VVID: A Delay Tolerant Data Dissemination Architecture for VANETs Using V2V and V2I Communication

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***Abstract*—Vehicular Ad-Hoc Networks (VANETs) have a highly dynamic network topology due to the constant and rapid movement of vehicles. Therefore, communication in VANETs is mostly affected with disruptions and delays as a result of network disconnections and partitions. Moreover, increasing the geographical coverage area for data dissemination while keeping the data-delivery delay low is a challenge. This paper first surveys the routing techniques in Delay Tolerant Networks (DTNs), and also the usage of DTN communication in VANETs. Then, the paper proposes a combined architecture of Vehicle-to-Vehicle (V2V) communication, DTN communication, and Vehicle-to-Infrastructure (V2I) communication as a large-scale data dissemination system for vehicular networks. We argue that the combined architecture enables data dissemination in a larger geographical area compared to a V2V communication model, and efficiently deals with disconnectivity and network partitions that mostly occurs in sparse networks.**

***Keywords*-VANET; DTN; V2V Communication; V2I Communication.**

I. INTRODUCTION

Wireless communication in Vehicular Ad-Hoc Networks (VANETs) enables information exchange between vehicles (V2V communication) and between vehicles and road-side infrastructure (V2I communication). Since vehicles are moving, network topology is constantly changing. Therefore, VANETs are highly dynamic and have most characteristics of Mobile Ad-Hoc Networks (MANETs) [1]. However, VANETs behave in different ways than conventional MANETs, since vehicle movements are constrained by roads and mobility patterns can be predicted to some extent. Furthermore, vehicles have different characteristics than conventional nodes in MANETs. There are numerous applications in the domain of VANETs and they can be used for different purposes like improving safety (accident avoidance, incident notification), improving driving (congestion monitoring, parking space allocation) and commercial services (business, entertainment).

Our current work, described in [2], optimizes communication in VANETs with context-based grouping mechanism based on common spatio-temporal characteristics (location, direction, speed and time) and shared interests. Each group is represented by vehicles with special responsibilities that specify which context information can be distributed inside the group and between the groups. The large-scale simulated experiments show that our context-based grouping mechanism significantly reduces the overall network traffic usage, irrelevant and redundant information flow and the processing overhead.

Our experiment on very large-scale realistic traffic data shows that despite the benefits of group-based communication, there is still a considerable number of vehicles that are far away from the crowded areas and are not in contact with other vehicles. These vehicles form single-vehicle groups and while they are disconnected from the rest of the traffic, they cannot participate in the propagation of information. These vehicles can come in contact with other vehicles later on, but they lose all the information propagated during their disconnection.

Taking advantage of temporary connections to propagate information is the focus of delay-tolerant communication. A delay-tolerant network is composed of nodes with bidirectional links together. These links may disconnect and connect as a result of mobility or failure. When two nodes are connected, they have the opportunity to exchange data. In a delay-tolerant communication system, nodes, instead of only receiving and forwarding the information, also save the information in a buffer to exchange it later on, when they come in contact with other nodes. This model is usually referred to as the *store-carry-forward* model. This characteristic of the delay-tolerant communication matches with what our group-based communication is lacking. Adding delay-tolerant communication capability helps our current system to increase its information propagation coverage to less crowded areas where there is very limited connection.

The contribution of the paper is a hybrid architecture called VVID that combines V2V, V2I, and Delay Tolerant Network (DTN) communication models in order to address the current issues in vehicular communication such as geographical scalability, information coverage in sparse networks, and smart and timely dissemination of information.

The rest of the paper is organized as follows: Section II describes the routing techniques in DTNs. In Section III, we survey recent work in the area of DTN communication in VANETs. In Section IV, we propose and describe a hybrid architecture for the efficient data dissemination in VANETs that combines V2V, V2I and DTN communication models. Section V concludes the paper.

II. Routing techniques in DTNs

As mentioned in [3], DTNs are often described with various phrases, such as eventual, partially, intermittently or transient connected networks, opportunistic networking, and space-time routing. All aforementioned terminologies are used to describe a network where end-to-end connectivity is not assumed and communication is affected with disruptions and delays as a result of network disconnections and partitions. The best example of DTNs are MANETs since nodes in such networks are usually moving and network structure is constantly changing. To overcome all mentioned shortcomings, efficient routing protocols are required. As described in [3], based on network time-evolving topology they can be categorized as routing protocols for deterministic or stochastic time-evolving networks. If all future topologies of the network are completely known or predictable then deterministic routing can be applied. There are three different approaches: (i) Space time routing; (ii) Tree approach; and (iii) Modified shortest path approach. They are all based on modeling the dynamics of the network as a space-time graph or tree and then selecting the final path depending on requirements (shortest time or minimum number of hops). In dynamic networks, where network behavior is random, future network topology is unknown and cannot be predictable. Therefore, to deliver packets from source to destination routing protocols for stochastic time-evolving networks should be applied. There are five different approaches:

- Epidemic routing-based approach [4], [5], [6], [7]: The classic example is to flood the message through the network. However, this approach is very costly and can cause network congestion. Another example is to deliver message only when source and destination are within communication range. Although this approach has minimal overhead, the delay is often very long. The best results are obtained with approaches that are trade-off between these two extreme examples. Another example is spray routing. The idea is to first unicast sprayed packet to a node close to destination and afterwards multicast traffic within the vicinity of the last-known location of the destination. Furthermore, by adding relay nodes between source and destination routing performances can be significantly improved.
- History or predication-based approach [8], [9]: In this approach the link forwarding probability is estimated based on the one-hop or end-to-end information. Nodes can interrogate each other to learn more about network topology and nodal capacity to make intelligent routing decisions. One-hop information is usually obtained by exchanging the information between two nodes when they meet. The selection of the next hop can be based on the various metrics, such as: spatial location, bandwidth, relative velocity/mobility between two nodes, vicinity of the candidate, capability of the candidate and data transmission time.
- Model based approach [10]: It is based on modeling motion patterns of mobile nodes for a better selection of relaying nodes and a determination of receiver's location without flooding the network. For example, in VANETs, the two mostly used vehicle traffic models are: highways and city traffic models.
- Node movement control-based approach [11] [12]: Controlling node mobility can improve overall system performance. There are different ways to control node mobility such as modifying nodes trajectories, using virtual mobile nodes that travel through the network and collect and deliver messages, controlling the mobility of autonomous agents, using Message Ferries (single or multiple) to provide communication services for nodes in the network, using snake and runners protocols and using DataMules.
- Coding based approach [13], [14]: Erasure coding and network coding techniques are used in this approach. In erasure coding technique an original message is encoded into a large number of coding blocks but can be decoded if smaller number of blocks is received. With this technique worst case delay can be significantly improved. In network coding, intermediate nodes, instead of simply forwarding the packets they receive, can combine some received packets and send them out as a new packet. By using this technique, packet delivery ratio could be much higher.

III. DTN communication in VANET

There are several works that apply DTN routing techniques in VANETs. Yang and Chuah [15] presented Ferry Based Interdomain Multicast Routing Scheme (FBIMR) in DTNs where ferries are used to deliver multicast messages across groups that are partitioned. They are investigating how different buffer sizes, numbers of ferries and ferry speeds impact on the delivery performance in VANETs. They concluded that by increasing the buffer size (from 1000 to 2500 packets) the delivery ratio is improved but the average delay is increased and data efficiency is decreased. Furthermore, when the packet rate is higher than 1 pkt/s delivery ratio is significantly increased and delay is decreased. With increasing the ferry speed from 15 m/s to 30 m/s delivery ratio is much higher and delay is lower.

Zhao et al. propose an infrastructure-to-vehicles data dissemination system with a buffering mechanism to increase the data dissemination coverage [16]. In their system, there are several data centers installed along a road. These data centers periodically broadcast data to the vehicles along the road. This procedure is called Data Pouring (DP). The vehicles that receive a broadcast, buffer the data and re-broadcast it in the intersections. Therefore, the system covers not only the road covered with data centers, but also the intersecting roads. The authors call this mechanism as *DP with Intersection Buffering (DP-IB)*.

VADD (Vehicle-Assisted Data Delivery in

VANET) [17] adopts the idea of store-carry-forward communication model to deal with the intermittent connectivity in VANETs. Moreover, VADD tries to predict the mobility of the vehicles in order to forward packets to the best route with the lowest data delivery delay. In VADD, vehicles store and carry the information, and forward them in the intersections. Based on the technique used for road selection at the intersections, the authors propose three different VADD protocols, and evaluate them in terms of packet-delivery ratio, data packet delay and traffic overhead.

DV-CAST [18] is a vehicular broadcast protocol that aims to address both the broadcast storm problem [19] and the disconnected network problem, in order to build a system that works efficiently in dense and sparse network areas. DV-CAST consists of three main components, namely neighbor detection, broadcast suppression, and store-carry-forward mechanisms. Neighbor detection mechanism provides the local connectivity information, and on the basis of this information, broadcast suppression mechanism or store-carry-forward mechanism is used to deal with the dense or the sparse network situations respectively. DV-CAST is evaluated only in highway scenarios and the authors are planning to extend their solution to urban environments as well.

SRD [20] is a dissemination protocol for VANETs, which employs different strategies for dense and sparse networks. SRD uses broadcast suppression techniques in dense networks, in order to avoid the broadcast storm problem. In sparse networks, SRD uses store-carry-forward communication model, in order to take advantage of the mobility of the nodes, and disseminate information in parts of the network that are geographically separated. The authors show through simulations that SRD outperforms DV-CAST [18] in terms of delivery ratio and network traffic overhead.

GeoDTN+Nav [21] is another hybrid routing protocol, which combines geographic routing and DTN forwarding. In dense or connected VANETs it uses geographic routing and routes packets in two modes: greedy and perimeter mode. It is able to estimate network partition and then improves packet delivery by switching to the DTN mode. Furthermore, authors propose Virtual Navigation Interface (VNI) that provides generalized route information in order to choose forwarders in partitioned networks. Performance evaluation shows that GeoDTN+Nav outperforms conventional geographic protocols in packet delivery ratio. However, the tradeoff is an increased delivery delay.

Bitaghsir and Hendessi [22] proposed an intelligent routing protocol for DTNs, which is similar to the GeoDTN+Nav protocol presented in [21]. For the dense or connected VANETs they both use the same geographic routing. However, for the delay tolerant forwarding the intelligent routing protocol considers other useful parameters in order to choose the best node for storing and carrying the packets. Furthermore, the genetic algorithm is used to train the DNT node evaluation system and to determine how important each parameter is in the simulation environment. Performance evaluation results show that each new generation of parameters obtained by the genetic algorithm decreases the average delivery delays and increases average delivery ratio.

GeoSpray [23] is a hybrid geographic routing protocol that takes advantages of multiple-copy and single-copy routing schemes. First it performs ”control spraying” by distributing a limited number of bundle copies to the network nodes that go closer (and/or arrive sooner) to the bundle destination. Afterwards, it switches to a forwarding scheme where it combines several control data sources to perform routing decisions. In the end, in order to improve resource utilization, it clears delivered bundles across the network nodes. Performance measurement results show that it improves the delivery probability and reduces delivery delay, comparing with the other multiple-copy and single-copy routing schemes.

While the mentioned systems use DTN communication to cover the sparse areas of network, none of these systems provide a solution for communication in geographically large vehicular networks. The simulations are done in areas with dimensions of a few kilometers, and the number of vehicles is limited to a few hundred. In order to cover geographical areas with dimensions of hundreds of kilometers, one cannot only rely on multihop V2V communication, as it increases the propagation delay, decreases the delivery ratio, and imposes heavy overhead, since the vehicles must buffer many messages, keep them for a log period and carry them for large distances.

IV. Problem Statement and Proposed Solution

In our previous work [2], we took advantage of the network of vehicles, and used this ad hoc network in order to disseminate important information among vehicles. We evaluated our mechanism using simulations. We measured parameters such as network traffic, message delivery effort and relevancy of the delivered information. However, we encountered several limitations while evaluating our mechanism using simulations. For example, it was not possible to simulate large datasets because it requires considerable amount of time, resources and computational power. Furthermore, due to the lack of a global view over the ad hoc networks, it is difficult to analyze the structure of the groups and their connectivity in the network using simulation.

Therefore, we developed a tool using Prolog for analysis of vehicular ad hoc networks. This tool receives the traces of movements of the vehicles for a certain time period as an input. On the basis of the logic of a routing protocol, our tool measures the desired network parameters. By using our tool, we can now measure the number of groups at each snapshot of the time. We also measure parameters such as the average number of vehicles in each group, the number of connections between the groups, the shortest paths between groups and the graph diameter of the network. An important contribution of this work is the ability to analyze a potentially large network with a massive number of vehicles such as a VANET. In our experiment, we use a real-life vehicular dataset [24] with 260,000 vehicles recorded over a period of 24 hours.

An important observation during the analysis of a large-scale vehicular network was the existence of many single vehicles at each snapshot. These single vehicles are the ones that are moving in sparse parts of the network, and do not have any connection to the rest of the vehicles in the network. These vehicles can later on move into the denser areas and come in contact with other vehicles. However, these vehicles lose the opportunity of obtaining some important information while they are not connected to the rest of network.

The intermittently connected nature of vehicular networks requires a communication mechanism that can tolerate disconnectivities and delays more than the conventional IP delays. This is the main motivation behind delay tolerant communication. We believe that adding delay tolerant communication capability to our system can improve the coverage of information dissemination, and prevents losing important information caused by temporary disconnectivities.

We define a set of requirement for a data dissemination system in vehicular networks:

- **Coverage of Information**: We want to disseminate information to as many vehicles as possible, in a large geographical area of hundreds of kilometers, including areas with low density of vehicles.
- **Timeliness**: Fast dissemination of urgent information in a matter of seconds. Certain types of information such as reports of an accident or a hazard must be disseminated quickly in the few-kilometer vicinity of the incident.
- **Smart Dissemination**: Disseminate information based on the interest of vehicles. Prevent the dissemination of irrelevant information.
- **Minimal infrastructure**: The system must use as less infrastructure as possible. Infrastructure costs money, and is a point of failure, in contrast with infrastructure-less systems that are mostly cheap and more fault tolerant.

We propose an architecture for data dissemination in vehicular networks to address the above requirements. The architecture uses V2V communication, DTN communication, and V2I communication, combined together to build

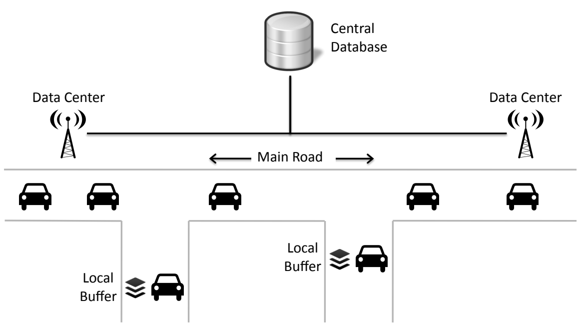


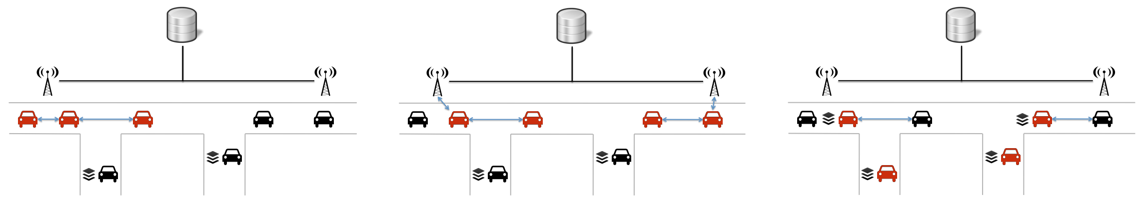
Figure 1. Main elements of the proposed architecture for data dissemination in vehicular networks.

a system that can cover a big geographical area, handle disconnections and communication disruptions, and disseminate urgent information with a small delay. Figure 1 shows a simplified overview of our proposed architecture.

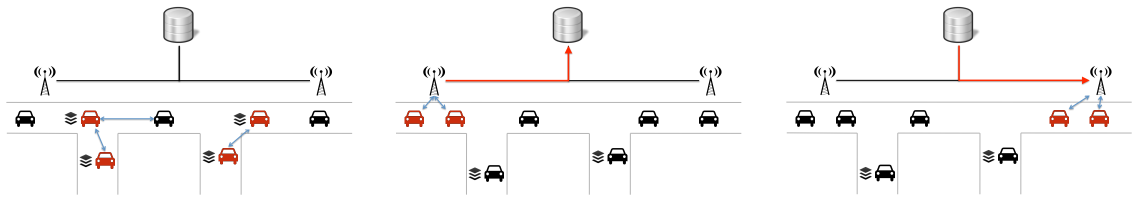
We summarize the tasks of the three communication models used in our architecture as follows:

- **V2V Group-based communication**
  - **Share urgent information**: In case of emergency, such as reporting an accident, the vehicles use V2V communication to propagate the information in their vicinity, up to a certain hop limit (e.g., 10 hops). Therefore, the urgent messages are propagated with the lowest delay in a limited geographical area (see Figure 2a).
  - **Relay other information towards data centers**: Vehicles use V2V communication to relay non-urgent information towards data centers, so that the data centers can store them in the central database (see Figure 2b).
- **DTN communication**
  - **Buffer received data**: Vehicles store the received information in their buffers (see Figure 2c), and keep the buffer up-to-date by removing the old information.
  - **Exchange in case of contact with other vehicles**: When vehicles come in contact with each other, they compare each others buffer, and exchange the information that each vehicle is missing. Thus, the vehicles that are disconnected from the network of vehicle have the chance to receive the disseminated information with a delay (see Figure 2d).
- **V2I communication**
  - **Store the data collected by vehicles**: Data centers receive the propagated information in the network of vehicles and store them in the central database (see Figure 2e).
  - **Rebroadcast in other data centers based on the area of relevance**: Depending on the context, the stored information in the database can be rebroadcasted by the other centers, in other geographical areas (see Figure 2f).

In the VVID architecture, there are several data centers installed along the main highways that are all connected to a central database. These data centers do not have to cover the whole highway. They are only placed at specific parts of the highways with major traffic flow. When the vehicles move into the covered area of a data center, they can communicate with the data center and share information. The vehicles can also communicate together and share information without using the data center, according to our multi-hop group-based data dissemination protocol [2]. Moreover, the vehicles can buffer data to form a history of the recent information they have received. In sparse parts of the network, there are not enough vehicles to form a connected network of vehicles, and therefore, multi-hop communication is not effective without a store-carry-



(a) Urgent information dissemination. (b) Relay messages towards data centers. (c) Buffering newly received messages.



(d) History exchange upon contact with other vehicles. (e) Sending messages from vehicles to data centers. (f) Broadcasting the collected data in other data centers.

Figure 2. The combination of V2V, V2I and DTN communication model used in VVID architecture.

forward technique. In the sparse areas, vehicles exchange their received information history with other vehicles upon contact, in order to disseminate information to the vehicles that are disconnected from the rest of the network.

V. Conclusion and Future Work

Efficient data dissemination in vehicular networks is a challenge. A desired dissemination system must propagate urgent information in a timely manner, cover a large geographical area, cover the sparse part of the network, and prevent the propagation of irrelevant information. We propose a hybrid architecture for efficient data dissemination in vehicular networks called VVID that combines V2V, V2I and DTN communication models, in which pure V2V communication is used to propagate urgent information, a combination of V2V and V2I is used to propagate information in a large geographical area, and DTN communication to cover the sparse parts of network.

As future work, we will evaluate the proposed system in terms of network traffic, delivery delay, and relevance of information using simulation with realistic vehicular traces.

References

[1] Y. Toor, P. Muhlethaler, and A. Laouiti, “Vehicle ad hoc networks: applications and related technical issues,” *Communications Surveys Tutorials, IEEE*, vol. 10, no. 3, pp. 74 –88, quarter 2008.

[2] K. Paridel, T. Mantadelis, A.-U.-H. Yasar, D. Preuveneers, G. Janssens, Y. Vanrompay, and Y. Berbers, “Analyzing the efficiency of context-based grouping on collaboration in vanets with large-scale simulation,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 3, pp. 1–16, May 2012.

[3] Z. Zhang, “Routing in intermittently connected mobile ad hoc networks and delay tolerant networks: overview and challenges,” *IEEE Communications Surveys Tutorials*, vol. 8, no. 1, pp. 24–37, 2006.

[4] A. Vahdat and D. Becker, “Epidemic routing for partially-connected ad hoc networks,” Duke University, Tech. Rep. CS-200006, Apr. 2000.

[5] M. Grossglauser and D. N. C. Tse, “Mobility increases the capacity of ad hoc wireless networks,” *IEEE/ACM Trans. Netw.*, vol. 10, no. 4, pp. 477–486, Aug. 2002. [Online]. Available: http://dx.doi.org/10.1109/TNET.2002.801403

[6] D. Nain, N. Petigara, and H. Balakrishnan, “Integrated routing and storage for messaging applications in mobile ad hoc networks,” *Mob. Netw. Appl.*, vol. 9, no. 6, pp. 595–604, Dec. 2004. [Online]. Available: http://dl.acm.org/citation.cfm?id=1035715.1035720

[7] F. Tchakountio and R. Ramanathan, “Tracking highly mobile endpoints,” in *Proceedings of the 4th ACM international workshop on Wireless mobile multimedia*, ser. WOWMOM ’01. New York, NY, USA: ACM, 2001, pp. 83–94. [Online]. Available: http://doi.acm.org/10.1145/605991.606003

[8] M. Musolesi, S. Hailes, and C. Mascolo, “Adaptive routing for intermittently connected mobile ad hoc networks,” in *Proceedings of the Sixth IEEE International Symposium on World of Wireless Mobile and Multimedia Networks*, ser. WOWMOM ’05. Washington, DC, USA: IEEE Computer Society, 2005, pp. 183–189. [Online]. Available: http://dx.doi.org/10.1109/WOWMOM.2005.17

[9] C.-C. Shen, G. Borkar, S. Rajagopalan, and C. Jaikaeo, “Interrogation-based relay routing for ad hoc satellite networks,” in *Global Telecommunications Conference, 2002. GLOBECOM ’02. IEEE*, vol. 3, nov. 2002, pp. 2920 – 2924 vol.3.

[10] Z. D. Chen, H. Kung, and D. Vlah, “Ad hoc relay wireless networks over moving vehicles on highways,” in *Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing*, ser. MobiHoc ’01. New York, NY, USA: ACM, 2001, pp. 247–250. [Online]. Available: http://doi.acm.org/10.1145/501449.501451

[11] S. Dolev, S. Gilbert, N. A. Lynch, E. Schiller, A. A. Shvartsman, and J. L. Welch, "Virtual mobile nodes for mobile ad hoc networks," in *in DISC04*, 2004, pp. 230–244.

[12] R. C. Shah, S. Roy, S. Jain, and W. Brunette, "Data mules: Modeling a three-tier architecture for sparse sensor networks," in *In IEEE SNPA Workshop*, 2003, pp. 30–41.

[13] S. Jain, M. Demmer, R. Patra, and K. Fall, "Using redundancy to cope with failures in a delay tolerant network," in *Proceedings of the 2005 conference on Applications, technologies, architectures, and protocols for computer communications*, ser. SIGCOMM '05. New York, NY, USA: ACM, 2005, pp. 109–120. [Online]. Available: http://doi.acm.org/10.1145/1080091.1080106

[14] Y. Wang, S. Jain, M. Martonosi, and K. Fall, "Erasure-coding based routing for opportunistic networks," in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*, ser. WDTN '05. New York, NY, USA: ACM, 2005, pp. 229–236. [Online]. Available: http://doi.acm.org/10.1145/1080139.1080140

[15] P. Yang and M. Chuah, "Efficient interdomain multicast delivery in disruption tolerant networks," in *Mobile Ad-hoc and Sensor Networks, 2008. MSN 2008. The 4th International Conference on*. IEEE, 2008, pp. 81–88.

[16] J. Zhao, Y. Zhang, and G. Cao, "Data pouring and buffering on the road: A new data dissemination paradigm for vehicular ad hoc networks," *Vehicular Technology, IEEE Transactions on*, vol. 56, no. 6, pp. 3266–3277, 2007.

[17] J. Zhao and G. Cao, "Vadd: Vehicle-assisted data delivery in vehicular ad hoc networks," *Vehicular Technology, IEEE Transactions on*, vol. 57, no. 3, pp. 1910–1922, 2008.

[18] O. Tonguz, N. Wisitpongphan, and F. Bai, "Dv-cast: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *Wireless Communications, IEEE*, vol. 17, no. 2, pp. 47–57, 2010.

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

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

[21] P.-C. Cheng, K. C. Lee, M. Gerla, and J. Härri, "Geodtn+nav: Geographic dtn routing with navigator prediction for urban vehicular environments," *Mobile Networks and Applications*, vol. 15, no. 1, pp. 61–82, 2010.

[22] S. A. Bitaghsir and F. Hendessi, "An intelligent routing protocol for delay tolerant networks using genetic algorithm," in *Smart Spaces and Next Generation Wired/Wireless Networking, 11th International Conference, NEW2AN 2011, and 4th Conference on Smart Spaces, Proceedings*, ser. Lecture Notes in Computer Science, vol. 6869. Springer, 2011, pp. 335–347.

[23] V. Soares, J. Rodrigues, and F. Farahmand, "Geospray: A geographic routing protocol for vehicular delay-tolerant networks," *Information Fusion (to appear)*, 2012.

[24] V. Naumov, R. Baumann, and T. Gross, "An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces," in *Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing*. ACM, 2006, pp. 108–119.