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Cloud Computing Concept for Intelligent Transportation Systems

Paweł Jaworski, Tim Edwards, Jonathan Moore, Keith Burnham

Abstract — **In this paper a cloud computing based urban traffic control system is proposed. Its goals are to increase road throughput and optimise the traffic control for increased safety of the participants, reduced fuel consumption and carbon emissions. The urban vehicle control scenario assumes that the speed of each vehicle in the controlled area is set by an off-board control unit that supervises each traffic intersection. The software component responsible for that is called an Intersection Control Service (ICS). From the system's point of view, the vehicles are treated as cloud services and are discovered and invoked using a cloud computing methodology. Geographical multicast addressing is used to target all vehicles in the specified areas. ICSs are part of a city/region wide cloud system that coordinates flow of traffic between intersections. The system's optimisation objective is carried out on several planning planes simultaneously, the lowest being local to a single intersection and the highest being an entire city or region level. The ICS gathers traffic data from various sensors around the intersection, and from the vehicles themselves, creating a dynamic situation map which can be used to assess the road situation and perform short term predictions for vehicle control purposes.**

I. INTRODUCTION

Heavy traffic and the resulting congestion has become a serious issue in many cities worldwide. The existing road infrastructure cannot keep up with constantly increasing numbers of vehicles, resulting in various forms of decreased traffic performance. In most urban cases road capacity cannot easily be increased, the limiting factors include lack of space for new roads and high redevelopment costs. One of the aims of Intelligent Transportation Systems (ITS) is to introduce advanced traffic flow control methods to increase throughput and safety of existing road infrastructure.

Recent years have seen rapid development of radio telecommunications technologies. In 2010 IEEE specified the 802.11p Wireless Access in Vehicular Environments (WAVE) communications standard, which can be used as an inexpensive and reliable point to point short distance communication method for ITS [1]. Additionally most of world's major cities are covered with high speed 3G (UMTS, HSPA) cellular networks offering high data rates with relatively low latency. Although vehicle control itself does not require large transmission speeds, and will most probably be based on 802.11p, extra bandwidth provided by 3G services could be utilised for providing additional ITS services such as positioning.

Using a distributed computing framework ICS can realise a control strategy imposed by Area Management Services (AMS). AMS are responsible for gathering and processing statistical data, and generating the control plan and objectives for the ICS. The benefits of applying city wide, situation aware, ITS include: the ability to control, model and predict traffic flow, prioritisation of public transport vehicles, and optimised route planning for emergency services.

II. OFF-BOARD CONTROL PARADIGM

The cloud computing based off-board control system is being developed at MIRA as a part of the Network Assisted Vehicle (NAV) project. Its goal is to create a vehicle that is able to interact with roadside infrastructure. The main emphasis is placed on the off-board control paradigm. Contrary to other autonomous or semi-autonomous vehicle projects [2], [3], [4] where all the control actions are calculated on-board of the affected vehicle, the NAV relies on external processing and decision making for control.

Currently only a longitudinal vehicle control system is being developed, with full control considered for the future. The longitudinal vehicle control problem can be solved using two levels of control. The low level controller follows a defined reference speed by sending demands to brake and throttle actuators. The high level controller calculates the speed demands based on the road situation.

With an on-board control scenario each vehicle would have to carry a large amount of sensors and possess large processing power to assess the road situation and calculate its own speed demand. The off-board longitudinal control paradigm assumes that the speed demand is calculated outside of the affected vehicle, thus leaving data gathering and processing to an external unit (in this case the ICS and associated services). The external control unit can serve multiple vehicles at the same time using geographical multicast addressing. Off-board decision making could be more optimal compared to a number of independent on-board controllers, as the situation image constructed and resulting control action is consistent throughout the affected area.

Two mechanisms for applying control to the vehicles are considered. The first is a direct control approach, where a low level controller affects brake and accelerator actuators directly. The second design is based on a human in the loop control scenario. An on-board device acts as an advisory system, displaying current speed demand and relying on the driver to follow it. Because of safety and legal concerns, the direct control approach is likely to be constrained to proving ground use only in immediate future. Nevertheless it might

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P. Jaworski is with MIRA Ltd, Nuneaton, Warwickshire, UK (phone: +44 24 7635 5211; email: pawel.jaworski@mira.co.uk), as part of a PhD with Coventry University

T. Edwards is with MIRA Ltd, Nuneaton, Warwickshire, UK (email: tim.edwards@mira.co.uk)

J. Moore is with MIRA Ltd, Nuneaton, Warwickshire, UK (email: jonathan.moore@mira.co.uk)

K. Burnham is with Coventry University, Coventry, Warwickshire, UK (email: k.burnham@coventry.ac.uk)

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be useful in developing and testing other ITS technologies. The advisory version of the system could be used on public roads as it has fewer safety implications.

In urban areas, where overtaking opportunities are limited, traffic control could be exercised by influencing behaviour of selected group of vehicles such as buses, taxies and emergency vehicles.

III. RELATED WORK

The most of ITS related projects aim to increase road safety and/or increase its throughput. SAFESPOT [5] was a project which aimed to improve safety of road transport by means of cooperative data acquisition and decision making. The system extends the driver's awareness by displaying appropriate safety related messages. It collects data from various sources, including other vehicles and roadside infrastructure, builds a dynamic map of the current situation and is capable of predicting potentially dangerous situations. The concept of local dynamic maps has been adapted for use in the proposed cloud system as part of the ICS for modelling, predicting and decision making purposes.

The roadside infrastructure and the vehicles communicate using wireless networks. Rapid changes in topology of such networks make basic operations, such as routing, more challenging. Such highly dynamic inter-vehicle networks have been called VANETs [6], [7] (Vehicular Ad-hoc Networks). VANETs are intended for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Communications in VANETs rely on dynamic multi-hop routing of messages, sometimes with geographical addressing principles included [8].

The problems faced by the radio communication part of the proposed systems are somewhat similar to the problems researchers encountered while developing VANETs. The cloud system uses its own routing services between its components. For communication with the vehicles it will rely on VANET-type geo-addressing based addressing.

Use of cellular networks in ITS is usually limited for V2I communication. Increasing quality and capacity of cellular networks made the authors in [9] to consider using cellular networks for V2V communication as well. The system proposed in this paper considers using a cellular network to access non-core ITS services.

IV. CLOUD COMPUTING APPROACH TO ITS

There are many definitions of what a computing Cloud is. It is often compared to Grid computing and it is sometimes difficult to draw a clear boundary between them [10]. The term 'Grid' was introduced to reflect the way computational resources are used. In Grids computational power is accessed on demand, in a similar manner to drawing electricity from an electrical power grid hence the name [11]. Some sources describe the Cloud as an evolved version of the Grid [12]. The Cloud extends the Grid by adding virtualisation of hardware and changing the way the resources are accessed. A Grid focuses on resource sharing and a Cloud uses virtualisation methods to create a dedicated resource or service when required. Both Clouds and Grids have service oriented architectures. A service in this context might be access to infrastructure (Infrastructure as a service –IaaS), a dedicated, possibly virtualised, platform (Platform as a Service – PaaS) or software (Software as a Service - SaaS).

The system proposed in this paper is a collection of software services (SaaS) interacting with each other and forming a distributed processing system. The other features common to Grids and Clouds include heterogeneity and virtualisation [13]. The hardware and software architecture of the service is irrelevant as long as it presents a standardized communication interface to system users and other services.

The dynamic and scalable nature of cloud systems, makes assuring an appropriate level of security is a difficult task. Strong security measures might limit the flexibility of the system but the alternative is a low security system, which is unacceptable for an application regarding transportation and public safety. Many of the security issues originate from the fact that most grids and clouds use the internet as its primary connectivity method [14], [15]. The design of the ITS system proposed in this paper assumes that the users (vehicles) do not invoke the ITS services directly (Radio Communication Nodes and Services act on their behalf). This allows an additional layer of security to be introduced by isolating the core communication network of the system from the users. The prototype system developed at MIRA will initially be confined to secure test network, relying on isolation as its primary security measure. As the system grows it will be necessary to introduce more widely applied client and service authentication.

The proposed system has been designed with the principles of Cloud/Grid computing in mind, placing scalability as a number one priority. All the tasks performed by the system were instantiated as Cloud services linked together by a uniform IP network. System services are built upon heterogeneous software and hardware platforms, from high level Java applications on rack servers through to C++ programs on embedded PCs and compact C applications running on microcontrollers.

Although the system proposed in this paper has some features of both Cloud and Grid systems, and thus may not be considered a proper cloud system according to some definitions [16], it has the majority of the features of both Grid and Cloud systems described in [11], [12] and [15]. It is a scalable, service oriented and distributed processing architecture which aims to increase reliability and decrease costs of processing large amounts of data. It was chosen to term it a Cloud system because current Grid computing is mainly targeted at large scale scientific computing, and for the proposed system scalability is the most important feature.

V. CORE ITS SERVICES

The main objective of the proposed ITS system is area wide management of traffic flow aiming to maximise traffic throughput and increase safety of all traffic participants. It is realised by a distributed control system based on cloud computing principles. The system operates by means of interaction between its components, called services, using a uniform connectivity layer. Services required for the system to function have been termed core services:

1) *Intersection Control Service*

Intersection Control Services (ICS) are responsible for managing a single intersection. They are a cloud representation of Intersection Control Nodes (ICN). An ICN is a piece of roadside infrastructure managing the intersections basic functions such as setting traffic lights, detecting and managing hardware faults. ICS subscribe for data from geographical regions associated with the managed intersection. They compute a representation of the current road situation using dynamic data received from all associated sources and (stored) static road layout information. ICS controls traffic by generating a speed demand to all vehicles in a given geographical region and by issuing commands to the ICN it is associated with.

2) *Area Management Service*

Area Management Services (AMS) is aware of the road network topology and aim to optimise traffic flow on a macro scale (between intersections). An area is represented by a graph, in which vertexes are intersections (each managed by an ICN-ICS pair) connected by roads (edges).

3) *Service Discovery System*

Service discovery is one of the key problems in service oriented distributed processing architectures. The Service Discovery System (SDS) holds, and keeps up to date, a database of services and the geographical areas affected by them. There can be several instances of SDS in one system but service data consistency has to be kept. This is usually done in Cloud and Grid systems by using data replication techniques, as described in [17] and [18].

4) *Local Routing Service*

Each node and service using geographical addressing has a Local Routing Service (LRS) associated with it. The LRS receives messages and detects which nodes subscribe for those messages based on location information from the message. The information about services and their associated geographical areas is provided by the SDS so that an LRS can be defined as a local agent of the SDS, limited to keeping routing information only.

5) *Radio Communication Service (RCS)*

Similarly to ICS being a service representation of an ICN, a Radio Communication Service (RCS) is a service wrapper for Radio Communication Nodes (RCN). Each instance of RCS handles a single radio module and allows communication between cloud services and vehicles in the affected area (determined by the RCNs radio coverage).

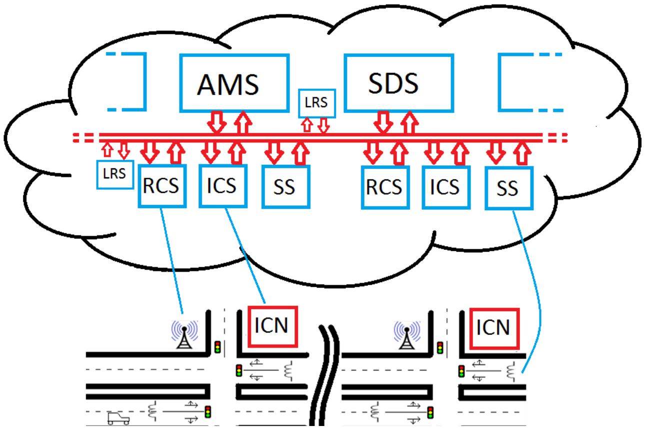

Fig. 1. ITS Service Model

6) *Sensor Service*

A Sensor Service (SS) is a wrapper for devices, such as cameras and in-road induction loops, providing data about the current road situation. The SS, based on data from the associated Sensor Node (SN), is able to determine the geographical position of detected objects and, using LRS, relay the measurement to all other services interested in this area.

7) *Other Services.*

This concept paper describes only the core ITS services. Nevertheless the design allows other types of services to be created easily. Such additional services could include:

- Route calculator
    - A service able to calculate the best route for a given vehicle taking into account traffic data from AMS.
- Point of interest locator
    - A service finding POI (parking, petrol stations) closest to the selected area. Additional data such as the number of free spaces and petrol prices could be made available as well.
- Emergency vehicle routing service
    - Emergency vehicles could be registered to this service, it would use the route calculator service to calculate best paths and request a priority passage through intersections on route.
- Modelling and simulation service
    - A service designed to be used by ICS, providing modelling and simulation capabilities on a high performance computer or a computing cluster.

VI. TYPES OF ADDRESSING

The proposed traffic control system uses geographical addressing for routing its messages. Although vehicles are treated as cloud services, discovery and invoking them separately would introduce unnecessary communication overhead. In order to reduce bandwidth requirements, multicast geographical addressing will be used. Currently geographical multicast addressing is used mainly in dynamic ad-hoc networks [19], [20]. The proposed system uses cloud service discovery mechanisms to identify radio services associated with a given region thus achieving geo-addressing. Each radio communication service is aware of the geographical area covered by its radio. This information is published with a service description and is used by Service Discovery Systems and Local Routing Services to select the appropriate radio services to use. In the following use case example routing a message between an ICS and a vehicle is explained:

1) Vehicle announces its position
    - a) Vehicle transmits its GPS position
    - b) Infrastructure radio modules receive, form a position update request and invoke their LRS
    - c) LRS finds all services that subscribe for data from the area the vehicle is in and forwards the request to them
    - d) Target services (mainly ICNs) receive and process the position update request
2) ICS issues a speed demand for a region
    - a) ICS sends the request to LRS
    - b) LRS finds radio services handling the said area and forwards the request to them
    - c) Required RCNs transmit the request to all vehicles within their coverage
    - d) Vehicle(s) receives the request(s) and checks if it is located in the affected area

An example of geographical addressing of vehicles in a given area is shown in Figure 2. In the example the target area is in covered by two radio services, therefore both of them will be used to cover the whole requested area.

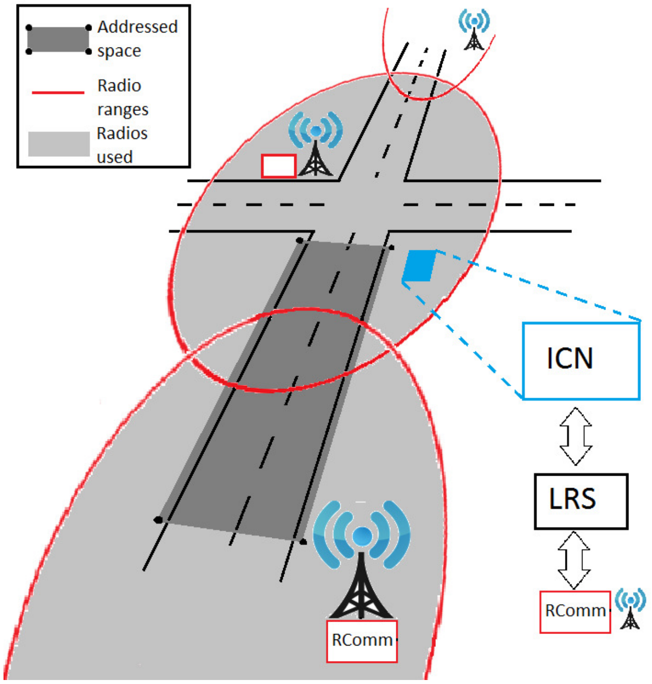

Fig. 2. Geographical addressing

There are two modes for defining the geographically addressed area considered currently:

- Polygon
    - The addressed space is defined as a polygon formed by a given set of vertices
- Circular or elliptic area
    - A circle with a known centre and radius
    - An ellipse with known foci and radii

Although geo-addressing is dominating the way of addressing in the proposed system, classical unicast communication may also be used, through different radio interfaces, for invoking non-core services. An example of this would be using a best route calculation service or POI locator through a 3G network.

VII. SYSTEM UNDER DEVELOPMENT AT MIRA

A prototype cloud computing based ITS system is under development by MIRA Ltd and Coventry University as a part of the innovITS ADVANCE city circuit and Network Assisted Vehicle (NAV) projects. The innovITS ADVANCE city circuit is an ITS test facility which aims to recreate urban traffic scenarios in a safe and controlled environment. The site is equipped with various wireless communication systems, all of which are accessible from the site's control network. Types of radio interfaces that will be in use with the cloud ITS system include:

- 802.11p
- Motorola Motomesh (Mesh 4G)
- Wi-Fi (802.11a/b/g/n)
- Cellular Networks: GSM (2G) and UMTS (3G)

Implementing the proposed system on the innovITS site would make it possible to introduce virtual vehicles into the test scenario that would be, from the systems point of view, indistinguishable from real vehicles, thus allowing for reliable, repeatable and safe tests of ITS enabled vehicles.

VIII. SYSTEM DESIGN

1) ICS design

The main objective of an ICS is to manage traffic within its region of influence by issuing speed demands to vehicles. In order to do so an image of the current road situation has to be constructed. It is done by collecting data from many different sensing services and performing data fusion in order to construct a local dynamic map. The ICS are aware only of situations in their region of influence, however instructions received from AMS may enforce a different prioritising strategy for selected lanes and routes. Additionally ICS communicate with neighbouring ICS to negotiate synchronisation between their signalisation cycles. On intersections with dedicated turning lanes it is easy to detect the intended direction of the vehicles. This is not the case every time so the system could benefit from capable vehicles communicating their direction intent to the ICS.

2) AMS control goals

Area Management Services aim to optimise traffic in their region (area). They collect aggregated data from ICS and build an image of the area in the form of a weighted directed graph. Vertices in the graph are the intersections and edges are the roads between them. Using such a road situation representation it is possible to run graph algorithms to find best routes and influence the ICS to shift signalling priorities. A properly functioning AMS should:

- Create optimal vehicle routing plans to spread the road load throughout the region
    - By communicating with capable vehicles
    - Using displays on Variable Messaging Signs (VMS)
- Avoid jams and congestion by adjusting signalling cycles

Similar to ICS, AMS are able to communicate with their neighbouring counterparts in order to exchange information about the volume of traffic passing through between them.

3) *Level of influence*

The system's design allows for the situation where a vehicle is influenced by several ICNs. Therefore the vehicle has to be able to calculate the control input based on all received speed requests. This can be done by calculating a weighted average of all the received demands,

$$V_{ref} = \sum_{i=1}^{n} \alpha_i V_{(ref|i)} \qquad (1)$$

$$\sum_{i=1}^{n} \alpha_i = 1 \qquad (2)$$

where α is the weight of a given ICS's influence. The weights are calculated based on the vehicles distance from the command issuing intersection and its relative heading (intersections on vehicle's path receive higher priority than those being left behind). Applying such a method of handover between two influence areas prevents step demand changes and resulting jolts. Nevertheless the size and location of overlapping handover areas should be considered when designating ICS influence ranges to ensure that in critical intersection areas only one ICS is in control.

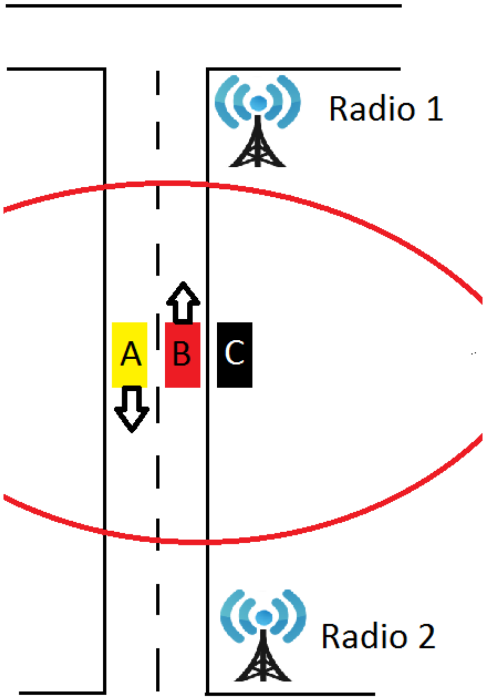

Fig. 3. Levels of influence

Figure 3 illustrates the level of influence weighting mechanism. Vehicle A is moving away from ICN 1 (represented for simplicity as Radio1), vehicle B is traveling in the opposite direction and Vehicle C Is stationary. Assuming that Vehicles A and B are traveling with the same velocity in opposite direction, the levels of influence of the involved ICNs are shown in Figure 4.

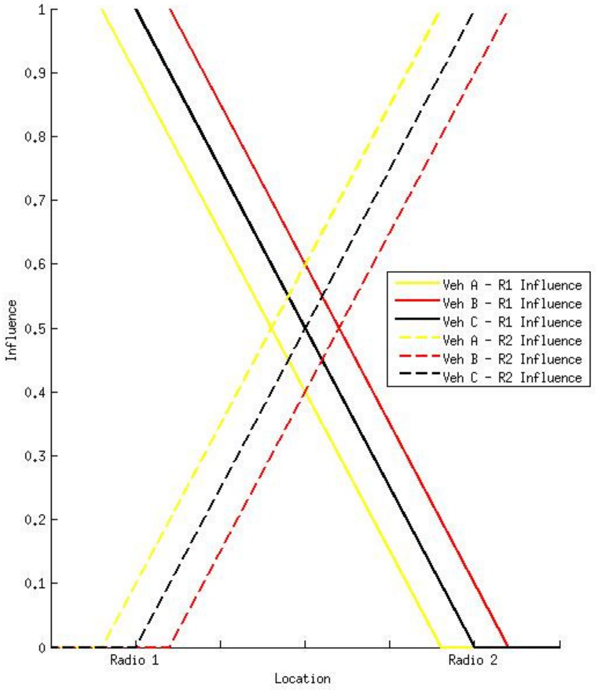

Fig. 4. Weighting function

4) *Privacy*

Privacy is a recognised and widely discussed issue in cloud computing [22]. Many drivers would not be content with using an ITS system knowing that their movement can be tracked. In [23] a privacy scheme for VANETs was introduced. It relies on forming group queries to enhance privacy of the vehicles when using location services. The system proposed in this paper relies on geographical addressing, therefore it does not require vehicles to provide unique identifiers thus it is unable to identify individual vehicles. However for access to other services, such as the location services, a privacy scheme will have to be implemented.

5) *Outside of the systems coverage*

The situation where a vehicle is outside a managed area or radio range has to be considered. Action taken in such a case depends on the variant of the system in use. In the case of an advisory system, the current speed limit should be obtained from roadside beacons and displayed. In the case of a directly controlled vehicle, the maximum allowed speed should be sustained or platooning behaviour should be performed when encountering a slower moving vehicle. If no information on the speed limit is available the control of the vehicle should revert back to the driver.

IX. PUBLIC ROAD IMPLEMENTATION FEASIBILITY

The vast majority of vehicles in use today are not equipped with ITS integrated satellite positioning system or inter-vehicle communications. Most intersections do not have enough sensing capabilities to provide a good image of the situation of the road. Implementing a wide area ITS could be an extremely costly and difficult operation if every intersection and every vehicle had to be fitted with additional hardware. The system proposed in this paper mitigates those problems by using a scalable modular architecture. In an initial phase of development the system could be installed on a small number of intersections with limited sensing capability. Additional sensors could be added to intersections in time, increasing accuracy of data measurement. Better measurements (more data for data fusion units) would result in better overall system performance. Similarly, the amount of vehicles equipped with a positioning system, display and communication technology would increase in time as well provided that the usefulness of the system could be demonstrated.

X. CONCLUSIONS

In this paper the concept of a Cloud computing based ITS was explored and an overview of such a system being developed at MIRA Ltd has been presented. The application of a Cloud methodology promises a scalable and robust ITS platform. The proposed system combines geographical addressing and cloud service discovery mechanisms for requesting routing. Use of multicast geographical addressing reduces network load and provides a simple and transparent addressing scheme.

The system will be implemented in its advisory form on public roads (in a limited test area) allowing a realistic proving ground without affecting the safety of traffic participants.

XI. REFERENCES

[1] D Jiang and L Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments," in *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*, 2008, pp. 2036-2040.

[2] L Cremean et al., "Alice: An information-rich autonomous vehicle for high-speed desert navigation," *The 2005 DARPA Grand Challenge*, pp. 437-482, 2007.

[3] A Kelly et al., "Toward reliable off road autonomous vehicles operating in challenging environments," *The International Journal of Robotics Research*, vol. 25, no. 449, pp. 5-6, 2006.

[4] R Behringer et al., "The DARPA grand challenge-development of an autonomous vehicle".

[5] F Bonnefoi, F Bellotti, T Schendzielorz, and F Visintainer, "SAFESPOT applications for infrastructure-based co-operative road-safety," in *14th World Congress and Exhibition on Intelligent Transport Systems and Services*, 2007.

[6] M Kafsi, P Papadimitratos, O Dousse, T Alpcan, and J.P Hubaux, "Vanet connectivity analysis," in *Proceedings of the IEEE Workshop*, New Orleans, LA, USA, December 2008.

[7] G Pallis, D Katsaros, M.D Dikaiakos, N Loulloudes, and L Tassiulas, "On the structure and evolution of vehicular networks," in *Modeling, Analysis & Simulation of Computer and Telecommunication Systems*, 2009, pp. 1-10.

[8] O Tonguz, N Wisitpongphan, F Bai, P Mudalige, and V Sadekar, "Broadcasting in VANET," in *2007 Mobile Networking for Vehicular Environments*, 2007, pp. 7-12.

[9] J Santa, A.F Gomez-Skarmeta, and M Sanchez-Artigas, "Architecture and evaluation of a unified V2V and V2I communication system based on cellular networks," *Computer Communications*, vol. 31, no. 12, pp. 2850-2861, 2008.

[10] Foster I, Zhao Y, Raicu I, and S Lu, "Cloud computing and grid computing 360-degree compared," *Grid Computing Environments Workshop, 2008. GCE'08*, pp. 1-10, 2008.

[11] I Foster and C Kesselman, *The grid: blueprint for a new computing infrastructure.*: Morgan Kaufmann, 2004.

[12] G.V Mc Evoy and B Schulze, "Using clouds to address grid limitations," in *Proceedings of the 6th international workshop on Middleware for grid computing*, 2008, p. 11.

[13] L.M Vaquero, L Rodero-Merino, J Caceres, and M Lindner, "A break in the clouds: towards a cloud definition," *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 1, pp. 50-55, 2008.

[14] N Nagaratnam et al., "The security architecture for open grid services," in *Global Grid Forum Recommendation*, 2003.

[15] V Welch et al., "Security for grid services," in *12th IEEE International Symposium on High Performance Distributed Computing*, 2003, pp. 48-57.

[16] M.A Vouk, "Cloud computing - Issues, research and implementations," *Journal of Computing and Information Technology*, vol. 16, no. 4, pp. 235-246, 2008.

[17] M Tang, B.S Lee, X Tang, and C.K Yeo, "The impact of data replication on job scheduling performance in the Data Grid," *Future Generation Computer Systems*, vol. 22, no. 3, pp. 254-268, 2006.

[18] C Nicholson, DG Cameron, AT Doyle, AP Millar, and K Stockinger, "Dynamic data replication in LCG 2008," *Concurrency and Computation: Practice and Experience*, vol. 20, no. 11, pp. 1259-1271, 2008.

[19] M Kihl, M Sichitiu, T Ekeroth, and M Rozenberg, "Reliable geographical multicast routing in vehicular ad-hoc networks," *Wired/Wireless Internet Communications*, pp. 315-325, 2007.

[20] F Rousseau et al., "Geo-mobility and Location Service in Spontaneous Wireless Mesh Networks," in *ICT-MobileSummit 2008 Conference Proceedings*, Stockholm, Sweden, 2008.

[21] G Toulminet, J Boussuge, and C Laurgeau, "Comparative synthesis of the 3 main European projects dealing with Cooperative Systems (CVIS, SAFESPOT and COOPERS) and description of COOPERS Demonstration Site 4," in *11th International IEEE Conference on Intelligent Transportation Systems*, 2008, pp. 809-814.

[22] S. Pearson, "Taking account of privacy when designing cloud computing services," in *Proceedings of the 2009 ICSE Workshop on Software Engineering Challenges of Cloud Computing*, 2009, pp. 44-52.

[23] K Sampigethaya, M Li, L Huang, and R Poovendran, "Amoeba: Robust location privacy scheme for vanet," *Selected Areas in Communications, IEEE Journal on*, vol. 25, no. 8, pp. 1569-1589, 2007.