Accelerated Service Discovery in Vehicular Networks

Christiane Reinsch*†, Qi Wang*, Ansgar Gerlicher†, Christos Grecos*
*School of Computing, University of the West of Scotland, Paisley, Scotland
{christiane.reinsch, qi.wang, christos.grecos}@uws.ac.uk
†University of Media, Stuttgart, Germany
gerlicher@hdm-stuttgart.de

***Abstract*—Service discovery in vehicular networks has been extensively investigated in literature. Collecting and disseminating data in high mobility networks in a reliable and efficient way without exhausting network bandwidth is still challenging, due to unreliable channel access in broadcast scenarios and thus results in loss of time through resending packets. Sending delta information to reduce network traffic, grouping vehicles of same direction and velocity into clusters, performing multiplexing to access the shared wireless network channel are interesting existing approaches in vehicular networks. Discovery protocols do not profit from a combination of those techniques yet. This paper proposes the High Mobility Gossip-Konark for high mobility vehicular networks. Simulations underline the proposed design.**

Keywords*—*vehicular network; service discovery; clustering; TDMA; Gossip-Konark

I. Introduction

Vehicle-to-vehicle and vehicle-to-infrastructure networks have been considered as one of the most promising research due to their potential role in enhancing safety and efficiency of traveling. Exchanging information in a scalable, reliable, and quick way without exhausting bandwidth is a requirement for vehicular applications. An efficient and reliable communication technology is important for safety critical applications with low latency needs. For example, fast transmission of information on upcoming obstacles on the road is important for a safety critical application like *cooperative collision warning*. Live traffic updates which can be used to enhance *route guiding* in car navigation is a further example.

Based upon lower-level network protocols, *service discovery protocols* and *data dissemination protocols* are located. While service discovery protocols are typically used in mobile ad-hoc networks to locate services provided by other nodes, a data dissemination protocol is a known concept in wireless sensor networks (WSN); it allows aggregating and forwarding sensor data. Both share the common conceptual idea of *collection and distribution* of data. Current research in these protocols focuses on solutions for vehicular networks [1]. Service discovery protocols like Konark [2] originate from MANETs designed for low mobility of the network nodes. An extension to the original Konark named Gossip-Konark [3] introduces a concept of faster discovery by exchanging delta information. While the Konark service discovery protocol family is not designed for high-mobility vehicular scenarios, its promising scalability makes it worth to investigate its adaptability to vehicular networks.

This work presents a new approach to enable fast service discovery with low bandwidth usage for an increasing number of vehicles. By combining the Gossip-Konark protocol with a cluster based concept and the usage of predefined channel access mechanisms for each network node, the proposed *High Mobility Gossip-Konark* (HMGK) protocol is suitable for the high mobility world of vehicular networks:

- *Clustering:* Nodes are clustered according to their direction and velocity by the network medium access layer.
- *Changed service advertisement:* On entry into a cluster, the entering node triggers a service advertisement round.
- *Delta geocast rounds:* Service discovery information is exchanged within a geographical zone of interest through broadcast messages within a cluster. These *geocast* messages are limited by the cluster's transmission range.
- *Predefined time slots:* A collision-free multiple medium access approach restricts the sending phase of nodes to dedicated time slots in delta geocast rounds. This helps to reduce packet loss and retransmission due to collisions. During the other time slots, nodes listen to other nodes' discovery messages and update their local service databases.
- *Lightweight implementation* below or next to other network stacks like TCP/IP.

This paper is structured as follows: section II presents an overview of related work on vehicular network architectures and clustering approaches, describes service discovery search methods and the Gossip-Konark protocol. Based on the latter, a new approach for a service discovery protocol is discussed in section III. Section IV evaluates this new approach with simulations. Finally, we conclude in section V.

II. Related Work

A. Contemporary Network Architectures

Wireless vehicular ad-hoc networks like 802.11p are highly dynamic. Due to vehicles entering and leaving each other's transmission range, many problems hinder reliable communication between nodes. Shared media access is one of them. The 802.11 family uses carrier sensing multiple access with collision avoidance (CSMA/CA). Here a node performs physical carrier sensing to determine if the channel is busy or idle. The node transmits data if it detects that the channel is idle for a certain time duration, otherwise it waits a random back-off time before retrying.

To prevent collisions induced through hidden stations, virtual carrier sensing is used. Before sending data, a Request-To-Send (RTS) frame is transmitted. On receiving RTS, the receiver replies with Clear-To-Send (CTS). Any node other than the sender and the receiver defers its transmission while the sender transmits the data. For broadcasts, 802.11 does not use virtual carrier sensing as multiple CTS responses would collide. Instead, it relies on physical carrier sensing. The overall broadcast scheme degrades rather rapidly when the number of competing nodes increases within a region [4].

978-1-4799-5863-4/14/$31.00 ©2014 IEEE

Günter et al. remark in [5] that certain road scenarios and virtual carrier sensing of the 802.11 family are problematic in broadcast scenarios where hidden station problems are a major cause of data loss due collisions. To minimize collisions, they propose a cluster based approach for a medium access layer. This medium access layer clusters the vehicles using a weighted clustering algorithm based on relative distances and velocities. Further it manages medium access by assigning bandwidth to the nodes via a time division multiple access (TDMA) based schedule.

In contrast, LTE4V2X [6] is a centralized vehicular network organization based on LTE: It uses a centralized clustering mechanism where the LTE's eNodeB is responsible for organizing the decentralized vehicular 802.11p network. It keeps the 802.11p bandwidth free of cluster organization messages. On this framework, Remy et al. [7] propose a data collection and dissemination protocol and use a TDMA-based approach for message exchange during cluster building.

IEEE 1609.4 [8] defines a channel access pattern based on TDMA using the global positioning system (GPS) satellites as clock source. All nodes regularly synchronize on a dedicated control channel for service advertisement. For these short service messages, it uses a dedicated lightweight network protocol instead of TCP/IP.

B. *Service Discovery Search Methods*

There are mainly two types of service discovery search methods to obtain information about network nodes and their offered services: (i) *passive discovery* or *push model* – services or brokers announce their services, and (ii) *active discovery* or *pull model* – network nodes need information about service or brokers and send discovery messages. In general, typical protocols implement both methods. The advertised services can either be local ones or global ones offered by others.

In mobile networks with a dynamic fluctuation of nodes and a continuously reorganizing network structure, regular maintenance techniques are not sufficient for keeping information up-to date. Typically, two methods for solving this problem are used: (i) a *reactive method*, where information changes according to events in the network, e.g. the route to a server is no longer available; and (ii) a *proactive method*, where nodes maintain a consistent view by periodically exchanging update messages.

C. *Gossip-Konark Service Discovery Protocol*

The Konark service discovery protocol [1] is designed for slow mobile ad-hoc networks with non real-time usage scenarios like printing in an office in mind. It defines a service discovery protocol based on an XML-based service description, service delivery via SOAP, and service discovery search methods. The Gossip-Konark (GK) protocol, an extended form, optimizes the service discovery process by using delta messages to announce new services rather than transmitting all previously known services again. Konark's service discovery mechanism supports both push and pull modes. It provides local caches in all devices to maintain local and remote services previously announced.

To advertise and discover services, GK uses *fixed multicast addresses* to define the members of the delta multicast round. Only members that received the *initial* message of a round are part of this round. Therefore, the reception of the initial message defines who participates in the delta multicast. So members arriving later to the transmission range of the ongoing delta multicast round are not able to participate in this round. This has the advantage that new nodes do not send redundant service information, but the whole service discovery process takes longer. When the network size increases, the efficiency of discovering services degrades and the network overhead increases.

In contrast to the original protocol, GK proposes a message exchange round, which is triggered by a service request or by a service description that was not previously announced in other messages sent in the same round. Thus unnecessarily repeated delivery is suppressed by caching information and network bandwidth usage is reduced. In addition, the multicast round is scheduled by waiting a random time so that the network can avoid a storm of immediate simultaneous multicasts and has time to listen to other node's multicast rounds to learn of available services.

In the following, we focus on the algorithmic aspects of the search methods. Rather than the web-based implementation of the original Konark protocol, we use a low-overhead binary protocol which better suits vehicular use case scenarios.

III. High Mobility Gossip-Konark Protocol

The proposed *High Mobility Gossip-Konark* (HMGK) protocol is a new protocol for high mobility vehicular networks. After defining the goals of the protocol, we discuss the details of the implementation, especially the cluster based optimizations, service advertisement, and service discovery methods.

A. *Goals*

- *Efficiency:* HMGK targets a high *service discovery rate*, which is the median of all nodes' ratio of known services to the total number of available services in the network.
- *Timeliness:* A short average waiting time until other nodes' services are known. GK takes potentially longer due to random back-off wait times and not using a reactive service advertisement method on cluster entry.
- *Reliability:* The probability that a potential user of a service can communicate with the service provider in a stable way. HMGK achieves this by the mobility information.
- *Scalability:* The goal for scalability is to achieve a stable average overhead per node regardless of the number of nodes, and the overhead should be kept low, comparable to existing GK schemes.

We have a live traffic update application in mind that exchanges sensor data that can be used for route guidance.

B. *Assumptions on the Underlying Network Layer*

1. A node is able to detect when it enters a cluster.
2. A node is able to reach all other nodes in its cluster.
3. Geocast messages are limited to nodes within a cluster.
4. A dedicated node in the cluster, the *cluster head*, grants *time slots* in a TDMA schedule to the members in its cluster.
5. Nodes can move between clusters.
6. *Gateway nodes* are members of two or more clusters at the same time and pass service knowledge between the clusters.

These assumptions are for example valid for the cluster based medium access layer in [5] or a 802.11p network with cluster heads selection via LTE in [6].

C. *Service Propagation*

In cluster based networks such as developed in [5] [6] the *knowledge of the services* propagates through the network by the following mechanisms:

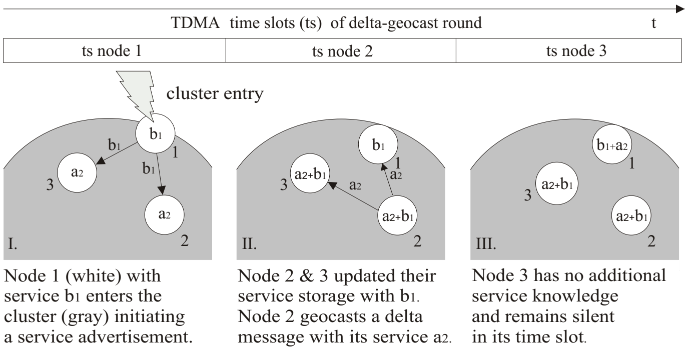

Fig. 1: Delta-geocast round triggered through service advertisement on cluster entry.

1. Nodes cache service information in the dissemination process. Services can be local to a node or provided by others.
2. A node passes information on all known services to its surrounding neighbors, the cluster members via service advertisement and service discovery messages.
3. Nodes move between clusters and spread their service knowledge within the global network.
4. A service's *lease time* guarantees actuality. As soon as the lease time expires, the service is no longer disseminated.
5. Services of other nodes have a *hop count*. The hop count is incremented on every reception of a foreign service.

Both hop count and lease time limit the distribution of services in the network in both space and time. The hop count limits the diameter of service knowledge, and a short lease time prevents old services from being requested.

D. Clustering

Derived from [5], clustering is based on the *mobility vector* M_v, which is based on the difference of velocity of the nodes:

$$M_v = \frac{1}{k_1 * N} * \sum_{i=1}^{N} dv_i \quad (1)$$

A node with similar velocity to most nodes in its neighborhood will cause less changes in the cluster membership than a node which is much faster or slower than the rest. k_1 is used for normation, so that the mobility results in a dimensionless value. N is the number of neighbors, and dv_i is the relative velocity to neighbor i. Optimal cluster head selection is made within the cluster by using a weight factor W_v:

$$W_v = w_1 \Delta_v + w_2 D_v + w_3 M_v \quad (2)$$

A node is better qualified to be a cluster head the smaller Wv is. w_1, w_2 and w_3 are weight factors with values between 0 and 1. Δ_v is the connectivity and is given as the difference to the optimum number of neighbor nodes. The distance D_v is the mean value of all distances to the neighbors.

E. Delta Geocast Rounds

We extend the *delta multicast round* concept of the original GK [3] to a novel cluster based *delta geocast round* concept. Service knowledge is distributed by single geocast message in a cluster. A single geocast message transmits only the delta information on the service knowledge of a node, see Fig. 1.

On reception of a service advertisement message, a node updates its service storage depending on the lease and hop count. It answers only if it has service information on not yet announced local and foreign services. Then it transmits a delta message containing these unannounced services only. As all other nodes receive these delta geocast messages as well, the delta geocast round ends quickly, as the service knowledge is distributed immediately to all nodes.

Delta geocast rounds are used for both *service discovery* and *service advertisement*. To prevent packet collisions during these delta geocast answers, the cluster head allocates dedicated time slots to the nodes. This enhances the quality of the service discovery process. Answering only when adding service knowledge also reduces the overall number of discovery messages. The finite character of the delta geocast round and the limitation of message exchange to a single cluster enhance the quality of the service discovery process further.

F. Service Discovery

The passive service discovery process uses a *reactive push method* on cluster entry as Fig. 1 shows. The new node entering the cluster starts a delta geocast round as initiator. For active service discovery, an *active pull* model is used to discover services in a delta geocast round. A node needing a service starts the delta geocast round as initiator. In both methods, the initiator sends a message in the first time slot to announce its own known services to the other cluster members via geocast. The delta-geocast round ends as soon as all nodes within the cluster have answered with their additionally known services.

G. Addressing

The original GK uses a *fixed multicast address* to define the members of the delta multicast round. Only members that received the *initial* message of a round are part of this round. Members arriving late to the transmission range of the ongoing delta multicast round are not able to participate initially.

In contrast, the proposed HMGK protocol does not use the fixed multicast address concept, because its cluster concept knows the receivers of the delta geocast round messages. Later arriving nodes in an already running delta geocast round can immediately participate in the ongoing round.

IV. Evaluation

This section discusses a simulation of the proposed HMGK protocol using the *OMI Traffic Simulator* [9]. The simulation takes place in the city of Ulm with a realistic urban mobility model. We compare HMGK to the original GK protocol with multicast (GKo) and geocast addresses (GKm), the latter being an intermediate step towards HMGK. The quality of a service discovery protocol can be described by a high *service discovery rate* and a low *signaling overhead*, i.e. acceptable network signaling overhead induced through service delivery messages.

The service discovery rate quantifies both efficiency and timeliness of the service discovery process. The service discovery rate is defined as the average ratio of the number of the known services of a node to the network's overall number of services. A high service discovery rate near the 100% mark describes a good distribution of service knowledge in a network. Also, a high gain towards this mark is an indicator for fast distribution of service knowledge.

The signaling overhead is defined as the average number of bytes per second sent by each node for service discovery means. An asymptotically constant amount of network signaling overhead in bytes for an increasing number of nodes is an indicator for scalability. Typically, lower numbers are better, as less network bandwidth is required for service discovery. For scalability, the values should remain constant for an increasing number of nodes.

A. Simulation Scenario

Simulation takes place on top of the cluster based medium access layer proposed in [5]. Clustering defines and limits the scope of geocast rounds and TDMA defines the time slots during geocasts. Fig. 2 shows the number of participants in different states in the network during the simulation:

a. *Active vehicles* describe the overall number of vehicles in the cluster. Nodes are generated exponentially and are entering and leaving the network during simulation.
b. *Cluster heads* are nodes that span a cluster. The number of cluster heads remains at about 25 vehicles.
c. *Cluster members* are vehicles that participate in a *single* cluster only. Their number range between 10 and 25.
d. *Gateway nodes* are members of *multiple* clusters. Their number grows at a similar rate with the number of vehicles.
e. *Undecided nodes* are not part of any cluster and are not able to communicate for a certain amount of time. Their number also range between 0 and 25.

We conducted simulations in a 4500 m $*$ 4500 m square area, see Fig. 3. The velocity varies from 30 km/h to 50 km/h (urban area). During the simulation phase of 60 s, the number of vehicles increases from 230 to 365. Cluster lifetime is about 7 s. UDP/IPv4 is used for the original and the modified Gossip-Konark protocol. HMGK uses a lightweight non TCP/IP stack (overhead 8 byte). Each node provides two randomly chosen services out of 50 with a maximum lease time of 30 s as listed in table I.

B. Simulation Results

In Fig. 4, HMGK is compared to the original GK with fixed multicast (GKo) and with geocast addressing (GKm). It compares the signaling overhead in bytes per second of the three protocols for an increasing number of active vehicles, shown on the right axis:

- GKo with fixed multicast addressing shows a linear low signaling overhead compared to geocast addressing (GKm and HMGK).
- GKm with geocast addressing shows a slightly increasing signaling overhead compared to GKo with fixed multicast addresses. That happens, because in ongoing delta geocast rounds, newly joining nodes send redundant service information as assumed in section III.

TABLE I: Simulation Parameters

Parameter	Value
Simulation area (urban)	4500 m $*$ 4500 m
Simulation time	60 s
Iteration number for each simulation case	10
Number of nodes	230 - 365
Number of services	50
Initial position	random
Vehicle speed	30-50 km/h
Advertisement interval push	2 s
Maximum lease time	30 s
Maximum Gossip-Konark RND wait time	30 s
Hop count limit	5
Weight factors w_1, w_2 and w_3	0.4, 0.3, 0.3
Propagation model	electromagnetic wave

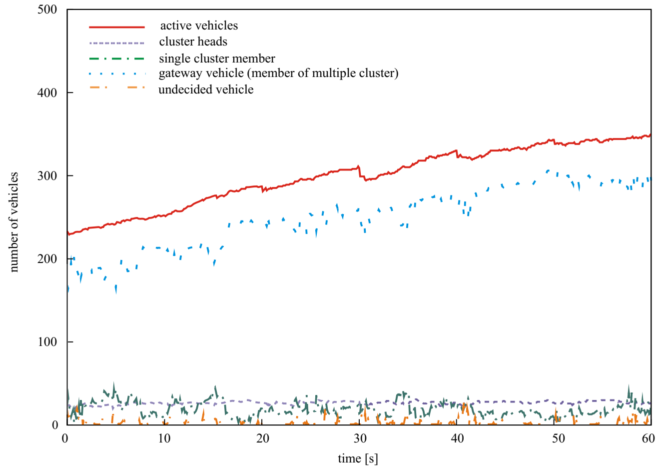

Fig. 2: Number of vehicles

- Initially, HMGK oscillates in signaling overhead due to the high mobility of the nodes entering clusters and triggering service advertisement phases. HMGK exposes an oscillating behavior because of frequent cluster changes. However, the overall trend follows the GK approaches.

HMGK, GKm and GKo show a similar good scalability behavior: the used bandwidth shows a linear trend for an increasing number of vehicles. Fig. 5 shows the service discovery rate:

- GKm with fixed multicast addresses starts slowly and exposes a slow growth. After 30 s, it reaches a service discovery rate of about 55%.
- GKo without fixed multicast addresses starts faster and reaches a discovery rate of 80% after 6 s, then it exposes a slower linear growth. It reaches 95% after 30 s.
- HMGK exposes a fast growth to 80% in 3 s and then slowly continues to approach the 99% mark.

C. Discussion of Simulation Results

Fig. 2 shows fluctuations in the number of gateway nodes and member nodes, which is an indicator for frequent cluster changes. HMGK mirrors these fluctuations in the oscillating behavior in Fig. 4. Reactive push on cluster entry, initiated through gateway nodes, increases signaling overhead because a gateway is able to participate in overlapping delta geocast rounds. HMGK uses a lightweight non TCP/IP stack to compensate the signaling overhead induced through gateway nodes entering a cluster.

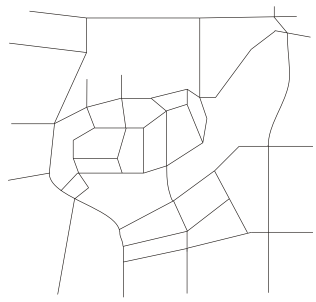

Fig. 3: Urban street layout, 4500 m * 4500 m

978-1-4799-5863-4/14/$31.00 ©2014 IEEE

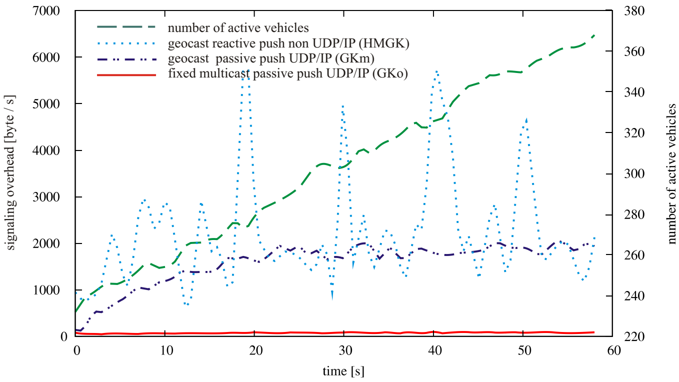

Fig. 4: Signaling overhead

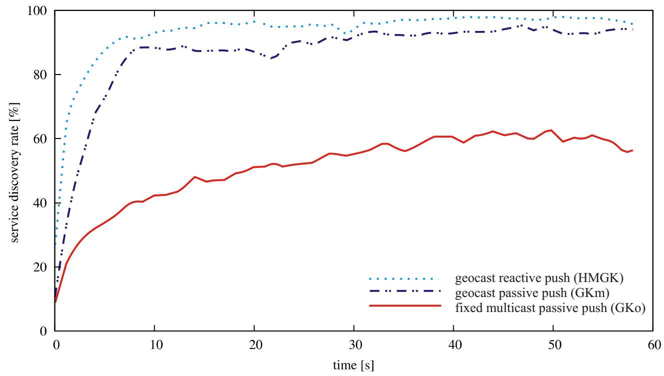

Fig. 5: Service discovery rate

At the beginning of the simulation as shown in Fig. 5, a lot of nodes remark a cluster change and initiate a discovery round. Thus the service discovery rate with reactive method (HMGK) is higher than the original and modified Gossip-Konark (GKo and GKm) approach with passive push.

The sharp increase of HMGK in Fig. 5 is caused by new nodes in unknown state entering the clusters and triggering delta geocast rounds. Also, GKo and GKm use random wait times between their delta rounds. This slows down the overall discovery process compared to the TDMA approach of HMGK.

Due to the passive push advertisement method every 2 s of GKm and GKo, the nodes need a longer time until the service knowledge has reached all nodes in the network.

A *reactive trigger on cluster entry* is the most efficient method. It is dependent on how often a cluster change occurs. This also causes a higher signaling overhead, but this increase in signaling overhead is acceptable for today's mobile networks.

V. Conclusion

This paper proposes the *High Mobility Gossip-Konark* (HMGK) protocol with the following novel improvements to the original Gossip-Konark (GKo) service discovery protocol:

1. Use of a *clustering* approach which eliminates the need of building multicast groups as in the original model, by using the mobility vector of the clustering mechanism.
2. Use of *time division multiple access* to get rid of the random wait time: A faster and more reliable delta information round is achieved through the usage of dedicated time slots for communication of the cluster members in delta *geocast* rounds. The learning time becomes predictive, organized and is no longer randomly chosen.
3. A *reactive method* is used instead of a passive push method: On cluster entry, each new node sends out a service discovery message. Service information is distributed just between members of the same mobility vector.
4. *Elimination of the fixed multicast addresses* to enable service discovery of nodes that arrive late in a discovery round: new nodes are now immediately able to collect and exchange their knowledge within the actual initiated round.
5. A *lightweight implementation* below or next to other network stacks like TCP/IP reduces the protocol overhead.

All these improvements increase the discovery rate and the timeliness of the service discovery process. Simulation results in urban area scenarios show, that the usage of cluster building and timing behavior of the network accelerates and enhances the efficiency of the service discovery process at the cost of a moderate increase in signaling overhead. For future work, we plan to extend the simulation with small cells managing the cluster organization in urban area.

References

[1] S. Mehar, S.-M. Senouci, and G. Rémy, "Dissemination protocol for heterogeneous cooperative vehicular networks," in *Wireless Days (WD), 2012 IFIP, no. 1*, 2012, pp. 1–6.

[2] S. Helal, N. Desai, V. Verma, and C. Lee, "Konark – a service discovery and delivery protocol for ad-hoc networks," in *2003 IEEE Wireless Communications and Networking, 2003. WCNC 2003, Vol. 3*, 2003, pp. 2107–2113.

[3] B.-I. Lim, K.-H. Choi, and D.-R. Shin, "An architecture for lightweight service discovery protocol in MANET," in *Computational Science - ICCS 2005, Vol. 3*, 2005, pp. 963–966.

[4] J.-M. Choi, J. So, and Y.-B. Ko, "Numerical analysis of IEEE 802.11 broadcast scheme in multihop wireless ad hoc networks," in *ICOIN*, ser. Lecture Notes in Computer Science. Springer, 2005, pp. 1–10.

[5] Y. Günter, B. Wiegel, and H. P. Großmann, "Medium access concept for VANETs based on clustering," in *IEEE 66th Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007*, 2007, pp. 2189–2193.

[6] G. Remy, S.-M. Senouci, F. Jan, and Y. Gourhant, "LTE4V2X: LTE for a centralized VANET organization," in *2011 IEEE Global Telecommunications Conference (GLOBECOM 2011)*, 2011, pp. 1–6.

[7] ——, "LTE4V2X - impact of high mobility in highway scenarios," in *Global Information Infrastructure Symposium (GIIS)*, 2011, pp. 1–7.

[8] Q. Chen, D. Jiang, and L. Delgrossi, "IEEE 1609.4 DSRC multi-channel operations and its implications on vehicle safety communications," in *2009 IEEE Vehicular Networking Conference (VNC)*, Oct 2009, pp. 1–8.

[9] "The OMI Traffic Simulator." [Online]. Available: www.uni-ulm.de/en/in/institute-of-information-resource-management/research/inter-vehicle-communication/traffic-simulator.html?print=1