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Raptor Codes for Infrastructure-to-Vehicular Broadcast Services

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***Abstract*—One of the important applications to be available in vehicular ad-hoc networks are value-added or infotainment services. However, vehicular communication suffers from high packet loss due to challenging channel characteristics such as huge Doppler spread and multipath fading. This makes current IEEE 802.11p standard for vehicular network based on the ARQ scheme inefficient. Therefore, the highly scalable and fault-tolerant properties offered by rateless code makes this a promising area of research. This paper investigates the implementation of a systematic Raptor codes for a broadcast service in infrastructure-to-vehicular communications. The code performance in terms of the decoding probability of success, mean decoding time and mean aggregate throughput are presented.**

***Index Terms*—Vehicular networks, IEEE 802.11p, Raptor code, Fountain code, infrastructure-to-vehicular communication.**

I. INTRODUCTION

THERE has been limited work on Wireless Access for Vehicular Environment (WAVE) for infotainment application. Most of the research contributions in Vehicular Ad Hoc Networks (VANETs) have been concentrated around safety applications. Only recently, analysis on infotainment applications for VANETs have been considered. Examples of these applications are on-board Internet, media downloading, map update and e-commerce.

In this paper, we consider a scenario where infrastructure offers infotainment broadcast to all vehicles passing through it. To cater for high bandwidth applications such as infotainment broadcast, the infrastructure partitions the original message into a number of smaller packets before transmitting. Because the vehicles are moving at a high speed in a lossy channel, there is a high possibility that the vehicles will leave the roadside infrastructure before the whole message is received. For a broadcast communication pattern, a typical ARQ (Automatic Repeat reQuest) scheme is inadequate because of high latency and the requirement for each specific packet to be received correctly.

Instead, we propose a new coding scheme using a systematic Raptor code. While Raptor codes are one of the most prominent classes of rateless code because of its reduced complexity, a systematic code construction is beneficial for immediate decoding of nodes with good channel conditions. With rateless codes, the packets are encoded into a possibly limitless number of source symbols that are independent between one another. As long as sufficient packets are received at the decoder, it is possible for the vehicle to recover the original data successfully. We analyse two types of infrastructure-based vehicular communication, namely a pure I2V (infrastructure-to-vehicular) communication and secondly a combination of I2V and V2V (vehicular-vehicular) communication also known as the I2V2V communication. With I2V communication, once a vehicle has left the infrastructure communication range, it needs to wait until it comes across the next infrastructure to resume the reception. On the other hand, with I2V2V communication, vehicles are able to continue the infotainment reception even outside the roadside infrastructure communication range, i.e. from surrounding vehicles that have successfully decoded the original message. This paper analyses the vehicles probability of success in completing the infotainment reception, the mean decoding time and mean aggregate throughput in varying highway densities.

The paper is organised as follows. Section II provides an overview of related works on rateless codes for wireless communication. Section III details the cross-layer system model and assumptions for systematic Raptor codes for an infrastructure-to-vehicular (I2V) infotainment application. Raptor codes performance against the IEEE 802.11p ARQ procedures are discussed in Section IV. Finally, concluding remarks are reported in Section V.

II. RELATED WORKS

Rateless codes, also known as fountain codes, for value-added services have been proposed in fixed wireless [1]–[3] as well as mobile wireless networks [4]–[6]. This is motivated by its robustness to network dynamics due to the code universal property in the sense that it operates near-capacity for any channel erasure probability less than 1 [7]. Besides that, the rateless property that allows potentially infinite block length is suitable for scalable communication. A number of codes that belong in the fountain code classes are LT codes, Online codes and Raptor codes. Recently, a systematic Raptor code has been standardized as the Application Layer Forward Error Correction (AL-FEC) for 3GPP Multimedia Broadcast/Multicast Service (MBMS) [8] and Digital Video Broadcasting-Handheld (DVB-H) to support scalable video and mobile TV services.

Fountain codes have also been proposed as the AL-FEC for file transfer in WLANs [3] and VANETs [4]. Normally, File Transfer Protocol (FTP) requires a TCP transport protocol

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for a reliable and in-order data transmission which is time-inefficient especially in lossy networks such as WLANs and VANETs. Instead, file transfer coded with fountain code made it possible to use the real-time but unreliable UDP transport protocol. In this case, the reliability of packet transmission is provided by fountain code itself because with this coding scheme, the order of packet arrival does not matter and as long as sufficient number of packets is received, the file transfer can be decoded at the receiver.

Besides as an error control mechanism, rateless codes have been identified as the ideal companion to network coding to improve network throughput. In [1], a combination of rateless code and decode-and-forward (DF) relaying is proposed as the wired network peer-to-peer (p2p) multimedia streaming protocol known as *rStream*. With this protocol, once enough encoded symbols are received and successfully decoded, the relay will generate new re-coded symbols using randomly chosen degree from a LT code Robust Soliton Distribution (RSD) before forwarding. This eliminates the content reconciliation phase i.e. receiving nodes do not need to sort out packets from multiple sources because all received symbols are unique. In [2], network coding for video streaming is proposed based on non-systematic Raptor codes for wireless mesh network.

In a vehicular environment, [5], [6] explored the use of fountain code for advertisement dissemination not only when vehicles are within the road side infrastructure coverage area (I2V), but also continue receiving the encoded packets from surrounding vehicles (V2V) thereafter. [5] proposed communication with a single access point (AP) only with a set of control packets as well as re-coding and dissemination rules defined. Meanwhile, [6] studied the effect of buffer constraint in an I2V2V rateless encoded advertisements as an improvement to store-and-forward multihop routing in a sparse network.

III. PROPOSED MODEL FOR I2V COMMUNICATION

We consider two types of infrastructure-based vehicular communication scenarios, namely a pure I2V (infrastructure-to-vehicular) communication and secondly a combination of I2V and V2V communication, also known as the I2V2V communication. Our proposal is different from other earlier works because we consider that the I2V communication is not limited to a single infrastructure. With I2V communication, once a vehicle has left the infrastructure communication range, it needs to wait until it comes across the next infrastructure to continue the reception. On the other hand, with I2V2V communication, vehicles are able to continue the infotainment reception even outside the roadside infrastructure communication range through V2V communication. However, only vehicles which have successfully decoded the K infotainment source block are eligible to act as a new source. Before acting as the new source, the packets are re-coded again to ensure that they are unique from each other. We assume that all vehicles are aware of the current location of other vehicles through periodic status beacons transmitted in a separate control channel that does not interfere with the infotainment broadcast channel, as proposed in the IEEE 802.11p standard. If more than one eligible vehicle is present outside the infrastructure range, the selection of the V2V communication pair is based on the vehicle which is closest to the receiver. This is in order to achieve the best error rate performance and least latency. The vehicle switches back to I2V communication when it comes into contact with a new infrastructure.

Raptor codes are known to perform best in erasure channels wherein they achieve universal, capacity approaching rates. The Cyclic Redundancy Check (CRC) detects and discards erroneous packets, therefore the assumption that the packet at higher layer behaves similarly to a binary erasure channel (BEC) can be made. This offers a perfect opportunity for implementation of Raptor codes. The packet fragmentation procedure for Raptor codes is comparable to the optional block acknowledgment (BA) algorithm proposed in the IEEE 802.11e MAC standard [9], but with a modified setup and acknowledgment procedure. This was proposed in earlier work in [10] but for fixed WiFi connection. In this work, we propose the modified BA procedure for use in vehicular networks, which we shall refer to Raptor-coded acknowledgment (r-ACK).

In the standard, a block of packet (i.e. source block) is fragmented into multiple smaller packets (i.e. source symbols) and sent into the channel one after another, with only a single pair of acknowledgment packet trigger/response is required at the end of the transmission to inform the sender on which source symbols are required for retransmission. In a typical BA scheme, the acknowledgment request is triggered by the *sender* and receiver will respond by providing feedback information on missing packets. Each specific missing packets are retransmitted until all packets in the source block are successfully received, thus requiring *multiple* pairs of BA trigger and response packets. This is a major drawback in terms of channel utilization and packet latency performance especially for high packet loss conditions in a vehicular environment.

The r-ACK model improves the standard by applying rateless encoding to the fragmented source symbols before transmission, thus getting rid of the requirement to know which exact source symbols are missing. Rateless codes allow a continual stream of additional symbols to be generated in the event that the original symbols could not be decoded. When enough encoded symbols are received and the generated decoding matrix is of full rank, the vehicle would be able to successfully decode the original source block. With the r-ACK scheme, the acknowledgment packet is triggered by the *receiver* (i.e. vehicle) to tell the sender to stop transmitting encoded symbols. This is different than a typical block acknowledgment scheme, where the acknowledgment request is triggered by the sender (i.e. infrastructure). The r-ACK is smaller in size and simplified because there need not be any information on which source symbols to be retransmitted. It also ensures that only a *single* r-ACK is required for each vehicle.

The communication sequence of a typical block acknowledgment scheme consists of 3 phases, the setup phase (T_{setup}) which among others communicate the number of source symbols in the source block, the data transmission stage (consisting of time to transmit header T_H, time to transmit payload T_P, and short interframe duration $SIFS$, for each N source symbols) and the block acknowledgment trigger/response phase ($T_{BAtrigger+response}$). These phases are represented in eq. (1). According to the IEEE 802.11e block acknowledgment, $N = K$ during the first transmission attempt, but in a lossy channel the data and acknowledgment phases need to be repeated multiple times to successfully decode the source block, with $N < K$. However for the r-ACK scheme, all the phases need only be once with $N = K + \varepsilon$, where ε equals to number of encoded symbols overheads required.

$$T_{rACK} = T_{setup} + N \cdot (T_H + T_P + SIFS) + T_{BAtrigger+response} \quad (1)$$

Additionally, we propose in the I2V communications the use of the systematic Raptor codes as in the 3GPP MBMS standard [8]. The main reason for this is because with a systematic code construction, users experiencing good channel conditions can immediately recover the original message. In the meantime, users with bad channel conditions will still be able to recover the message from the transmitted redundant symbols.

To model the erasure rates at specific distances, we utilized a detailed IEEE 802.11p physical layer OFDM simulator that have been developed in our previous work in [11]. To model the vehicular channel, we have developed a fast fading Rayleigh channel using the Clarke's model [12], with an rms delay that is consistent with a vehicular channel measurements conducted in [13]. To recover the channel state information (CSI) at the receiver Viterbi decoder, we utilized a midamble pilot-aided approach in [14], with 30 OFDM symbol spacing. This spacing is chosen based on the space-time correlation function given in eq. (2), where $J_0(.)$ is the zero-th order Bessel function of the first kind, v is the velocity, $f_d = v/\lambda$ is the Doppler spread, and Δt is the distance traversed.

$$\rho(\Delta t) = J_0(2\pi f_d v \Delta t) \quad (2)$$

The output of the simulator is the packet error rate (PER) against signal-to-noise ratio (SNR) curves that was presented in our earlier work in [11]. The SNR values are converted to distance measurements, d using a log-distance path loss model with path loss exponent, γ of 2.4 as proposed in [15], given in eq. (3) where P_T is the transmit power, G_T and G_R is the transmitter and receiver antenna set at 0dB, and λ is the signal wavelength. The PER curves shall also be used as the channel erasure rates at the Raptor encoder. While higher modulation scheme increases the transmission throughput, it also degrades the packet error performance.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi}\right)^2 \left(\frac{1}{d}\right)^\gamma \quad (3)$$

The benefit of r-ACK against the standard ARQ scheme can be immediately observed by the maximum throughput that is defined as S_{max} =*Payload/Transmission cycle* in Fig. 1. Here, we defined the transmission cycle as the duration to complete successful transmission on K source symbols assuming that there is a single user in the link (no collision occur). The IEEE 802.11p [16] has specified the physical layer data rate and receiver threshold for each of the modes as can be seen in Table I. Based on the transmit power and path loss model assumption in eq. (3), the receiver thresholds give forth the different communication ranges for each mode. The table shows that while higher modulation increases throughput, it causes reduction to the communication range. It is also seen that although S_{max} increases when higher modes are used, the normalized maximum throughput actually decreases. We defined the normalized maximum throughput as S_{max}/R_d, where R_d is the physical layer data rate. This is because the mode-dependent data packet duration (T_P) is reduced, but parameters such as SIFS and DIFS is independent of the mode. Thus, the transmission cycle of higher modulation scheme has a higher percentage of overhead. In our analysis, we assume the payload is 512 bytes, as recommended in the 3GPP/MBMS standard [8]. A small packet size is chosen to minimize the PER effect on performance.

Table I
MODES PARAMETERS

Modes	Data rate,R_d (Mbps)	RxSen sitivity (dB)	Comm. Range (m)	S_{max}/R_d ARQ (%)	S_{max}/R_d r-ACK (%)
BPSK 1/2	3	-85	320	68	83
BPSK 3/4	4.5	-84	290	61	81
QPSK 1/2	6	-82	240	56	79
QPSK 3/4	9	-80	200	48	75
16QAM 1/2	12	-77	150	42	72
16QAM 3/4	18	-73	100	33	65
64QAM 1/2	24	-69	70	28	63
64QAM 3/4	27	-68	60	26	59

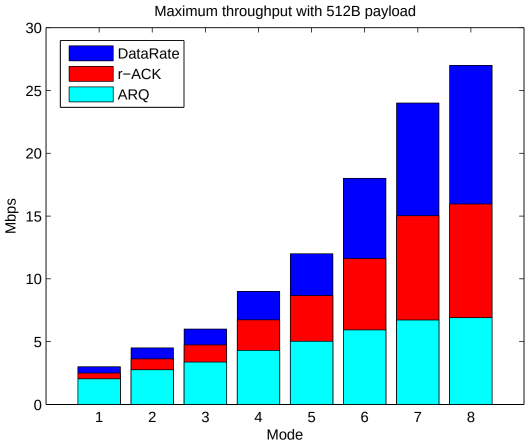

Figure 1. IEEE 802.11p performance at different modes

IV. NUMERICAL RESULTS

We consider an I2V scenario on a highway as depicted in Figure 2, where R is the infrastructure communication range. We chose this mobility model because it is one of the most challenging scenarios in vehicular communications, where high relative speeds and more frequent network topology

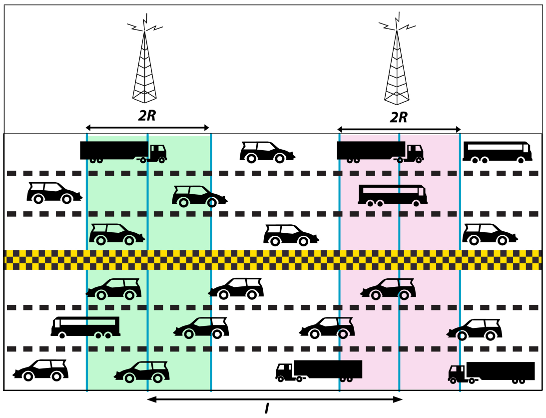

Figure 2. I2V infotainment broadcast on highways

changes are found on highways. For simplicity of analysis, we assume a highway segment of length, $L = 2\,km$ with two infrastructure nodes with $I = 1\,km$ spacing between them. Other simulation parameters used are shown in Table II. We used a 6-lanes bidirectional highway mobility model having a Poisson distribution with an average speed of 100 km/h. This is in accordance with model used in previous works [17], [18]. The initial vehicles location is also assumed to have an average inter-vehicle spacing dependent upon the highway traffic density β. New vehicles arrival rate is assumed to be 2 vehicles/s. The focus of this section is to evaluate the performance of our proposed Raptor encoded rateless (r-ACK) scheme against the ARQ scheme proposed in the IEEE 802.11p standard [16]. A Monte Carlo simulation methodology is used to find the vehicles average probability of success in completing the infotainment broadcast, the mean decoding time and mean aggregate throughput in varying highway densities.

Table II
SIMULATION PARAMETERS

Parameters	Value	Parameters	Value
message length (source block)	512 KB	Source symbol, K (payload size, P)	1000 (512 B)
Transmit power, P_T	23 dBm	PHY preamble	$40\mu s$
Propagation delay, δ	$1\mu s$	min. contention window, W_0	15
Slot time, σ	$13\mu s$	SIFS	$32\mu s$

Fig. 3 shows the instantaneous packets collected for a single vehicle in a specific location on the highway. The infrastructure nodes are located at position $500m$ and $1500m$. Since we consider a broadcast infotainment to all vehicles, link adaptation is unsuitable for implementation. Instead, we assume that all infrastructure and vehicles operate using the same mode. We compare two main modes, QPSK 1/2 and 16QAM 1/2 (having $240m$ and $150m$ communication range when transmit power, $P_T = 23dBm$). The results show that the proposed r-ACK scheme always outperforms the ARQ scheme because infrastructure sends packet continuously without waiting for feedback on each of the packet, thus capitalizing on the channel bandwidth and good channel conditions for useful data. It is also observed that there are some void areas where I2V communication does not take place because the infrastructure spacing is higher than the maximum communication range. In order to have a continuous packet reception in this void area, we propose a combination of I2V and vehicular-to-vehicular (V2V) communication with the fountain codes, known as the I2V2V communication. It can be seen in the figure that this allows continuous packet collection.

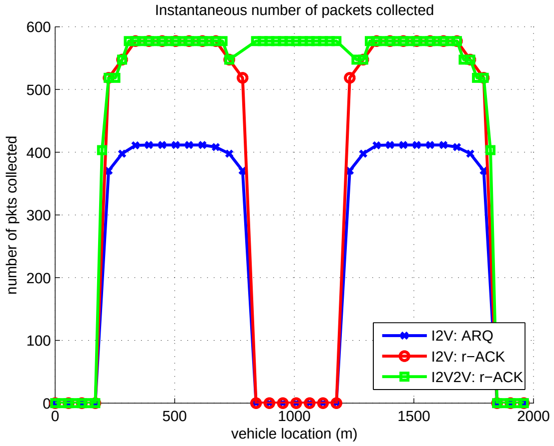

Figure 3. I2V using mode 3 according to highway scenario in Fig. 2

The decoding success probability is given by the number of vehicles that manage to complete recovering the $K = 1000$ source symbols against total number of vehicles present in the environment throughout the $20s$ simulation time. Fig. 4(a) shows that Raptor codes enable more vehicles in the environment to complete decoding the original message (source block) as compared to the ARQ scheme. The improvement is ~15% for I2V and ~25% for I2V2V. The mean decoding time is defined as the average decoding time of vehicles which successfully complete the decoding, as presented in Fig. 4(b). It is observed that the mean decoding time is significantly reduced as vehicle density increases. The r-ACK in an I2V communication decoding time is ~10% shorter than ARQ scheme, while I2V2V communication further reduced it to be ~30% shorter than the ARQ scheme. Finally, Fig. 4(c) shows the mean aggregate throughput analysis of the successfully decoded nodes for the three schemes above. I2V broadcast is minimally impacted by the traffic density. Our proposed r-ACK scheme offers up to 40% and 55% aggregate throughput improvement for I2V and I2V2V communication accordingly against the ARQ scheme. This is due to the continuous encoded symbols transmission with minimal feedback required. It is seen that there is a trade-off between probability of success against mean decoding time and aggregate throughput for high modulation schemes. The probability of success is reduced because the communication range is smaller and worse packet error performance for a higher modulation scheme, leading to reduced number of eligible vehicles to forward the re-coded message. However, a higher modulation offers the benefit of reduced mean decoding time due to the shorter transmission cycle and higher data rate.

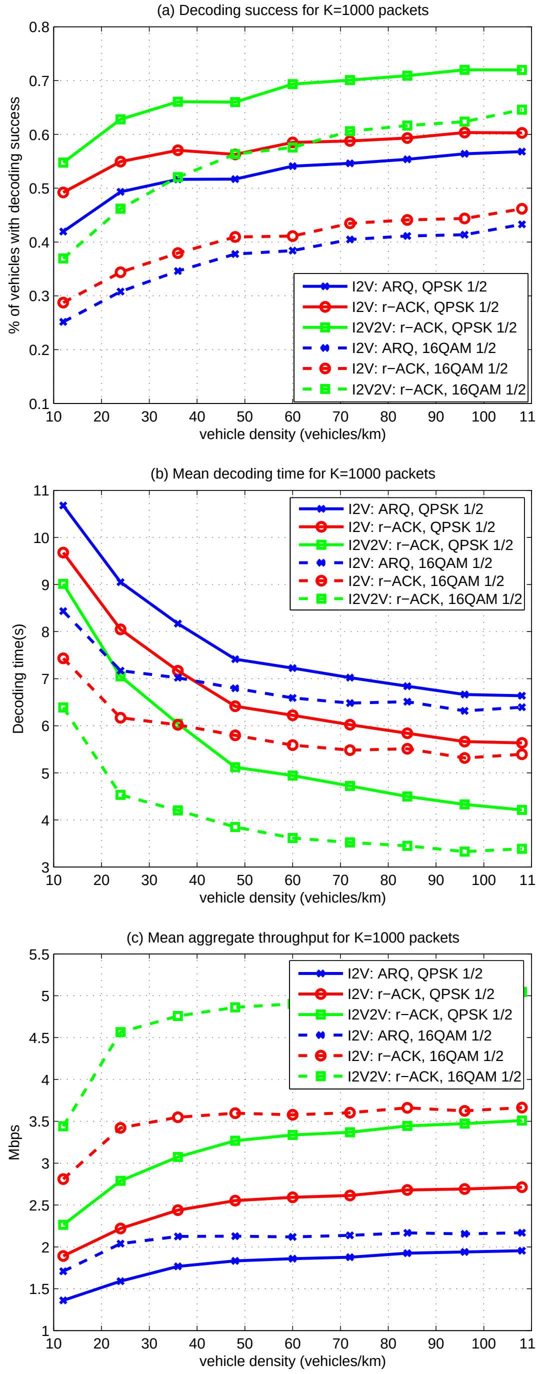

Figure 4. I2V probability of success analysis

V. CONCLUSIONS

In this paper, we have investigated the performance of systematic Raptor codes in a pure I2V (infrastructure-to-vehicular) and I2V2V (infrastructure-to-vehicular and vehicular-to-vehicular combination) scenario against the ARQ method proposed in the IEEE 802.11p standard for infotainment broadcast on highways. It is shown that the proposed r-ACK (Raptor-coded acknowledgment) scheme outperforms the ARQ scheme in terms of vehicles decoding probability, mean decoding time and aggregate throughput, with I2V2V having a more significant improvement compared to I2V communication. In addition, it can be concluded that the ARQ scheme inefficient for broadcasting. A trade-off between probability of decoding success against mean decoding time and mean aggregate throughput is seen for higher modulation scheme.

REFERENCES

[1] C. Wu and B. Li, "rStream: Resilient and Optimal Peer-to-Peer Streaming with Rateless Codes," *IEEE Transactions on Parallel and Distributed Systems*, vol. 19, no. 1, pp. 77 –92, Jan. 2008.

[2] N. Thomos and P. Frossard, "Raptor network video coding," in *Proceedings of the International Workshop on Mobile Video*. New York, USA: ACM, 2007, pp. 19–24.

[3] H. Chen, R. Maunder, and L. Hanzo, "Fountain-Code Aided File Transfer in 802.11 WLANs," in *IEEE 70th Vehicular Technology Conference Fall 2009 (VTC 2009-Fall)*, Sep. 2009, pp. 1–5.

[4] S. Yousefi, T. Chahed, M. Moosavi, and K. Zayer, "Comfort Applications in Vehicular Ad Hoc Networks Based on Fountain Coding," in *IEEE 71st Vehicular Technology Conference (VTC-Spring '10)*, May 2010.

[5] P. Cataldi, A. Tomatis, G. Grilli, and M. Gerla, "A Novel Data Dissemination Method for Vehicular Networks with Rateless Codes," in *IEEE Wireless Communications and Networking Conference (WCNC '09)*, Apr. 2009, pp. 1–6.

[6] M. Sardari, F. Hendessi, and F. Fekri, "DMRC: Dissemination of Multimedia in Vehicular Networks Using Rateless Codes," in *IEEE INFOCOM Workshops 2009*, Jun. 2009, pp. 1–6.

[7] A. Shokrollahi, "Raptor Codes," *IEEE Transactions on Information Theory*, vol. 52, no. 6, pp. 2551–2567, Jun. 2006.

[8] 3GPP TS 26.346, *Multimedia Broadcast/Multicast Service (MBMS); Protocols and codecs*, Std., Rev. 9.3.0, Jun 2010. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/26346.htm

[9] IEEE 802.11-2007, *(Revision of IEEE Standard 802.11-1999)*, Std., 2007.

[10] S. Chieochan and E. Hossain, "Wireless Fountain Coding with IEEE 802.11e Block ACK for Media Streaming in Wireline-cum-WiFi Network: A Performance Study," *IEEE Transactions on Mobile Computing*, no. 99, p. 1, 2010.

[11] N. F. Abdullah, A. Doufexi, and R. J. Piechocki, "Spatial Diversity for IEEE 802.11p Post-Crash Message Dissemination in a Highway Environment," in *IEEE 71st Vehicular Technology Conference (VTC-Spring '10)*, May 2010, pp. 1–5.

[12] D. Tse and P. Viswanath, *Fundamentals of wireless communication*. New York, NY, USA: Cambridge University Press, 2005.

[13] D. Matolak, I. Sen, W. Xiong, and N. Yaskoff, "5 GHz wireless channel characterization for vehicle to vehicle communications," in *Proceedings of IEEE Military Communications Conference (MILCOM '05)*, vol. 5, Oct. 2005, pp. 3016–3022.

[14] S. I. Kim, H. S. Oh, and H. K. Choi, "Mid-amble aided OFDM performance analysis in high mobility vehicular channel," in *IEEE Intelligent Vehicles Symposium (IVS '08)*, Jun. 2008, pp. 751–754.

[15] Y. Zang, L. Stibor, G. Orfanos, S. Guo, and H.-J. Reumerman, "An error model for inter-vehicle communications in highway scenarios at 5.9 GHz," in *Proceedings of the International Workshop on Performance Evaluation of Wireless Ad hoc, Sensor, and Ubiquitous Networks*. New York, USA: ACM, 2005, pp. 49–56.

[16] IEEE 802.11p-2010, *Amendment to IEEE Std 802.11-2007: Wireless Access in Vehicular Environments (WAVE)*, Std., Jul 2010.

[17] X. Chen, H. Refai, and X. Ma, "Saturation Performance of IEEE 802.11 Broadcast Scheme in Ad Hoc Wireless LANs," in *IEEE 66th Vehicular Technology Conference, 2007 (VTC-2007 Fall)*, Oct. 2007, pp. 1897–1901.

[18] K. Hafeez, L. Zhao, Z. Liao, and B. Ma, "Performance analysis of broadcast messages in vanets safety applications," in *IEEE Global Telecommunications Conference (GLOBECOM '2010)*, Dec. 2010, pp. 1–5.