Resilient P2P Multimedia Exchange in a VANET

N. Qadri, M. Fleury, M. Altaf, B. R. Rofoee, and M. Ghanbari
School of Comp. Sci. and Electronic Eng.
University of Essex
Colchester, UK
{nnawaz, fleum, maltaf, brahim, ghan}@essex.ac.uk

Abstract—**Multimedia exchange within a Vehicular Ad Hoc Network (VANET) may be facilitated by exploiting the peer-to-peer (P2P) paradigm. 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 slice compensation scheme employing spatial Multiple Description Coding to provide error resilience as a solution to these problems. Results show constant good quality video despite increasing packet loss ratios.**

Keywords—error resilience, peer-to-peer, VANET, video streaming

I. 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 in 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 stop 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. (We take progressive download to be a hybrid form of streaming that has one of the characteristics of simple file download, in that data *may* be buffered on a disc rather than a small RAM buffer prior to playout but also has one of the characteristics of streaming in that playout starts when the first chunk in sequence arrives and is continuous thereafter.) The vehicles act as peers in the P2P overlay network. The encoded video sequence is divided into chunks and streamed from multiple peers to a single destination that lacks some or all of the sequence. Progressive download implies that display is overlapped with delivery, implying that packets within chunks cannot be resent as this would cause time gaps in the display. Therefore, it is important to minimize packet loss. This is also 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 path communication is common in this type of network because single paths are frequently broken or those paths may experience poor channel conditions. Moreover, 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 of the need to include additional intra-coded frames [5]; 2) if error drift between the descriptions is to be avoided specialist codecs are required [6].

In this paper, for VANETs we introduce spatial decomposition of a video frames into slices (see Section II), through checkerboard Flexible Macroblock Ordering (FMO) [7] in the H.264/Advanced Video Codec (AVC), which allows lost chunks from one description to be reconstructed from chunks in another description. As the same frame structure is preserved, no extra frames are required and error drift is actively prevented by the decomposition. This is a continuation of earlier work by us, e.g. [8], on MDC and P2P for mobile ad hoc networks (MANETs). A contemporaneous use of this form of MDC for mobile links was reported in [9].

A slice is a sub-frame unit of error resilience bounded by decoder re-synchronization markers. In H.264, each slice forms a Network Abstraction Layer (NAL) unit [10], which in turn has a Real Time Protocol (RTP) header. When chunks are reordered in the 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. Moreover, VANETs do not suffer from energy loss as would result from large buffers in other ad hoc networks. Video error resilience [10] through Gradual Decoding Refresh (GDR) was also applied.

These measures are 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. In fact, the extra capacity is not required for the 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.

It is possible to distinguish at least two types of automotive VANET environment [11]: 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 exploration exists [12], though not by the P2P paradigm. 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 [13], driver behavior in the presence of other vehicles [14] is also accounted for in an Intelligent Driver Model (IDM). In car-following models of which the IDM 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 overtakes in another lane. Therefore, we use VanetMobiSim mobility modeling, taking groups of roads that intersect at traffic lights to illustrate the findings.

II. FMO SLICE COMPENSATION SCHEME

Fig.1 is an example of our P2P slice compensation scheme for MDC with FMO, assuming the receiver lacks all of the video sequence. Within a stream before decomposition into two descriptions, an initial intra-coded I-frame is followed by predictive-coded P-frames, supported by GDR. Notice that Bi-predictive (B)-frames do not occur in the less complex Baseline profile of H.264. The *same* video stream transported in MDC form is 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.

The associated slice numbers in Fig. 1 do not refer to a decoding sequence but to the original display frame order, as output by the encoder. Suppose P_{4S1} and P_{6S1} from MDC 1 and P_{2S1}, P_{4S1}, P_{6S0} and P_{6S1} from MDC 2 are lost. P_{2S1} of MDC 2 can be directly replaced by P_{2S1} of MDC 1. P_{4S1} of MDC 2 can be reconstructed from P_{4S0} from MDC 2. (There are other possibilities.) Similarly, a lost P_{6S1} can be decoded from P_{6S0} of MDC 1. To reconstruct P_{4S1} and P_{6S1} the properties of checkerboard FMO are used.

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.

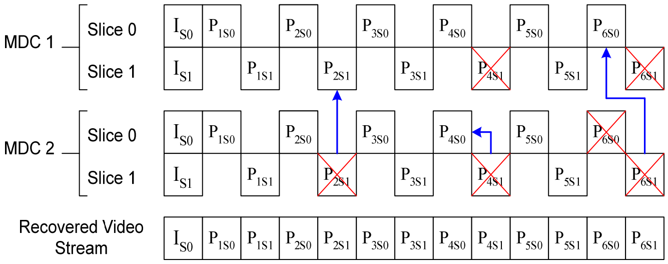

Fig. 1. An example of the proposed slice compensation scheme with MDC and FMO, with arrows indicating the relation ship “can be reconstructed from”

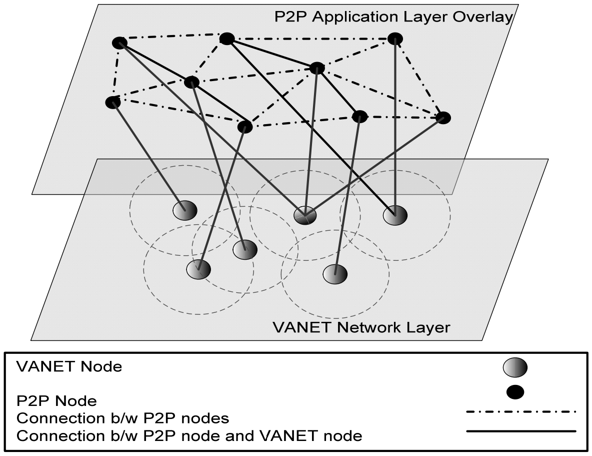

Fig. 2. An example of a P2P application overlay over an ad hoc network, after [15].

III. P2P MULTIMEDIA EXCHANGE

A. *P2P multimedia distribution over a VANET*

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 [8] over a MANET and VANET [16]. However, the combination of progressive download of video over a VANET appears unique. Fig. 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.

Fig. 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 peers within the P2P network. These peers 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

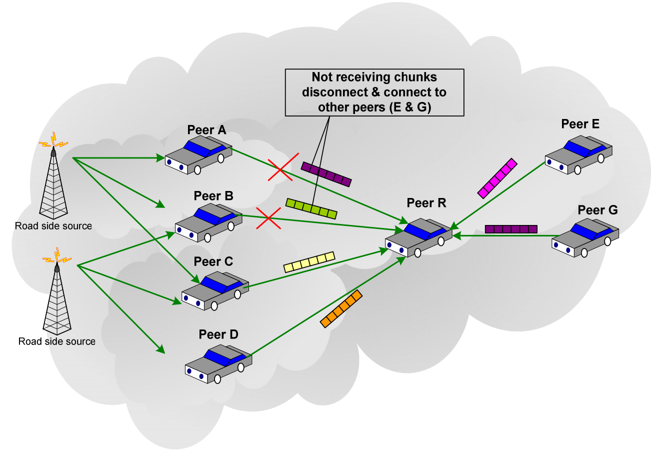

Fig. 3. Mesh-based P2P topology sending video chunks from roadside sources to peers within the VANET, from which the chunks are distributed over multiple paths

purposes. Organization of the P2P overlay and the process of locating suitable senders is outside the scope of this paper, 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 them correctly ordered to its playback buffer. The decoder renders the video from its playback buffer, taking advantage of our slice compensation scheme outlined in Section II to reconstruct missing data.

IV. MODELING P2P OVER A VANET

A. *Simulation methodology*

We employed the well-known Global Mobile System Simulator (GloMoSim). IP framing was employed with UDP transport. 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 with 95% confidence intervals established for each data point.

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. Though more detailed path-loss models are possible, as noted in [17] 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 at 1/2 coding rate was simulated. (The similarly robust alternative is the default QPSK at 1/2 coding rate, though the data rate (6 Mbps) was excessive for our needs.) 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.

TABLE I. SETTINGS FOR ROAD LAYOUTS AND MOBILITY MODEL

Global Parameters	
Terrain Dimension	1000 m^2
Graph type	Space graph
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
Recalc. of movement parameters time	0.1 s
Safe deceleration	4 m/s^2
Politeness factor when changing lane	0.5
Threshold acceleration for lane change	0.2 m/s^2

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

B. *Mobility modeling*

The downtown topology of VanetMobiSim [13] was selected. In the simulations, a square 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 I. The number of traffic lights (at intersections) and time interval between changes was also defined.

The Intelligent Driver Model (IDM), introduced in Section I accords with car following model developed elsewhere [14] 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.

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.

C. *Optimized multi-path routing protocol*

The opportunity was taken to test a multi-path routing protocol that more closely matched our needs, which was for reduced hop count as well as maximally disjoint paths. Reducing the hop count is the main way of reducing packet loss. The protocol follows the Split Multi-Routing (SMR) protocol proposed in [17]. However, only one of the paths returned by the receiver or destination was chosen at any one time. Therefore as there are already multiple routes available by virtue of the P2P distributed delivery system, the main benefit of multi-path routing is the ability to swap routes if one path becomes unavailable. The following changes were made to SMR:

- The receiver node does *not* return the first Route Request (RREQ) message it receives as the route with the minimum delay, as occurs in SMR.
- Instead, the route selection mechanism is modified to take account of the number of hops as well as the disjoint nodes factor.
- The source of the RREQ packets does not start transmitting data packets unless it has established two paths to the destination., Otherwise, after the time for receiving two paths expires, route discovery is reattempted.
- If both of 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.

D. *Video source*

The 1065 frame 'Paris' video sequence (available as raw YUV from http://trace.eas.asu.edu/yuv/index.html) showing a spatially complex studio scene from Japanese TV 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 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 I).

As mentioned in Section II, 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, it has a 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 simulator introduced a packet length error dependency.

scene changes, but out of fairness the intra-coded frame method of spatial interpolation was 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 or the choice could be made dynamically, on the continuity at macroblock boundaries.

V. SIMULATION RESULTS

We compared the slice compensation scheme of Section II to a simple form of MDC. In the simplified MDC, there were just two senders and chunks formed by slicing without FMO. In this scheme, slice 0 is taken from the top half of a frame and slice 1 is taken from the bottom part of a frame. The slice 0s formed one description and slice 1s formed the other description. 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 and previous frame replacement is required. Recall from Section IV.A that handover of senders also 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). The need to accommodate FMO mapping information [7] in the NAL unit generally results in larger FMO slicing packets compared to simple slicing.

In terms of network performance, Fig. 4 shows that, for both variants of MDC, as the density of the network increases then 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 when 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. In these runs, the packet loss ratio was as high as 40%, which explains the large 95% confidence intervals.

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 5, 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 result the routing protocol has to 'work harder' to maintain the low packet loss routes, as

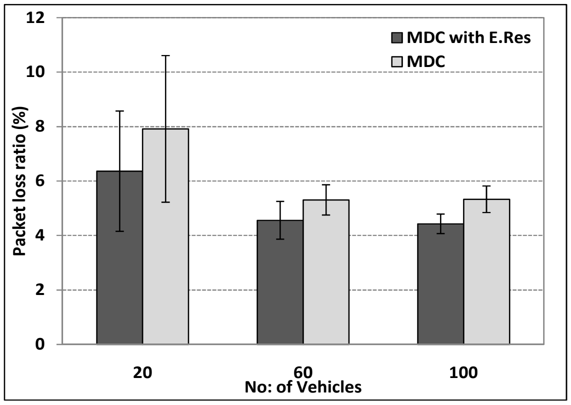

Fig. 4. Mean packet loss ratio by VANET size with and withour error resilience (R. Res) showing 95% confidence intervals

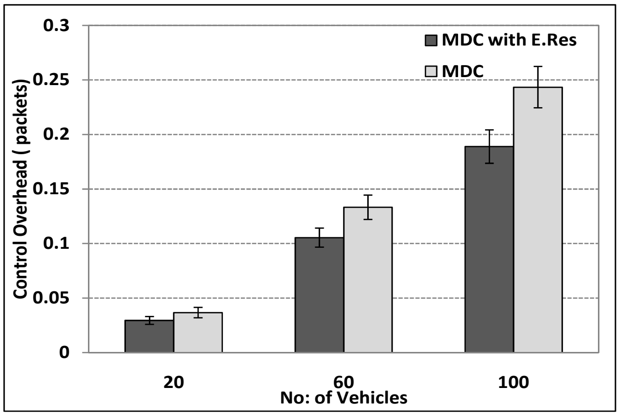

Fig. 5. MDC per packet overhead by VANET size with and without error resilience (E. Res) showing 95% confidence intervals

shown in Fig. 4. As is clear from Fig. 5, 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.

Fig. 6 shows the resulting video quality for one of the fifty simulation runs. The run was selected so that the indicators were within the confidence intervals of Figs. 4 and 5. Also included in Fig. 6 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.

VI. CONCLUSION

The main contribution of this paper has been a slice compensation scheme combined with P2P video delivery over a VANET. A secondary contribution is an improved multi-routing algorithm, which together with the slice compensation scheme considerable reduces the impact of packet loss, leading to stable video quality. Investigations of the benefits of this scheme are at an early stage and it remains to find the relative contributions of each of the components to the successful outcome.

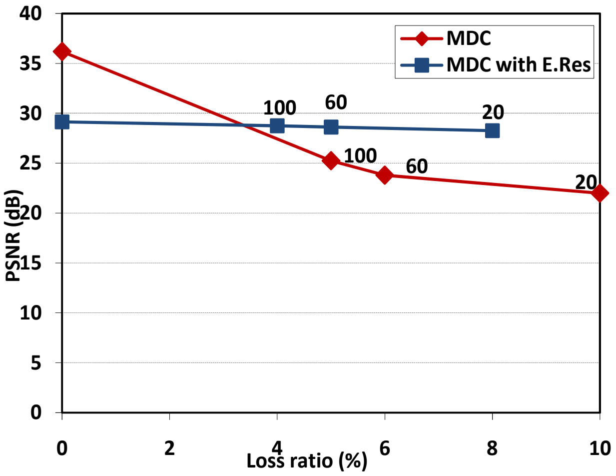

Fig. 6. Example MDC video quality with and without error resilience, annotated with network size.

REFERENCES

[1] D. Jiang and L. Delgrossi, “IEEE 802.11p: Towards an international standard for wireless access in vehicular environments,” *IEEE Vehicular Technol. Conf.*, May 2008, pp. 2036-2040

[2] S. Biswas, R. Tatchiko, and F. Dion, “Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety,” *IEEE Comms. Mag.*, vol. 44, no. 1 pp. 74-82, Jan. 2007

[3] C. Lochert, B. Scheuerrmann, C. Wewetzer, A. Luebke, and M. Mauve, “Data aggregation and roadside unit placement for a traffic information system,” *5th ACM Workshop on VehicularAr Inter-NETworking*, Sept. 2008 , pp. 58-65

[4] P. Frossard, J. C. de Martin, and M. R. Civanlar, “Media streaming with network diversity,” *Proc. of IEEE*, vol. 96, no. 1, pp. 39-53, Jan. 2008

[5] J. Apostolopoulos, “Reliable video communication over lossy packet networks using multiple state encoding and path diversity,” *Visual Communs.: Image Processing*, pp. 392-409, Jan. 2001

[6] Y. Wang, A. R. Reibman, and S. Lin, “Multiple description coding for video delivery,” *Proc. of the IEEE*, vol. 93, no. 1, pp. 57-70, Jan. 2005

[7] P. Lambert, W. de Neve, Y. Dhondt, and R. Van de Walle, “Flexible macroblock ordering in H.264/AVC,” *J. of Visual Commun. and Representation*, vol. 17 , no. 2, pp. 358-378, Apr. 2004

[8] N. Qadri, M. Altaf, A. Liotta, M. Fleury, and M. Ghanbari, “Effective video streaming using mesh P2P with MDC over MANETS,” *J. of Mobile Multimedia*, vol. 5, no. 4, pp. 271-386, 2009.

[9] C. Lamy-Bergot, B. Candillon, B. Pesquet-Popescu, and B. Gadat, “A simple, multiple description coding scheme for improved peer-to-peer video distribution over mobile links,” in *Proc. IEEE Packet Coding Symposium*, Chicago, Apr. 2009.

[10] S. Wenger, “H264/AVC over IP,” *IEEE Trans. Circ. Syst. Video Technol.*, vol. 13, no. 7, pp. 645-656, July 2003

[11] O. K. Tonguz, W. Viriyasitavat, and F. Bai, “Modeling urban traffic: A Cellular automata approach”, *IEEE Comms. Mag.*, vol. 47, no. 5, pp. 142-150, May 2009

[12] M. Guo, M. H. Ammar, and E. W. Zegura, “V3: A vehicle-to-vehicle live video streaming architecture,” *3rd* in *Proc. IEEE Int’l Conf. on Pervasive Computing and Comms.*, Mar. 2005, pp. 171-180

[13] M. Fiore, J. Härri, F. Filali, and C. Bonnet, “Vehicular mobility simulation for VANETs,” *40th Annual Simulation Symp.*, Mar. 2007, pp. 301-307

[14] M. Treiber, A. Henneke, and D. Helbing, “Congested traffic states in empirical observations and microscopic simulations,” *Phys. Rev. E.*, vol. 62, issue 2, pp. 1805-1824, Aug. 2000

[15] L. B. Oliveira, I. G. Siqueira, and A. A.F. Loureiro, "On the performance of ad hoc routing protocols under a peer-to-peer application," *J. of Parallel and Distributed Computing,* vol. 65, no. 11, pp. 1337 - 1347, 2005

[16] N. Qadri, M. Altaf, M. Fleury, M. Ghanbari, and H. Sammak, "Robust video streaming over an urban VANET," in *Proc. 2nd IEEE Int'l Workshop on Selected Topics in Mobile and Wireless Computing*, Marrakech, Oct. 2009

[17] Y. Oda, K. Tsunekawa, and M. Hata, "Advanced LOS path-loss model in microcellular mobile communications," *IEEE Trans. Vehicular Technol.*, vol. 49, no. 6, pp. 2121-2125, Nov. 2000

[18] S.-J. Lee, and M. Gerla "Split multipath routing with maximally disjoint paths in ad hoc networks," in *Proc. IEEE Int'l Conf. on Communication (ICC)*, Jun. 2001, pp. 3201-3205