SCB: Store-Carry-Broadcast Scheme for Message Dissemination in Sparse VANET

Sok-Ian Sou* and Yinman Lee†

*Institute of Computer and Communication Engineering, Department of Electrical Engineering
National Cheng Kung University, Taiwan, Email: sisou@mail.ncku.edu.tw
†Department of Electrical Engineering, National Chi Nan University, Taiwan, Email: ymlee@ncnu.edu.tw

***Abstract*—To take on challenges of communication in sparse VANET, we propose a *Store-Carry-Broadcast* (SCB) scheme to assist message dissemination by broadcasting over a specific road segment instead of a single vehicle. In the SCB scheme, an opposite vehicle helps to disseminate the safety messages to oncoming vehicles traveling on the reverse lane by broadcasting. Compare with the well-known store-carry-forward broadcasting in VANET, the SCB scheme consumes much less network bandwidth in terms of the number of broadcasting performed. Extensive simulation results are presented to demonstrate that when the traffic density is low or when the DSCR penetration rate is low, our proposed SCB scheme significantly reduced both broadcast overhead as well as delivery delay in sparse VANET.**

***Index Terms*—Broadcasting, network connectivity, vehicular traffic modeling, disconnected network, store-carry-forward.**

I. Introduction

Data communication in *Vehicular Ad hoc Networks* (VANETs) is a challenging task due to a high mobility and constantly changing topology. In recent years, the interest in research on VANETs has increased dramatically. IEEE 802.11p and 1609 standards are under development to support vehicle-to-vehicle and vehicle-to-infrastructure communications. In VANET, vehicles communicate with other nodes through the *Dedicated Short Range Communication* (DSRC) wireless devices [1], [2], [3], [4]. Based on DSRC technology, several advanced solutions in intelligent transportation have arisen to improve traffic safety as well as drivers' comfort. Safety applications are of special interest because they are expected to significantly reduce fatalities and economic losses caused by traffic accidents. Examples of safety applications are emergency warning messages and cooperative collision avoidance [5], [6], [7]. The major characteristic for these applications is that data should be disseminated fast and reliable enough to a large number of vehicles by broadcasting [8].

In VANET, the vehicles' connectivity heavily depends on the time-varying traffic flow and the penetration rate of the DSRC market [9]. First, the VANET connectivity is weak in low traffic flow hours. Second, the penetration rate of the DSRC-equipped vehicles is still relatively low. Even in the U.S., the penetration rate of the DSRC-equipped vehicles is only about 7% and is expected to take long time to reach close to 100% market penetration [10]. Because of the sparse distribution on vehicles with DSRC devices, simply utilizing the conventional ad-hoc routing protocols is not enough for achieving a satisfactory performance in VANET [11], [12].

In *Mobile Ad Hoc Networks* (MANET), a special mobile node is designated to collect (store and carry) and deliver (forward) messages among disconnected ad-hoc nodes under traditional *Store-Carry-Forward* (SCF) scheme [13]. VANET is a special type of MANET in which vehicles with DSRC devices act as mobile nodes. The SCF scheme can be utilized in VANET to solve disconnection problems in many occasions. Several practical issues with SCF scheme have been addressed. For example, Zhao and Cao proposed several vehicle-assisted data delivery (VADD) protocols to store-carry-forward packets to the best road with the lowest data delivery delay [14]. Kitani *et al.* proposed to use buses as message ferries to travel along regular routes to assist message delivery [15]. Tonguz *et al.* proposed a distributed vehicular broadcasting protocol (DV-CAST) that employs the SCF scheme when a disconnected vehicle is found [16].

Based on the above discussion, it is obvious that the SCF scheme plays an essential role in VANET consisting of opportunistic links and time-varying topology. There are several challenges in using the SCF scheme on VANET. First, the waiting time for a VANET cluster's tail to meet an opposite forwarder can not be guaranteed. Long temporal delay for waiting a forwarder in SCF scheme was pointed out especially when the penetration rate of DSRC devices is low [17]. Second, overhead for packet delivery in SCF scheme, such as an extra relaying hop is needed, should be considered in cost measurement. As the density of DSRC devices decreases, the number of disconnected nodes increases and the number of SCF operations performed by opposite forwarders increases. Therefore, to reduce SCF overhead, it is extremely important to avoid assigning multiple SCF forwarders when one is better for performing multiple times of SCF operations among consecutive disconnected vehicles. Surprisingly, there is no existing work to explore and discuss the above issues. Performance of such opportunistic communication protocols

The work of S.-I. Sou was sponsored in part by the National Science Council (NSC), Taiwan, under the contract number NSC 100-2221-E-002-184- and NSC 100-2221-E-006-200-. The work of Y. Lee was sponsored in part by the NSC, Taiwan, under the contract number NSC 100-2221-E-260-013-.

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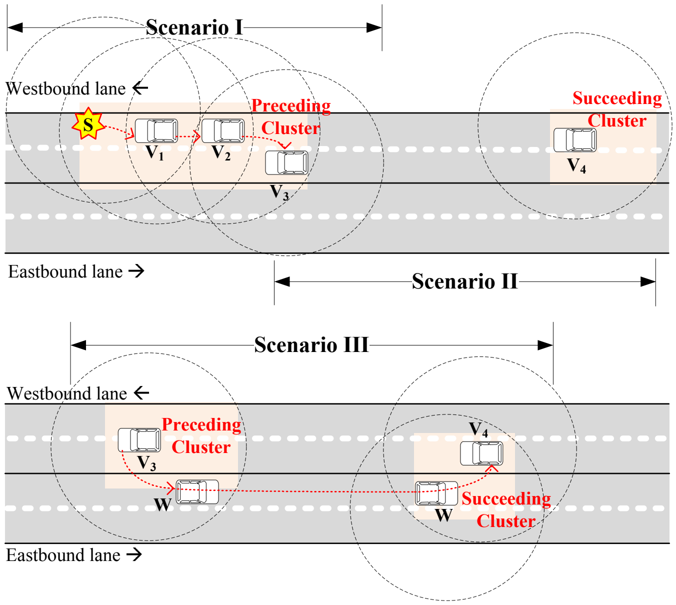


Fig. 1. The VANET scenario for safety message broadcasting.

in vehicular environments is still an open question. To take on challenges of communication in sparse VANET, this paper proposes a *Store-Carry-Broadcast* (SCB) scheme to assist message dissemination by broadcasting in sparse VANET. Specifically, an opposite vehicle helps to carry and disseminate the safety message to oncoming vehicles traveling on the reverse lane. The number of broadcasting depends on the VANET connectivity that counts upon the current vehicle's density and the penetration rate of DSRC devices.

Our contribution is twofold: First, we improve the SCF scheme for broadcasting in sparse VANET that can achieve significantly less transmission overhead. Second, we investigate the improvement in VANET in terms of the broadcast overhead and the corresponding delay to disseminate a message from the source to all potential destinations located on a given road segment.

This paper is organized as follows: Section II gives the background of broadcasting in VANET. Section III proposes the SCB scheme to reduce the broadcast overhead in sparse VANET. Section IV uses extensive simulation to show the numerical results when using the SCB scheme. Finally, Section V provides a conclusion.

II. Broadcast-based message delivery in VANET

This section gives background on broadcast-based message delivery. We first make the following definitions:

Definition 1. A *disconnected vehicle* is a vehicle whose distance to the preceding vehicle on the same lane is longer than the DSRC transmission range R.

Definition 2. A *cluster* contains a group of vehicles traveling on the same direction. The cluster's head is a disconnected vehicle. Two consecutive vehicles in a cluster are connected, i.e., the inter-spacing between them is less than R.

Fig. 1 illustrates three VANET scenarios for message broadcasting. A fixed node $\mathbf{S}$ (representing a source) broadcasts a safety message to vehicles heading to a hazard. We consider the westbound lane as the interested region of the safety message. In scenario I, $\mathbf{S}$ and vehicles $\mathbf{V_1}, \ldots \mathbf{V_3}$ are in a same VANET cluster on the westbound lane. The message issued by $\mathbf{S}$ can be successfully delivered to vehicles $\mathbf{V_1}, \mathbf{V_2}, \mathbf{V_3}$ through direct transmission. In scenario II, $\mathbf{V_4}$ is disconnected from the preceding vehicle $\mathbf{V_3}$, and hence $\mathbf{V_4}$ can not receive the message broadcasted by $\mathbf{V_3}$. To solve this network disconnection problem (especially due to low traffic flow or low DSRC market penetration), one usually employs the SCF scheme to bridge the gap between two disconnected vehicles. In scenario III, a VANET cluster's tail ($\mathbf{V_3}$) designates a vehicle ($\mathbf{W}$) as a forwarder. $\mathbf{W}$ is traveling along the opposite lane of $\mathbf{V_3}$ and is responsible for carrying a packet to the disconnected vehicle ($\mathbf{V_4}$). Therefore, the message is delivered along the routing path $\mathbf{V_3} \rightarrow \mathbf{W} \rightarrow \mathbf{V_4}$. For convenience, we refer vehicle ($\mathbf{W}$) as an *SCF forwarder* in the above traditional SCF scheme.

There are some previous works that address the broadcast messaging in VANETs. In [18], for instance, Farnoud *et al.* used a positive orthogonal code to distribute a transmission pattern for broadcast messages. In [19], the authors used stationary support units to improve the refreshing rate of the information dissemination in city scenarios. Besides the aforementioned issues, the message routing and delivery problems are also among the key concerns in VANETs. In [20], the authors investigated the *Delay Tolerant Networks* (DTN) where an end-to-end route between mobile nodes does not exist. Naumov et al. studied in [21] VANET routing protocols by using mobility information obtained from a vehicular traffic simulator based on real road maps. The authors also discovered that AODV protocol exhibits serious performance problems, such as low packet delivery ratio. In [22], the authors focused on network fragmentation scenarios in VANETs with real-world vehicular mobility models and provided an SCF solution to routing in disconnected networks.

The aforementioned broadcast approaches do not strictly consider the potentially long delay and the overhead incurred in finding a suitable SCF forwarder. When there are many disconnected vehicles located on the broadcasting area, it requires a long delay in finding suitable forwarders for several times. To reduce SCF overhead, it is extremely important to avoid assigning multiple SCF forwarders when one is better to perform multiple times of SCF operations among consecutive disconnected vehicles. This paper proposes an SCB scheme which assigns an opposite vehicle as a helper to perform multiple times of broadcasting over a specific road segment for sparse VANET. Specifically, we identify the VANET condition when the SCB scheme outperforms the traditional SCF scheme.

III. Store-Carry-Broadcast (SCB) Scheme

In this section, we propose an SCB scheme for broadcasting in sparse VANET. Let the penetration probability that a vehicle

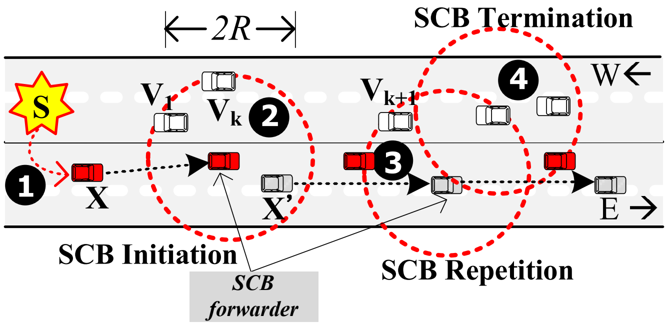


Fig. 2. The illustration of the scenario using the SCB scheme.

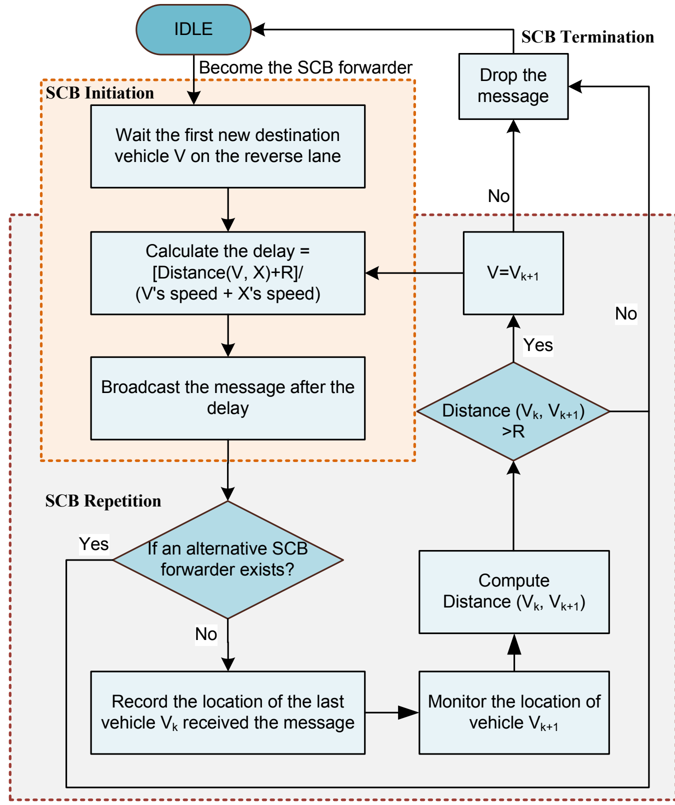


Fig. 3. The routing flow algorithm for SCB scheme.

is equipped with DSRC radios and *Global Positioning System* (GPS) receivers be ρ. Each vehicle periodically broadcasts a `beacon` message to its one-hop VANET neighbors. Upon receiving a `beacon` message from the neighbor, each vehicle can compare its GPS information to determine the neighbor's position and whether the neighbor is moving in the same direction or in the opposite direction. Through `beacon` message exchanging, each vehicle can maintain its local topology (which contains the list of one-hop neighbors who are leading, following or moving in the opposite direction, respectively). For a typical VANET environment whose topology does not change much in a millisecond or even a second, the beacon frequency of 1-4 Hz is enough.

Fig. 2 shows a VANET architecture containing a straight road segment with vehicles traveling in eastbound and westbound directions. Suppose that node **S** has a message to broadcast to following westbound vehicles. The operating flow of the SCB scheme are highlighted as follows:

1) In the SCB scheme, when node **S** is disconnected from its succeeding vehicle $\mathbf{V_1}$, **S** initiates the SCB operation. That is, **S** transmits the message to an opposite vehicle **X** that works as the *SCB forwarder*. Then the SCB forwarder is responsible to *broadcast* the message to the destination vehicles following **X**. This state is referred to as "SCB initiation".
2) In the traditional SCF scheme, when a SCF forwarder receives the message from **S**, it only needs to forward the message to the first succeeding vehicle of **S** (see vehicle $\mathbf{V_1}$ in Fig. 2). To minimize the broadcast overhead, in the SCB scheme, the SCB forwarder maximizes the broadcast range of $2R$ to increase the number of new destination vehicles. In Fig. 2, vehicles $\mathbf{V_1} \ldots \mathbf{V_k}$ are covered by one broadcast hop issued by **X**.
3) To avoid an unnecessary two-hop SCB operation, after a message broadcast, the SCB forwarder **X** first checks whether other alternative SCB forwarders exist. An alternative SCB forwarder is an eastbound neighbor vehicle of **X** that is closer to vehicle V_{k+1} than **X**. Since these alternative SCB forwarders are neighbors and their positions are known, the one that has the shortest distance to $\mathbf{V_{k+1}}$ (see $\mathbf{X'}$ in Fig. 2) automatically becomes the new SCB forwarder. If there is no alternative SCB forwarder, **X** will remain the SCB forwarder of the message.
After the selection, the SCB forwarder keeps monitoring the connection status of the next destination vehicle $\mathbf{V_{k+1}}$. When the SCB forwarder (**X** or $\mathbf{X'}$) discovers that the next destination vehicle $\mathbf{V_{k+1}}$ disconnects from its preceding vehicle $\mathbf{V_k}$, the SCB forwarder automatically broadcasts the message to the next group of new destination vehicles, which starting from $\mathbf{V_{k+1}}$. This automatic operation is referred to as "SCB repetition".
4) When the SCB forwarder discovers that the next destination vehicle connects to its preceding vehicle, it drops the message. This state is referred to as "SCB termination".

Fig. 3 illustrates the detailed routing flow algorithm for the SCB scheme. Our proposed algorithm exhibits several advantages compared to previous works: First, the opposite vehicle **X** can greedily achieve an effective range with a road-level length of $2R$ to disseminate message for more destination nodes traveling on the reverse lane. Second, an automatic "SCB repetition" is performed when a broadcast group's tail ($\mathbf{V_k}$) and the next destination vehicle ($\mathbf{V_{k+1}}$) are disconnected. Third, a better eastbound vehicle can be automatically selected as the next SCB forwarder ($\mathbf{X'}$) due to the nature of wireless broadcast. We note that there is a two-hop broadcast overhead incurred in the "SCB initiation" and only one-hop broadcast overhead for that in the "SCB repetition". The "SCB repetition" is used to avoid unnecessary relay hops incurred in spares VANET.

IV. Performance Evaluation

In this section, we use a discrete event-based C++ simulator to validate the network layer performance achieved by the SCB scheme. We investigate the simulation results in terms of the broadcast overhead and the average delivery delay. For demonstration purposes, we consider the VANET topology on a 5-km straight road with one lane in each direction. Each data point on the plots is an average of $1,000,000$ samples of such cases.

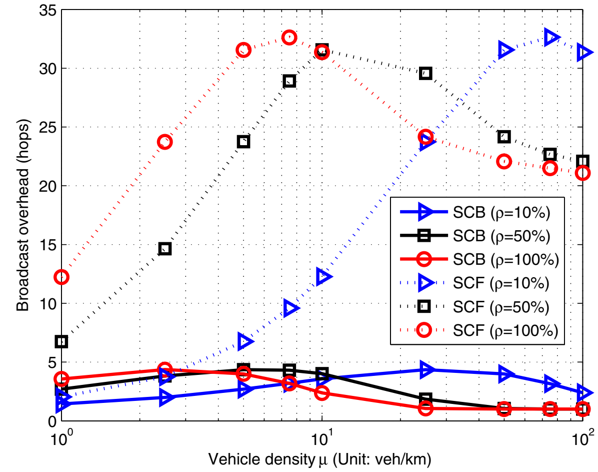
A. Simulation model

The network topology, the vehicle mobility pattern and the network communication model are described as follows: We use 250 m as the default value of DSRC transmission range R. The network performance of our proposed SCB scheme is compared to the traditional SCF scheme incurred in a 5-km straight road. For fair comparison, we assume the traditional SCF scheme can suppress all redundant retransmissions perfectly in the message broadcasting. Vehicles traveling westbound will assist store-carry-forward or store-carry-broadcast if the network on the eastbound is disconnected.

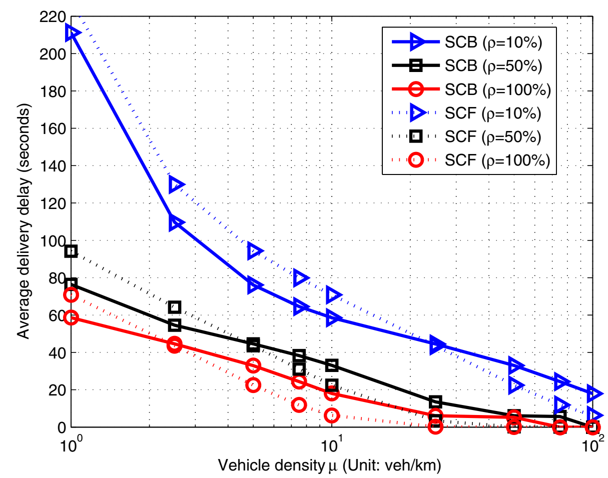
The MAC/PHY layers' spatial delay (which is typically on the order of milliseconds) is much smaller compared with the store-carry-forward temporal delay (which is typically on the order of seconds). Here, we assume ideal MAC/PHY layers where a message arriving at network layer gets transmitted right away without any contention at the MAC layer and all the transmitted messages arrive at the intended destination in an error free manner. Therefore, the spatial delay can be neglected. The default traffic density is of 10 veh/km. The speeds of the vehicles traveling eastbound and westbound are $v_e = 30$ m/s and $v_w = 30$ m/s, respectively.

B. Numerical Examples

Fig. 4 plots the broadcast overhead and the average delivery delay against vehicle density with the SCB scheme and the SCF scheme, respectively. Compared with the SCF scheme, our proposed SCB scheme can greedily achieve a $2R$ effective range and save a large amount of broadcast load. The SCB scheme outperforms the traditional SCF scheme in terms of broadcast overhead against all vehicle densities. Fig. 4 (a) shows that the number of broadcast hops with our proposed SCB scheme is significantly reduced by 40% - 85% compared to that with the SCF scheme in most cases. An interesting observation is that the number of broadcast hops incurred with both schemes are not monotonically increasing functions of vehicle density. For example, when $R = 250$ m and $\rho = 50\%$, the broadcast overhead under $\mu = 10$ veh/km is larger than other vehicle densities in both the SCF scheme and the SCB scheme. The broadcast overhead of vehicle density in a sparse VANET is significantly different from that in a well-connected VANET.



(a) The average number of hops



(b) The average delivery delay

Fig. 4. Effects of the vehicle density μ.

Fig. 4 (b) plots the average message delivery delay against the vehicle density. On one hand, the SCF scheme (i.e., using direct transmission combined with opportunistic store-carry-forward delivery) achieves good performance only when the density of VANET nodes (i.e., the DSRC devices) is high. More specifically, when the vehicle density or the DSRC penetration rate is high, the message broadcasting is mainly performed by the destination vehicles themselves via direct wireless transmission; therefore, the average delivery delay is mostly lower in the SCF scheme when $\rho \geq 50\%$ (see the dashed lines). On the other hand, in sparse VANET, *the SCB scheme outperforms the SCF scheme in both broadcast overhead as well as the average delivery delay*, which is the key result of this paper. This amazing result is explained as follows: In the SCF scheme, it could require more than one SCF forwarder for the broadcast delivery on a road segment when the vehicle's density is low, and the waiting times taken might be very long in such cases. As a result, the SCB scheme yields a better performance to the SCF scheme when the VANET is sparse.

In summary, compared to the SCF scheme, the SCB scheme always incurs less broadcast overhead. When the VANET is dense, the SCB scheme probably yields a longer delivery delay. However, the SCB scheme greatly improves both the broadcast overhead as well as delivery delay in sparse VANET. For example, at the penetration rate of 10% and the vehicle density μ of 10 veh/km, the broadcast overhead not only greatly reduced by 70% but also the average delivery delay decreased by 18% of the traditional SCF scheme. Our work indicates how to smartly apply the SCB scheme in broadcast-based applications over condition of sparse VANET.

V. CONCLUSIONS

This paper investigated the network performance that uses an opposite vehicle as a helper to disseminate safety message to vehicles traveling on its reverse lane. We propose a *Store-Carry-Broadcast* (SCB) scheme to assist message dissemination by broadcasting over a specific road segment instead of a single vehicle. In the SCB scheme, an opposite vehicle helps to disseminate the safety message to oncoming vehicles traveling on the reverse lane by broadcasting.

Extensive simulation results are presented to demonstrate that the broadcast load can be significantly reduced by $40\% - 85\%$ on a 5-km road segment when using the SCB scheme. Compared with the SCF scheme, the SCB scheme reduces a significant amount of broadcast hops without increasing much delivery delay. In sparse VANET, even the delivery delay can be greatly reduced. Our work provides output metrics on how to smartly apply the SCB scheme in broadcast-based applications over different kinds of vehicle density to balance the outcome. As a final remark, the SCB scheme is scalable and can be applied to both highway and urban road scenarios. As part of our future work, the immediate goal is to assess the interference/contention incurred by the PHY/MAC channel due to the time-varying wireless environment.

REFERENCES

[1] NHTSA, "Second Annual Report of the Crash Avoidance Metrics Partnership, April 2002 - March 2003," in *National Highway Traffic Safety Administration, DOT HS 809 663*, Jan. 2003.

[2] NHTSA, "Third Annual Report of the Crash Avoidance Metrics Partnership, April 2003-March 2004," in *National Highway Traffic Safety Administration, DOT HS 809 837*, Feb. 2005.

[3] D. Jiang, and L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments," in *IEEE Vehicular Technology Conference*, May. 2008.

[4] Society of Automotive Engineers, SAE J2735 Standard: Dedicated Short Range Communications (DSRC) Message Set Dictionary.

[5] Q. Xu, R. Sengupta, and D. Jiang, "Design and analysis of highway safety communication protocol in 5.9 GHz dedicated short range communication spectrum," *Proc. IEEE VTC*, vol. 57, no. 4, 2003, pp. 2451–2455.

[6] J. Yin, *et al.* "Performance evaluation of safety applications over dsrc vehicular ad hoc networks," in *VANET '04: Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, pages 1–9, 2004.

[7] S. Biswas, R. Tatchikou, F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," *IEEE Communications Magazine*, vol. 44, no. 1, pp. 74–82, Jan. 2006.

[8] O. K. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, and V. Sadekar, "Broadcasting in VANET," in *IEEE INFOCOM MOVE Workshop*, May 2007, pp. 7–12.

[9] S. Panichpapiboon, S. and W. Pattara-atikom, "Connectivity Requirements for Self-Organizing Traffic Information Systems," *IEEE Trans. Veh. Technol.*, vol. 57, no. 6, pp.3333 -3340, Nov. 2008.

[10] F. Bai, and B. Krishnamachari, "Spatio-temporal variations of vehicle traffic in VANETs: facts and implications," in *VANET '09: Proceedings of the sixth ACM international workshop on Vehicular Internetworking*, pages 43–52, 2009.

[11] H.-Y. Huang, *et al.*, "Performance Evaluation of SUVnet With Real-Time Traffic Data," *IEEE Trans. Veh. Technol.*, vol. 56, no. 6, pp.3381-3396, Nov. 2007.

[12] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *WMCSA '99: Proceedings of the Second IEEE Workshop on Mobile Computer Systems and Applications*, 1999, pp. 90.

[13] W. Zhao, M. Ammar, and E. Zegura, "A message ferrying approach for data delivery in sparse mobile ad hoc networks," in *MobiHoc '04: Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing*, pages 187–198, 2004.

[14] J. Zhao, and G. Cao, "VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks," *IEEE Trans. Veh. Technol.*, vol. 57, no. 3, pp.1910–1922, May 2008.

[15] T. Kitani, *et al.* "Efficient vanet-based traffic information sharing using buses on regular routes," in *IEEE Vehicular Technology Conference*, pages 3031–3036, May 2008.

[16] O. K. Tonguz, N. Wisitpongphan, and F. Bai, "DV-CAST: A distributed vehicular broadcast protocol for vehicular Ad Hoc Networks," *IEEE Wireless Communications Magazine*, vol. 17, no. 2, pp. 47–57, Apr. 2010.

[17] A. Kesting, M. Treiber, D. Helbing, Connectivity Statistics of Store-and-Forward Intervehicle Communication, *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 1, pp.172-181, Mar. 2010.

[18] F. Farnoud and S. Valaee, "Reliable broadcast of safety messages in vehicular ad hoc networks," in *IEEE INFOCOM 2009*, Apr. 2009, pp. 226–234.

[19] C. Lochert, B. Scheuermann, M. Caliskan, and M. Mauve, "The feasibility of information dissemination in vehicular ad-hoc networks," in *Fourth Annual Conference on Wireless on Demand Network Systems and Services*, Jan. 2007, pp. 92–99.

[20] K. Fall, "A delay-tolerant network architecture for challenged internets," in *SIGCOMM '03: Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications*, 2003, pp. 27–34.

[21] V. Naumov, R. Baumann, and T. Gross, "An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces," in *MobiHoc '06: Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing*, 2006, pp. 108–119.

[22] N. Wisitpongphan, F. Bai, P. Mudalige, V. Sadekar, and O. K. Tonguz, "Routing in sparse vehicular ad hoc wireless networks," *IEEE Journal on Selected Areas in Communications,*, vol. 25, no. 8, pp. 1538–1556, Oct. 2007.