CaSSaM: Context-aware System for Safety Messages Dissemination in VANETs

Alexis Yáñez
Department of Electrical Engineering
Universidad de Chile
Santiago, Chile
alexis.yanez@ing.uchile.cl

Sandra Céspedes
Department of Electrical Engineering
Universidad de Chile
Santiago, Chile
scespedes@ing.uchile.cl

Javier Rubio-Loyola
Centre for Research
and Advanced Studies (CINVESTAV)
Tamaulipas, México
jrubio@tamps.cinvestav.mx

***Abstract*—Context-aware systems have a high potential of application in mobile networks because the context in which they operate is highly dynamic. In particular, vehicular ad-hoc networks (VANETs) provide scenarios where context-aware systems could be critical to enhance the performance of protocols that depend on network and traffic conditions, to detect hostile environments as well as to offer a novel way to make decisions in real-time. In this paper, we present CaSSaM, a context-aware system that combines information in a decentralized way, from the state of the communications network and the vehicular traffic, with the aim at classifying the scenario in which the VANET is operating. With information about the operation scenario, it will be possible for protocols, for example, a dissemination mechanism, to adequate its parameters with the values that work best in such a context, improving in this way the general performance of the protocol. Our initial results show the evaluation of a well-known dissemination mechanism, namely the "Slotted 1-persistence", with different values of parameters according to different operation scenarios. We show how the VANET performance could be improved, or worsened, by choosing different parameter values, and how CaSSaM can help in selecting the proper set of values when the scenario of operation is known.**

I. Introduction

Thanks to the development of technologies that allow connectivity in vehicular environments, a variety of applications have been proposed that can use this network with different objectives: from sending alerts to people about real-time road hazards to avoid the most common traffic accidents [1], [2], to allowing the transfer of large amounts of data for entertainment applications such as music, video, Internet access, among others [3].

In terms of safety applications, these can significantly reduce the number of accidents on the route. For example, it is possible to reduce the number of collisions by 60% thanks to the Forward Collision Warning (FCW) application [4]. These applications are based on dissemination mechanisms that allow to deliver one or more alert messages to vehicles that are within the area of influence of an event. In ad-hoc mobile networks, the dissemination mechanisms generally do not use acknowledgments (*ACK*), so it is usually not possible to detect packet losses when there are poor conditions in the communications network [5].

In VANETs, it is necessary not only to deliver emergency messages with the least possible delay, but also to guarantee the reliability of the delivery, so the design of dissemination protocols constitutes a challenging problem for the deployment of security applications [6]. One of the key challenges when designing dissemination protocols is the fact that vehicular environments should be characterized as highly dynamic contexts, with conditions that would vary depending on the type of route, time of day, location, traffic density, among other parameters.

Depending on the applications, dissemination can be done only to neighboring vehicles (*single-hop*) or to all vehicles that are in the area of interest through multi-hop dissemination [7]. A very common problem that rakes place during dissemination is the so-called *broadcast storm* problem [8], which occurs when many vehicles send information at the same time. In networks with high vehicular density, i.e., with a high number of nodes in the VANET, packet collisions occur, causing a decrease in the quality of communication and the impossibility of delivering the emergency messages of the dissemination protocol.

To address the problems during dissemination, protocols have been tailored to address, for example, low and high vehicular density scenarios [9], [10], whereas other schemes are designed for the characteristics of urban environments [11], or specific road areas like intersections [5]. In multi-hop dissemination there are several proposals, some aimed at making the forwarding opportunistically [12], others aimed at modifying dynamically the *beaconing* to decongest the network [13], [14]. Other approaches have applied genetic algorithms to choose the best position to perform multi-hop transmission, looking for the optimum configuration parameters with other methodologies such as fuzzy sets based on rules [15].

In general, dissemination mechanisms are evaluated according to the following performance metrics [10]:

- Packet Delivery Ratio (*PDR*): represents the average number of messages received by vehicles within an area of interest. PDR is expressed as a percentage of the total number of messages sent by the source node. This metric is also known as dissemination coverage.
- Number of transmissions: corresponds to the total number of transmissions made via *broadcasting*.
- Delay: it is the average of the time it takes since the

978-1-5386-6820-7/18/$31.00

source node sends a packet until it is received by each vehicle in the area of interest.
- Dissemination speed: represents the speed with which the message is disseminated to vehicles in the area of interest. To acquire this metric, the source node sends the message only once and then the coverage increment must be calculated as a function of time. If the coverage increases significantly in a small period, it means that the dissemination protocol has a high performance with respect to this metric.

By knowing the characteristics of the operation scenario, the dissemination mechanisms could take advantage of the knowledge obtained from their environment to set the appropriate parameter values, and in turn, this could improve the aforementioned performance metrics. However, in ad-hoc networks, it is assumed there is no centralized database where to store reports on the state of the communications network nor the state of vehicular traffic. So for a particular node, it is not trivial to determine the general context where protocols and applications are operating.

In this paper we present CaSSaM, a *context-aware* system that facilitates the adequate selection of parameters to achieve the best performance of a dissemination protocol in a VANET. Although most of the dissemination mechanisms are parameterizable, the lack of knowledge of the environment in which they operate makes it difficult for the protocols to adapt to the actual conditions of the environment. Our proposal intends, based on indirect information, to classify in a decentralized manner the type of scenario in which the dissemination protocol must operate, so that its parameters can be adjusted to the operating environment. The preliminary results demonstrate that CaSSAM improves the performance of the dissemination protocol while using the same dissemination mechanisms, with self-adaptive parameters according to the actual environment in which the protocol operates.

The rest of the paper is organized as follows: Section II describes previous works that propose the use of *context-aware* systems in vehicular environments. Section III presents the proposed architecture for classification of scenarios for VANETs. Section IV discusses the preliminary results in adjusting parameter values of a dissemination mechanism. Finally, the conclusions and future work are presented in Section V.

II. Related work

Context-aware systems are characterized by being aware or being sensitive of the situation (or context) in which they operate, either in physical, virtual or user's environment [16]. The context is understood as "*any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and the applications themselves*" [17].

These systems are able to adapt, exploiting the knowledge acquired through sensors, other nodes or through the infrastructure available on the route. In vehicular environments, *context-aware* systems focus mainly on the area of service recognition and location on the route [18], [19]. In [17] the authors describe various approaches that have used *context-aware* systems for the detection of specific events, for example in security, entertainment, and traffic management applications. To the best of our knowledge, there is only one work that addresses the problem of disseminating information of accidents based on warning message considering the information of the vehicular context [20]; however, the scheme does not consider the traffic of the communications network in the context definition.

Routing in VANETs is another area of research related to our work. In [21] the authors present an approach to provide Internet access to support interactive and entertainment applications in VANETs. In [22] the authors employ the source and destination location of nodes as the context information; then, they elaborate a routing mechanism that seeks to reduce packet losses due to saturation in the cache of each vehicle while avoiding network overload. In [23] the authors define the vehicular context based on parameters like speed of each node and inter-vehicular distance. This context information is evaluated and taken into account while selecting the appropriate transmission speed considering the conditions of the link layer. The approach produces important VANET performance enhancements in terms of data transmission rates between vehicles.

Dressler et al. present a classification of different *broadcasting* mechanisms and their effect in the performance of different VANET applications [24]. The main contribution consists in the differentiation of broadcasting schemes based on client applications. Authors in [25] describe a context-aware system that identifies potential accidents and pro-actively enable security mechanisms before the accident occurs. The information acquired from the sensors in the vehicles (i.e., data prior to the accident) is analyzed to predict a certain collision and its severity; in this way, the system launches a timely warning. In [26] the authors propose a context-aware system to improve the way in which information is acquired to avoid redundancy in the information collected by a group of nodes, whereas the authors in [27] propose a MAC layer context-aware protocol based on Bayesian networks with the aim at enhancing the performance of the VANET in highly congested scenarios. The approach presented in [27] produces a substantial improvement compared to the CSMA/CA mechanism adopted by the IEEE 802.11-OCB standard, whose performance is seriously affected in highly congested environments.

III. CaSSaM: Context-aware System for Safety Messages Dissemination

This section describes the core contribution of this paper. Fig. 1 shows the general architecture of our proposed *context-aware* system. The purpose of the system is to classify the scenario in which a VANET node operates based on indirect information that combines information from the communications network and the vehicular traffic. The state of the communications network is obtained from the following statistics:

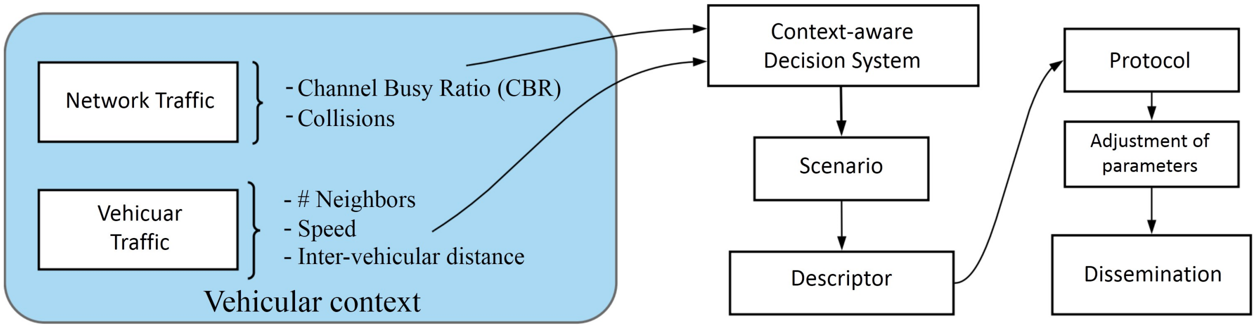


Fig. 1. CaSSaM architecture

- *Channel Busy Ratio (CBR)*: *CBR* is obtained from the MAC layer. CBR is the time during which the channel is busy (i.e., sending packets) in a time interval. This metric is used by the CSMA/CA protocol and it is calculated as follows:

$$CBR = \frac{t_{busy}}{t_{interval}}, \tag{1}$$

  in this case $t_{interval} = 1$ $[sec]$.
- Collisions: refer to the number of times that two or more packets collide when several nodes transmit simultaneously. Although it is not possible to obtain a value for this metric in a distributed way, it is possible to produce an estimate through the measurement of the number of times a packet is re-sent by a particular sending node. In our proposal the re-send value is set in three trials. In other words, three unsuccessful attempts to send a packet is considered as a possible collision.

On the other hand, to establish the state of vehicular traffic, the following sources of information are used:

- Number of neighbors: the number of neighboring vehicles is obtained through the *beacons*, with a list that stores the source addresses of the received messages.
- Speed: this information is extracted directly from the vehicle and it can be updated in real time.
- Inter-vehicular distance: this information can be extracted from the *beacons* as well as from sensors or radars installed in the vehicle.

From the last group of information, it is possible to classify the scenario of a VANET node with respect to the vehicular traffic. Previous works where mathematical models are applied to find the relationship between these variables and vehicular congestion, had been able to identify and accurately predict the degree of local vehicular congestion [28], [29], [30].

The information described above is the input of the CaSSaM system. The information is processed with a classification stage in which it is determined the scenario of the VANET node. Following on, the CaSSaM system assigns a descriptor that prescribes indications to the dissemination protocol about which parameters to adjust for a better performance, or even to suggest the use of a different dissemination protocol.

IV. Preliminary results

This section demonstrates the effectiveness of the adjustment of dissemination parameters according to the context where the VANET nodes are immersed. It is expected that the adjustment will be prescribed according to the scenario classifier of the CaSSaM system, which is currently under development.

A. Dissemination mechanism chosen for the evaluation

The *Slotted 1-persistence* protocol [31] is a dissemination mechanism that gives the priority of retransmission to the farthest node of the sending node. For that, the protocol uses a waiting time before retransmitting, which varies according to the distance between nodes. When a node receives a packet, the protocol verifies the packet ID; if the packet is received for the first time and it the node has not received any duplicates before, the protocol assigns a time slot and the node performs a re-broadcast with a probability of 1 within the time slot $T_{S_{ij}}$ assigned. Otherwise, the packet is discarded.

The time slot can be obtained as indicated below:

$$T_{S_{ij}} = S_{ij} \times \tau, \tag{2}$$

where τ is the estimated delay of a hop, which refers to the sum of the propagation delay plus the delay of accessing the shared medium. S_{ij} is the assigned slot number that can be expressed as:

$$S_{ij} = N_S \left(1 - \left[\frac{min(D_{ij}, R)}{R}\right]\right), \tag{3}$$

where D_{ij} is the relative distance between the nodes i and j, R is the transmission range, and N_S is the default slot number. N_S must be chosen as a function of the traffic density.

This protocol has been chosen because it solves the problem of broadcast storms and because it needs only the information about the position of the sending and receiving nodes to operate. It is also one of the most used protocols in the literature for its simplicity and because it was one of the first protocols proposed for dissemination.

B. Characterization of scenarios

To obtain the preliminary results, we employed the intersection illustrated in Fig. 2, which is deployed on an area of 1 km^2. The intersection has 3 and 4 lanes per road. In this scenario, vehicles are set through the SUMO simulator with 2 different densities: 31 veh/km and 81 veh/km. The densities seek to replicate the extremes of the ones reported in [15], although the application of greater densities, such as 133 veh/km, were not possible due to the use of an intersection as the simulation scenario.

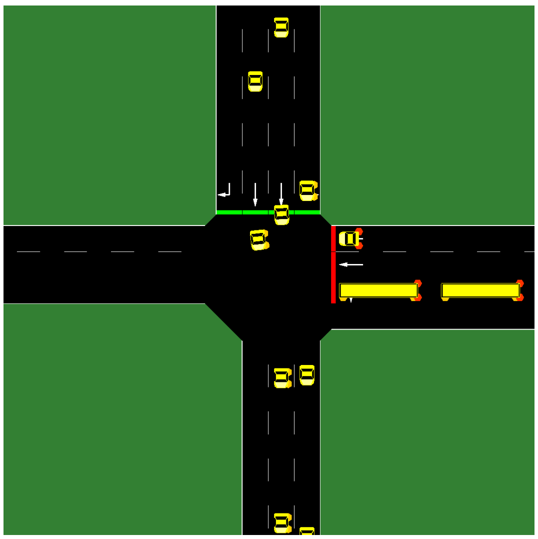


Fig. 2. Simulation scenario

The scenario is evaluated with different configurations of the following network parameters:

- *Beaconing* frequency varying between 2 Hz and 10 Hz. These messages carry mandatory information for the operation of safety applications: position, velocity, and acceleration of the vehicle.
- *Wave Service Advertisement messages (WSA)* with frequency of 1 Hz. These messages are included to simulate traffic on the network corresponding to various on-route services (i.e., traffic from safety applications). They are additional load to the beaconing that operates permanently.

It should be noted that in the simulation a packet for dissemination is generated only once by the source node, that is, only one packet of type *Wave Short Message* is generated to observe its behavior at the first instant of dissemination. The safety message is forwarded by the neighboring nodes throughout the entire map. Because of this, the *PDR* is only calculated for a single safety message, so this percentage is also a representation of the number of nodes in the entire map that received the message successfully.

Table I shows the details of the parameters used in the bidirectional simulator VEINS [32] employed for the evaluation.

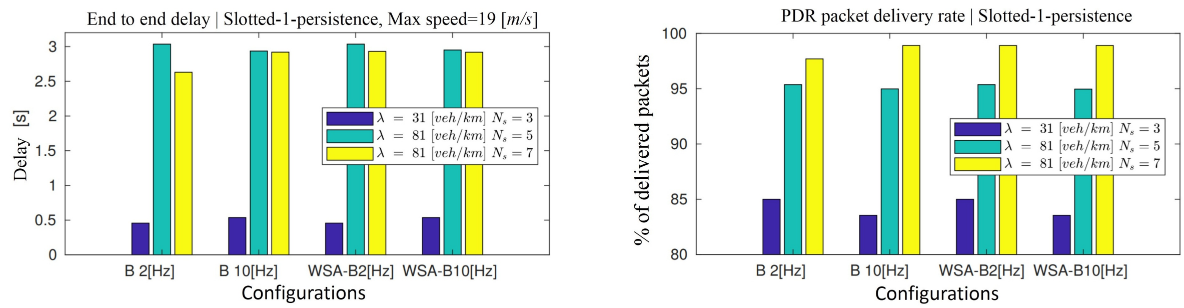
TABLE I
SIMULATION PARAMETERS

Physical layer	
Frequency	5.89 GHz
SimplePathLoss Model	$\alpha = 2$
Transmission power	20 mW
Receiver sensitivity	-89 dBm
Thermal noise	-110 dBm
Antenna type	Monopole
Link layer	
Bit rate	6 $Mbps$
Congestion Window	[15, 1023]
Slot time	13 μs
SIFS	32 μs
DIFS	58 μs
Messages	
Beaconing frequency	2 Hz and 10 Hz
Beacon size	256 $bits$
WSA frequency	1 Hz
WSA size	250 $bits$
WSM size	1024 $bits$
Simulation	
Simulation time	40 s and 60 s
Total roadway length	2.14 km
Vehicular density	$\lambda = 31$ and 81 veh/Km
Max speed	19 m/s
Vehicle type	Buses and cars
Slotted-1-Persistence	
τ	5 ms
$Range$	500 m
N_s	3 and 5

C. Discussion of results

First, two traffic densities ($\lambda = 31$ veh/km and $\lambda = 81$ veh/km) are used to observe the effect of vehicular traffic on the dissemination mechanism. In the first case, when $N_s = 3$, the protocol performs well in terms of delay and speed of dissemination; nevertheless, the performance in terms of the PDR is below 85%. In the second case, the delay performance gets worse when $N_s = 5$; nevertheless, both the PDR and dissemination speed improve, as observed in figures 3a, 3b and 4. The values $N_s = 3$ and $N_s = 5$ are the ones suggested by the authors of this mechanism for low and high density scenarios, respectively [31].

To the best of our knowledge, the effect of N_s (see equation 3) has not been evaluated in the literature for particularly dense scenarios. In the following we present an evaluation of the protocol's performance considering two congestion values ($N_s = 5$, $N_s = 7$). The results show that, when $N_s = 7$, a great difference is observed with respect to the speed of dissemination being much higher (around 4 orders of magnitude) than for $N_s = 5$ (see figures 4 and 5). On the other hand, the delay and PDR improve slightly with higher values of N_s for high density scenarios. Furthermore, it can be observed that the increase in the beaconing frequency directly affects the dissemination speed for all values of N_s in both cases of congestion, whereas for the delay and PDR, the increase in beaconing frequency also produces negative effects but with a smaller impact. Therefore, if a given node is immersed in a scenario of high traffic density and high load in the channel due to beaconing and WSA messages, it would



(a) Average delay in receiving emergency message

(b) Emergency message delivery percentage

Fig. 3. Evaluation of Slotted 1-persistence in scenarios of high/low vehicular density and high/low network congestion. B represents *beaconing* and WSA is the load of service messages in the channel (*Wave Service Advertisement*)

be recommended to use a value of $N_s = 7$. On the contrary, if a given node operates in a low density and low load scenario of beaconing (i.,e, $1\ Hz$) it would be recommended to use a value of $N_s = 3$.

TABLE II
DELAY AT FIRST HOP, 81 veh/km, $Ns = 5$

Configuration	Delay average	# of Nodes
Only beaconing (2 Hz)	0, 000273	170
Only beaconing (10 Hz)	0, 000236	170
WSA and beaconing (2 Hz)	0, 000273	170
WSA and beaconing (10 Hz)	0, 000236	170

TABLE III
DELAY AT FIRST HOP, 81 veh/km, $Ns = 7$

Configuration	Delay average	# of Nodes
Only beaconing (2 Hz)	0.000246	186
Only beaconing (10 Hz)	0.000273	186
WSA and beaconing (2 Hz)	0.000273	186
WSA and beaconing (10 Hz)	0.000273	186

Our next analysis focuses on the average delay of nodes that receive the emergency message in the first hop. The average coverage of the multi-hop, illustrated in Fig. 3a, includes vehicles that enter the scenario after the generation of the WSM message, which may produce worse values in the delay. The results presented in Table II and Table III demonstrate that the average delay for vehicles that are in the first hop is much better (it is reduced by 4 orders of magnitude) than the general average of the whole map presented in Fig. 3a. In addition, the number of covered nodes increases by choosing $N_s = 7$ with respect to $N_s = 5$, which means that more nodes receive the WSM message in a reduced time, being consistent with the increase in the dissemination speed.

The CaSSaM system uses context-oriented information to adapt the parameters of a dissemination mechanism in operation. In addition, this information can be useful to modify other parameters of vehicular communications, for example, when vehicles are operating in low density scenarios and low level of channel occupancy, CaSSaM may prescribe the nodes to increase the frequency of the beaconing to improve the accuracy of the cooperative knowledge (i.e., the location information and mobility of neighboring vehicles) with certainty that the performance of the dissemination mechanism will be enhanced.

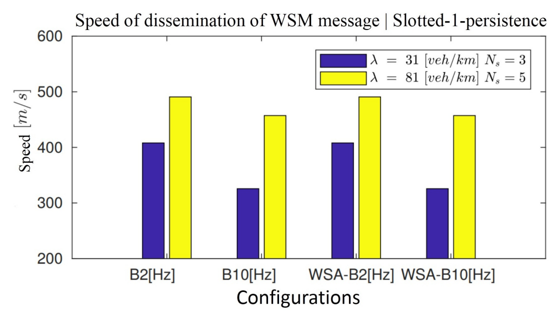


Fig. 4. Speed of dissemination for slotted-1-persistence for $Ns = 3$ and $Ns = 5$

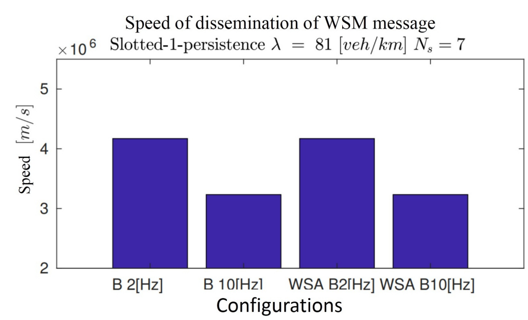


Fig. 5. Speed of dissemination for slotted-1-persistence for $Ns = 7$

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have demonstrated that context information can be exploited to change the parameters of a dissemination mechanism in vehicular scenarios, to improve its performance significantly. In this regard, context information is not limited only to the characteristics of the vehicular traffic but it can also include the state of the communications network. All in all, context information is advantageous to make important decisions about the communications in the ad-hoc network, for example, in the adjustment of the beaconing frequency to guarantee the operation of safety applications. In our on-going work, we are implementing the scenario classifier based on a *machine learning* algorithm, so that the system can classify the scenario in which a VANET node operates automatically and in real time. Future work also considers a more elaborated evaluation of the context-aware system with other dissemination mechanisms to evaluate their performance depending on the evaluation scenario.

VI. Acknowledgment

This work has been partially funded through the FONDECYT Initiation 11140045 project, the National Council of Research and Technology of Mexico (CONACYT) through grant FONCICYT/272278, and CONICYT Chile through the RETRACT project ELAC2015/T100761.

References

[1] X. Ma, J. Zhang, X. Yin, and K. S. Trivedi, "Design and analysis of a robust broadcast scheme for VANET safety-related services," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 1, pp. 46–61, 2012.

[2] B. Hassanabadi and S. Valaee, "Reliable periodic safety message broadcasting in VANETs using network coding," *IEEE Transactions on Wireless Communications*, vol. 13, no. 3, pp. 1284–1297, 2014.

[3] J. J. Alcaraz, J. Vales-Alonso, and J. Garcia-Haro, "Control-based scheduling with QoS support for vehicle to infrastructure communications," *IEEE Wireless Communications*, vol. 16, no. 6, pp. 32–39, 2009.

[4] K. D. Kusano and H. C. Gabler, "Comparison of expected crash and injury reduction from production forward collision and lane departure warning systems," *Traffic injury prevention*, vol. 16, no. sup2, pp. S109–S114, 2015.

[5] G. Tan, Y. Yin, J. Bu, and N. Ding, "An ivc broadcast scheme based on traffic phase for emergency message dissemination at road intersection," in *Complex, Intelligent, and Software Intensive Systems (CISIS), 2013 Seventh International Conference on*. IEEE, 2013, pp. 59–65.

[6] Y. Bi, H. Zhou, W. Zhuang, and H. Zhao, *Safety Message Broadcast in Vehicular Networks*. Springer, 2016.

[7] O. K. Tonguz, N. Wisitpongphan, and F. Bai, "Dv-cast: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *IEEE Wireless Communications*, vol. 17, no. 2, 2010.

[8] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," *Wireless networks*, vol. 8, no. 2-3, pp. 153–167, 2002.

[9] R. S. Schwartz, R. R. Barbosa, N. Meratnia, G. Heijenk, and H. Scholten, "A directional data dissemination protocol for vehicular environments," *Computer Communications*, vol. 34, no. 17, pp. 2057–2071, 2011.

[10] B. Tian, K. M. Hou, and H. Zhou, "The traffic adaptive data dissemination (TrAD) protocol for both urban and highway scenarios," *Sensors (Switzerland)*, vol. 16, no. 6, p. 920, jun 2016. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/27338393

[11] M. Hager, L. Wernecke, C. Schneider, and J. Seitz, "Vehicular ad hoc networks: Multi-hop information dissemination in an urban scenario," in *Telecommunications and Signal Processing (TSP), 2015 38th International Conference on*. IEEE, 2015, pp. 65–70.

[12] M. Li, K. Zeng, and W. Lou, "Opportunistic broadcast of event-driven warning messages in vehicular ad hoc networks with lossy links," *Computer Networks*, vol. 55, no. 10, pp. 2443–2464, 2011.

[13] S. Bolufé, S. Montejo-Sánchez, C. Azurdia-Meza, S. Céspedes, R. Demos Souza, and E. M. García, "Dynamic Control of Beacon Transmission Rate and Power with Position Error Constraint in Cooperative Vehicular Networks," in *33rd ACM/SIGAPP Symposium On Applied Computing (SAC), Pau, France*, Apr 2018.

[14] R. Oliveira, C. Montez, A. Boukerche, and M. S. Wangham, "Reliable data dissemination protocol for VANET traffic safety applications," *Ad Hoc Networks*, vol. 63, pp. 30–44, 2017.

[15] A. Galaviz-Mosqueda, S. Villarreal-Reyes, H. Galeana-Zapien, J. Rubio-Loyola, and R. Rivera-Rodriguez, "Genetic tuning of fuzzy rule-based systems for multi-hop broadcast protocols for VANETs," *Telecommunication Systems*, vol. 63, no. 3, pp. 399–420, 2016. [Online]. Available: "http://dx.doi.org/10.1007/s11235-015-0129-z

[16] S. Poslad, "Context-aware systems," *Ubiquitous Computing: Smart Devices, Environments and Interactions*, pp. 213–244, 2009.

[17] H. Vahdat-Nejad, A. Ramazani, T. Mohammadi, and W. Mansoor, "A survey on context-aware vehicular network applications," *Vehicular Communications*, vol. 3, pp. 43–57, 2016. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2214209616000036

[18] K. Abrougui, A. Boukerche, and R. W. N. Pazzi, "Design and evaluation of context-aware and location-based service discovery protocols for vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 717–735, 2011.

[19] W. Woernd and R. Eigner, "Collaborative, context-aware applications for inter-networked cars," in *Proceedings of the Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, WETICE*. IEEE, 2007, pp. 180–185. [Online]. Available: http://ieeexplore.ieee.org/document/4407149/

[20] H. Zarza, H. Karimi, S. Mohammad, S. Y. Hosseini, H. R. Ataeian, and H. Rostami, "Cagfp: context aware geocast forwarding protocol for inter-vehicle communication," in *21st Iranian Conference on Electrical Engineering (ICEE), IEEE, Mashhad, Iran*, 2013.

[21] N. Alsharif, S. Cespedes, and X. S. Shen, "ICAR: Intersection-based connectivity aware routing in vehicular ad hoc networks," in *IEEE International Conference on Communications*. IEEE, jun 2013, pp. 1736–1741. [Online]. Available: http://ieeexplore.ieee.org/document/6654769/

[22] R. B. Soares, E. F. Nakamura, C. M. Figueiredo, and A. A. Loureiro, "VCARP: Vehicular Ad-hoc Networks context-aware routing protocol," in *Proceedings - IEEE Symposium on Computers and Communications*. IEEE, jul 2012, pp. 000 442–000 447. [Online]. Available: http://ieeexplore.ieee.org/document/6249336/

[23] P. Shankar, T. Nadeem, J. Rosca, and L. Iftode, "CARS: Context-aware rate selection for vehicular networks," in *Proceedings - International Conference on Network Protocols, ICNP*. IEEE, oct 2008, pp. 1–12. [Online]. Available: http://ieeexplore.ieee.org/document/4697019/

[24] F. Dressler, F. Klingler, C. Sommer, and R. Cohen, "Not All VANET Broadcasts Are the Same: Context-Aware Class Based Broadcast," *IEEE/ACM Transactions on Networking*, vol. PP, no. 99, pp. 1–14, 2017.

[25] D. Böhmländer, T. Dirndorfer, A. H. Al-Bayatti, and T. Brandmeier, "Context-aware system for pre-triggering irreversible vehicle safety actuators," *Accident Analysis and Prevention*, vol. 103, pp. 72–84, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.aap.2017.02.015

[26] Z. Amjad, W. C. Song, K. J. Ahn, and M. Shoaib, "Context aware data aggregation in vehicular ad-hoc networks," in *NOMS 2016 - 2016 IEEE/IFIP Network Operations and Management Symposium*. IEEE, apr 2016, pp. 1257–1260. [Online]. Available: http://ieeexplore.ieee.org/document/7502998/

[27] S. Yi, W. Lai, D. Tang, and H. Wang, "A context-aware MAC protocol in VANET based on Bayesian Networks," in *9th International Conference on Communications and Networking in China*. IEEE, aug 2014, pp. 191–196. [Online]. Available: http://ieeexplore.ieee.org/document/7054284/

[28] M. Gramaglia, M. Calderon, and C. J. Bernardos, "Abeona monitored traffic: Vanet-assisted cooperative traffic congestion forecasting," *IEEE vehicular technology magazine*, vol. 9, no. 2, pp. 50–57, 2014.

[29] L. Rui, Y. Zhang, H. Huang, and X. Qiu, "A new traffic congestion detection and quantification method based on comprehensive fuzzy assessment in vanet," *KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS*, vol. 12, no. 1, pp. 41–60, 2018.

[30] M. Milojevic and V. Rakocevic, "Distributed road traffic congestion quantification using cooperative VANETs," *Ad Hoc Networking Workshop (MED-HOC-NET), 2014 13th Annual Mediterranean*, pp. 203–210, 2014.

[31] N. Wisitpongphan, O. Tonguz, J. Parikh, P. Mudalige, F. Bai, and V. Sadekar, "Broadcast storm mitigation techniques in vehicular ad hoc networks," *IEEE Wireless Communications*, vol. 14, no. 6, pp. 84–94, 2007.

[32] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *IEEE Transactions on Mobile Computing*, vol. 10, no. 1, pp. 3–15, January 2011.