network simulator was conducted. Specifically, the OverSim framework for overlay and peer-to-peer networks with a patched INET framework model are adopted in their simulation scenarios. Moreover, at the application level, a P2P live streaming system is used. The physical distribution of mobile nodes is generated randomly. They performed tests in different scenarios.

5.1.3. Jiang – Wireless Networks

Jiang *et al*. propose a QoE prediction model, which incorporates the sender bitrates, dropping probability and frame rate into the QoE calculation [62]. Some parameters in the prediction model are obtained by a nonlinear regression analysis of the QoS parameters. The model is used in their QoE-driven channel allocation scheme for secondary users and cognitive radio networks (CRN) base station (BS).

To evaluate the system performance, they derived an analytical Markov model combining the ON/OFF model of PCs and the service queuing model. They studied the performance of multimedia transmission of images and H.264 videos. They used MATLAB to calculate the QoE and QoS parameters.

5.1.4. Zhang – Wireless Networks

Zhang *et al*. in [63] propose a logarithmic QoE model built upon experiments relating to the content cache management for HTTP ABR streaming. The model is formulated as a constrained convex optimization problem over wireless networks. They adopt a two-step process to solve the snapshot problem. First, using the Lagrange multiplier method to obtain the numerical solution of the set of playback rates for a fixed number of cache copies and characterize the optimal solution analytically. Second, they develop three alternative search algorithms (*i.e*., exhaustive search, Dichotomous-based search, and variable step-size search) to find the optimal number of cached files. In their paper, they present a simplified QoE model, in which the user experience depends on two system parameters, including the required playback rate and the actual playback rate. The model is used in a QoE-optimal scheme for the individual content cache management in HTTP ABR streaming.

5.1.5. Sanchez – MANET

Sanchez *et al*. in [64] proposed a model to measure the QoE of video streaming over MANETs. The QoE model has been calculated in terms of MOS (Mean Opinion Score), from a parametric model. It allowed them to obtain accurate video-MOS estimations by means of the Packet Loss Rate (PLR) and the video-coding bit-rate (Br) parameters.

For model validation, they used the simulation framework OMNET++ v4.4, with the Inet-Manet framework v2.2. They carried out simulations with different scenarios.

5.1.6. Bampis – Mobile Network

Bampis *et al*. proposed the MultiQE model for QoE prediction in their continuous Quality of Experience prediction engine over mobile networks [65]. Prediction is based on a non-linear autoregressive model with exogenous outputs (NARX) recurrent neural networks. The QoE prediction model is driven by three QoE-aware inputs:

- an objective measure of perceptual video quality,
- rebuffering aware information and
- a memory of prior events affecting QoE (recency).

They trained and tested their method on QoE dataset containing continuous time subjective scores of viewed video content on a mobile device. They used MATLAB to implement the model.

After model training and validation, MultiQoE is used for QoE prediction in real-time without any intervention of real end users. MultiQoE gives scores in terms of MOS. To test Multi QoE, simulation experiments were carried out using Network Simulator 2.34, Evalvid tool, MSU Video Quality Measurement Tool (VQMT) and the Neural Networks was built using MATLAB.

5.1.7. Wang – LTE Network (Mobile)

Wang *et al*. proposed the HTTP Adaptive Streaming (HAS) QoE prediction methods based on multi-segment and multi-rate features of HAS with data mining over LTE networks [66]. They designed two sets of methodologies to evaluate the HAS QoE, including regression and classification. In the regression method, they proposed the evolved Peak Signal-to-Noise Ratio (ePSNR) model using differential PSNR (dPSNR) statistics as the segment features to estimate HAS QoE. In the classification method, they proposed the improved weighted *k*-nearest neighbours (WkNN) by using dynamic weighted mapping according to the position of video chunk to meet the dynamic segment and rate features of HAS.

In order to train and test these methods, they built a real-time HAS video-on-demand (VOD) system in LTE network and did subjective test in different video scenes encoded in H.264 format. With the MOS, the regression and classification methods were trained to predict the HAS QoE.

In Table 4, we summarize the evaluated aspects of studied models and in Table 5 their technical aspects.

To apply these models in VANETs, several specific features must be considered such as the high mobility of vehicles, topology fast changes, frequent network disconnections and V2V communications. For mobile networks, QoE models must take into consideration the fast handover and geolocation of vehicles.

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5.2. QoE Models for Video Streaming over VANET

In this section, we present the QoE models for video streaming over VANETs. We start by describing these models and then proceed to their evaluation.

Table 4. Evaluated aspects of studied QoE models for video streaming over Wireless Network, Mobile Network and MANETs.

Author	**System Influence Factors**				**H.I.Fs**	**C.I.Fs**	**QoE prediction**	**Mapping function**
	Network	**Media**	**Content**	**Device**				
Cerqueira [60]	No	Frames losses	Motion and complexity levels	No	No	No	Multiple Artificial Neural Network	MOS
Fung [61]	Packet Loss, Packet Delivery, Video Packet Size,		Resolution	/	/	Resource Contribution	Mathematical model	MOS
Jiang [62]	No	Sender bitrates, dropping probability, frame rate	No	No	No	No	Analytical	MOS
Zhang [63]	No	Playback rate, actual playback rate	No	No	No	No	Logarithmic	MOS
Sanchez-Iborra [64]	Packet Loss Rate	video-coding bit-rate	/	/	/		Mathematical	MOS
Bampis [65]	/	Video quality, rebuffering	/	/	/	Prior events affecting QoE	NARX (ANN)	/
Wang [66]	No	Bit rates, video segment	No	No	No	No	Statistical model	MOS

Table 5. Technical aspects of studied QoE models for video streaming over Wireless Network, Mobile Network and MANETs.

Author	Communication V2V	Infrastructure	Video reference	Validation tools	Model mobility	Environment	Protocol	Video service
Cerqueira [60]	/	Yes	No	MATLAB + Network Simulator 2.34	/	/	/	Video streaming
Fung [61]	No		No	Omnet++, OverSim, INET	/	No	Propose a protocol	P2P live video streaming
Jiang [62]	/	/	/	Markov Models +MATLAB	/	/	/	HTTP adaptive bit rate streaming
Zhang [63]	/	Yes	/	/	/	/	/	HTTP adaptive bit rate streaming
Sanchez-Iborra [64]	Device to device	Yes	No	Omnet++ v4.4 + InetManet V2.2	/	/	BATMAN, OLSR, AODV	Video-streaming
Bampis [65]	/	Yes	/	MATLAB		/	/	Video on mobile device
Wang [66]	/	/	No	Lab simulation+ statistical validation	/	/	/	Video-on-demand

5.2.1. Asefi

Asefi *et al*. proposed a quality of service (QoS) model based on video distortion in their cross-layer path selection scheme for video streaming over VANETs in an urban environment [67]. In the proposed scheme, the video is streamed from a RSU to a destination vehicle via multi-hop communication. The objective in the path selection is to minimize application layer video distortion. The distortion is the summation of encoding distortion, distortion due to delay and distortion due to packet loss in VANET. To calculate the distortion, in their model they used Distortion of packet due to encoding, Rate of encoder video packet, Rate of video packet and End-to-end delay factors.

To evaluate their model, a mathematical model for an urban architecture was used. They streamed a 20 seconds of MPEG encoded video with 30 frames per second rate in dense and sparse scenarios. They used the PSNR to measure the performance of the routing protocol.

The first problem in this model is the assumption of a wide availability of roadside units. The issues of ad hoc communication are mostly neglected. The model can be applied only for streaming of all the videos from one RSU to the destination vehicle. They didn't consider channels and external interference. In the validation, they fixed the average arrival rate of the vehicles.

5.2.2. Pham

Pham *et al*. proposed a QoE model for video streaming for VANETs [68]. The QoE is evaluated as MOS at the destination vehicle. They used the Pseudo-Subjective Quality Assessment (PSQA) tool to obtain the MOS. They studied the impact of loss rate (LR) and mean loss burst size (MLBS) on MOS. The model is combined with OLSR protocol for the path selection from the source to the destination.

They evaluated the performance of the proposed mechanism using Network Simulator (NS) version 2.35. The Bonn Motion tool was used to create the Manhattan Grid scenario. They compared the performance of their protocol with AODV and MPOLSR protocols for video streams. The number of video streams varied from 1 to 8. The video is requested by the vehicle from one of four servers.

The proposed model has some limits. They used only two parameters: loss rate (LR) and Mean loss burst size (MLBS). They did not consider the MOS of every intermediate node but only that of two-hop nodes. PSQA tool takes only network-oriented parameters. Moreover, they did not take into consideration the path lifetime.

5.2.3. Wolfinger

Starting from the fact that in IPTV, the main influencing factor of QoE for users is TV channels availability, Wolfinger *et al.* introduced a new model to measure the QoE in [69]. It is an analytical model that predicts the blocking probability of TV channels for channel-switching-induced and handover-induced blocking events in IPTV services in VANETs.

They proposed two models, one for all IPTV users and the other for individual users. The first model is used to predict the QoE when a channel is demanded (watched) by more than one user. The second model is used to predict the QoE when a channel is demanded (watched) by individual users.

In their paper, they focused on the model related to individual users. In their proposed model, they calculate channel-switching and handover in a cell of the access network.

To validate their model, they implemented the model and applied a numerical case study scenario to obtain the QoE. They compared the analytical results to simulation results and found that they are close enough.

The proposed model has some limits:

- They did not take in account V2V communications.
- They assumed that a high number of installed RSU cover the entire road.
- They did not measure the quality of the video received by the end-user.
- They assumed that vehicles are driving at a constant speed in their lane.
- They assumed that the maximum bandwidth available in a cell and the data rate required to send to each TV channel are constant.

5.2.4. Yaacoub

Yaacoub *et al.* proposed a QoE model measured in terms of the PSNR and of two other parameters that depend on the video characteristics as QoE metrics [70]. The model used in their techniques is based on grouping the vehicles into cooperative clusters. In each cluster, the cluster head receives the video over long-range cellular links and multicasts it to vehicles in its cluster over IEEE 802.11p.

To validate their proposition, simulations in MATLAB were implemented in a highway environment. They used four scalable video coded (SVC) sequences. Three scenarios were investigated in these simulations:

- the video is transmitted to a moving vehicle via RSUs,
- the video is transmitted to a moving vehicle using LTE BS, and
- booth RSUs and LTE BS transmit the video.

The proposed QoE model has some limits:

- Video distortions caused by compression method at the source are neglected.
- PSNR needs the original video to be calculated and is not well correlated to the subjective quality that end users perceive.
- They did not explain how to calculate the QoE parameters.
- They did not specify which video characteristics represent the QoE parameters.
- Their proposed scheme needs LTE BS and RSU to be deployed on the side of highway.
- The scheme is applicable only with infrastructure, which is the initial source of video stream.
- The solution is not bandwidth-efficient because of the large amount of data sent and lost due to packet losses.

5.2.5. Quadros

In [71], authors propose a model to calculate QoE as a function of Mean Square Error and distortion. They used this model in their protocol called quality driven beaconless multi-criteria video streaming management protocol for VANETs.

The QoE model is designed for MPEG standard which defines that the Group of Pictures (GoP) is composed of a combination of three frame types, namely I (Intra), P (Predictive), and B (Bidirectionally predictive) frames. QoE in this model is affected by frame types (I, P, B), codec configurations, and losses. It is used to select the best next hop and to switch to other routes as soon as a lower quality is identified. They consider 40dB as the highest video quality, and the lowest video quality has values below 20dB.

To validate their proposition, they conduct a simulation using SUMO, EvalVid (A Video Quality Evaluation Tool-set) and Network Simulator version 2.33. To demonstrate the impact of their model in delivering QoE aware video flows in VANETs, they used a geographic routing approach called VIRTUS, Dynamic Backbone Assisted (DBA) MAC protocol and Beaconless Routing protocol (BLR) are used for comparison.

The proposed model has the following limits:

- It did not take into account the routing path lifetime and multiple flows.
- It could not be used with RSU.
- In the model, the video must be streamed only from vehicles.
- It did not consider context and human factors.
- It is applicable only in highway environment.
- It is used only for MPEG standard.

5.2.6. Immich

Immich *et al*. proposed a self-adaptive forward error correction based proactive error recovery mechanism and QoE-driven mechanism to shield video transmissions over VANETs (SHIELD) [72]. SHIELD uses several video characteristics and specific VANET details to safeguard real-time video streams against packet losses. It combines network density, signal-to-noise ratio, packet loss rate, and the vehicle's position to better protect the video sequences and enhance the QoE. The mechanism uses Unequal Error Protection (UEP) because not all video packets have the same importance to ensure the final video quality. To improve these issues, SHIELD adopts a Hierarchical Fuzzy System (HFS) that estimates the QoE by combining network quality indicator and video characteristics. To establish network quality indicator, it evaluates four parameters which are SNR, PLR, the network density and the position of vehicles. To establish video characteristics indicator, it evaluates six parameters, which are temporal intensity, spatial complexity, frame size, frame type, resolution and macro block detail.

To validate the proposed mechanism, they conducted simulations for urban and highway environments. The Network Simulator 3 (NS-3) was used to conduct the experiments. All videos were encoded with H.264, GoP length of 19:2, where three different resolutions were used, namely 1080p, 720p, and SVGA. For each resolution, 10 videos were chosen to be transmitted. To send videos, they used Evalvid Tool. The mobility traces were generated using the Simulation of Urban MObility (SUMO). For the routing protocol, Cross-Layer, Weighted, Position-based Routing (CLWPR) were used.

The model has some limits:

- If the infrastructure is available, it could be used, but the optimizations are to be performed only on the communication between the vehicles.
- They used few videos and network parameters.
- Device related and context influence factors are not considered.
- The impact of delay in QoE, which has a great effect, is not studied.

5.2.7. Sarwar

Sarwar *et al*. modeled the QoE as a mapped function to MOS [73]. The proposition consists of an adaptive selection of application QoS parameters and an IVT handover decision mechanism for providing seamless imagery effect and enhance user's multimedia perception. The suggested architecture can provide a sustainable channel rate based selection of content source, media resolution, and codec to improve the perceived visual quality. They proposed a model of Handover/Handoff management to avoid a necessary handover. The parameters used in the QoE model are the media codec, frame rate, display screen size and the user requested frame rate.

The model has been tested by simulations under Inet and Veins frameworks of OMNET++ and SUMO traffic simulator, in urban environment. They used these parameters: compression algorithms such as MPEG-2, MPEG-4, H.264, and SVC, packet drop ratio (PDR), average packet delay (APD), content source, media codec, and resolution.

The main limit of this model is the use of one hop vehicle-RSU communication and there is no multi-hop V2V communication which is the main characteristic of VANETs. The model could be applied only in urban environment. No information about the QoE model parameters is given.

5.2.8. Oche

Oche *et al*. proposed an objective real-time multimedia service QoE prediction model based on a multivariate statistical approach, in conjunction with regression analysis that estimates perceived multimedia service quality as a function of aggregated QoE influencing weighted parameters [39]. To structure the proposed QoE prediction model, they segment the multimedia/VANET distribution network into a framework of three quality optimization components, taking into account the service source quality, the network resource constraint and the human factor in determining the overall QoE. The QoE is estimated as a weighted sum of the QoE influencing parameters. The influencing parameters in their work are divided into two categories:

- technique parameters which are for application layer: frame rate, and bit rate, for network layer: packet loss, throughput and delay,
- no-technique parameters (context), which are user's physical environmental (city/highway/rural), user terminal resolution and user gender.

To validate the model, they used a statistical method in highway and city environments with infrastructure RSU to support V2V and V2I communications. They also used Markov chains Monte Carlo (MCMC) simulation to generate gender, environmental and user terminal resolution. As technique parameters, they used their previous results of simulation under NS2 [74].

This model suffers from the problem that parameters in the ordered logit model are obtained through the maximum likelihood technique (point estimate) where the estimations are only valid for current network connectivity matrix. This means that they did not consider the topology change, which is the main feature of VANETs. They did not use any mobility. The model did not consider the encoding distortion at the source and packet loss in the area of the wired segment of the network connection path. For validation, they made statistical methods instead of tests using video streaming. Furthermore, the values of jitter, buffer, video content coder, routing protocol, gender, environment and user terminal resolution, are not taken from simulation, but are randomly generated.

5.2.9. Fei Sun

Fei Sun *et al*. proposed a QoE evaluation model established by using empirical data for vehicular video streaming performed in cellular networks [75]. They also developed a mathematical relationship between the streaming bit rate and caching storage space of base station of cellular networks. Then, they formulated a distributed caching management for vehicular video streaming as a constrained optimization problem and solved it using the generalized reduced gradient method. In their system, the video is divided into different blocks, and then some adjustments are made to the bitrates of each video segment, with considerations on the limited caching space.

The video is streamed via cellular networks from sever to vehicles. The mobility of users's vehicles in cellular networks is modeled as Hyper Erlang distribution. Their QoE evaluation model is based on Weber Fechner law, which follows logarithmic laws. The QoE influence factors used are bit rate and videos types.

They used MATLAB to implement their proposed QoE centric distributed caching approach in cellular networks. They evaluate their work in different scenarios by changing the number of cells, caching space size and vehicle's density.

The model suffers from the following limits:

- The model is applicable only in VANETs video streaming under cellular networks.
- They suppose that the user subscribes to one video.
- There is no V2V communication.
- They studied few influence factors.
- The user's location and mobility are pre-calculated and estimated when users subscribe to video services.
- It cannot be used in scenarios when vehicles send videos.
- There is a need to consider geolocation data for the vehicular multimedia content distribution in cellular networks.

6. Discussion and Future Issues

The Table 6 and Table 7 summarize the aspects evaluated by models discussed above, as well as how many different aspects were evaluated in each model and technical aspect of studied models. Different angles were taken when it comes to factors used in the models, method of prediction and mapping, some technical aspects.

The state of the art of QoE modeling of video streaming over VANETs is reviewed, evaluated and criticized. The proposed models have many limits and drawbacks, which open a wide door of challenges and issues.

6.1. Model's Limits

The study of existing models has shown several limits, which can be summarized as follows.

6.1.1. Restrained Number of Models

There are only few proposed models dealing with QoE over VANETs. This interesting research area did not get attention it deserves. Consequently, existing models are far from being perfect. Thorough studies and much effort are to be devoted in order to propose more appropriate models.

6.1.2. Models Formulation

The study of existing and recent models reveals that the relationship between QoE and its influencing factors is complex and nonlinear. This relationship has not been fully understood to allow developing of an accurate and representative model for QoE. The use of machine learning techniques could give an added value to this domain. It provides a theoretical and methodological framework to quantify the relationship between influencing factors to predict the QoE.

6.1.3. Influence Factors

Studied models show that only a limited number of influencing parameters are considered. This cannot provide an accurate prediction of the QoE for end-users. These models neglect the effect of important parameters like human and context influence factors, except for the previously discussed Oche model. Moreover, Oche model considers only three parameters: gender, terminal resolution and user's physical environment. The influence factors have not been fully investigated or quantitatively modeled. This is due to their mathematical scaling, which is still a very challenging task. The focus of formulated models is put on network-related and media-related parameters neglecting other influencing factors as content-related, device-related, and human and context influence factors.

6.1.4. Unrealistic VANET Scenarios

The QoE video streaming models were simulated in unrealistic scenarios. Abstract mobility models, simplified signal propagation models, no consideration of obstacles, which block the radio signal and hence will cause high video packet loss. Models need to be re-evaluated using realistic vehicular scenarios.

6.1.5. Performance Evaluation

The proposed models seem to have good performance parameters according to suggested scenarios in their databases. Unfortunately, there is no performance evaluation and comparison of different models in other databases. To evaluate them objectively, they must be tested under different databases with various conditions.

Table 6. Evaluated aspects of studied QoE models of video streaming over VANETs.

Author	System Influence Factors				H.I.Fs	C.I.Fs	QoE prediction	Mapping function	Video codec
	Network	Media	Content	Device					
Asefi [67]	packet rate, delay	encoding packet loss, encoder packet rate	No	No	No	No	No	No	/
Pham [68]	Loss rate, mean loss burst size	No	No	No	No	No	PSQA	MOS	/
Wolfinger [69]	Channels witching, hand over	No	No	No	No	No	Analytical	one blocking per hour to be acceptable + switching greater than 0.2 will be unacceptable for the user	/
Yaacoub [70]	No	Frame rate, spatial resolution, spatial, temporal variances	No	No	No	No	Analytical	$Q = 0$ best quality $Q = 100$ worst quality	Two layers scalable video coded (SVC)
Quadros [71]	No	Frame types, codec configurations	No	No	No	No	Analytical	40dB = highest video quality 20dB < lowest video quality	MPEG-4
Immich [72]	SNR, PLR, network density, position of vehicles	Frame size, frame type, resolution, macroblock detail	motion activity: temporal intensity, spatial complexity	No	No	No	Fuzzy System	/	Codec H.264
Sarwar [73]	No	Media codec, frame rate	No	Screen size	No	No	Analytical	MOS	MPEG-2, MPEG-4, H.264, SVC
Oche [39]	Packet loss, throughput, delay	Frame rate, bit rate	No	Terminal resolution	gender	user's physical environment (city, and highway/ rural)	Statistical	MOS	MPEG-4
Sun [75]	No	Bit rate	Videos types	No	No	No	Weber Fechner law (logarithmic laws)	MOS	/

Table 7. Technical aspect of studied QoE models of video streaming over VANETs.

Author	Communication V2V	Infrastructure	Video reference	Validation tools	Model mobility	Environment	Protocol	Video service
Asefi [67]	No	RSU & AR	FR (PSNR)	Analytical	No	Streets in an urban	An enhanceed greedy georouting	Video streaming
Pham [68]	V2V	No	No	Simulation (NS2)	No	/	Modified OLSR	Video streaming
Wolfinger [69]	No	RSU	No	Simulation/ Analytical	Constant speed	Motorways	No	IPTV
Yaacoub [70]	V2V	RSUs and LTE BS	FR (PSNR)	Simulation (MATLAB)	Random	Highway	No	Video streaming
Quadros [71]	V2V	No	No	Simulation (NS2)	Realistic	Highway	No (new protocol)	Video streaming
Immich [72]	V2V	No	No	Simulation (NS3)	/	Urban and highway	Cross-Layer, Weighted, Position-based Routing (CLWPR)	Video streaming
Sarwar [73]	V2V	RSU	No	Simulation (OMNET++)	/	Urban	WAVE short message protocol (WSMP)	In-vehicle telescreen (IVT)
Oche [39], [74]	V2V	RSU	No	Simulation (NS2)	/	Highway and city	AODV	IPTV
Sun [75]	No	Base station (cellular network)	No	Simulation (MATLAB)	Hyper-Erlang distribution	No	No	VANET video streaming under cellular networks

6.1.6. Radio Access Technologies

VANET can use different radio access technologies (WiFi, WiMAX, LTE, 4G and 5G). Only one studied model is based on cellular networks but does not take into consideration the V2V communication. All the reviewed models neglect other technologies as WiFi, cellular networks or LTE.

6.1.7. Routing Protocols

Various underlying routing protocols were used in these models. Nevertheless, the choice of a particular protocol has never been justified. In our opinion, the routing protocol affects the QoE and must be considered as a parameter.

6.2. Future Issues

The following issues constitute some of the promising research directions towards developing new models to measure the QoE of video streaming over VANETs.

6.2.1. Influence Factors

The fundamental challenge of the quality predictor model is the choice of appropriate influencing factors to predict the QoE for all videos in different environments and scenarios. There is still an open issue on how to select the leading component from all possible system, context and human Influence factors in the design of QoE models.

6.2.2. Influence Factors' Relations

The influence factors have not been fully investigated or quantitatively modeled. This is because their mathematical scaling is still a very challenging task. Therefore, it is an open field of research to propose mathematical models or machine learning based models.

6.2.3. Influence Factors' Nature

The established models focus on measurable factors such as throughput, delay, jitter, or loss rate, and neglect immeasurable factors such as gender, environment and period of viewing, which have a great influence on QoE. To evaluate appropriately the QoE, models must consider all major influencing factors.

6.2.4. Realistic VANET Scenarios

The video streaming quality models must be simulated in realistic scenarios. Especially, the vehicular communications with wireless shadowing and fading channel deterioration, in addition to diverse environments: urban, rural and highway with obstacles and real mobility models.

6.2.5. Database for Performance Evaluation

The proposed models are tested in their own databases. It is desirable to elaborate test databases containing videos with different features and characteristics to validate the proposed models. It is also desirable to build a subjective database covering potential QoE influencing factors, video types, VANET characteristics and user characteristics. This database will serve as a reference to test the proposed QoE models.

6.2.6. Radio Access Technologies

The QoE video models over VANETs should be able to measure the QoE of various VANET architectures as with or without RSU, with or without cellular mobile networks and so forth. VANET can use different radio access technologies (WiFi, WiMAX, LTE, 4G and 5G) and credible models must take into consideration all technologies used.

6.2.7. Video Type and Codec

Different video types and codecs are developed like auto stereoscopic 3DTV (AS3DTV), 4K ultra high definition (4K-UHD), and super HDTV (SHDTV). Models should be easily customized to deal with various video coding.

6.2.8. Models Standardization

The study of QoS and QoE of video service in VANETs appeared many years ago, but till now there has been no standardization of influencing factors, methods of measurement or prediction of QoE. Most research focus on formulating models and trying to find a relation between the QoE and factors. It is important to address research to standardize the QoE over VANET for video service.

6.2.9. Routing Protocol for Video Streaming

The underlying routing protocols for VANETs should be evaluated and compared to find the most suitable one for video service over VANETs. In addition, new proposed routing protocols for video streaming over VANETs are of great interest.

7. Conclusion

Quantifying the QoE-QoS relationship is an extremely challenging task and the ultimate judge of telecommunication service quality. In this paper, various issues regarding the QoE of video streaming applications over VANETs are presented. We identified and summarized the most interesting factors that influence the end user QoE of video streaming. The influencing factors were classified in various categories and the recent research in this area has been thoroughly reviewed. Some QoE models of video streaming over wireless, ad-hoc, mobile and MANETs have been discussed. A special focus is put on VANETs where all the pertinent QoE models of video streaming found in the literature were presented, analysed and evaluated. Finally, the paper identified some challenges that still require innovative solutions for modeling the video quality in order to improve the

QoE perceived by users of a video streaming service. With regard to the challenges of QoE/QoS correlation modeling, there is still a need to identify and better understand many QoE influencing factors for a given type of service and to find out how they influence each other.

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