HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

Gaurav Kumar Singh

# Clustering in Vehicular Networks

Seminararbeit im Fach Informatik

29. Januar 2018

Please cite as:
Gaurav Kumar Singh, “Clustering in Vehicular Networks,” Seminar Thesis (Seminararbeit), Heinz Nixdorf Institute, Paderborn University, Germany, January 2018.

Distributed Embedded Systems (CCS Labs)
Heinz Nixdorf Institute, Paderborn University, Germany

Fürstenallee 11 · 33102 Paderborn · Germany

http://www.ccs-labs.org/

# Clustering in Vehicular Networks

Seminararbeit im Fach Informatik

vorgelegt von


**Gaurav Kumar Singh**

geb. am 10. November 1989
in Danapur, India

angefertigt in der Fachgruppe

**Distributed Embedded Systems**
**(CCS Labs)**

**Heinz Nixdorf Institut**
**Universität Paderborn**


| | |
|---|---|
| Betreuer: | **Jun.-Prof. Dr.-Ing. Christoph Sommer** |
| | **Prof. Dr.-Ing. habil. Falko Dressler** |
| Gutachter: | **Jun.-Prof. Dr.-Ing. Christoph Sommer** |
| | **Prof. Dr.-Ing. habil. Falko Dressler** |


Abgabe der Arbeit: **29. Januar 2018**

## Erklärung

Ich versichere, dass ich die Arbeit ohne fremde Hilfe und ohne Benutzung anderer als der angegebenen Quellen angefertigt habe und dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen hat und von dieser als Teil einer Prüfungsleistung angenommen wurde.
Alle Ausführungen, die wörtlich oder sinngemäß übernommen wurden, sind als solche gekennzeichnet.

## Declaration

I declare that the work is entirely my own and was produced with no assistance from third parties.
I certify that the work has not been submitted in the same or any similar form for assessment to any other examining body and all references, direct and indirect, are indicated as such and have been cited accordingly.

(Gaurav Kumar Singh)
Paderborn, 29. Januar 2018

# Abstract

This thesis captures an overview of ideas, techniques, results and future possibilities of clustering in vehicular networks. Clustering is a technique to group nodes based on a selected criteria which defines certain level of similarities among the nodes. Grouping the nodes together in such a way helps define or design a set of functionalities applicable only to the group and can be applied to the smaller sub-set. In a Vehicular Ad Hoc Network (VANET) environment, clustering presents possibilities to group vehicles based on a parameter of interest and help to reduce the network traffic, achieve better network throughput and effective information dissemination.

This thesis presents a set of parameter and respective methodologies based on them for VANETs as a comparative study. First chapter presents the motivation behind the clustering and outlines the basic set of problems which is presented by vehicular networks which the researches are trying to address. The second chapter describes the methodologies grouping them based on the main parameters used for clustering. The third chapter introduces the evaluation techniques along with some important metrics used to compare the effectiveness of the algorithms and analysis of results. Finally the thesis captures some ideas which will give an overview of the future research work on this topic.

# Contents

# Chapter 1

# Introduction

Along with the advancement in wireless networking in the past two decades, there has been a lot of research targeted towards developing techniques to minimize the network overhead and achieve effectiveness within the system. A special class of wireless network, Wireless Ad Hoc Network (WANET), which allowed nodes to communicate with each other without the need of special infrastructure such as bridges and routers was developed. WANET lead to use of wireless communication for special applications with needs of distributed control. Shortly, use of Mobile Ad Hoc Network (MANET) increased which allowed continuous movement of the nodes. This was followed by use of wireless networking among vehicles to create Vehicular Ad Hoc Network (VANET) which allows communication of various parameters among vehicles focussed towards applications for safety and cooperative driving. The use of wireless networks in various domains has lead to a lot of research focussed towards improvements and optimization which are often valid for all domains.

Clustering in wireless networks involves grouping nodes together which are geographically close to each other based on a certain set of parameters. Parameter selection for clustering depends mostly on the type of application which would use the clustered network. In VANETs, clustering of vehicles into groups provides a basis for limiting the networking overhead and interference by efficiently defining the target nodes for communication and designing filters to limit the traffic. Due to the possibility of selecting huge range of parameters, numerous solutions have been proposed which target various scenarios in the VANETs. Vodopivec, Bešter, and Kos [1] and Bali, Kumar, and Rodrigues [2] presents a detailed overview of research work in this field in past years. In the following sections we would look at some of the important terminologies to create a general overview of clustering in VANET and help us discuss and understand the methodologies better.

## 1.1 Terminologies

In this section, we look at some of the common terminologies used widely across the methodologies for clustering in VANETs.

- **Cluster Member (CM):** All the nodes which become part of the cluster and participate in the communication within the cluster.
- **Cluster Head (CH):** Each cluster is supposed to elect one of the CM to act as the CH based on some rules. It is possible for any CM to be elected as the CH but some of the algorithms may apply special requirements for a CM to be elected to ensure stability of the cluster. The responsibilities of a CH may vary but in general it is responsible for the maintenance of the cluster (addition and removal of nodes) and communication with the external nodes (other CHs and Road Side Unit (RSU)s).
- `HELLO` **Message:** Also referred as `DISCOVER`, is the first message sent by a vehicle to identify the presence of existing cluster. This is mostly a broadcast frame.
- `INVITE` **Message:** This is transmitted by a CH or a CM in respond to a received `HELLO` message if the requesting vehicle is found fit to join the cluster.

Figure 1.1 shows a typical cluster organization with one CH and multiple CMs.

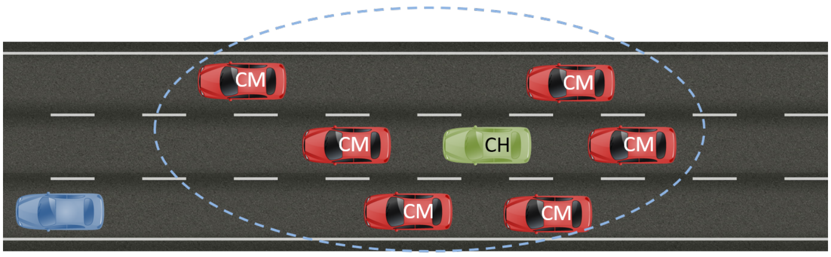



**Figure 1.1** – Typical VANET cluster

# Chapter 2

# Clustering methodologies

In order to achieve a robust and effective communication in the high mobility environment, VANET applications use various parameters to cluster the nodes into meaningful sub-groups based on the application requirement. This leads to a wide range of clustering methodologies which define applications specific algorithms useful for respective application or a generic algorithm with possibility to handle different requirements. In this chapter, we discuss some of the common parameters used individually or in combination with each other to define thresholds for vehicles to join cluster and cluster head selection along with some methodologies which uses them for clustering.

## 2.1 Clustering Parameters

Parameters play an important role to build stable cluster effectively which can be used to perform the application specific communication with minimal overhead. Some of the common parameters which are used by the algorithms to form basis for threshold calculation are summarized in Table 2.1.

| Parameter | Description |
|---|---|
| Vehicular mobility | This is the most common parameter used in the algorithms. Mobility of the vehicles are measured in terms of relative velocity and average velocity over time of the vehicle |

**Table 2.1** – Common clustering parameters

| Parameter | Description |
|---|---|
| Direction of the travel | In many cases, information to be shared between vehicles only has relevance if the vehicles share the same path and direction. This knowledge can be used by the algorithms for forming trajectory tables or assigning Road IDs to compare directions and route |
| Destination | Used by applications which give importance to route taken by the vehicles to provide longer stable cluster |
| Density | Mostly used to differentiate sparse and dense networks and define different communication model to ensure reliable communication in both scenarios |
| Unique ID | Simplest clustering parameter. Commonly used to identify and cluster vehicles requiring multi-hop reliable communication |
| Location | Used with application requiring location based information such as intersection support and congestion avoidance |

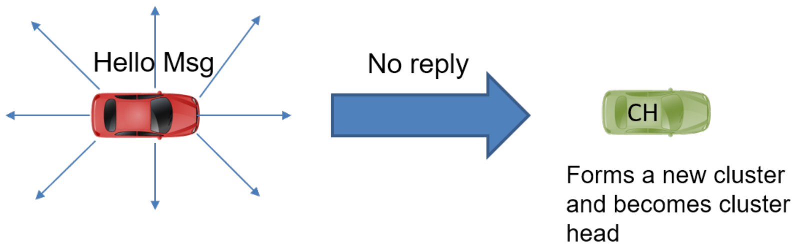
**Table 2.1** – Common clustering parameters contd...

## 2.2 Typical clustering Operations

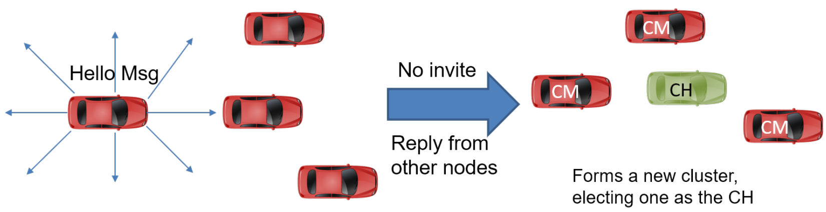
To group vehicles togethers there are two main set of operations used by the clustering algorithms. First is the cluster creation operations as shown in Figure 2.1.

As the name suggest these operations are used to create a new cluster after verifying the fitness of the participants. Figure 2.1a shows a case where there is no vehicle around. The vehicle first sends the `HELLO` messages to discover presence of other cluster and after a certain timeout identifies that there is no one around and starts a new cluster, becoming the new CH. The second operation depicted in Figure 2.1b is used when there are vehicles in the vicinity which have not yet formed any cluster. In this case the vehicles discover each other via `HELLO` messages and form a cluster followed by an election of the CH.

The second set of operations are used for cluster maintenance shown in Figure 2.2. Cluster joining operations shown in Figure 2.2a is used to add new members to the cluster. The request to join is initiated by the vehicle by sending the `HELLO` message. When the CH receives this message, it verifies if the vehicle is fit to join the cluster and then invites it using `INVITE` message. Cluster merging happens when two CH come in contact with each other as shown in Figure 2.2b. At this point the CHs




**(a)** Cluster creation with single vehicle




**(b)** Cluster creation with multiple vehicles

**Figure 2.1** – Cluster creation operations

decide to merge the clusters if the current state of the two cluster is similar in terms of the cluster parameters. After merging, one of the existing CH becomes the new CH of the merged cluster and the other CH becomes a CM.

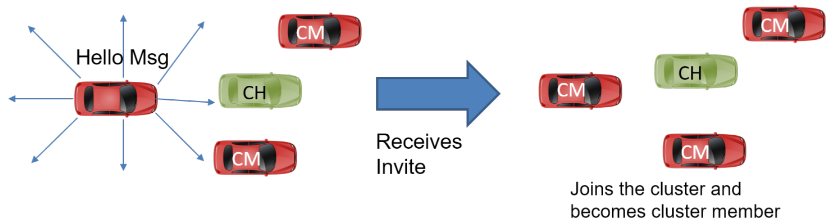
It should be noted that the actual implementation of these operations may change from one methodology to another depending upon the parameter and the use case for the clustering.

## 2.3 Methodologies

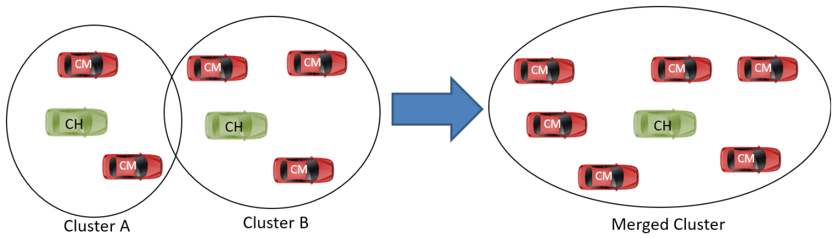
This section would present some of the methodologies which are popular and used as the basis for several algorithms designed for clustering in VANET.

### 2.3.1 Clustering using vehicular mobility

Vehicular mobility is one of the common and vastly used methodology for clustering. Relative velocity which can be used to differentiate the vehicles into different subgroups is used as one of the main parameters in such algorithms. The vehicle mobility is the main element affecting the network topology which the algorithms use to estimate dynamicity of the network and improve stability. Clustering algorithms presented by Arkian et al. [3], Dietzel, Balanici, and Kargl [4], and Morales, Hong, and Bang [5] use relative velocity as the main parameter to define the cluster joining and cluster head selection metrics.




**(a)** Cluster joining




**(b)** Cluster merging

**Figure 2.2** – Cluster maintenance operations

### 2.3.2 Clustering using direction and destination

It has been identified that vehicles which travel in same direction or to same destination are supposed to be benefited most if they share information to each other. This makes the direction of travel and destination based clustering other important parameters used for clustering. This methodology requires the vehicles to be equipped with Global Positioning System (GPS) devices to get accurate location information. There can be variations based on the calculation and comparison of the routes of the vehicles. The methodology presented by Kanemaru et al. [6] uses trajectory tables to store position information which is then shared and compared by the vehicles to check the direction and route of travel whereas methodology presented by Maslekar et al. [7] calculates the direction at intersection points based on the turn the vehicles are going to take. Mohammad and Michele [8] has proposed a method which uses lane based information to decide the direction and cluster the vehicles.

### 2.3.3 Clustering using vehicular density

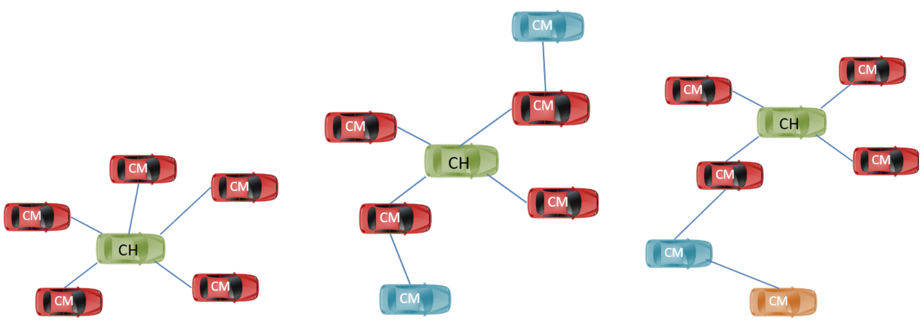
Density of the vehicles varies based on the environment considered. This is often utilized by the clustering algorithm as a important parameter to define different communication methodologies for dense network in city vs sparse network on highways. Aim of such algorithms is to reduce network congestion in cities by avoiding unnecessary flooding and provide longer network coverage on highways using long range communication. Kuklinski and Wolny [9] discusses one such algorithm which uses density based clustering to define different communication model based on connectivity and link quality estimates.

### 2.3.4 Hybrid clustering

Some application may require use of more than one parameter to make decision. Clustering algorithms defined for such application are complex and use multiple parameters in combination to each other. The clustering scheme proposed in [5] uses a combination of location, vehicular velocity and destination information to build up clusters which can adapt with changes in any of the parameters. Such methods are always complex and require a lot of communication between the vehicles to share real-time information.

### 2.3.5 Multi-hop clustering

The methodologies summarized till now in this section relies on one hop communication i.e. direct communication between the CH and the CM. The one hop based communication clustered face the problem of frequent handoffs between the clusters for members with high mobility. Multi-hop clustering methods try to address this issue by including N-hop members to the cluster. As shown in 2.3b and 2.3c, the multi-hop members communicate to the CH via the intermediate members and can be located a maximum of N-hop distance away from the CH. In a multi-hop clustering methodology, the `HELLO` messages contain additionally the number of current hops and are re-broadcasted by a node after adding themselves as a intermediate node. This forms the basis for identifying routes to the N-hop nodes after clustering. Zhang, Boukerche, and Pazzi [10] and Ucar, Ergen, and Ozkasap [11] present clustering methods based on multi-hop schemes along with vehicular mobility.




**(a)** 1 Hop **(b)** 2 Hop **(c)** 3 Hop

**Figure 2.3** – Multi-hop clustering (based on [11, Figure 1])

# Chapter 3

# Evaluation and analysis techniques

Implementing a proposed solution for VANET with real vehicles for testing is not straight forward. It always requires availability of various equipment and testing environment to implement a prototype system which would be suitable for evaluating the proposed method. Due to this, most of the authors of the proposed solution use simulation as the main method of evaluation and producing data for evaluation. This chapter will discuss some of the important tools and techniques used for evaluation of clustering methodologies for VANET and also present the common metrics derived from the simulation data for comparison.

Simulation for VANET involves two aspects, first is modelling the vehicular mobility and second is modelling the network communication between the vehicles. Another major challenge is to define the interlink between these models to build a realistic simulation environment. Some of the popular network simulators used are OMNET++[1], ns3[2] and VanetMobiSim [12]. Vehicular mobility can defined by SUMO [13] which is most popular tool capable of managing vehicular mobility via predefined traffic scenarios or some specific mobility model. Sommer, German, and Dressler [14] presented Vehicles in Network Simulation (VEINS) which defines extensions to interconnect OMNET++ and SUMO. A combination of these tools are used to provide simulation environments for evaluating the clustering methodologies.

## 3.1 Important parameters for evaluation

The simulation parameters play important role in effectively producing data which is suitable to derive metrics for evaluation. It mostly depends on the characteristics of the simulated model which in this case is clustering methods so mostly depends on the parameters Table 2.1 chosen for clustering and the some typical networking

[1] `https://www.omnetpp.org/`
[2] `https://www.nsnam.org/`

and vehicular mobility characteristics. Table 3.1 lists down some of the parameters along with there typical values in simulation environment.

| Parameter | values |
|---|---|
| Simulation Time | 120 s - 400 s |
| Route length | 3 km - 10 km |
| Average speed of Vehicles | 10 m/s - 40 m/s |
| Transmission rate | 6 Mbps - 27 Mbps |
| Communication range | 100 m - 400 m |
| Size of messages | 100 B - 150 B |
| No. of vehicles/Flow rate | 1800 vehicles/h - 3600 vehicles/h |

**Table 3.1** – Typical simulation parameters

## 3.2 Analysis of results

Once the data is captured using the simulation of the target clustering methods, it should be used for analysis against some metrics which allows comparative evaluation of the proposed schemes. Some of the important metrics which are used to compare the performance of the clustering algorithms for VANET are as follows.

- **Cluster head duration/Cluster lifetime**: Most important metrics used to measure the stability of clusters. Longer duration of CH is resultant of stable clusters which can perform better in a dynamic environment.
- **Number of clusters**: This metric gives quality of formation of the clusters. Higher number of clusters would lead to cluster merging and increased cluster formation overhead whereas smaller number means large cluster sizes which would result in cluster division due communication failures in high mobile environment.
- **Cluster member duration/Connectivity**: Longer member duration are important for stability and effective communication. Member duration is also a measure of connectivity and the link quality achieved by the clustering method which directly affects the network communication between the nodes.

# Chapter 4

# Conclusion

This thesis introduces the reader with the requirements for clustering in vehicular networks along with various terminologies and methodologies proposed in literature by various researchers. It also gives a brief overview of tools and metrics which are important for the evaluation of methodologies in VANET systems. The methodologies mentioned in this thesis only provides a brief introduction to the main ideas for clustering in vehicular networks to the reader.

Currently, there is a huge advancement being made in the wireless communication technologies which will open various new opportunities for improving the communication environment for VANETs in the future. Improved communication mechanisms for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication would provide more stable and reliable communication channels. Thus providing basis for improving existing clustering methodologies by extending them to use new technology and design new methodologies to achieve better performance in terms of stability and networking connectivity.

I believe this thesis should be a good starting point for introducing the concept of clustering in vehicular network and highlighting the important areas which the reader can further explore based on their needs.

# List of Abbreviations

| | |
|---|---|
| **CH** | Cluster Head |
| **CM** | Cluster Member |
| **GPS** | Global Positioning System |
| **MANET** | Mobile Ad Hoc Network |
| **RSU** | Road Side Unit |
| **V2I** | Vehicle-to-Infrastructure |
| **V2V** | Vehicle-to-Vehicle |
| **VANET** | Vehicular Ad Hoc Network |
| **VEINS** | Vehicles in Network Simulation |
| **WANET** | Wireless Ad Hoc Network |

# List of Figures

# List of Tables

# Bibliography

[1] S. Vodopivec, J. Bešter, and A. Kos, “A survey on clustering algorithms for vehicular ad-hoc networks,” in *2012 35th International Conference on Telecommunications and Signal Processing (TSP)*, Jul. 2012, pp. 52–56. DOI: 10.1109/TSP.2012.6256251.

[2] R. S. Bali, N. Kumar, and J. J. Rodrigues, “Clustering in vehicular ad hoc networks: Taxonomy, challenges and solutions,” *Vehicular Communications*, vol. 1, no. 3, pp. 134–152, 2014. DOI: https://doi.org/10.1016/j.vehcom.2014.05.004.

[3] H. R. Arkian, R. E. Atani, A. Pourkhalili, and S. Kamali, “Cluster-based traffic information generalization in Vehicular Ad-hoc Networks,” *Vehicular Communications*, vol. 1, no. 4, pp. 197–207, 2014. DOI: https://doi.org/10.1016/j.vehcom.2014.08.003.

[4] S. Dietzel, M. Balanici, and F. Kargl, “Short paper: Towards data-similarity-based clustering for inter-vehicle communication,” in *2013 IEEE Vehicular Networking Conference*, Dec. 2013, pp. 238–241. DOI: 10.1109/VNC.2013.6737622.

[5] M. M. C. Morales, C. S. Hong, and Y. C. Bang, “An Adaptable Mobility-Aware Clustering Algorithm in vehicular networks,” in *2011 13th Asia-Pacific Network Operations and Management Symposium*, Sep. 2011, pp. 1–6. DOI: 10.1109/APNOMS.2011.6077004.

[6] Y. Kanemaru, S. Matsuura, M. Kakiuchi, S. Noguchi, A. Inomata, and K. Fujikawa, “Vehicle clustering algorithm for sharing information on traffic congestion,” in *2013 13th International Conference on ITS Telecommunications (ITST)*, Nov. 2013, pp. 38–43. DOI: 10.1109/ITST.2013.6685518.

[7] N. Maslekar, M. Boussedjra, J. Mouzna, and L. Houda, “Direction based clustering algorithm for data dissemination in vehicular networks,” in *2009 IEEE Vehicular Networking Conference (VNC)*, Oct. 2009, pp. 1–6. DOI: 10.1109/VNC.2009.5416361.

[8] S. A. Mohammad and C. W. Michele, “Using traffic flow for cluster formation in vehicular ad-hoc networks,” in *IEEE Local Computer Network Conference*, Oct. 2010, pp. 631–636. DOI: 10.1109/LCN.2010.5735785.

[9] S. Kuklinski and G. Wolny, “Density based clustering algorithm for VANETs,” in *2009 5th International Conference on Testbeds and Research Infrastructures for the Development of Networks Communities and Workshops*, Apr. 2009, pp. 1–6. DOI: 10.1109/TRIDENTCOM.2009.4976256.

[10] Z. Zhang, A. Boukerche, and R. Pazzi, “A Novel Multi-hop Clustering Scheme for Vehicular Ad-hoc Networks,” in *Proceedings of the 9th ACM International Symposium on Mobility Management and Wireless Access*, ser. MobiWac ’11, Miami, Florida, USA: ACM, 2011, pp. 19–26. DOI: 10.1145/2069131.2069135.

[11] S. Ucar, S. C. Ergen, and O. Ozkasap, “VMaSC: Vehicular multi-hop algorithm for stable clustering in Vehicular Ad Hoc Networks,” in *2013 IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2013, pp. 2381–2386. DOI: 10.1109/WCNC.2013.6554933.

[12] M. Fiore, J. Harri, F. Filali, and C. Bonnet, “Vehicular Mobility Simulation for VANETs,” in *Simulation Symposium, 2007. ANSS ’07. 40th Annual*, Mar. 2007, pp. 301–309. DOI: 10.1109/ANSS.2007.44.

[13] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, “SUMO – Simulation of Urban MObility: An Overview,” in *SIMUL 2011*, S. Ũ. of Oslo Aida Omerovic, R. I. .-.-. R. T. P. D. A. Simoni, and R. I. .-.-. R. T. P. G. Bobashev, Eds., ThinkMind, Oct. 2011.

[14] C. Sommer, R. German, and F. Dressler, “Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis,” *IEEE Transactions on Mobile Computing*, vol. 10, no. 1, pp. 3–15, Jan. 2011. DOI: 10.1109/TMC.2010.133.