Video coding solutions for VANETs

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Introduction

The impending widespread deployment of Vehicular Ad Hoc Networks (VANETs) has created an opportunity for multimedia communication not only as part of vehicle safety provision, traffic management, and emergency response but also in the value-added 'infotainment' domain. The key feature of video distribution to the passengers of vehicles or crew members of emergency vehicles in the VANET is robustness and reliability, as the environment is highly error prone. As detailed below, complex movement patterns of vehicles and non-line-of-sight wireless propagation add to the challenge of multi-hop routing. One response to this challenge is through the error-resilience features of the H.264/AVC (Advanced Video Coding) codec, which together with multipath streaming, including peer-to-peer streaming [1], provide source coding solutions. Application-layer forward error correction (AP-FEC) as a general solution may replicate physical layer channel coding (unless the AP-FEC acts as a concatenated code), while error control through ARQ, apart from the additional latency introduced over multi-hop network paths, is unreliable when network links are constantly being broken.

In retrospect, three events may be singled out in the rise of VANET multimedia communication. Firstly in 1999, the US FCC allocated 75 MHz bandwidth of the 5.9 GHz spectrum to Dedicated Short Range Communication (DSRC), essentially for wireless communication between vehicles and from a vehicle to the network infrastructure, normally via roadside units. Secondly, the term Vehicular Ad Hoc Network (VANET) was first applied in the 2004 ACM international workshop of that name and since then academic activity has burgeoned. And thirdly, in 2005 video streaming over VANETs was suggested as a way of reporting traffic congestion and accidents [2], as captured by roadside cameras. In 2005 also, an early feasibility study [3] in Japan was testing streaming video between two vehicles. Imaginative ways of responding to urban emergencies [4] by streaming video to responding vehicles are one of a number of VANET initiatives by Mario Gerla's research group at the University of California, Los Angeles.

Multi-wireless-interface vehicles placed within cellular networks are already proposed [5] as a way to relieve congested cells. As new 'push' multimedia services are introduced into 3G cellular networks, the same services may be extended into VANETs. VANETs may also support the exchange or sharing of personal video clips (as occurs in social networks). Roadside sources of multimedia content [6], possibly linked in a backbone network, can disseminate pre-encoded video or serve to notify the passengers of a passing vehicle of available video sequences in circulation within the VANET.

VANET streaming characteristics

Though video streaming for Mobile Ad Hoc Networks (MANET) has been long investigated, for example [7], there are some important differences [8] between MANETs and VANETs. The mobility model often used in MANETs is random waypoint which is unconstrained either by the presence of buildings that occur in an urban road topology or the linear nature of a highway VANET. High speeds on highways may cause network fragmentation. VanetMobiSim [9] is openly available and includes modeling of driver behavior and deceleration/acceleration of vehicles when overtaking or changing lanes, especially within a city or the suburbs. Though car manufacturers are leading the way with microscopic level simulation modeling [10], there are generic features of vehicle mobility such as the nature of road obstacles including lane closures, uphill gradients, and potholes, which produce the same reactions the world over. Another difference is that in MANET research line-of-sight signal propagation models such as the two-ray ground propagation model are common, whereas it is becoming increasingly obvious that an urban environment will introduce reflections, diffraction and scattering due in part to the presence of urban 'canyons'. IEEE 802.11p based VANETs (there are some Code Division Multiple Access networks proposed) will be able to take advantage of the vehicle as an energy source. This does not mean that the control overhead of streaming across the network can be neglected, as this overhead still acts as a form of congestion, but it does remove a computational and storage restriction that affect MANET devices.

In Fig. 1a, a crash has occurred which can be captured by roadside cameras (on masts in the Figure) or by patrol cars, which commonly are equipped with cameras. Emergency vehicles such as the fire engine and ambulance are shown

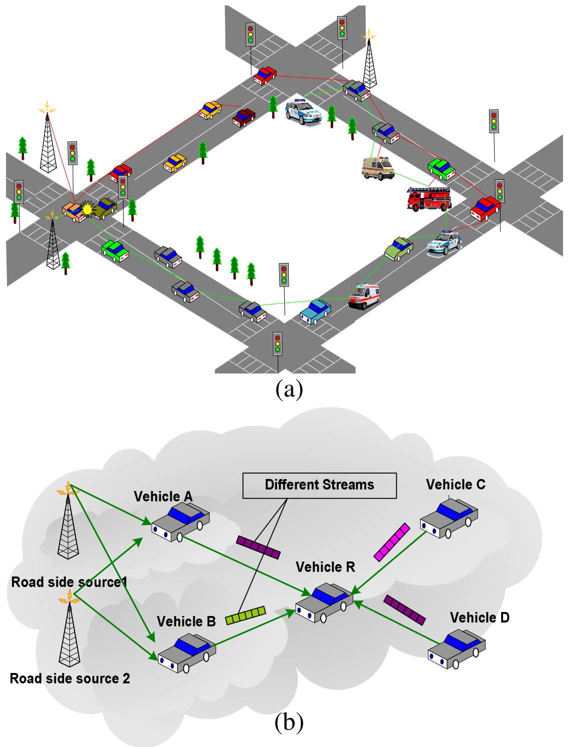

Figure 1. a) Simplified scenario of VANET multi-path streaming from a crash scene b) in P2P streaming of video clips a receiver conceptually receives four versions of the stream, two from vehicles that have already acquired a version of the video clip and two from vehicles capturing or relaying from roadside units.

making their way to the accident. An early view of the scene is a way that the responder vehicles can prepare while on route. As roadside, possibly high-rise buildings reflect the signal, propagation is likely to be along the roads and likewise diffraction of the signal will occur round corners. Therefore, it is difficult for emergency vehicles to communicate directly with each other even if they are within range. Consequently, we have proposed that to relay the video stream these vehicles form a multicast group embedded within a VANET formed by vehicles in the vicinity. Network coding has been introduced [11] as a way of protecting confidentiality in this type of situation but selective encryption of (say) motion vectors is another possibility which does not require action by non-emergency vehicles. The Figure shows two streams following multi-hop paths from the accident. In networking terms, path diversity helps to balance the load but in coding terms there is a natural mapping to Multiple Description Coding (MDC).

In Fig. 1b, P2P streaming is proposed as a solution to another application, when video distribution is less time-critical, as it indeed might be in 'infotainment' applications. Because passing vehicles may not linger sufficiently for a full video sequence to be transferred from a roadside unit, partial storage in any one vehicle may occur. Vehicles with partial video sequences may also later park or leave the vicinity. Fig. 2 is an example of our P2P slice compensation scheme for MDC. The *same* video stream transported in MDC form is

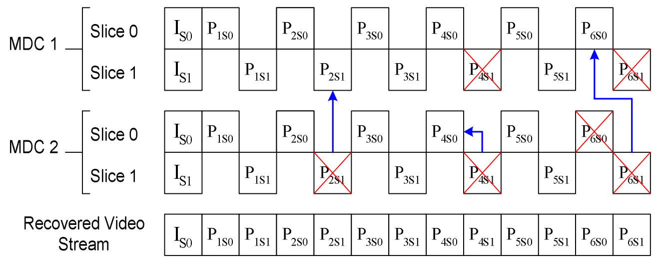

Figure 2. An example of the proposed slice compensation scheme with MDC and FMO, with arrows indicating the relation ship "can be reconstructed from"

available from two sets of peers (MDC 1 and 2). That is the MDC 1 and 2 streams are duplicates of each other that are transported using MDC and are NOT two descriptions of the same video. Each frame within a video stream (MDC 1 or 2) is further split into two slices (slices 0 and 1) to form two descriptions.

Source coding options

We have experimented with temporal MDC [12] using a type of Video Redundancy Coding (VRC) scheme [13] without back channel, which avoids the need for the specialist codecs associated with some other forms of MDC. VRC maintains synchronization, which was a problem with an earlier scheme. An issue with VRC is the extraction of independent odd and even frame streams, which reduces the coding efficiency derived from motion estimation. In contrast, H264/AVC's spatial Flexible Macroblock Ordering (FMO) [14] with the dispersed or checkerboard selection macroblock (MB) pattern as a form of MDC is attractive. If one of the descriptions for a frame is lost then the other can be used, as missing MBs can be error concealed using motion copy from adjacent MBs. Moreover, there is no duplication of data in the two streams, and mapping overhead is only apparent when at very low error rates. The 'bursty' output rate associated with distributing large I-frames is a problem for VANETs, because of the sudden influx of packets into the ad hoc network. H.264/AVC provides intra-MB refresh [15], which can be combined with FMO to reduce the latter problem. When intra-MB refresh is operated in row cyclic order, then synchronization occurs after every cycle. Another potential solution to achieving MDC is to employ redundant slices or pictures [16]. In this scheme redundant slices are encoded at a higher compression ratio than the slices they accompany in the stream. This can take place with two 'redundantly-sliced' streams of even and odd frames, using MB-refresh to avoid error propagation across the IPPPP…….. Group of Picture (GoP) structure. Compared to other forms of MDC, we found that redundant slices suffered heavier losses under burst error conditions. However, intuitively either the packet losses occur for redundant-slice bearing packets or the reduction in video quality from replacement by redundant slices is not as damaging as the complete loss of some frames.

An insight from the experience with redundant slice MDC is that in a VANET in particular the extra transmission energy consumed is not necessarily a handicap. Therefore, we have also proposed [17] that a redundant or duplicate base layer may be a way to effectively provide MDC. In this scheme, in a counter-intuitive way, the enhancement layer(s) *and* the original base layer are transported in one stream and the redundant base layer in another stream. Each stream follows a different route. In fact, on-going work for the H.264/SVC (Scalable Video Coding) extension will further extract just the key pictures as another stream. (In an 8-picture SVC GoP, the key picture content can be as low as 5% of the total data depending on spatio-temporal configuration, bearing in mind that the base layer only contains these key pictures and is more coarsely encoded than the enhancement layers.) If packets from key picture frames are lost then other packets bearing data from the SVC predictive structure have to be discarded, which without this robustness makes SVC problematic in the highly error-prone VANET environment.

Conclusion

However, before any of these robust schemes can be properly validated it is important to utilize mobility models that incorporate all the important factors and to develop propagation models that show how on average multimedia streaming will respond in a VANET environment. To that end we have elaborated an existing ray-tracing model for simulation purposes. This enhanced model can include the distance over which a signal is reflected and add the effect of roadside scattering such as from signs, street 'furniture' and foliage. This does mean that expertise in wireless *and* coding is required for VANET multimedia solutions, but in return for this versatility there is a potential rich range of coding possibilities that hopefully this Letter has outlined.

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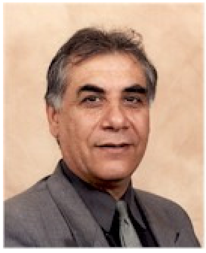

Mohammed Ghanbari (M'78, SM'96, F'01) is best known for his pioneering work on two-layer video coding for ATM networks (which earned him an IEEE Fellowship in 2001), now known as SNR scalability in the standard video codecs. He has served as an Associate Editor to IEEE Trans. on Multimedia (IEEE-T-MM from 1998-2004) He has registered for eleven international patents on various aspects of video networking and was the co-recipient of A.H. Reeves prize for the best paper published in the 1995 Proc. of IEE on the theme of digital coding. He is the co-author of "Principles of Performance Engineering", a book published by IET press in 1997, the author of "Video Coding: An Introduction to Standard Codecs", a book also published by IET press in 1999, which received the year 2000 best book award by the IEE, and the author of "Standard Codecs: Image Compression to Advanced Video Coding" also published by the IET press in 2003. Prof. Ghanbari has authored or co-authored about 500 journal and conference papers, many of which have had a fundamental influence in this field.

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