A Survey on Clustering Algorithms for Vehicular Ad-Hoc Networks

Samo Vodopivec, Janez Bešter, and Andrej Kos

***Abstract*—In the past few years we are witnessing increased interest in the research of inter-vehicle communications. Due to vehicle specific movement patterns new algorithms and solutions have to be developed. Clustering is a technique for grouping nodes in geographical vicinity together, making the network more robust and scalable. This article presents an overview of proposed clustering algorithms for use in vehicular ad-hoc network (VANET). We survey different clustering algorithms and highlight their objectives, features, specialties and possible limitations. Varieties of different approaches have been observed whereby typically each one focuses on different performance metric. Diverse are also complexities of algorithms and the input data they use and relay on. With this article, readers can have a more thorough and delicate understanding of ad hoc clustering and the research trends in this area. The most promising solutions show the significance of reused concepts from the field of social network analysis.**

***Keywords*—ad-hoc networking, clustering, mobile, VANET, vehicular**

I. Introduction

In the last decade ad-hoc networking is a very attractive topic among researchers. Numerous articles have been published with new solution proposals, extensions and improvements to existing methods and algorithm, theoretical analysis of the problems involved, simulation results etc. Let it be wired or wireless, focused on stationary, mobile, sensor or vehicular ad-hoc network, they all profited from it.

Clustering has been already extensively researched in the past. One of the most frequently mentioned clustering algorithms, MOBIC [1], focused on mobile ad-hoc networks was published in 2001 but his roots are even a few years older. Due to the fact that mobile and sensor ad-hoc networks gained research popularity a few years before vehicular ad-hoc networks (VANETs) a lot more articles with topic on clustering have been published from those specific fields. Consequently different surveys and overviews have already been written with the intention to give a brief overview and present this research field in mobile and sensor ad-hoc networks [2] – [4]. But to our best knowledge this is the first survey focused on the VANET clustering.

Manuscript received February 21, 2012. The work was supported by the Ministry of Higher Education, Science and Technology of Slovenia, the Slovenian Research Agency, and the Competence Center Open Communications Platform.

S. Vodopivec is with the University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia (phone: +386 1 4768 140; fax: +386 1 4768 732; e-mail: samo.vodopivec@fe.uni-lj.si).

J. Bešter is with the University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia (e-mail: janez.bester@fe.uni-lj.si).

A. Kos is with the University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia (e-mail: andrej.kos@fe.uni-lj.si).

II. What is Clustering?

Clustering is a process of grouping nodes (mobile devices, sensors, vehicles etc.) in geographical vicinity together according to some rules. These rules differ from one algorithm to another and are the key factor to build stable clusters.

Clusters are a sort of virtual groups that have been formed by a clustering algorithm. Each cluster has at least one cluster head (CH) that is selected or elected by other cluster nodes (CN). Usually each CN can be elected to a CH but in some algorithms different type of nodes have better prepositions to become one. For example, CN with additional 3G network connectivity can be better suited for CH than their non-3G neighbors. Some algorithms also define other types of nodes, e.g. cluster relays etc.

Cluster size varies from one cluster to another and is mostly dependant on the transmission range of the wireless communication device that a node uses. But some clustering algorithms also implement other filters that prevent some nodes to join a cluster. One of the most frequently used is the movement direction filter – a CN does not join a cluster whose CH moves in its opposite direction.

Due to radio signal propagation laws the ideal and intuitively most natural cluster is represented as a circle with CH in the center and CN around it as shown in Fig. 1. Each CN can communicate directly with its CH and two different CNs can communicate with each other either directly or, in the worst case, via their CH. Such clusters are named 1-hop clusters as every two nodes can communicate in 1 hop or less with each other. But 1-hop is chosen only for simplicity reasons – solutions, although rare, exists that use more than 1 hop and those clusters are named n-hop clusters.

Cluster stability is an important goal that clustering algorithms try to achieve and is considered as a measure of performance of a clustering algorithm. Stability is important

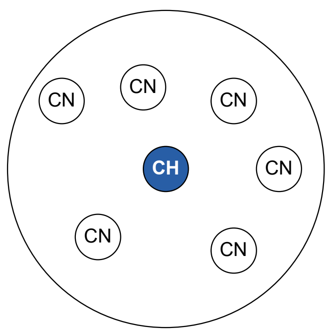

Fig. 1. Ideal cluster with cluster head in the center and cluster nodes around.

for the upper and lower communication layers whose performances can improve noticeably with the help of clusters. It allows spatial reuse of resources, simplifies routing and makes the network appear more stable in the view of each CN. Cluster stability can be defined in different ways but most frequently used are the number of CH changes and number of a CN changing its CH. By carefully selecting the CH and nodes that form a particular cluster their stability can be dramatically improved.

III. Clustering Solutions

Table I represents a short comparison of the different clustering solutions presented in this document. It is intended as a overview of different parameters in use. For additional information see algorithm description in this document and/or original reference document. The short descriptions do not present how each algorithm works but outlines the algorithm specifics that are promising, new or uncommon compared to other.

MOBIC [1] is a clustering algorithm designed for mobilead-hoc networks (MANET) that works also in VANETs. It is based on the Lowest-ID algorithm but uses signal power levels mobility metric derived from successive receptions instead. Its performance is moderate as it is not designed and/or optimized for VANET but it is frequently used for comparison with other VANET clustering solutions.

In [5] authors present a direction based clustering algorithm suitable for urban area. Clusters are formed before road intersections and are based on the predicted traveling path. The vehicles that take the same turn in the intersection are clustered together. The vehicle location, destination and route must be known in advance for algorithm to work, so good digital maps and accurate location information (GPS or equivalent) are needed. Knowing the destination could be a problem through as users usually do not use navigation system for known routes.

The AMACAD [6] algorithm tries to accurately follow the mobility pattern of the network and prolong the cluster lifetime and reduce the global overhead. As the vehicle destination is the key factor in the algorithm the metric for clustering decision takes into account current location, speed and both relative and final destination. There might be a problem with knowing the final destination a priori as drivers usually do not use navigation system for known routes. Cluster size is variable according to vehicle density, speed and required minimum bandwidth or QoS where parameters can be predefined or provided on the fly from vehicle sensors and application profiles.

One of the rare multi-hop clustering solutions is presented in [7] and uses relative mobility between multi-hop distanced vehicles as the metric. It is calculated from beacon (radio propagation) delay on each node, aggregated and propagated back to other nodes. Cluster head becomes the node with smallest aggregate mobility value. Cluster stability is also increased with postponing the re-clustering process for some time when two cluster heads come in range. This avoids unnecessary re-clustering when, for example, two cluster heads from different direction meet for a few seconds. Simulation runs with freeway and Manhattan mobility model and 2, 3 and 5 hop clustering depth show that multi-hop clustering prolongs the cluster head and member duration and lowers the number of cluster head changes.

Forming stable, long living clusters for reliable communication is also the goal of [8]. They propose clustering with a complex metric which takes into account the density of connection graph, traffic conditions and link quality. The later is derived from node movement prediction, available from GPS or other similar system, and signal to noise ratio (SNR) of the link. The group membership lifetime counter is used to provide a method to check reliability of a node before attaching it to cluster, avoiding unnecessary re-clustering. The algorithm behaves differently in sparse and dense parts of the network, where in the first case the communication is more unreliable than in the other.

VWCA [9] is a solution that uses a complex metric to increase cluster stability and connectivity. The metric is calculated from distrust value, number of neighbors based on dynamic transmission range and vehicle movement direction. Apart from that the paper also proposes an algorithm to monitor behavior of vehicles in the network to detect abnormal vehicles in the system and a technique for adaptive allocation of transmission range. The later enables compensation for the variable node density.

Modified DMAC [10] is an attempt to improve the original Basagni's Distributed and Mobility-Adaptive Clustering algorithm. Its goal is to increase the cluster stability by avoiding re-clustering when groups of vehicles move in the different directions. For this to work each node needs to know its current location, velocity and moving direction, which is received from GPS or similar service. The parameter freshness is the additional safety factor for unneeded re-clustering. Freshness is calculated between two nodes receiving their hello messages and their movement direction data. It designates the expected time nodes will be able to communicate and avoids re-clustering in cases when direction is the same but communication time will be short, for example when overtaking. The time to live (TTL) parameter in messages also allows the construction of multi-hop clusters, which is an uncommon but highly welcome feature.

In [11] authors present novel approach using Affinity Propagation algorithm for clustering that minimizes both relative mobility and distance between cluster head and nodes. It is a distributed mobility-based clustering algorithm focused on cluster stability, where stability is defined by long cluster head duration, long cluster member duration and low rate of cluster head change. The affinity metric consists of responsibility and availability parameters shared between neighboring nodes. Responsibility indicates how well suited is one node to become exemplar and availability indicates the desire of a node to become an exemplar. Each node then independently makes the decision about clustering. Due to used similarity function that evaluates current and future node positions, where data is provided from GPS service, the stability is further increased as the vehicles moving in opposite direction are not clustered together.

Cluster overlapping, that is one of the very rare features in clustering, is present in RMAC [12]. This is achieved with dual state nodes, where a cluster head of one cluster is a member node of one or more another clusters. Using this

TABLE I
CLUSTERING ALGORITHMS OVERVIEW

	Metic	Radius	Location	Cluster density	Simulation	Published
MOBIC [1]	radio power levels	1-hop		not mentioned	ns-2	2001
Kayis [17]	speed	1-hop	GPS	speed dependant	not simulated	2007
Su [15]	direction	1-hop	GPS	traffic direction dependant	Matlab	2007
MDMAC	speed, location, direction	N-hop	GPS	traffic direction dependant	JiST/SWANS++, VanetMobiSim	2008
Rawshedh [20]	speed, location, direction	1-hop	GPS	speed dependant	own C testbed	2009
Maslekar [19]	location, direction	1-hop	GPS, maps	not mentioned	NCTUns	2009
RMAC [12]	speed, location, direction	1-hop	GPS	clusters overlap, node can be a part of many clusters	ns-2	2009
APROVE [11]	distance and speed proximity	1-hop	GPS	traffic direction dependant	ns-2	2009
DBC [8]	connection graph density, link quality, traffic conditions, node reputation and movement prediction	1-hop	GPS	two operating modes depending on density	JiST/SWANS++, VanetMobiSim	2009
Almalag [21]	lane with most traffic	1-hop	detailed maps, lane recognition	radio propagation specific	ns-3	2010
Wang [16]	separately vehicle density, link quality and sustainability	1-hop	GPS	not mentioned	MOVE, ns2	2010
ALM [18]	variance in relative mobility	1-hop	GPS	not mentioned	SUMO, SIDE/SMURPH	2010
VWCA [9]	distrust, direction	1-hop	known location	adjustable	Matlab	2010
AMACAD [6]	location, speed, relative and final destination	1-hop	known destination, GPS, road statistics	adjustable	own Java testbed	2011
HCA [10]	radio range	4-hop		radio propagation specific	OMNeT++, SUMO	2011
ASPIRE [13]	network criticality	1-hop		not mentioned	ns-2	2011
Zhang [7]	relative mobility (radio propagation)	N-hop		not mentioned	ns-2	2011
Maslekar [5]	direction	1-hop	GPS, maps	traffic direction dependant	NCTUns	2011
Rawashdeh [22]	speed, location, direction	1-hop	known location	speed dependant, different speed overlapping	own C testbed	2012

feature the communication between clusters is routed through cluster heads only. All cluster member nodes are within communication range of their cluster head however not all nodes in range of cluster head necessarily belong to that cluster. The algorithm considers speed, location and direction of travel as the clustering metric where the data is provided via GPS or similar service. Zone of interest, a circular area centered on a node and limited by some predefined radius, is also introduced as an extension to the communication range.

ASPIRE [13] is based on local network criticality and clustering in a distributed manner. Its ultimate aim is to create large clusters and provide high network connectivity. It is willing to sacrifice low cluster head durations or high number of cluster head changes for example, if those changes result in better connectivity. The nature of criticality metric, which captures the robustness of the network, inherently has memory. Cluster stability is also increased with postponing the re-clustering process for some time when two cluster heads come in range. This avoids unnecessary re-clustering when, for example, two cluster heads from different direction meet for a few seconds.

Apart from other clustering algorithms HCA [14], a fast randomized clustering and scheduling algorithm, follows a different concept. Instead of carefully selecting the initial cluster heads and creating the most stable clusters it tries to construct clusters as fast as possible and leaving the cluster optimization to the maintenance phase. The only limiting factor in cluster size is radio propagation and even this is avoided by implementing 2-hop clustering. It does not use any location services because of its simplicity. Consequently it does not support any optimizations related to node movement pattern that could improve cluster stability and cluster head duration.

The solution presented in [15] is focused on improving the MAC layer by clustering vehicles and allowing the cluster head to coordinate their access to shared medium. Its goal is to guarantee real-time delivery of safety messages and make non real-time V2V communication more efficient. The implemented clustering algorithm uses vehicle movement direction as the clustering metric so it relies on some location service such as GPS or similar.

Authors of [16] compare passive clustering solutions with three different metrics: vehicle density, link quality and link sustainability. Vehicle density is measured with counting received beacon frames from neighboring vehicles. Link quality is expressed in terms of bi-directional transmission quality of link and link expiration time is used as link sustainability metric. For calculating the metrics a vehicle uses by GPS or other location service provided position and movement parameters. The algorithm defines that the first node claiming to become a cluster head will dominate the rest of nodes within its communication range. Also a single cluster has at least two gateway nodes for intra-cluster communication.

In [17] reliability in inter-vehicle communication is assured by clustering formation in a special way. Vehicular nodes in the cluster are identified and assigned by specific task. Clustering formation protocol is based upon the passive clustering model that requires no protocol specific packets or signals for clustering purposes. All the clustering dependent information is piggybacked in the packet header. The algorithm divides the vehicles in different speed groups and these speed groups are then divided into clustering groups. Each vehicle knows its cluster group from its speed and vehicles inside a cluster group form a cluster by selecting a cluster head etc. Vehicles from different clustering groups in geographical vicinity are separated with usage of different Code Division Multiple Access orthogonal codes. This allows overlapping clusters to share the medium more efficiently.

Authors of [18] present a new beacon-based clustering algorithm aimed at prolonging the cluster lifetime in VANETs. It uses a new aggregate local mobility (ALM) criterion as a metric to decide upon cluster re-organization. ALM weight represents the ratio between two successive takes of the distance between a node and its neighbor. The position information used in calculations is derived from GPS or similar location service. A node-s ALM is the variance of the relative mobility over all neighbors of a node. The intuition behind this scheme is that a node with less variance relative to its surroundings is a better (more stable) choice for a cluster head.

Another clustering solution, presented in [19], proposes a direction based clustering algorithm for data dissemination. In this approach a packet is forwarded to vehicles only if they are moving along the same direction. It is assumed that each participating vehicle knows its own position using GPS and is equipped with digital maps to determine its traveling direction. The map is split up into different regions with each region having its own unique id. On a given lane four clusters will be formed, depending on the predicted direction of vehicles in intersections. The first vehicle entering a region in a particular direction is considered as cluster head. Each cluster head is able to determine the density of vehicles in its cluster and support the traffic management system with this data, thus helping to manage the traffic effectively.

The paper [20] proposes a new approach for grouping vehicles, showing similar mobility patterns, in a cluster and at the same time tries to minimize the total number of created clusters. A new multi-metric cluster head election technique has also been developed. Only the vehicles with similar moving pattern - speed and traveling direction - are grouped together in a cluster. This creates more stable clusters with longer lifetime. The mobility data is provided from GPS or similar location service. Difference in transmission range for service and control channel is also taken in account in the algorithm. Cluster formation is always originated from the slowest vehicle or the vehicle whose members belong to other clusters.

The method for selecting a cluster head based on the lane where most of the traffic will flow is presented in [21]. It is focused on urban usage scenario and based on the assumption that each vehicle knows its exact lane on the road via a lane detection system and an in-depth digital street map that includes lane information. Detecting the lane is a challenging task where supplementary systems such as visual lane recognition, LIDAR etc. will have to be used.

In [22] a speed-overlapped clustering method for highways is presented. It defines stable and unstable clustering neighbors depending on their speed and relative movement direction. Clusters are formed only in between stable neighbors and clustering can be initiated only from the fastest or slowest vehicle. As many other solution this one also depends on the location service. Another weakness is a single vehicle left out alone when its speed deviates too much from the speed of other vehicles in the cluster.

IV. OPEN CHALLENGES

Generally two different approaches for vehicle clustering can be observed. The first is location service dependant and uses information such as speed, location and movement direction for clustering. The other one uses different measurable parameters such as radio propagation, relative mobility, vehicle density, connectivity etc., but not many of them together. Both approaches are based on mathematically measurable parameters and ignore sociological aspects [23] such as why the driver is on the go and in what context the drive is taking place so there is plenty of room for new proposals. Research on clustering solutions with combined metrics should also be done. Location services might not provide the needed accuracy everywhere or will not be available at all [24], [25] so more work is needed on location independent clustering solutions. Providing highly accurate digital maps that are needed by some solutions presents a challenging task and could slow down the deployment so pros and cons of map based solutions should be researched.

Many of the presented algorithms use metrics derived from the same input parameters where among them location and radio signal strength are the most popular. Focus should be put on evaluation of those common metrics to highlight the most useful ones, merge similar ones etc. This would allow researchers to concentrate their work on extending and optimizing the most prospective ones. Self learning or self adapting metrics should also be studied.

Presented clustering algorithms are optimized for different goals e.g. cluster stability, fast cluster formation, overhead minimization etc. where the most popular among them is definitely the cluster stability. More research effort should be put in defining and ranking the goals that clusters and clustering algorithms should try to achieve. We believe that one of the most important goals is providing good quality of experience (QoE) for safety and emergency services which is closely related to excellent connectivity, communication reliability and limited maximum latency. An analysis like the [26] focused on clustering would be highly welcome. More work should also be put in multi-hop and multi-homing capable clustering solutions.

For performance evaluations of clustering algorithms common metrics are used such as cluster head stability, cluster head changes, average cluster stability etc. These terms are quite generic so their scientific definition and explanation with VANET specifics is needed to provide consistency between different scientific researches. Their correlations and effects between them should also be analyzed and presented.

Fair comparison of different clustering solutions is a hard task due to non-existent standard testing procedures and scenarios so more work and standardization is needed in this area. Different network simulators should be evaluated and presented with all the relevant parameters including MAC, radio signal range, packet size, bit rate etc. Test scenarios with different vehicle movement patterns should be provided.

It is important to define the methodology, test parameters and evaluation methods for ranking the measurements. Traces of real vehicular movement for all participating vehicles in a limited geographical area would be the first step towards the real life testing of the technology. Defined and standardized testing procedures would be also useful in other VANET areas, for example in VANET routing protocols.

V. Conclusion

This article has surveyed most interesting and promising clustering algorithms for VANETs. The article serves as a guide to promote understanding and proliferation of ideas with highlighting the open challenges and issues. The field of VANET clustering is already a hot research topic and we believe it will continue to stay there for another few years. We expect increased research on the topic of more advanced clustering algorithms, evaluation and comparison of clustering algorithms, preparation of simulation data and scenarios etc. One of the bigger challenges remaining are real-life experiments outside laboratory walls.

Our group is focusing the research on clustering solution that exploits sociological patterns of vehicular movement. We are working on identifying common attributes and parameters to use them as metrics as we believe that cluster lifetime and vehicle connectivity can be further improved that way.

References

[1] P. Basu. (2011, April). A Mobility Based Metric for Clustering in Mobile Ad Hoc Networks. International Conference on Distributed Computing Systems Workshop. [Online]. pp. 413-418. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=918738

[2] J. Y. Yu. (2005, first quarter). A Survey of Clustering Schemes for Mobile Ad Hoc Networks. IEEE Communications Surveys [Online]. pp. 32-47. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1423333

[3] A. A. Abbasi. (2007, June). A survey on clustering algorithms for wireless sensor networks. ScienceDirect Computer Communications [Online]. pp. 2826-2841. Available: http://www.sciencedirect.com/science/article/pii/S0140366407002162

[4] S. Chinara. (2009, May). A Survey on One-Hop Clustering Algorithms in Mobile Ad Hoc Networks. Journal of Network and Systems Management [Online]. pp. 183-207. Available: http://www.springerlink.com/content/d793q24794033l05/

[5] N. Maslekar. (2011, July). A stable clustering algorithm for efficiency applications in VANETs. 7th International Wireless Communications and Mobile Computing Conference (IWCMC). [Online]. pp. 1188 – 1193. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5982709

[6] M.M.C. Morales. (2011, September). An Adaptable Mobility-Aware Clustering Algorithm in vehicular networks. 13th Asia-Pacific Network Operations and Management Symposium (APNOMS). [Online]. pp. 1-6. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=6077004

[7] Z. Zhang. (2011). A novel multi-hop clustering scheme for vehicular ad-hoc networks. Proceedings of the 9th ACM international symposium on Mobility management and wireless access. [Online]. pp. 19-26. Available: http://dl.acm.org/citation.cfm?id=2069135

[8] S. Kuklinski. (2009, April). Density based clustering algorithm for VANETs. TridentCom 2009. [Online]. pp 1-6. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4976256

[9] A. Daeinabi. (2010, July). VWCA: An efficient clustering algorithm in vehicular ad hoc networks. Journal of Network and Computer Applications. [Online]. pp. 207-222. Available: http://www.sciencedirect.com/science/article/pii/S1084804510001384

[10] G. Wolny. (2008, October). Modified DMAC Clustering Algorithm for VANETs. International Conference on Systems and Networks Communications, 2008. [Online]. pp. 268-273. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4693682

[11] C. Shea. (2009, November). Mobility-Based Clustering in VANETs Using Affinity Propagation. Global Telecommunications Conference, 2009. [Online]. pp. 1-6. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5425236

[12] R. T. Goonewardene. (2009, June). Robust mobility adaptive clustering scheme with support for geographic routing for vehicular ad hoc networks. Intelligent Transport Systems. [Online]. pp. 148-158. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5071784

[13] A. Koulakezian. (2011, August). ASPIRE: Adaptive Service Provider Infrastructure for VANETs. Master thesis at The University of Toronto. [Online]. Available: http://hdl.handle.net/1807/29581

[14] E. Dror. (2011, June). Fast randomized algorithm for hierarchical clustering in Vehicular Ad-Hoc Networks. The 10th IFIP Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net). [Online]. pp. 1-8. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5970488

[15] H. Su. (2007, November). Clustering-Based Multichannel MAC Protocols for QoS Provisionings Over Vehicular Ad Hoc Networks. IEEE Transactions on Vehicular Technology. [Online]. pp. 3309-3323. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4357429

[16] S.S. Wang. (2010, May). Performance evaluation of passive clustering based techniques for inter-vehicle communications. Wireless and Optical Communications Conference (WOCC). [Online]. pp. 1-5. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5510657

[17] O. Kayis. (2007, September). Clustering Formation for Inter-Vehicle Communication. Intelligent Transportation Systems Conference, 2007. [Online]. pp. 636-641. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4357779

[18] E. Souza. (2010, May). A New Aggregate Local Mobility (ALM) Clustering Algorithm for VANETs. International Conference on Communications (ICC). [Online]. pp. 1-5. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5501789

[19] N. Maslekar. (2009, October). Direction based clustering algorithm for data dissemination in vehicular networks. Vehicular Networking Conference. [Online]. pp. 1-6. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5416361

[20] Z. Y. Rawshdeh. (2009, September). Toward Strongley Connected Clustering Structure in Vehicular Ad Hoc Networks. Vehicular Technology Conference Fall (VTC 2009-Fall). [Online]. pp. 1-5. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5378799

[21] M.S. Almalag. (2010, October). Using traffic flow for cluster formation in vehicular ad-hoc networks. Conference on Local Computer Networks (LCN). [Online]. pp. 631-636. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5735785

[22] Z. Y. Rawashdeh. (2012, January). A novel algorithm to form stable clusters in vehicular ad hoc networks on highways. EURASIP Journal on Wireless Communications and Networking. [Online]. Available: http://jwcn.eurasipjournals.com/content/2012/1/15

[23] D. Katsaros. (2010, November/December). Social Network Analysis Concepts in the Design of Wireless Ad Hoc Network Protocols. IEEE Communications Society. [Online]. pp. 23-29. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5634439

[24] A. Štern, "Space weather effects on intelligent transportation systems," in *Proc. 18th International Symposium on Electronics in Traffic, ISEP 2010*, Ljubljana, Slovenia, 2010

[25] A. Štern, "Vulnerability of GPS receivers to solar radio bursts," in *Proc. Electrotechnical and Computer Science Conference ERK 2011*, Portorož, Slovenia, 2011

[26] M. Boban. (2008, November). What is the Best Achievable QoS for Unicast Routing in VANET?. IEEE GLOBECOM Workshops. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4746654