Enhanced Spring Clustering in VANETs with Obstruction Considerations

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***Abstract*—Vehicular networks have a diverse range of applications that varies from safety applications to comfort applications. Clustering in VANETs is of crucial importance for addressing the scalability problems of VANETs. The performance of communication protocols is greatly influenced by the existence of vehicles in the neighborhood; vehicles acting as obstacles change the behavior of protocols when different density, speed and car sizes scenarios are investigated since reliable communication range among vehicles varies. The *Enhanced Spring Clustering* is a new distributed clustering protocol, which forms stable clusters based on vehicle dimensions. An investigation of the performance of the *Enhanced Spring Clustering* in realistic environments is presented confirming its superiority over the examined, competing clustering protocol.**

I. Introduction

To enhance the safety of drivers, to provide a comfortable driving environment and to contribute to fuel economy, messages for different purposes need to be sent to vehicles through intervehicle communications. An important issue for a VANET system is the broadcast storm problem that is present in high density environments. Of the solutions proposed for scaling down networks with large numbers of nodes, network clustering is among the most investigated for mobile ad hoc networks [1], [2], for sensor ad hoc networks [3], [4], and for vehicular ad hoc networks [5], [6], [7].

The basic idea is that of grouping network nodes that are in physical proximity. The subsequent backbone uses the induced hierarchy to form a communication infrastructure that is functional in providing desirable properties such as minimizing communication overhead, choosing data aggregation points, increasing the probability of aggregating redundant data, and so on.

In Figure 1 an accident happens in a highway at a point in time where traffic is intense, and we also suppose that the vehicles approaching the place of accident are able to "detect" the accident. The accident results in the highway being blocked. In such a situation density of vehicles increases dramatically and a clustering method is necessary for the proper dissemination of safety messages.

Spring Clustering which was introduced [5] forms stable clusters based on force directed algorithms. The proposed method uses a mobility metric based on "forces" applied between nodes according to their current and their future position and their relative mobility. The clusterhead change of Spring Clustering is relatively low and the overall performance of the method is stable to different topologies and transmission ranges.

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Though, that protocol suffered from the fact that it treated vehicles only as senders, relays and receivers and not as part of the environmental obstacles. A number of V2V measurements have been performed to study the statistical properties of V2V propagation channels [8], [9]. In [10] it is observed that in rush hours the received signal strength gets worse compared to no traffic hours for the same part of an open road. These observed differences can only be related to other vehicles obstructing Line-of-Sight (LOS), since the system parameters remained the same during the measurements. Recent work reported in [11], [12] showed that vehicles as obstacles have an important influence on the behavior of a VANET system.

Highly realistic channel models [13] gives results that are in very good agreement with the real world. However, these models are computationally too expensive making them impractical for extensive simulation studies. In [11] it is shown that the vehicles as obstacle have a significant impact on LOS obstruction in both the dense and sparse vehicular networks, therefore, shadow fading effects due to other vehicles are very important to be included in channel models.

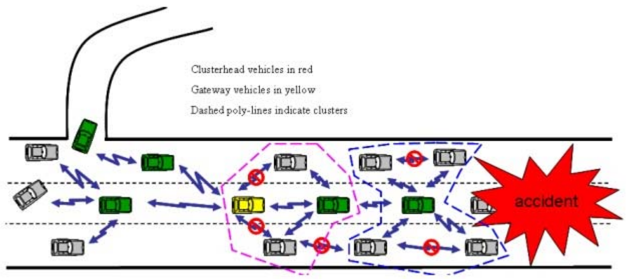

Fig. 1. Illustration of an example where vehicle clustering is important.

A. Contributions

The present work presents a new clustering protocol for VANETs, namely the *Enhanced Spring Clustering* protocol with incorporates vehicles Several scenarios are investigated in a highway environment where traces are created by out mobility model. Mobility traces can also be loaded by SUMO [14] in order to investigate more complex scenarios. The reliable communication range that is produced by simple diffraction models, depends on cars density, velocity and car's dimensions changing the overall performance of communication protocols. The article makes the following contributions:

- Proposes the Enhanced Spring Clustering protocol by incorporating vehicle heights in clusterhead election.
- Evaluates the performance of Enhanced Spring Clustering under different network characteristics (density, velocity, car dimensions, placement of antenna).
- Incorporates vehicles as obstacles in a VANET simulator.
- Calculates reliable communication range for every pair of nodes at every instance based on the diffraction caused by obstructing vehicles.

II. Spring Clustering

Spring Clustering is based on force-directed algorithms. The force-directed assign forces among the set of edges and the set of nodes in a network. The most straightforward method is to assign forces as if the edges were springs and the nodes were electrically charged particles. The entire graph is then simulated as if it were a physical system. The forces are applied to the nodes, pulling them closer together or pushing them further apart.

Vehicles periodically broadcast beacon messages. The beacon message consists of node Identifier (ID), node location, speed vector, total force F, state and timestamp. Node location is used in order to calculate the distance between the nodes. Each node i using the information of the beacon messages calculates the pairwise relative force F_{relij} for every neighbor j using the Coulomb law.

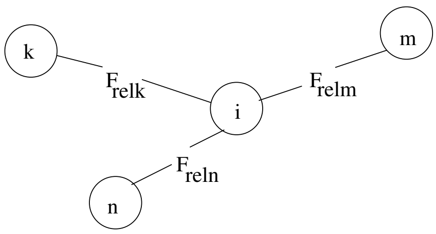

Fig. 2. Relative forces applied to vehicle i.

Vehicles that move to the same direction or towards each other apply positive forces while vehicles moving away apply negative forces. The node with the highest positive force, in its one hop neighborhood, is elected clusterhead.

A. *Special role of vehicles – Enhanced Spring Clustering*

In the Spring Clustering method, vehicles that follow predefined routes or keep a relative constant velocity are favored to become clusterheads due to being more stable in terms of mobility. Except from being best candidates based on mobility criteria, tall vehicles like trucks and busses suffer less from vehicle obstruction. The maximum distance over which communication is still possible is significantly larger than when neither the transmitter nor the receiver is a tall vehicle. Selecting tall vehicles as clusterheads increases the probability that members stay for a longer time connected to them. The correct choice of the clusterhead is very important for the stability of the method, the cluster lifetime and the overhead involved in forming and maintaining these clusters. In Sp-Cl parameter q_i [5] is used to favour vehicles (according to their paths, driver habits, etc.) to become clusterheads, strengthening positive forces applied to these nodes and weakening negative ones.

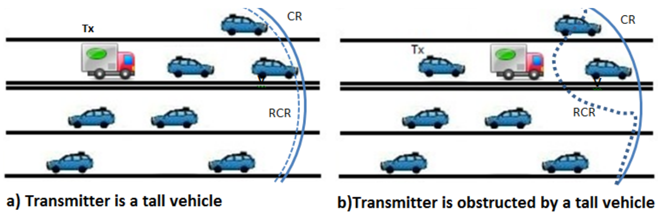

Fig. 3. Reliable communication range is significantly larger for tall vehicles

In Figure 3 when a tall vehicle is the transmitter the reliable communication range (RCR) is almost the same to the ideal communication range (CR) when vehicle obstruction is neglected (a). When a car being a transmitter is obstructed by a tall vehicle the reliable communication range is strongly affected in the area around the obstacle (b). Taking this characteristics in mind we incorporate height as a criterion for the clusterhead election. When a node i finds itself to be among the tallest in its one-hop neighborhood then parameter q_i is used to favor it become a clusterhead. In order for this new criterion to be incorporated to our method an extra byte is added to the beacon message. The beacon message now except from node Identifier (ID), node location, speed vector, total force F, state and timestamp, also includes vehicle height or, for simplicity, a vehicle category in terms of tall or short. The new method is called Enhanced Spring Clustering (ESC).

III. Network Model

A. *VANET diffraction models*

Several propagation models applied in VANET research can be used to quantify the impact of vehicles as obstacles on the electromagnetic wave propagation. Geometry based deterministic models are used to analyze particular situations. A highly realistic model, based on optical ray tracing was proposed in [13]. The accuracy of the model is achieved at the expense of high computational complexity and location-specific modelling. There are simplified geometry based deterministic models [11], [15]. In particular, the research work proposed by Boban et al. in [11] derive a simplified geometry-based deterministic propagation model, in which the effect of vehicles as obstacles on signal/wave propagation is isolated and quantified while the effect of other static obstacles (i.e., buildings, overpasses, etc.) is not considered. The research work in [11] focuses on vehicles as obstacles by systematically quantifying their impact on line of sight and consequently on the received signal power.

For the received power level, the impact of obstacles can be represented by signal attenuation. This increase in attenuation is due to the diffraction of the electromagnetic waves. To model vehicles obstructing the line of sight, we use the knife-edge attenuation model.

If only one obstacle is located between Tx and Rx, then the single knife-edge model described in ITU-R recommendation [16] is used. If the direct line-of-sight is obstructed by a single knife-edge type of obstacle, we use the following diffraction parameter v:

$$\nu = h * \sqrt{\frac{2}{\lambda} * (\frac{1}{d1} + \frac{1}{d2})} \quad (1)$$

where h is the height of the top of the obstacle above the straight line joining the two ends of the path. If the height is below this line, h is negative. d1 and d2 are distances of the two ends of the path from the top of the obstacle.

The diffraction loss can be closely approximated by

$$A_d = \begin{cases} 6.02 + 9.00\nu + 1.65\nu^2 & \text{if } -0.8 \leq \nu < 0 \\ 6.02 + 9.11\nu - 1.27\nu^2 & \text{if } 0 \leq \nu < 2.4 \\ 12.953 + 20\log\nu & \text{if } \nu \geq 2.4 \end{cases}$$

When two or more vehicles exist between the transmitter and receiver horizons then diffraction loss is calculated using the Epstein-Peterson method [17]. The diffraction loss is taken as the sum of the individual knife edges according to Figure 4.

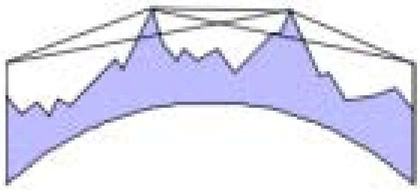

Fig. 4. Epstein-Peterson method.

B. Placement of antennas

The antennas in vehicles are usually mounted either on the roof or inside the vehicle (e.g., under the windshield, in rear view mirror, on a seat or near a dashboard). The effect of the antenna placement in vehicles is significant [12]. The differences in the cumulative link packet error rates are until $25 - 30$ % depending on the antenna locations under LOS conditions. This is due to the fact that the height of the antenna affects the attenuation caused by obstructing vehicles. In order to make the environment more realistic we incorporated the placement of the antenna in our simulation environment. The model used has cars that either have the antenna mounted on the roof at a height of 10cm above the car or under windshield at 50cm below the height of the car.

C. Obstructed Line Of Sight

To separate the Line Of Sight from OLOS (Obstructed Line Of Sight) and NLOS (No Line Of Sight) cases at every time instance we use a simple algorithm to detect intersections between line segments. Every node in the simulator is represented as a rectangle occupying an area of the simulation space. For every pair of nodes we draw a line connecting their antennas. If the line intersects with one rectangle then the single knife model is used to calculate the additional loss. In case when the line crosses more than one rectangle then the Epstein-Peterson model is used.

In our simulator the vehicles are produced by our generator. In case where the vehicles are coming from a mobility simulator like SUMO the same procedure is used. When the cars are blocked by a building then we have a NLOS situation. In this case it is impossible to make a straight line between the two vehicle positions without being obstructed by a building and the transmission range is usually limited to a few meters. In the scenarios investigated in this research we are focused to find the impact of vehicles in reliable transmission range and for that reason when we have NLOS situation we consider the range to be zero.

When the line connecting two vehicles is obstructed by another car then we say that we have a OLOS situation (Obstructed line of sight). According to the number of obstructing vehicles the corresponding diffraction method is used to calculate the power loss and determine the reliable communication range among the nodes. OLOS situations are very important since vehicles, due to diffraction, have different communication ranges with their neighbors according to their environment. The implementation of the simulator that incorporates the vehicles as obstacles is presented in simple steps in the next section.

IV. VANET IMPLEMENTATION

- Every vehicle and building is modelled as a rectangle with proportional dimensions.
- For every instance and pair of nodes a straight line is drawn from antenna position of each TX vehicle to the antenna position of each RX Vehicle.
- If the line does not touch any other rectangle, TX/RX has LOS.
- If the line passes through one rectangle at least , LOS is obstructed by a vehicle or by a building, the two cases can easily be distinguished by using the geographical information available in simulator or by the sizes of the obstacles.
- Once the propagation condition is identified, the simulator can simply use the relevant model to calculate the power loss.
- According to power loss the reliable communication range (RCR) between each pair of nodes for every time instance is calculated.
- Enhanced Spring Clustering performance is evaluated according to reliable communication ranges.
- Enhanced Spring Clustering is evaluated according to proper clusterhead election.

V. SIMULATION AND PERFORMANCE EVALUATION

A simulation study was conducted to evaluate the performance of our protocol using a custom simulator. The competitor is the Spring Clustering method [5], since it is shown there that it is superior to many current high-performance VANET clustering protocols. In our simulation, we consider various road traffic and network data parameters. The simulation environment (Figure 5) is a two direction, 3-lane per direction highway with a turn in order to evaluate the performance of the scheme. All nodes are equipped with GPS receivers and On Board Units (OBU). Location information of all vehicles/nodes, needed for the clustering algorithm is collected with the help of GPS receivers. The only communications paths available are via the ad-hoc network and there is no other communication infrastructure. The power of the antenna is P_{tx} = 18dBm and the communication frequency f is 5.9 Ghz.

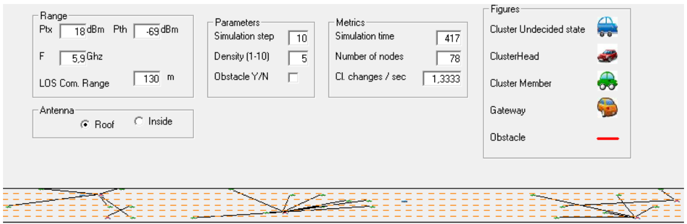

Fig. 5. Simulation environment.

The communication range of the vehicles is calculated according to Table I. In our simulations, we use a minimum sensitivity (P_{th}) of -69 dBm which gives a transmission range of 130 for LOS.

Data Rate (Mb/sec)	*Minimum Sensitivity(dBm)*
3	-85
4.5	-84
6	-82
9	-80
12	-77
18	-70
24	-69
27	-67

TABLE I
MINIMUM SENSITIVITY IN RECEIVER ANTENNA ACCORDING TO DATA RATE.

In a situation of OLOS the reliable communication range (RCR) is calculated according to:

$$P_{tx} - FPLS - A_d < P_{th} \quad (2)$$

where the value of d is the biggest one that makes Equation 2 true and FPLS is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. FPLS is calculated according to Equation 3

$$FPLS = 92.45 + 20 * Log(RCR) + 20 * Log(f). \quad (3)$$

A. *The mobility model*

The arrival rate of the vehicles follows the Poison process with parameter λ. The speed assigned to the vehicles is according to the lane it chooses to follow according to Table II.

Lane	*Speed km/h*
1	80
2	100
3	120

TABLE II
SPEED PER LANE FOR BOTH DIRECTIONS.

The density of the vehicles depends on parameter λ. The number of vehicles per lane is between (2 -15 v/km/Lane) depending on the speed being used and the value of parameter λ according to Table III.

Parameter λ	ν*/km/lane*
3	8-15
5	5-9
7	3-6

TABLE III
DENSITY PER LANE.

B. *Evaluation criteria*

In order to evaluate the effect of vehicles as obstacles in the performance of Enhanced Spring Clustering method we conducted several simulation scenarios. The vehicles that enter the simulation are of 25 % trucks with average height of 2.5 meters, when the rest of the cars have height of 1.5 meters. The placement of the antenna is in the roof of the car at a height of 10 decimeters above the car or inside the car at a height of 0.5 meter below the roof of the vehicle(e.g., 2 meters for trucks and 1 meter for cars).

We measured how density of the cars affects the performance of our method when cars are treated as obstacles. We observed that the placement of the antenna inside the car gives a big difference in reliable communication range and to the overall performance of the clustering.

We also measured how the ratio of tall vehicles affect the reliable communication range. We investigated how favoring tall vehicles to become clusterheads (Enhanced Spring Clustering) in a realistic scenario, where reliable communication range is computed among each pair of nodes, makes the method more stable.

Clustering performance. In order to evaluate the effect of OLOS in stability of our clustering method we created scenarios of different car densities. The results clearly indicate that vehicles as obstacles have a significant impact on the formation of clusters in a typical VANET clustering method compared to those acquired when we neglect this phenomenon. This is due to the fact that the medium contention is overestimated in models that do not include vehicles as obstacles in the calculation and that the reliable communication range is considered to be significantly bigger than in the real world (Figure 6).

Also, the number of mean cluster change (Figure 7) and the average lifetime (Figure 8) of clusters are also affected when the cars are treated as obstacles in the simulation.

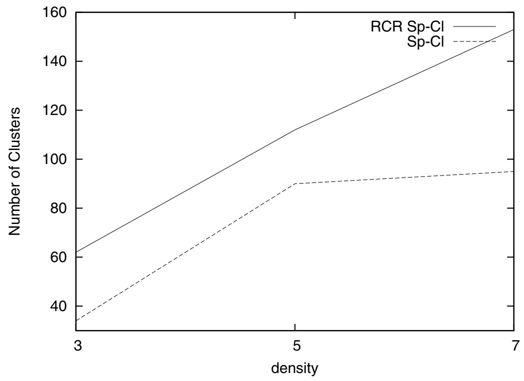

Fig. 6. Impact of OLOS in average number of clusters

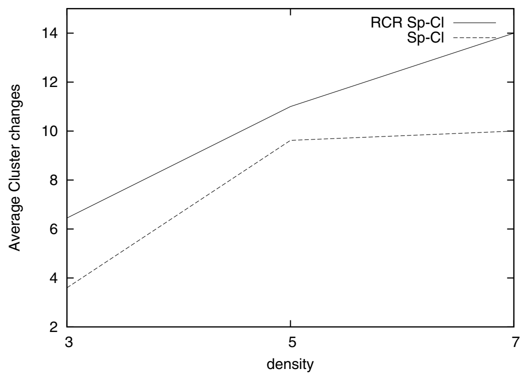

Fig. 7. OLOS influence average cluster changes / vehicle

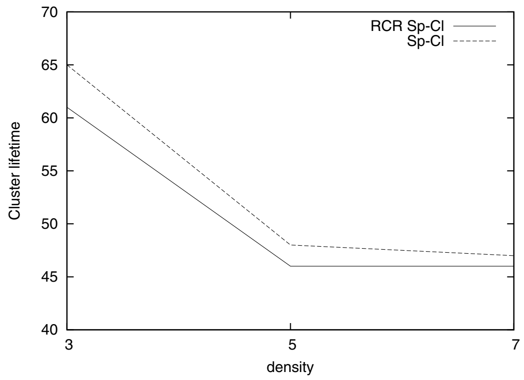

Fig. 8. Average cluster lifetime under OLOS

The obstructing vehicles decrease reliable communication range which leads to what is called a lost link event, causing the presence of often transition events to vehicles. Nodes that loose communication with their neighbors, due to attenuation by obstructing vehicles, leave their clusters, join other nearby ones or form new clusters degrading the overall performance of the clustering method.

Antenna placement. The placement of the antenna inside the car or at the roof of it, plays a significant role at the attenuation caused by the obstructing cars. Table IV shows mean reliable communication range for different antenna placements. When the antenna in mounted inside the car it is under windshield at 50cm below the height of the car and the cars enter the simulation with parameter $\lambda = 5$.

placement	RCR	A_d
roof	80	10
inside	45	25

TABLE IV
ANTENNA PLACEMENT.

Tall vehicles. When the percentage of the tall vehicles (trucks) increases the mean reliable communication range is strongly affected. This is due to the fact that the attenuation caused by this vehicles when in the middle of the communication range of other cars is bigger. The reliable communication range, when there is an obstacle between transmitter and receiver, drops to almost half of the static communication range when 50 % of the cars are tall vehicles and increases again as this percentage increases.

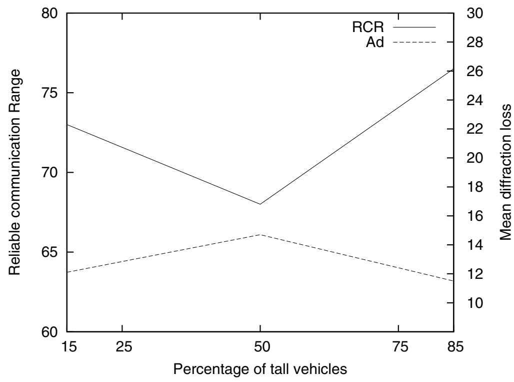

Fig. 9. Number of Trucks (tall vehicles) influence reliable communication range

Special role of vehicles. In order to evaluate how favoring tall vehicles to become clusterheads affects Enhanced Spring Clustering, we created scenarios of different vehicle distributions. The average density is of $\lambda = 5$, the percentage of tall vehicles is 15% and all vehicles move to the same direction. The simulations showed that favoring tall vehicles in a realistic scenario, where reliable communication range is computed among each pair of nodes, makes Enhanced Spring Clustering more stable (Figure 10).

This is due to the fact that tall vehicles have biggest average reliable communication range (RCR) with their neighbors compared to short vehicles, since the latter are more vulnerable to diffraction losses. This phenomenon doesn't show up when obstructing vehicles are neglected, since in that situation all

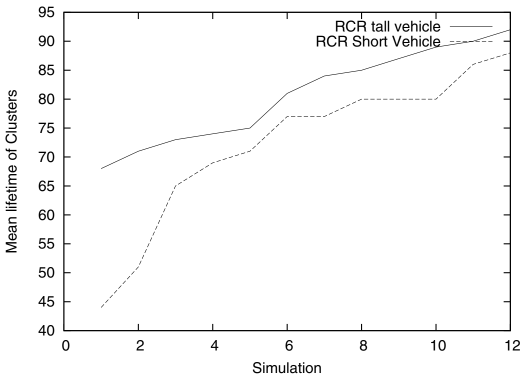

Fig. 10. Tall vehicles play significant role in Spring Clustering.

vehicles have static communication ranges (CR) with all their neighbors, independently of their height or other obstructing cars (Figure 11).

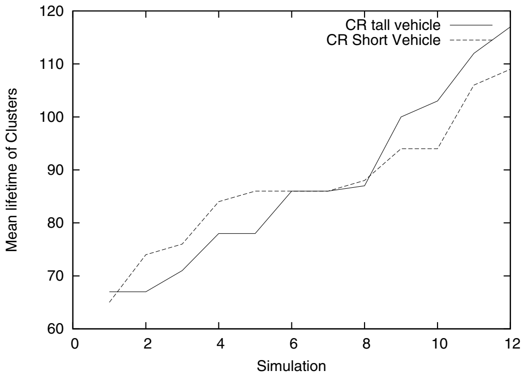

Fig. 11. Height of clusterhead does not affect Spring Clustering's performance, when static communication range is used

Average number of clusters and mean cluster transitions per vehicles also follow the same patterns, showing that Enhanced Spring Clustering which assigns special roles to tall vehicles is more stable than the initial one.

VI. Conclusions

Treating vehicles as obstacles, has a significant impact on the reliable communication range. Reliable communication range that is calculated for every pair of nodes for every time instance according to the attenuation caused by obstructing vehicles is exploited for the design of a new VANET clustering protocol, namely the Enhanced Spring Clustering algorithm. It is shown that significant benefits are observed when the height of vehicles is taken into account when electing clusterheads; this feature is in the heart of the Enhanced Spring Clustering. This behavior is observed only in a realistic scenario where reliable communication range is computed among each pair of nodes instead of using a static communication range for all pairs of vehicles. The incorporation of heights in clusterhead election makes the method more stable. More sophisticated approaches where the relative heights of vehicles according to the heights of all its neighbors are under investigation in order to further stabilize Spring Clustering.

References

[1] A. Amis, R. Prakash, T. Vuong, and H. D.T., "Max-min d-cluster formation in wireless ad hoc networks." in *Proceedings of the IEEE Conference on Computer Communications (INFOCOM)*, 2000, pp. 32–41.

[2] C. Tselikis, S. Mitropoulos, N. Komninos, and C. Douligeris, "Degree-based clustering algorithms for wireless ad hoc networks under attack," *IEEE Communications Letters*, vol. 16, no. 5, pp. 619–621, 2012.

[3] N. Dimokas, D. Katsaros, and Y. Manolopoulos, "Energy-efficient distributed clustering in wireless sensor networks," *Journal of Parallel and Distributed Computing*, vol. 70, no. 4, pp. 371–383, 2010.

[4] O. Younis, M. Krunz, and S. Ramasubramanian, "Node clustering in wireless sensor networks: Recent developments and deployment challenges," *IEEE Network magazine*, vol. 20, no. 3, pp. 20–25, 2006.

[5] L. Maglaras and D. Katsaros, "Distributed clustering in vehicular networks," in *Proceedings of the International Workshop on Vehicular Communications and Networking (VECON)*, 2012.

[6] M. Ni, Z. Zhong, and D. Zhao, "MPBC: A mobility prediction-based clustering scheme for ad hoc networks," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 9, pp. 4549–4559, 2011.

[7] S. Vodopivec, J. Bester, and A. Kos, "A survey on clustering algorithms for vehicular ad-hoc networks," in *Proceedings of the International Conference on Telecommunications and Signal Processing (TSP)*, 2012, pp. 52–56.

[8] I. Sen and D. W. Matolak, "Vehicle channel models for the 5-GHz band," *IEEE Transactions on Intelligent Transportation Systems*, vol. 9, no. 2, pp. 235–245, 2008.

[9] A. Paier, J. Karedal, N. Czink, C. Dumard, T. Zemen, F. Tufvesson, A. F. Molisch, and C. F. Mecklenbräuker, "Characterization of vehicle-to-vehicle radio channels from measurements at $5.2GHz$," *Wireless Personal Communications*, vol. 50, no. 1, pp. 19–32, 2009.

[10] J. S. Otto, F. E. Bustamante, and R. A. Berry, "Down the block and around the corner: The impact of radio propagation on inter-vehicle wireless communication," in *Proceedings of the IEEE International Conference on Distributed Computing Systems (ICDCS)*, 2009, pp. 605–614.

[11] M. Boban, T. T. V. Vinhoza, M. Ferreira, J. Barros, and O. K. Tonguz, "Impact of vehicles as obstacles in vehicular ad hoc networks," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 1, pp. 15–28, 2011.

[12] S. Kaul, K. Ramachandran, P. Shankar, S. Oh, M. Gruteser, I. Seskar, and T. Nadeem, "Effect of antenna placement and diversity on vehicular network communications," in *Proceedings of the IEEE Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)*, 2007, pp. 112–121.

[13] J. Maurer, T. Fugen, T. Schafer, and W. Wiesbeck, "A new inter-vehicle communications (IVC) channel model," in *Proceedings of the IEEE Vehicular Technology Conference – Fall*, vol. 1, 2004, pp. 9–13.

[14] D. Krajzewicz, G. Hertkorn, C. Rossel, and P. Wagner, "Sumo (simulation of urban mobility); an open-source traffic simulation," *4th Middle East Symposium on Simulation and Modelling (MESM)*, pp. 183–187, 2002.

[15] J. B. H. Ledy, P. A. M., H. B., and V. R., "A semi-deterministic channel model for VANETs simulations," *International Journal of Vehicular Technology*, 2011.

[16] D. Krajzewicz, G. Hertkorn, C. Rossel, and P. Wagner, "Propagation by diffraction." *International Telecommunication Union Radiocommunication Sector, Geneva, Recommendation P.526*, 2007.

[17] J. Epstein and P. D. W., "An experimental study of wave propagation at $850MC$," *Proceedings of the IRE*, vol. 41, no. 5, pp. 595–611, 1953.