Robust P2P Multimedia Exchange within a VANET

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Multimedia exchange within a Vehicular Ad Hoc Network (VANET) may be facilitated by exploiting the peer-to-peer (P2P) paradigm for which a multi-path routing protocol has been designed to reduce packet loss. Urban VANETs are characterized by restricted vehicle mobility, driver actions, and bunching at obstacles, leading to wireless interference and broken links. Similarly P2P communication relies on distributed sources which are intermittently available. However, routing packets over multiple hops and multiple paths still results in packet losses, resulting in poor quality reconstructed video at a receiver. This paper proposes a novel slice compensation scheme employing spatial Multiple Description Coding to provide error resilience as a solution to these problems. Results show constant good-quality video even if packet losses rates increase.

Keywords *error resilience, multi-path protocol, peer-to-peer, VANET, video streaming*

1 Introduction

The IEEE 802.11p standard [1] operating in ad hoc mode will facilitate Vehicular Ad Hoc Network (VANET) development, taking advantage of 75 MHz of spectrum (separated into seven 10 MHz channels) widely available in the 5.9 GHz range. As a result, increased safety and traffic efficiency [2] may arise from in-vehicle WLAN provision. Additionally, value-added services such as ‘infotainment’ and business applications [1] are contemplated. Roadside sources of multimedia content [3], possibly linked together by a backbone network, can disseminate pre-encoded video or serve to notify a passing vehicle of available video sequences in circulation within the VANET.

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. The insight of this paper is that video can still be delivered from distributed senders if vehicles form a Peer-to-Peer (P2P) network, because the video can be progressively downloaded from multiple vehicles that have at some time passed a roadside source. These vehicles act as peers in the P2P overlay network. The encoded video sequence is divided into chunks and sent from multiple peers to a single destination that lacks some or all of the sequence. Progressive download implies that display is overlapped with delivery, meaning that packets within chunks cannot be resent as this would cause time gaps in the display. Therefore, it is important to minimize packet loss. Minimal packet loss is also required because in motion compensated predictive coding loss of a packet will cause error propagation, resulting in video quality degradation that unless corrected spreads out from a lost packet.

Multiple Description Coding (MDC) of the video [4] enables the path diversity of the underlying VANET to be exploited by sending alternative descriptions of the video from different peers. Temporal decomposition of the video into multiple descriptions is common but has two problems: 1) though the bandwidth over any one path is reduced, the efficiency decreases because in practical scheme [5] there is a need to include additional intra-coded frames; and 2) if error drift between the descriptions is to be avoided specialist codecs are required [6], which are not widely available.

Therefore, we introduce spatially-decomposed MDC into P2P networks by splitting encoded video into slices through checkerboard pattern Flexible Macroblock Ordering (FMO) [7] in the H.264/Advanced Video Codec (AVC). As the same frame structure is preserved, no extra frames are required and temporal error drift is actively prevented by the decomposition. A slice is a sub-frame unit of error resilience bounded by decoder re-synchronization markers, which delimit entropic decoding (the final stage in a hybrid codec such as H.264). In H.264, each slice forms a Network Abstraction Layer unit [8], which in turn is encapsulated in a Real Time Protocol (RTP) packet (prior to passing to the IP protocol stack). When chunks are reordered in the P2P cache or buffer-map of the destination prior to decode and playback, if there are still missing chunks or chunks lacking some slices, checkerboard FMO can aid decoding through the mechanism of error concealment. In fact, checkerboard is the only available H.264 FMO pattern that assists error concealment in this way. Moreover, VANETs facilitate the provision of P2P buffer-maps because they do not suffer from energy loss, as would be a problem with large buffers in other types of ad hoc network.

Video error resilience [8] through Gradual Decoding Refresh (GDR) [9] was also applied. This measure is necessary, despite the 3–27 Mbps supported by IEEE 802.11p, because vehicle mobility still causes broken links and traffic congestion results in wireless interference at the points where vehicles congregate. In fact, the extra 802.11p capacity is not required for the compression efficient H.264/AVC, resulting in delivery at a faster rate than is required at a cost in the need to protect against packet loss.

Figure 1 is an example of our P2P slice compensation scheme for MDC with FMO, assuming the receiver lacks all of the video sequence. Within the stream before decomposition into descriptions, an initial intra-coded I-frame is followed by a series of predictively-coded P-frames. By the insertion of spatially coded rows of macroblocks, GDR serves to anchor the predictions of subsequent P-frames in the event of the complete loss of a prior P-frame. However, GDR avoids the need for intra-coded I frames, which can cause sudden increases in the datarate. Notice that Bi-predictive (B)-frames do not occur in the less complex Baseline profile of H.264, making the Baseline profile suitable for mobile devices.

In Fig. 1, the same video stream is available from two sets of peers (MDC 1 and 2). That is MDC 1 and 2 are duplicates of each other. Each frame with a video stream is further split into two slices (slices 0 and 1) to form two descriptions, resulting in four sender streams in all. The associated slice numbers in Fig. 1 do not refer to a decoding sequence but to the original display frame order, as produced by the encoder. Suppose P_{4S1} and P_{6S1} from MDC 1 and P_{2S1}, P_{4S1}, P_{6S0} and P_{6S1} from MDC description 2 are lost. P_{2S1} of MDC 2 can be replaced by P_{2S1} of MDC 1. P_{4S1} of both the descriptions can be decoded from P_{4S0} of any description and similarly P_{6S1} can be decoded from P_{6S0} of MDC 1, both using the properties of checkerboard FMO. However if only one stream (MDC 1 or 2) and no error resilience were used then it would not be possible to recover the lost frames. Furthermore, one row of macroblocks per slice in turn is coded in intra mode (rather than inter mode) in order to increase error resiliency, as that portion of the P-frame can readily be decoded without any prior reference frame. Thus, GDR further helps restore frames reconstructed through FMO.

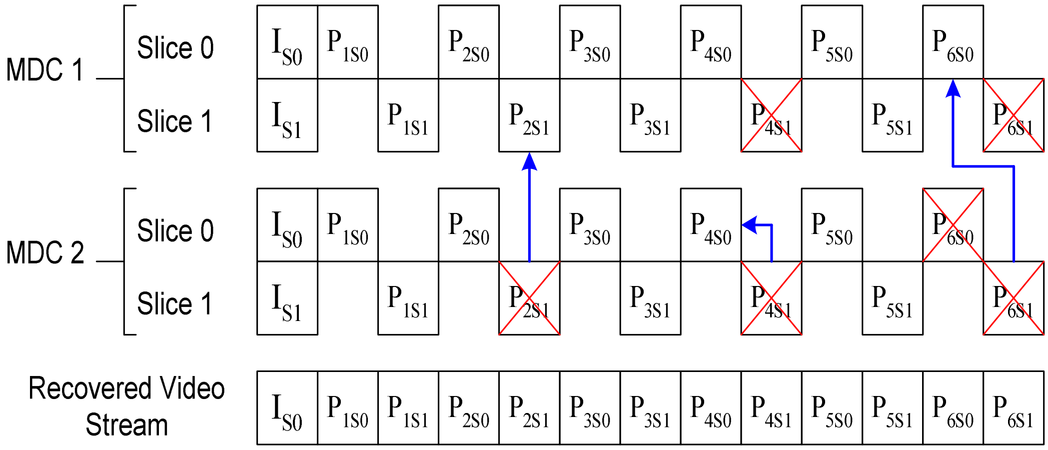

Figure 1. An example of the proposed slice compensation scheme with MDC and FMO, with arrows indicating the relation ship "can be reconstructed from"

It is possible to distinguish at least two types of automotive VANET environment [10]: 1) urban and suburban networks; and 2) highway and rural areas and in this paper we consider the former. For video streaming over a highway, earlier investigation exists [11], though not over a P2P overlay and mainly from the perspective of how to 'trigger' the collection of the video by forwarding requests to vehicles further along the highway. Urban VANETs (but not highway VANETs) are distinguished by relatively slow speeds due to traffic congestion and the presence of obstacles such as road intersections and traffic lights. In VanetMobiSim [12], driver behavior in the presence of other vehicles [13] is also accounted for in an Intelligent Driver Model (IMD). In car-following models of which the IMD is an improved version, a driver does not approach a vehicle arbitrarily closely as can occur in some mobility models but will de-accelerate if another car is ahead or overtake in another lane. Therefore, we use VanetMobiSim mobility modeling, taking groups of roads that intersect at traffic lights to illustrate the findings.

Multi-path communication is attractive [14] in this type of network because single paths are frequently broken or paths may experience poor channel conditions. Therefore, this paper also introduces Multipath (MP)-Dynamic Source Routing (DSR), which for any one connection provides a choice of several disjoint or near disjoint paths selected to potentially reduce packet loss (through smaller hop counts).. MP-DSR was employed because it provided improved performance over single path data transfer but otherwise the main thrust of this paper is towards video delivery rather than protocol development. We now consider how a P2P overlay facilitates the transfer of streamed media over a VANET.

2. Multimedia exchange over a P2P overlay

Both VANETs and P2P networks are decentralized, autonomous and highly dynamic in a fairly similar way. In both cases, network nodes contribute to the overall system performance in an intermittent and unpredictably manner but nonetheless exhibit a high level of resilience and availability.

Prior work has explored the possibility of file download [15] or mesh-P2P streaming [16] over a Mobile Ad Hoc Network. However, the combination of progressive download of video with a VANET appears unique to this paper. Figure 2 illustrates a P2P application overlay over a VANET, in which an overlay network is placed over the network layer. The overlay node placement is logically different to that of the physical placement of the nodes.

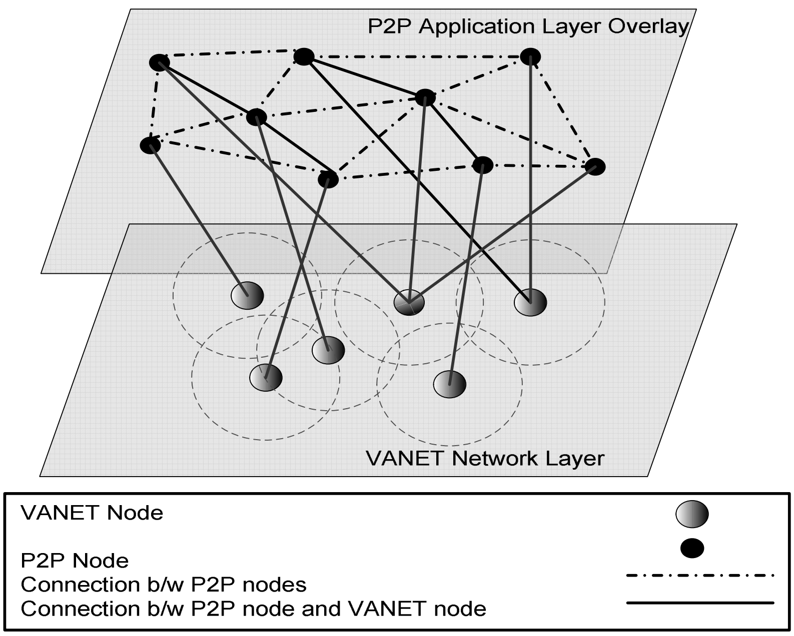

Figure 2. An example of a P2P application overlay over an ad hoc network, after [15]

Figure 3 is a logical representation of the progressive download scheme, in which, after distribution of video chunks by roadside units acting as sources to passing vehicles, these vehicles act as nodes within the network. These nodes may upload or download at the same time. As soon as a sender receives chunks it can send them to other peers. A single receiver vehicle must receive at least two descriptions and each description must be delivered from multiple peers. However, a receiver may well try to connect to other sending peers in a process called handover. A handover generally occurs due to two reasons: 1) the receiver is receiving few or no chunks from its current senders or 2) for load balancing purposes. Organization of the P2P overlay and the process of locating suitable senders is outside the scope of this paper as it is a topic that has been extensively explored elsewhere [17], though roadside units could act as classical P2P servers in that respect. The receiver stores the received chunks from different peers into its buffer-map. Having buffered a certain number of contiguous chunks, it then sends the chunks in correct order to its playback buffer. The decoder renders the video from its playback buffer, taking advantage of our slice compensation scheme outlined in Section 1 to reconstruct missing data. We now consider how to model this system.

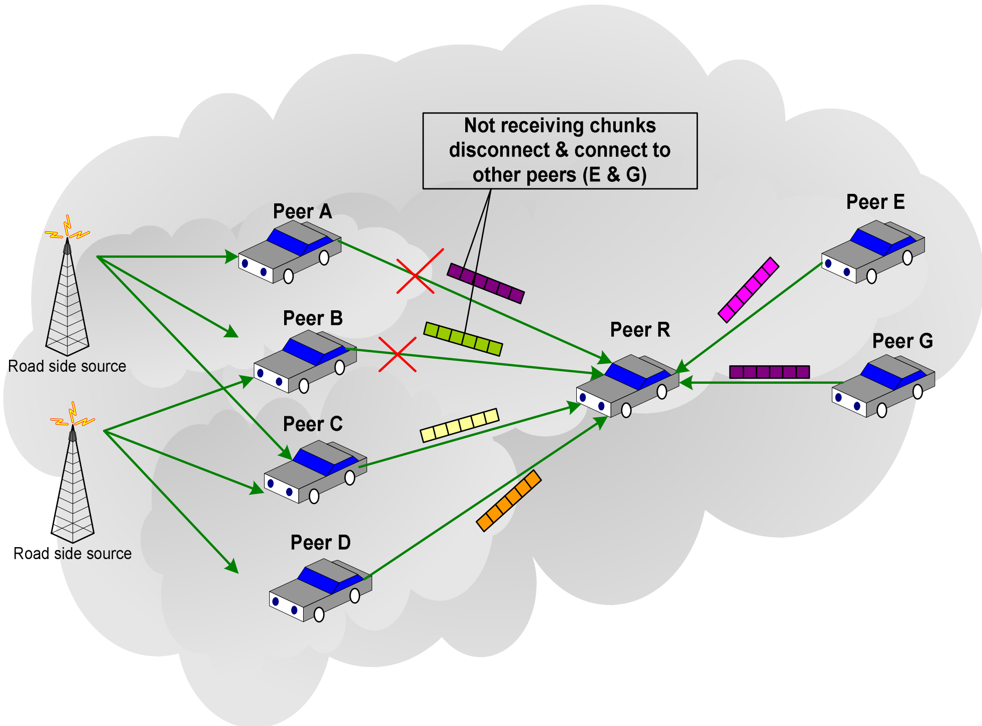

Figure 3. Mesh-based P2P topology sending video chunks from roadside sources to peers within the VANET, from which the chunks are distributed over multiple paths

3. Modeling P2P over a VANET

Simulation is the main tool for research on VANETs [18], because the complex vehicle mobility models that arise are unlikely to be represented analytically, with a large number of variables (vehicle density, car speeds, driver behavior, road obstacles, road topologies …) and it is difficult to conduct repeated live experiments.

3.1 Simulation methodology

We employed the Global Mobile System Simulator (GloMoSim) [19]. IP framing was employed with UDP transport. Total simulation time was 900 s, which started after an initial period without video exchange imposed by VanetMobiSim in order that the mobility model reached steady state. There was one video clip and one destination vehicle with four senders at any one time. GloMoSim has been altered so that nodes start at random locations rather than at the origin. Data points are the average (arithmetic mean) of 50 runs in order to better reach convergence.

A two-ray propagation model with an omni-directional antenna height of 1.5 m at receiver and transmitter was selected for which the reflection coefficient was -0.7, which is the same as that of asphalt. The plane earth path loss exponent was set to 4.0 for an urban environment, with the direct path exponent set for free space propagation (2.0). Though more detailed path-loss models are possible, as noted in [20] the two-ray model is effective when line-of-sight is present because the path loss characteristics are dominated by the interference between the direct path and the road-reflected path.

The IEEE 802.11p transmission power was set to 23 dBm (0.2 W) with a range of 300m, to reduce interference as much as possible within the city. Receiver sensitivity was set to -93 dBm. IEEE 802.11p's robust Binary Phase Shift Keying (BPSK) modulation mode[1] at 1/2 coding rate was simulated. The resulting bitrate is at the lower end of IEEE 802.11p's range at 3 Mbps. Bit Error Rate (BER) modeling within the simulator introduced a packet length error dependency.

To simulate handover, new sending peers were selected by the destination approximately every 7.5 s. As GloMoSim does not conveniently allow automatic selection of peers, choice of new sending peers was hard-wired into the simulations.

[1] The similarly robust alternative is QPSK at 1/2 coding rate, which is the default modulation mode for IEEE 802.11p, though the data rate (6 Mbps) was excessive for our needs.

3.2 Mobility modeling

The downtown topology of VanetMobiSim [11] was selected. In the simulations, a 1000 × 1000 m^2 area was defined and vehicles were initially randomly placed within the area. Other settings to do with road cluster density, intersection density, lanes (2) and speeds are given in Table 1. The number of traffic lights (at intersections) and time interval between changes was also defined.

The Intelligent Driver Model (IDM), introduced in Section 1 accords with car following model developed elsewhere [13] and based on live observations. VanetMobiSim adds to this with modeling of intersection management (IDM-IM). The IDM-IM is extended to include lane change behavior in the IDM-LC model, which was used in our simulations.

Global Parameters	
Simulation Time	900 s
Terrain Dimension	1000 x1000 m^2
Graph type	Space graph (Downtown model)
Road Clusters	4
Intersection Density	$2e^{-5}$
Max. traffic lights	10
Time interval between traffic lights change	10000 ms
Number of Lanes	2
Min. Stay	10 s
Max. Stay	100 s
Nodes (vehicles)	20, 60, 100
Min. Speed	3.2 m/s (7 mph)
Max. Speed	13.5 m/s (30 mph)
IDM-LC Model	
Length of vehicle	5 m
Max. acceleration	0.6 m/s^2
Normal deceleration	0.5 m/s^2
Traffic jam distance	2 m
Node's safe time headway	1.5 s
Recalculation of movement parameters time	0.1 s
Safe deceleration	4 m/s^2
Politeness factor of drivers when changing lane	0.5
Threshold acceleration for lane change	0.2 m/s^2

Table 1. Settings for road layouts and mobility model

The micro-mobility models presented by VanetMobiSim are of increased sophistication in driver behavior, which together with wireless channel increase the realism and reduce optimistic assessments of what can be achieved in a

VANET. Unfortunately, when driver behavior is introduced into simulations it is no longer possible to easily examine node speed dependencies, as the vehicles will have a range of speeds depending on local conditions, though the minimum and maximum speeds are not exceeded.

3.3 Video source

The 1065 frame 'Paris' video sequence[2] showing a spatially complex TV studio scene was encoded with the JM v.15 H.264/AVC software. The Constant Bitrate (CBR) target bitrate was 64 kbps for Quarter Common Intermediate Format (176 × 100 pixel/frame) at 15 frame/s. This rate results in an average RTP packet size before slicing of around 520 B. The Baseline Profile of H.264/AVC was selected with the frame type structure of an I-frame followed by all P-frames, i.e. IPPP…, using GDR to reduce error propagation (refer back to Section 1).

As mentioned in Section 1, checkerboard FMO can work through error concealment to restore missing data. The checkerboard type stands apart from other FMO types, as it does not employ adjacent macroblocks as coding references, which decreases its compression efficiency and the relative video quality after decode. However, due to the availability of safely decoded macroblocks at the vicinity of lost ones and hence its better error concealment property. Consequently, the rate of decrease in video quality with an increase in loss rate is lower than for the other pre-set types.

A motion-vector-based error concealment method performs best except when there is high motion activity or frequent scene changes, but, out of fairness, the intra-coded frame method of spatial interpolation was also tested, as this can provide smooth and consistent edges. Both methods were applied and the superior result in terms of average (arithmetic mean) Peak Signal-to-Noise Ratio (PSNR) across the video sequence was selected. In practice, either one or the other method of error concealment would be selected throughout or the choice could be made dynamically by examining the continuity at macroblock boundaries.

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[2] Available as raw YUV from http://trace.eas.asu.edu/yuv/index.html

4. Multi-path routing protocol

4.1 Protocol description

The opportunity was taken to test a modified multi-path routing protocol (MP_DSR) that more closely matched our needs, which was for reduced hop count as well as maximally (node) disjoint paths. Reducing the hop count is the main way of reducing the risk of packet loss, though it may coincidentally also reduce delay. The protocol modifies the Split Multi-Routing (SMR) protocol proposed in [21], to select for reduced hop count rather than reduced end-to-end delay. Like SMR, the modified version also selects for path disjointness and in practice was applied to the selection of two routes, though the scheme is extendible to more than two routes. Once multiple (two) routes are established then video data chunks are sent by multiplexing them across those routes. The following changes were made to SMR:

- Unlike SMR, the destination node does *not* always select the route indicated by the first arriving Route Request (RREQ) message but sets a timer and collects all RREQs that arrive before the timer expires.
- The route selection mechanism is modified at the destination to take account of the number of hops as well as the disjoint nodes factor. If there are enough routes to justify the procedure the collected routes are pruned so that their hop counts fall below a threshold. The similarity of route pairs is then calculated. One way to do this is to count the number of nodes each route has in common. A cost function can then be formed consisting in our case of the addition of the similarity measure and the number of hops in each route. The required number of routes is then selected by taking the paths in order of minimum cost function.
- The source of the RREQ packets does not start transmitting data packets unless it has established a number of paths to the destination. Paths are notified to the source by sending a Route Reply (RREP) message from the destination. Otherwise, after the time for receiving at least one path expires, route discovery is reattempted.
- If all the routes subsequently fail, a sender uses routes obtained from gratuitously returned Route Reply (RREP) messages to salvage routes if the

gratuitous routes' hop counts are not more than the maximum hop counts of failed routes.

Otherwise, protocols procedures follow those of SMR. For example, like SMR and unlike the well-known single-path DSR routing protocol [22], intermediate nodes do not return RREP messages. This is because: returning these RREP messages reduces the number of disjoint path notifications arriving at the destination; and pre-established routes held in intermediate nodes' caches are hidden from the destination.

4.2 P2P streaming performance

The advantage to be gained from multipath routing with MP-DSR was checked against single path DSR, which is apt as SMR itself is a multipath extension of DSR. Just two routes were selected for each connection. From Figs. 4 to 6 (the average of fifty runs) there is a consistent gain from using the multi-path protocol across all categories of comparison. An interesting observation is that control overhead actually decreases with the multi-path protocol, confirming earlier investigation [22]. There is a reduction in transmission energy usage from the reduction in overhead packets but as VANET vehicles usually have their own power sources, it is more significant that the general network congestion is reduced in the event of other traffic sharing the network. Delay is also reduced as has been anticipated [23] because otherwise line breaks lead to retransmitted packets causing delay. For the scenarios herein, MP-DSR did not degrade with increased network density in the way reported for SMR [14] in similar sized networks (though for random waypoint mobility). However, further exploration of this topic is a diversion from the main topic of this paper, which is the feasibility of P2P video streaming with the MDC error resilience scheme.

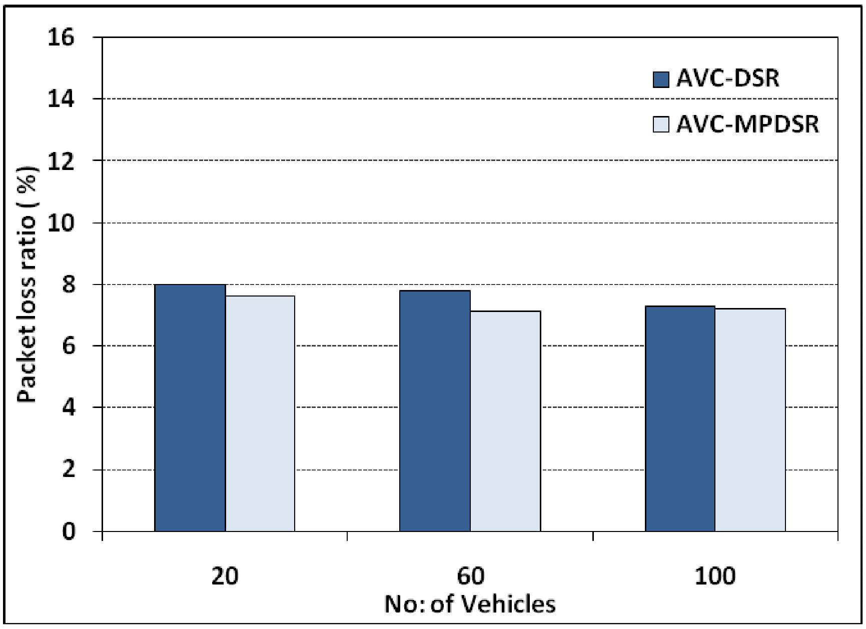

Figure 4. Comparison of the packet loss ratio between H.264/AVC unicast streaming (AVC) with single path routing using DSR and multi-path routing using MP-DSR

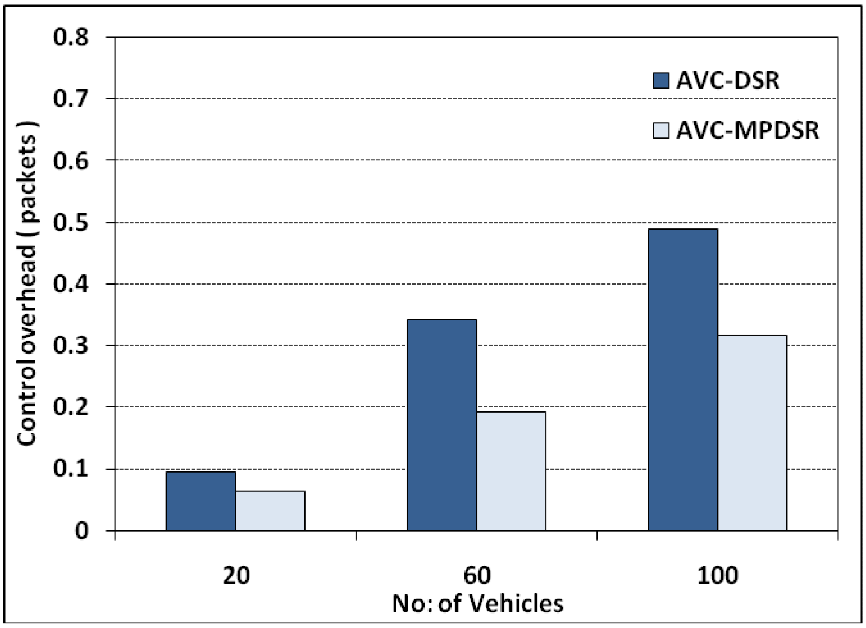

Figure 5. Comparison of the control packet overhead between H.264/AVC unicast streaming (AVC) with single path routing using DSR and multi-path routing using MP-DSR

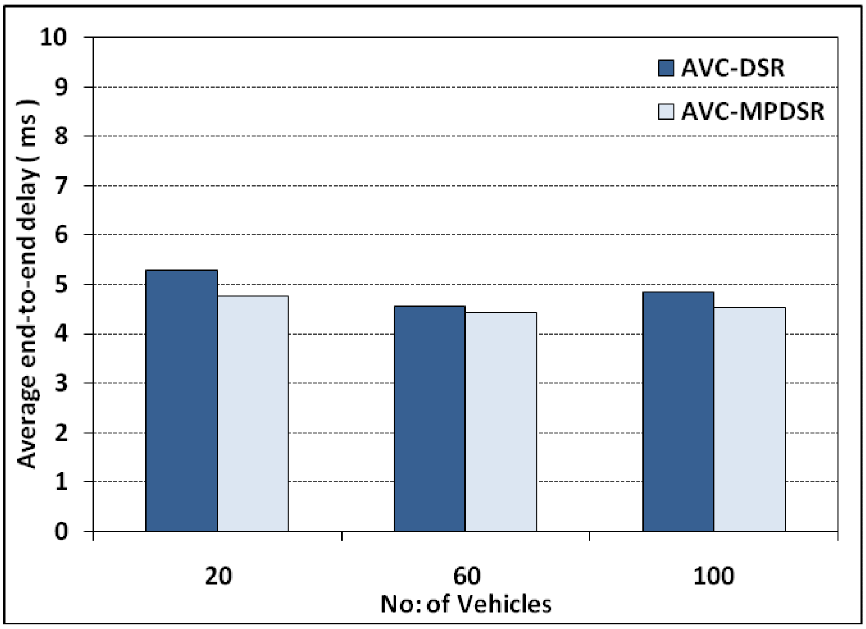

Figure 6. Comparison of the end-to-end delay between H.264/AVC unicast streaming (AVC) with single path routing using DSR and multi-path routing using MP-DSR

5. Overall evaluation

5.1 Video performance

We compared the slice compensation scheme of Section 1 to a simple form of MDC. In the simplified MDC, there were just two senders and a duplicate set of chunks was sent from each sender, i.e. no slicing occurred and consequently just one set of chunks over one path was sent from each of two senders. Obviously, if packets from one chunk are lost then these can be replaced by those from the other but if the same packet is lost from both senders then reconstruction is no longer possible. In that case, previous frame replacement only is available, causing freeze frame effects. Recall that handover of senders occurs periodically.

In the case of the slice compensation scheme, the chunk size was set to 30 RTP packets, each bearing one H.264 NAL unit, implying 15 frames per chunk or 1 s of video at 15 fps. The FMO NAL unit size was approximately half that of the size before slicing, i.e. RTP packet size was around 260 B (CBR video is never exactly CBR because of coding issues). In the simplified scheme, the RTP packets without FMO slicing were not exactly the same as two single slice RTP packets because of the need to accommodate FMO mapping information [7] in the

NAL unit.

As a benchmark, both MDC schemes were compared to ‘AVC’, that is P2P with the Advanced Video Codec for compression without using MDC. However, for all schemes tested in this Section, MP-DSR routing was employed.

In terms of network performance, Figure 7 shows that for both variants of MDC, as the density of the network increases, the packet loss ratio (number of lost packets to total sent) decreases. The bars reflect average (arithmetic means). Because of path diversity the number of packets lost is much reduced compared to what one would normally expect. Moreover, the packet loss ratios for the slice compensation scheme (labeled MDC with E. Res) are consistently below those of the simplified MDC scheme. Therefore, there is a gain from increasing the number of paths from two to four. In fact, the ratios are also stable as the number of vehicles is increased from 60 to 100, implying an efficient solution once a certain network density has been reached. However, a problem now arises at the sparse density of 20 vehicles. This is because in some of the fifty test runs it was likely that the vehicles were widely separated and road obstacles reduced the chance of the vehicles approaching close enough to facilitate chunk exchange.

Mean per packet overhead (measured in terms of additional packets required to route each packet) increases with the number of vehicles in the network, Fig. 8, reflecting the extra hops traversed. This effect is a consequence of the extra congestion and interference introduced by more dense networks in an urban VANET. As a consequence, the routing protocol has to ‘work harder’ to maintain the low packet loss routes, as shown in Fig. 7. Clearly from Fig. 8, the multi-path routing protocol when used with more senders (four rather than two) becomes progressively better, presumably because it has a better chance to find some of its routes more efficiently than others, increasing the overall efficiency. An end-to-end delay comparison is presented in Fig. 9. This shows that the delay from waiting for the MDC packets exceeds that of the unicast solution, which is intuitively unsurprising as there are more paths over which packets can be delayed in an MDC scheme. However, the levels of delay are in the low millisecond range, which are negligible even in an interactive video application, making any differences insignificant.

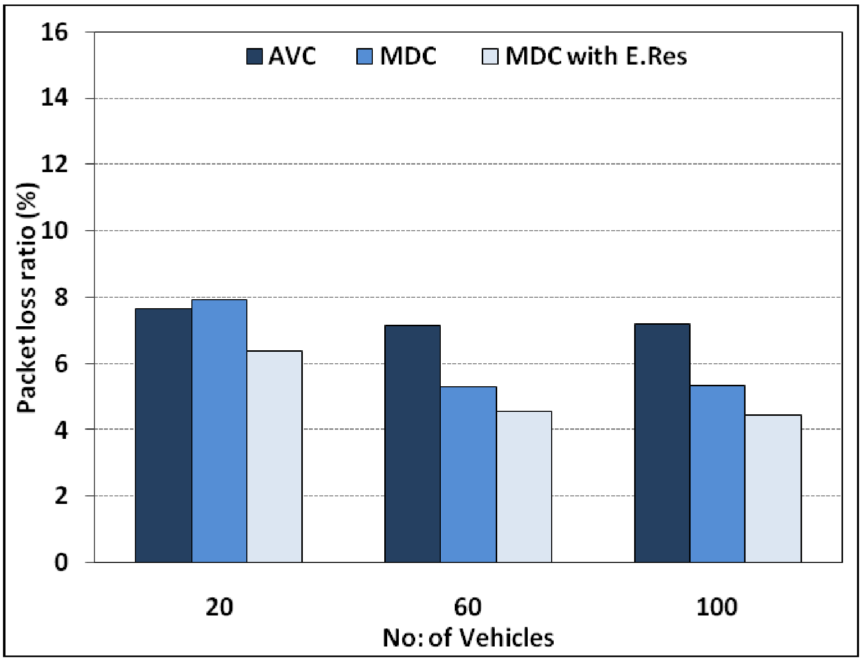

Figure 7. Comparison of the packet loss ratio between H.264/AVC unicast streaming (AVC), MDC and MDC with error resilience (MDC with. E. Res) with MDC schemes using MP-DSR

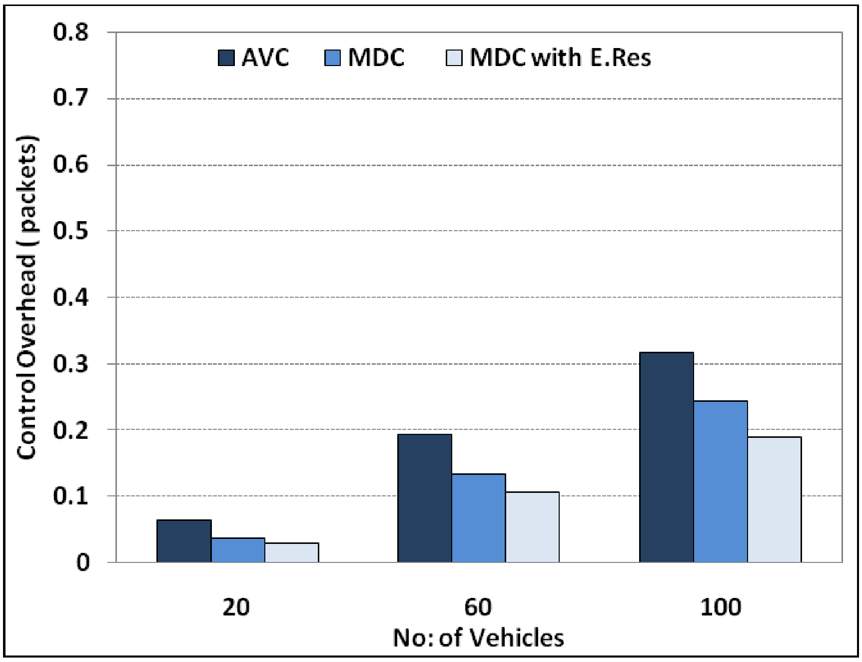

Figure 8. Comparison of the control packet overhead between H.264/AVC unicast streaming (AVC), MDC and MDC with error resilience (MDC with. E. Res) with MDC schemes using MP-DSR

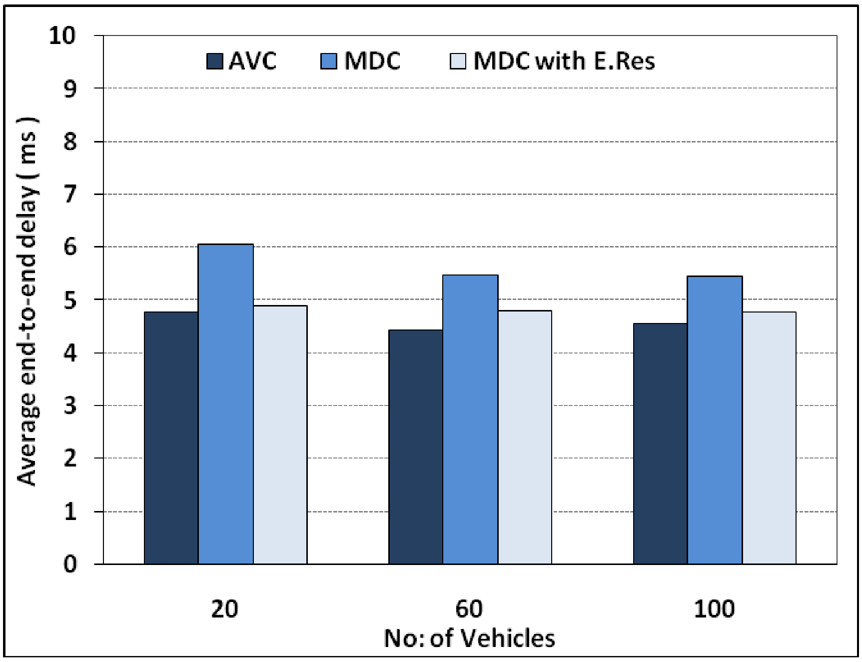

Figure 9. Comparison of the end-to-end delay between H.264/AVC unicast streaming (AVC), MDC and MDC with error resilience (MDC with. E. Res) with MDC schemes using MP-DSR

Figure 10 shows the resulting video quality for a typical simulation run. Also included in Fig. 10 is the PSNR for zero packet loss. This shows that there is a considerable penalty from using FMO because the extra bits taken up in macroblock mapping, for a given fixed target CBR, are no longer available to improve the video quality. Nevertheless H.264/AVC has achieved good QCIF quality at the low datarate for both schemes. However, when the packet loss ratio increases due to FMO with error concealment the slice compensation scheme is able to almost completely maintain video quality, while the simple MDC scheme results in deteriorating quality. Below 25 dB quality is barely acceptable and would be rejected by users even in the knowledge that it is a mobile application.

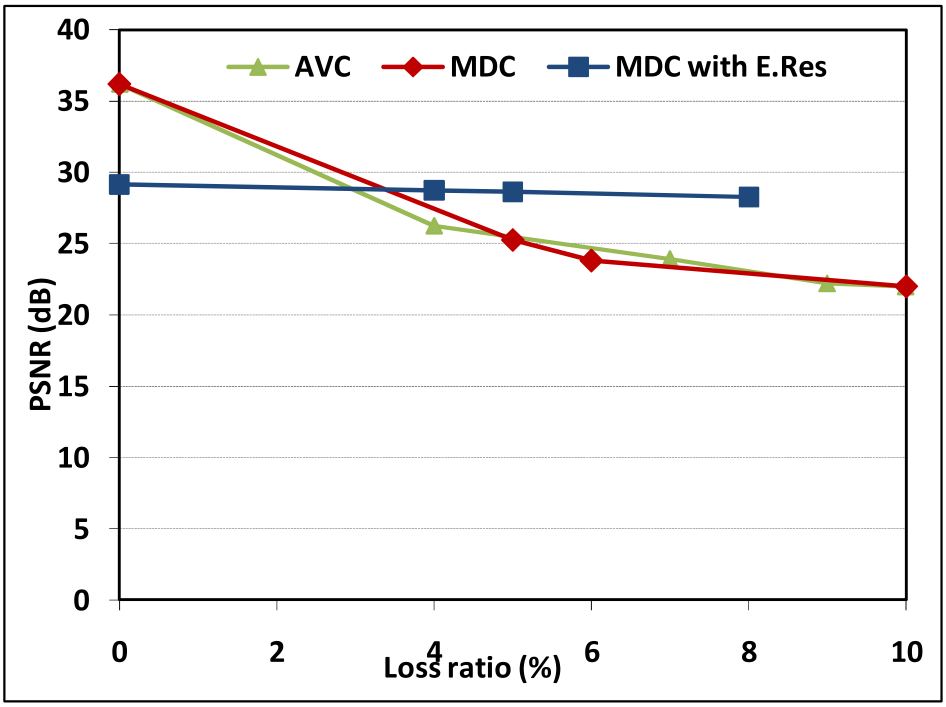

Figure 10. Comparison of the video quality between H.264/AVC unicast streaming (AVC), MDC and MDC with error resilience (MDC with. E. Res) with MDC schemes using MP-DSR

6. Related work

It is the transience of the video sources in a VANET that poses a problem to video communication on a highway [11], as the sources can quickly be isolated by a network partition [24]. On the other hand, even at fast car speeds (up to 65 mph) it is possible [25] to achieve a 1 Mbps data rate with an IEEE 802.11b system operating with a range of 250 m. Guo et al. [11] modeled multiple video sources traveling on a 4-5 lane highway in Atlanta. Video was collected by sending from a car approaching a destination a request trigger to a camera on a remote vehicle passing a destination region. Video transport back to the requestor was by a store-carry-and-forward sub-system, though the method was not detailed [11]. The main analysis [11] concerned the delay characteristics, whereas in fact end-to-end delay can be absorbed by a large on-board buffer, at a cost in start-up delay.

If data from the initial frame of a Group of Pictures are lost or corrupted then errors may propagate for around 1 s at slow scan rates until the next reference frame. An extension [26] of the work by Guo et al. [11] simulated a two-ray wireless propagation model and imposed a Forward Error Control (FEC)-based solution through network coding. Unfortunately, though network coding of FEC and in particular rateless error coding is an effective means of limiting the impact of packet erasures upon streamed video, it depends on action by intervening nodes. When these nodes are not possible destinations and consequently may not be expected to make special provision for video data, then network coding is not feasible.

7. Concluding remarks

The main contribution of this paper has been a slice compensation scheme combined with P2P video delivery over a VANET. The P2P streaming system appears to be an ideal way to organize video distribution, given the dynamic nature of the underlying VANET in which vehicles are continually moving out of range or simply ceasing to transmit when parked. Some form of protection in the harsh wireless conditions is inevitable when transmitting fragile compressed video streams. A secondary contribution is a modified multi-path routing algorithm, which together with the slice compensation scheme reduces the impact of packet loss, leading to stable video quality. In fact, the version of MP-DSR presented in this paper is one of a family of such multi-path protocols that can be designed to benefit either reduced packet loss, or reduced delay, or reduced overhead (or a mixture of these criteria). Future exploration will examine the relative merits of these protocols, now that the advantage for video streaming has been established.

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