# Evaluation Of Interference-Cancellation Based MAC Protocol For Vehicular Communications

Kiran Kumar Gogineni Vishnu* and Krishna R. Narayanan†
Department of Electrical & Computer Engineering,
Texas A&M University, College Station, USA
Email: {*gvkk123,†krn}@tamu.edu

***Abstract*—We evaluate a new MAC layer algorithm based on slotted ALOHA with successive interference cancellation(SIC) for IEEE 802.11p vehicular communications standard and test it by taking into consideration the performance of underlying physical layer in the presence of a realistic empirical fading channel model. The performance of slotted ALOHA-SIC MAC scheme with respect to average packet loss ratio, throughput, and channel access delay is studied. This scheme can significantly improve the channel access delay and throughput performance in vehicular networks when compared to the carrier sense multiple access scheme proposed in 802.11.**

***Index Terms*—vehicular communications, 802.11p, slotted ALOHA, successive interference cancellation, IRSA, CSMA/CA**

## I. Introduction

Vehicular communications form an important part of future intelligent transport systems. Wireless connectivity between vehicles can enhance safety in vehicular networks and enable new services such as adaptive traffic control, collision detection and avoidance. Development of vehicular ad-hoc networks(VANETs) requires accurate models for estimating the propagation channel and for determining the achievable packet transmission delay and reliability at the physical layer.

Based on the IEEE 802.11 wireless LAN standard [1], a standard termed as IEEE 802.11p was proposed [2] for implementing VANETs to provide wireless access in vehicular environments (WAVE). Together, these standards provide the specifications for the wireless LAN medium access control (MAC) and physical layers (PHY). Examining the 802.11p standard from the MAC layer perspective, carrier sense multiple access with collision avoidance(CSMA/CA) contention scheme, which has been already in use in the WLAN standard [1] has been proposed for Vehicle-to-Vehicle(V2V) scenarios also. However, in an ad-hoc highway scenario with a periodic broadcast of time-critical packets, it has been shown that CSMA suffers from hidden node problem and results in the drop of a large number of packets because of the large delay associated with accessing the channel [3]–[6].

In order to overcome this problem, many solutions have been proposed based on either Time Division Multiple Access(TDMA) [3] or classical slotted ALOHA [6]. These schemes divide a fixed frequency channel into different time slots so that the contending users in a system transmit in their own time slots assuming that the users are network synchronized. These schemes, however, require a learning phase, increasing the channel access delay and they cannot guarantee high reliability as transmission errors during the learning phase renders the protocol to be unusable. Moreover, transmission by two or more users in the same time slot results in collisions which are discarded and that time slot is essentially rendered useless.

Even though ALOHA protocol is one of the oldest and simplest multiple access protocols, recent research with enhanced variations of slotted ALOHA has shown it to be an appealing solution for wireless networks with short packet lengths and low latencies. Improved versions of classical slotted ALOHA were proposed for satellite access packet networks where the diversity transmission of data bursts are combined with efficient interference cancellation techniques [7], [8]. One such scheme is contention resolution diversity slotted ALOHA(CRDSA), where each packet is transmitted twice by a user in a random fashion followed by successive interference cancellation(SIC) at receiver resulting in a better delay and throughput performance [9].

An improved version of this protocol named as irregular repetition slotted ALOHA(IRSA) is also proposed where a user transmits multiple copies instead of two based on a degree distribution [10]–[13]. The theoretical performance of such schemes with respect to throughput efficiency close to 100% was evaluated in [14], [15]. Recently, an application of adapting it to vehicular environments with an optimized degree distribution was proposed in [4], [5], [16], [17]. These random access schemes have been shown to be effective for transmission of unpredictable, small sized and time delay critical messages making them effective in VANETs.

However, most of these research entities focus entirely on MAC layer and use idealized physical layer models. They do not take into account the effect of propagation environment on the performance of lowest layer (i.e. the physical layer), and therefore on the performance of the entire system [4], [5], [10], [18], [19]. In this paper, we provide a joint PHY-MAC simulation of 802.11p [1] and evaluate the performance of slotted ALOHA with SIC(IRSA) [4] MAC scheme on vehicular networks by taking into consideration all of the above-mentioned details.

The main contributions of this paper can be summarized as follows:

- Implementation of IEEE 802.11p physical layer for vehicular communications as per the standard [1], [2].

978-1-5386-6358-5/18/$31.00 ©2018 IEEE

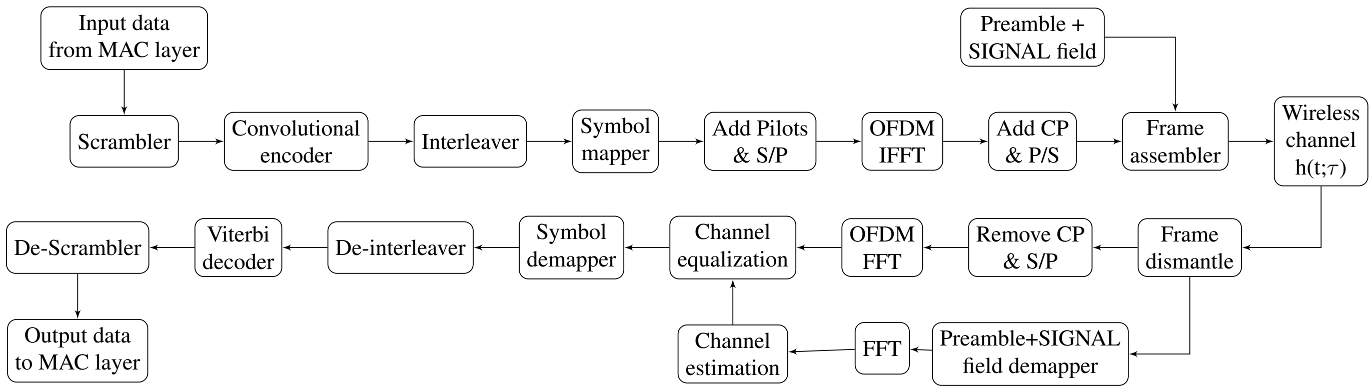


Fig. 1. IEEE 802.11p PHY layer block diagram.

- Implementation of an empirical wireless fading channel encountered in vehicular environments [20], [21] based on the field measurements for calculating average packet loss ratio and reliability analysis of the transmission.
- Implementation of slotted-ALOHA based MAC layer algorithm with successive interference cancellation(IRSA) for scheduling channel availability in multi-user vehicular environment [4], [14] and optimization of its parameters for VANETs.
- Performance evaluation of IRSA in vehicular networks under a joint PHY-MAC Layer simulation with respect to reliability(packet loss ratio and throughput) and channel access delay incurred for successful transmission.

## II. Physical Layer Description for 802.11p

Aimed at transmission over 5.725-5.825 GHz band with 10 MHz channel spacings, the 802.11p PHY entity specifies an orthogonal frequency division multiplexing (OFDM) system with data payload communication capabilities of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s. The system uses 52 subcarriers that are modulated using binary or quadrature phase shift keying (BPSK or QPSK) or using 16- or 64-quadrature amplitude modulation (16-QAM or 64-QAM). Forward error correction coding (convolutional coding) is used with a coding rate of 1/2, 2/3, or 3/4 [22]. A schematic block diagram of PHY layer encoding process is shown in Fig. 1.

Since the V2V propagation channel has a significant impact on the performance of communication system in VANETs, extensive research efforts have been made and two types of empirical vehicular channel models have been proposed [23], [24]. The first one is a small scale fading model based on Tap-Delay Line(TDL) [20] with Rayleigh/Rician fading on each tap while the second one is a large scale model with Nakagami-$m$ fading where $m$ represents the fading intensity and average received power [21]. These channel models successfully model fading & path-loss of V2V channels and provide reasonably accurate estimates of packet reception probability and loss ratio. The TDL Model has been used for the current analysis.

The TDL channel proposed by Acosta-Marum & Ingram in [20] proposes six kinds of environmental scenarios between vehicle to vehicle and vehicle to roadside transceiver units, each of which is modeled as a tap-delay line filter having filter coefficients given by Rayleigh/Rician fading process. Four kinds of Doppler spectral shapes(flat, round,classic-3, 6dB) were used for modeling fading process [25]. These were optimized based on empirical measurements and give us channel characteristics encountered in the vehicular environment.

## III. Slotted ALOHA with Successive Interference Cancellation

A bipartite graph based example for interference cancellation in IRSA is shown in Fig. 2.

We begin transmission by assuming that all users in a network decide on fixed packet size and format. Each user transmits a random number of packet replicas in a single MAC frame divided into a number of time slots. The random number is drawn from a degree distribution ($\lambda(x)$) optimized for the network parameters and is assumed to be known to all users in the network [4], [10], [13], [16]. Each packet transmitted contains information regarding the pointers to its copies i.e., the time slots in which the replicas are transmitted.

The received signal is buffered by a user whenever it is not transmitting. At any slot $i$, the received signal buffered by a user can be written as

$$y_i = \sum_{j \in U_i} h_{ij} x_j + w \tag{1}$$

where $x_j$ is a packet of the $j$th user, $h_{ij}$ is its corresponding channel coefficient and $w$ is the channel noise (AWGN). $U_i$ is the set of all users that are able to transmit in the $i$th slot of a receiving user.

A slot in which only one user has transmitted is called a singleton slot i.e., it contains only one packet. Since singleton slots do not contain any interference, each user decodes all the singleton slots in the MAC frame it has buffered.

Channel coefficients corresponding to the copies of a successfully decoded packet are then estimated and its replicas at other slots are reconstructed. The interference cancellation (IC) algorithm then works by canceling all the replicas that

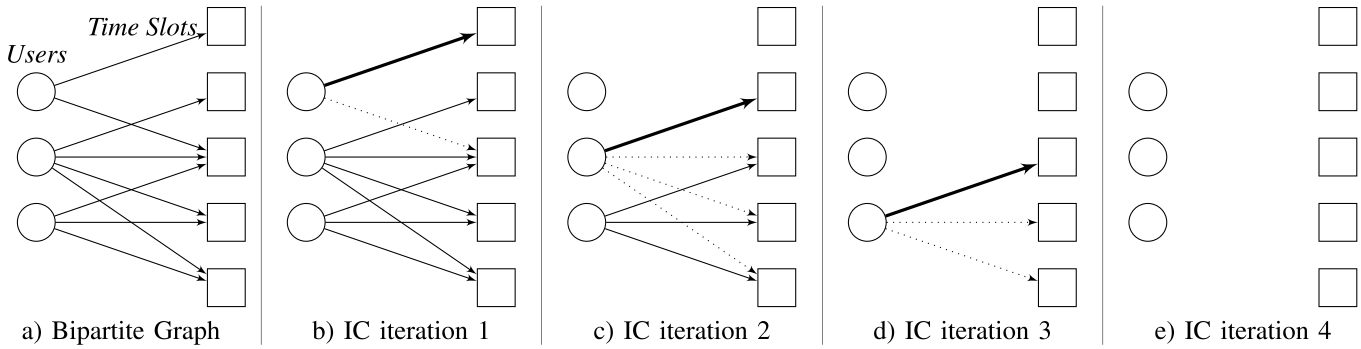


Fig. 2. Bipartite Graph representation of the successive IC process

[ Above figure shows the iterative decoding process used in IRSA. Users are denoted by circles and time slots by squares. Each edge denotes a transmission by an user in a time slot. Degree distribution used in this example is : $\lambda(x) = \frac{1}{3}(x^2) + \frac{1}{3}(x^3) + \frac{1}{3}(x^4)$. At each iteration, singleton slots (denoted by thick arrow) are decoded and the copies of corresponding packet (dashed arrows) are estimated and cancelled out. ]

are reconstructed. If a $k$th user is being decoded and has its replica at $i$th slot, then the signal at $i$th slot after IC is,

$$\tilde{y}_i = (\sum_{j \in (U_i - k)} h_{ij} x_j + w) + (h_{ik} x_k - \tilde{h}_{ik} x_k) \tag{2}$$

where $\tilde{h}_{ik}$ is the estimated channel coefficient.

Decoding proceeds further after subtracting the interference caused by the identified copies in a successive fashion until no more singleton slots are found.

The following *assumptions* are being made for executing IRSA.

- all users present in a network are both frame and slot synchronized. (can be achieved by GPS providing absolute time reference to users).
- the receiver is able to estimate the channel state information of packet replicas of successfully decoded packets with good accuracy using the channel estimation schemes [26]–[28].
- each user in the network transmits only one packet in a MAC frame (copies of the same packet are allowed but not different packets).

Assuming that there are $m$ users in a network with total of $n$ time slots in a single MAC frame, the channel load in the network is given by

$$G = m/n \tag{3}$$

A packet transmission attempt that does not get decoded at receiver after SIC can be considered as packet loss. In other words, if $p$ users out of $m$ users are not decoded after SIC, the MAC packet loss ratio is given by

$$PLR_{MAC} = p/m \tag{4}$$

The throughput $T$ of the MAC scheme is then given by the average number of successful packet transmissions per slot as:

$$T(G) = G(1 - PLR_{MAC}(G)) \tag{5}$$

## IV. Implementation & Simulation Results

To evaluate the performance of IRSA for vehicular networks, a joint PHY-MAC simulator was implemented using MATLAB [29]. An OFDM scheme based physical layer transceiver is implemented as detailed in clause 17 of 802.11 standard [1]. Empirical wireless channel models for vehicular networks based on Tap-Delay line model [20], [25] are used to evaluate the performance and reliability of physical layer under realistic vehicular conditions. For the IRSA MAC contention scheme, the theoretical framework proposed in [4], [10], [14] have been used. The simulation parameters are listed in Table I.

TABLE I
Simulation parameters

| Parameter | Value |
|---|---|
| ***PHY parameters for QPSK rate - $1/2$ - OFDM*** | |
| Data Rate | 6 Mbps |
| PHY preamble duration | $40\mu s$ |
| Packet size assumed | 400 bytes |
| ***Simulation parameters used in IRSA*** | |
| Frame duration | $100ms$ |
| Guard interval assumed | $5\mu s$ |
| Packet length for 400 byte packet | $576\mu s$ |
| Slot duration for 400 byte packet | $581\mu s$ |
| Number of slots in a frame | 172 |
| Degree distribution used for IRSA | $0.86x^3 + 0.14x^8$ |

The packet error rate plots for AWGN and vehicular channels mentioned in Acosta-Marum & Ingram TDL Model [20] are plotted in Fig. 3 as a function of $E_b/N_o$ for a packet size of 400 bytes and 6 Mbps data rate. It can be observed that the Vehicle to Vehicle (V2V) channels have a relatively higher packet error rate when compared to Vehicle to Infrastructure (V2I/RTV) channels which can be attributed to their relatively higher Doppler shifts.

To evaluate the performance of IRSA for VANETs with 802.11p PHY layer, *packet loss ratio* & *throughput* as func-

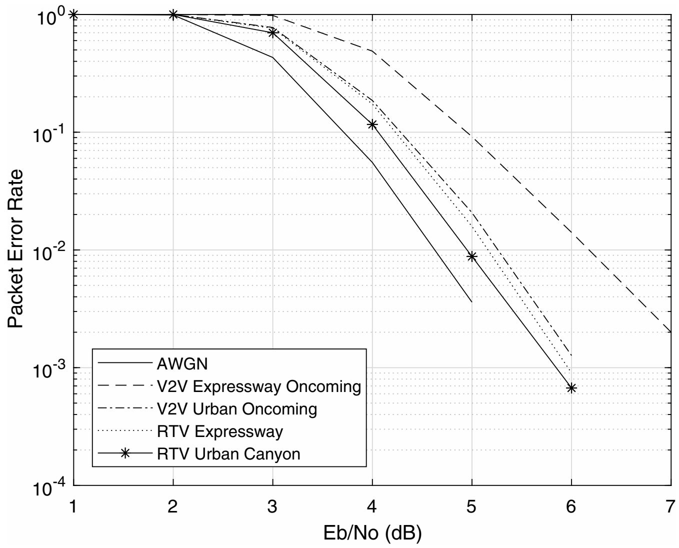


Fig. 3. PER for packet size of 400 bytes for QPSK with rate $1/2$

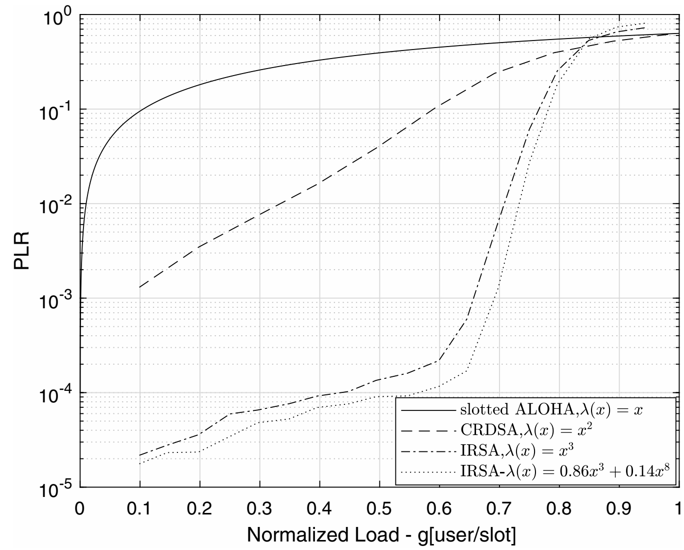


Fig. 4. Packet loss ratio for packet erasure channel with $\epsilon = 0$

tions of channel load are plotted. The parameters used for the simulation are listed in the Table I.

The packet loss ratio is first evaluated for different degree distributions of IRSA in an idealized packet erasure channel (PEC) with zero erasure probability ($\epsilon = 0$) to ensure the correct working of SIC algorithm and for verification with the existing results provided in [4], [9]. Simulation results for packet loss ratio and throughput are plotted in Fig. 4, 5 respectively.

An error floor exists in higher order degree distributions as observed in Fig. 4 which is mainly due to stopping sets, where a set of users cannot be resolved due to the selection of same slots for transmission.

Finally, the packet error rate and throughput performance of IRSA with degree distribution of $\lambda(x) = 0.86x^3 + 0.14x^8$ in AWGN, V2V and V2I channels [20] with 802.11p PHY are presented in Fig. 6 and 7.

It can be inferred from Fig. 7 that IRSA scheme results in a substantial improvement in throughput performance when compared to pure slotted ALOHA. Throughput close to 70% in AWGN channels and 50% in vehicular channels is achieved.

Fig. 8 shows a CDF plot for the minimum *channel access delay* (delay incurred by MAC contention scheme to send the packet to PHY layer in multi-user scenario) required for IRSA scheme. These values are calculated for the $100ms$ MAC frame duration for the IRSA scheme(Table I). It can be observed that all of the users in network obtain channel access during this duration. As observed in Fig. 7, as long as the throughput remains equal to normalized channel load, all users transmit successfully ($\sim$ 50-70% of channel load in vehicular networks) within a bounded time.

Since a direct comparison between CSMA/CA and IRSA might not be possible as CSMA is MAC Layer only protocol and IRSA is joint PHY-MAC protocol, we compare our results for IRSA with only a specific case of CSMA by considering

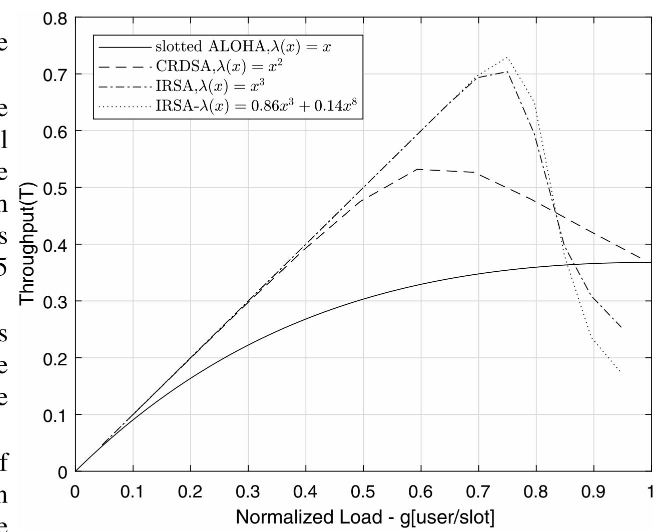


Fig. 5. Throughput vs channel load in packet erasure channel with $\epsilon = 0$

only the broadcast mode packets with the highest priority level and ignoring the hidden node problem. By setting the same simulation parameters (Data rate, Modulation, fading channel) as provided in Table I and [3] with AIFS time of $58\mu$s, the results depicted in Fig. 9 were achieved for CSMA channel access delay with varying channel loads.

It can be observed from Fig. 8 & 9, that the performance of CSMA is slightly better than IRSA in terms of channel access delay for simulation parameters considered in Table I. However, the CSMA algorithm we used here corresponds to highest priority packet delivery mode whereas IRSA being a random access scheme, will always have delay look like a step/ramp function. Even though the minimum delay is smaller for CSMA than IRSA, the worst case delay is random with CSMA. For IRSA, the worst case channel access delay is known and independent of network load and the propagation

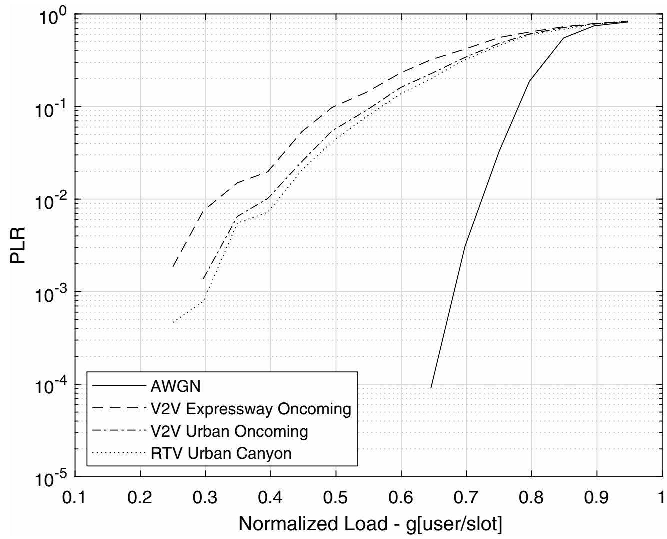


Fig. 6. PLR for packet size of 400 bytes for QPSK with rate $1/2$

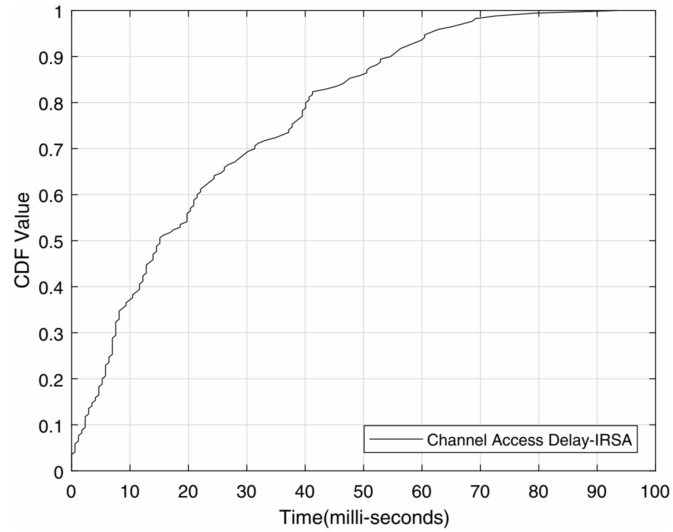


Fig. 8. CDF of channel access delay in IRSA for packet size of 400 bytes for QPSK with rate $1/2$

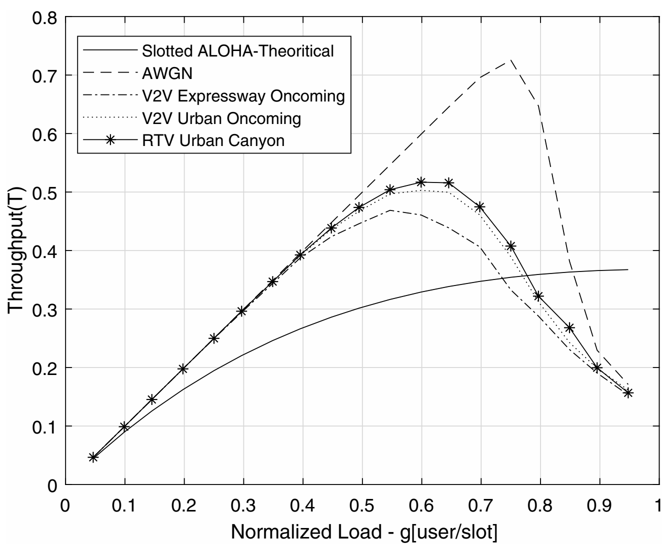


Fig. 7. Throughput vs channel load for packet size of 400 bytes for QPSK with rate $1/2$

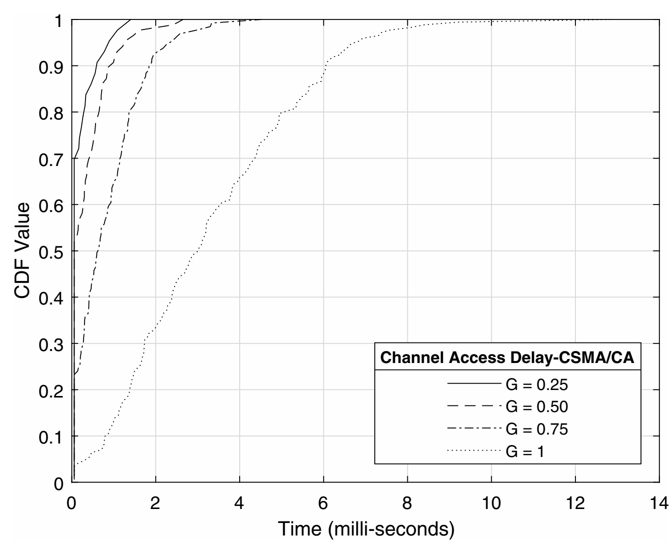


Fig. 9. CDF of channel access delay in broadcast CSMA/CA for varying channel load (G) (packet size of 400 bytes for QPSK with rate $1/2$)

channel. Also, since we are considering the ideal case scenario for CSMA/CA, we are completely ignoring the hidden node problem which can further increase the delay and collisions.

## V. Conclusion

By observing the simulation results, it can be concluded that the slotted-ALOHA SIC MAC scheme can provide higher throughput than classic ALOHA schemes by taking advantage of collisions. This also eliminates the hidden node problem faced in CSMA/CA. An upper bound on MAC-MAC channel access delay (equal to the MAC frame duration and SIC decoding delay) can be obtained, unlike CSMA/CA which utilizes back-off and handshaking mechanisms resulting in unpredictable channel access. By optimizing the packet degree distribution based on MAC frame duration, packet size & number of users; channel access delay can be further reduced to meet the needs of real-time vehicular applications.

## References

[1] "IEEE Standard for Information technology–Telecommunications and information exchange between systems Local and metropolitan area networks–Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE Std 802.11-2016 (Revision of IEEE Std 802.11-2012)*, pp. 1–3534, Dec 2016.

[2] "IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments," *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, pp. 1–51, July 2010.

[3] K. Bilstrup, E. Uhlemann, E. Ström, and U. Bilstrup, "On the ability of the 802.11 p MAC method and STDMA to support real-time vehicle-to-vehicle communication," *EURASIP Journal on Wireless Communications and Networking*, no. 1, p. 902414, 2009.

[4] M. Ivanov, F. Brannstrom, A. G. i Amat, and P. Popovski, "Broadcast Coded Slotted ALOHA: a finite frame length analysis," *IEEE Transactions on Communications*, 2016.

[5] M. Ivanov, F. Brnnstrm, A. G. i. Amat, and P. Popovski, "All-to-all broadcast for vehicular networks based on coded slotted ALOHA," in *2015 IEEE International Conference on Communication Workshop (ICCW)*, June 2015, pp. 2046–2050.

[6] H. A. Cozzetti, R. M. Scopigno, L. Casone, and G. Barba, "Comparative analysis of IEEE 802.11p and MS-Aloha in Vanet scenarios," in *2009 IEEE Asia-Pacific Services Computing Conference (APSCC)*, Dec 2009, pp. 64–69.

[7] R. De Gaudenzi, O. Del Rio Herrero, G. Gallinaro, S. Cioni, and P.-D. Arapoglou, "Random access schemes for satellite networks, from VSAT to M2M: a survey," *International Journal of Satellite Communications and Networking*, vol. 36, no. 1, pp. 66–107, 2018.

[8] G. Choudhury and S. Rappaport, "Diversity ALOHA–A random access scheme for satellite communications," *IEEE Transactions on Communications*, vol. 31, no. 3, pp. 450–457, 1983.

[9] E. Casini, R. De Gaudenzi, and O. D. R. Herrero, "Contention resolution diversity slotted ALOHA (CRDSA): An enhanced random access schemefor satellite access packet networks," *IEEE Transactions on Wireless Communications*, vol. 6, no. 4, 2007.

[10] G. Liva, "Graph-based analysis and optimization of contention resolution diversity slotted ALOHA," *IEEE Transactions on Communications*, vol. 59, no. 2, pp. 477–487, 2011.

[11] E. Paolini, G. Liva, and M. Chiani, "Coded Slotted ALOHA: A Graph-Based Method for Uncoordinated Multiple Access," *IEEE Transactions on Information Theory*, vol. 61, no. 12, pp. 6815–6832, Dec 2015.

[12] G. Durisi, T. Koch, and P. Popovski, "Toward Massive, Ultrareliable, and Low-Latency Wireless Communication With Short Packets," *Proceedings of the IEEE*, vol. 104, no. 9, pp. 1711–1726, Sept 2016.

[13] E. Paolini, "Finite length analysis of irregular repetition slotted Aloha (IRSA) access protocols," in *2015 IEEE International Conference on Communication Workshop (ICCW)*, June 2015, pp. 2115–2120.

[14] K. R. Narayanan and H. D. Pfister, "Iterative collision resolution for slotted ALOHA: An optimal uncoordinated transmission policy," in *Turbo Codes and Iterative Information Processing (ISTC), 2012 7th International Symposium on*. IEEE, 2012, pp. 136–139.

[15] C. Stefanovic and P. Popovski, "ALOHA Random Access that Operates as a Rateless Code," *IEEE Transactions on Communications*, vol. 61, no. 11, pp. 4653–4662, November 2013.

[16] M. Ivanov, F. Brnnstrm, A. G. i Amat, and P. Popovski, "Error Floor Analysis of Coded Slotted ALOHA Over Packet Erasure Channels," *IEEE Communications Letters*, vol. 19, no. 3, pp. 419–422, March 2015.

[17] A. Munari, M. Heindlmaier, G. Liva, and M. Berioli, "The throughput of slotted aloha with diversity," in *2013 51st Annual Allerton Conference on Communication, Control, and Computing (Allerton)*, Oct 2013, pp. 698–706.

[18] A. Mengali, R. D. Gaudenzi, and . Stefanovi, "On the Modeling and Performance Assessment of Random Access With SIC," *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 2, pp. 292–303, Feb 2018.

[19] A. Mengali, R. De Gaudenzi, and P.-D. Arapoglou, "Enhancing the physical layer of contention resolution diversity slotted ALOHA," *IEEE Transactions on Communications*, vol. 65, no. 10, pp. 4295–4308, 2017.

[20] M. A. Ingram, "Six time-and frequency-selective empirical channel models for vehicular wireless LANs," *IEEE Vehicular Technology Magazine*, vol. 2, no. 4, pp. 4–11, 2007.

[21] L. Cheng, B. E. Henty, D. D. Stancil, F. Bai, and P. Mudalige, "Mobile vehicle-to-vehicle narrow-band channel measurement and characterization of the 5.9 GHz dedicated short range communication (DSRC) frequency band," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 8, 2007.

[22] A. M. Abdelgader and W. Lenan, "The Physical Layer of the IEEE 802.11 p WAVE Communication Standard: The Specifications and Challenges," in *Proceedings of the World Congress on Engineering and Computer Science*, vol. 2, 2014.

[23] I. Ivan, P. Besnier, X. Bunlon, L. Le Danvic, M. Crussière, and M. Drissi, "Influence of propagation channel modeling on V2X physical layer performance," in *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on*. IEEE, 2010, pp. 1–5.

[24] C. F. Mecklenbrauker, A. F. Molisch, J. Karedal, F. Tufvesson, A. Paier, L. Bernadó, T. Zemen, O. Klemp, and N. Czink, "Vehicular channel characterization and its implications for wireless system design and performance," *Proceedings of the IEEE*, vol. 99, no. 7, pp. 1189–1212, 2011.

[25] C.-D. Iskander and H.-T. Multisystems, "A MATLAB-based object-oriented approach to multipath fading channel simulation," *Hi-Tek Multisystems*, vol. 21, 2008.

[26] R.-A. Stoica, S. Severi, and G. T. F. de Abreu, "A Self-Organizing Frequency Approach to 802.11 p Channel Estimation," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 7, pp. 1930–1942, 2017.

[27] V. Savaux, Y. Louët, M. Djoko-Kouam, and A. Skrzypczak, "Application of a joint and iterative MMSE-based estimation of SNR and frequency-selective channel for OFDM systems," *EURASIP Journal on Advances in Signal Processing*, vol. 2013, no. 1, p. 128, 2013.

[28] Z. Zhao, X. Cheng, M. Wen, B. Jiao, and C.-X. Wang, "Channel estimation schemes for IEEE 802.11 p standard," *IEEE intelligent transportation systems magazine*, vol. 5, no. 4, pp. 38–49, 2013.

[29] " MATLAB R2018a," The Mathworks, Inc., Natick, Massachusetts, 2018.