HIERARCHICAL WIRELESS FRAMEWORK FOR REAL-TIME COLLABORATIVE GENERATION AND DISTRIBUTION OF TELEMETRY DATA

A thesis submitted in partial fulfilment of the
Requirements of the Nottingham Trent University
For the degree of Doctor of Philosophy

Ismail Kucukdurgut

November 2010

Abstract

This project introduces a novel multidisciplinary approach combining Vehicular Ad Hoc Networks and Granular Computing, to the data processing and information generation problem in large urban traffic systems. It addresses the challenge of real-time information generation and dissemination in such systems by designing and investigating a hierarchical real-time information framework. The research work is complemented by designing and developing a simulator for such a system, which provides a simulation environment for the model developed.

The proposed multidisciplinary hierarchical real-time information processing and dissemination system framework utilises results from two different areas of study, which are Vehicular Ad Hoc Networks (VANETS) and Granular Computing concepts. Furthermore, a new geographically constrained VANET topology for information generation is proposed, simulated and investigated.

The simulator is developed to model the proposed system and to help with the proof of concept investigation of the system. Its components have been designed and implemented to demonstrate how such multidisciplinary architectures can be simulated. Simulations using the hierarchical information framework have been run, and the results reported in the thesis suggest the feasibility of the concept. The system model and the simulator demonstrate that building future large and complex systems in terms of scalability and real-time information induction based on distributed nodes environment algorithms is possible.

Both the system architecture and the simulator model are novel and they provide an important step towards achieving a solution to building infinitely scalable real-time information processing urban traffic systems.

Acknowledgements

I would like to express my gratitude to Dr. Evtim Peytchev for guidance and support throughout this work, which has been very helpful in moments of difficulty.

I would also like to thank all at the Nottingham Trent University staff, they have been very helpful and supportive over the years. Surely, they are some of the most dedicated, caring and professional people I have ever met. Special thanks to Mr. Alan Battersby and Dr. Richard Hibberd for their support and encouragement for taking this study.

Table of Contents

TABLE OF FIGURES

Table of Tables

Chapter 1

Introduction

1.1 Overview

Urban Traffic Systems are fast becoming a research and application area for information systems as vehicles are equipped with GPS equipment, and in-car computing devices are increasing. Vehicular Ad Hoc networks are becoming popular among the car manufacturers and the government agencies. Vehicular Ad Hoc Network communication equipment and radios are improving. Governments are regulating dedicated frequencies for vehicle communications, and road-side infrastructures for car-to-roadside communications are being planned. Already, government projects for road infrastructures are being built with redundant extra capacity for future road communications.

There is an explosion of data generated in urban traffic systems as vehicles become more and more computerized. Only 200 surveillance cameras of London generate 8m gigabytes of data everyday [103]. There are 28 million vehicles in Britain and it is increasing. It is impossible to centrally handle the amount of data generated by the vehicles at any given time. It would be impossible to gather and process all the data in urban traffic environment in real-time. Both gathering the infinite amount of data generated centrally and processing of it would be technically impossible. There is a need for distributed granular information generation which will give rise to real-time processing of the vehicle data generated.

New ways of information processing and knowledge generation are needed to deal with this problem. Finding new ways of dealing with this situation is one of the greatest challenges of the time.

This study is based on a vision that, in order to tame this explosive growth in data and process it in real-time, collaborative computing and multidisciplinary approach will be important.

"As we move further into the age of machine intelligence and automated reasoning, a daunting problem becomes harder and harder to master. How can we cope with the explosive growth in data, information, and knowledge? How can we locate and infer from decision-relevant information that is embedded in a large database" [104], which is unstructured, imprecise, and not totally reliable.

As information systems spread and advance, more and more data is generated and making sense of data in large data sets or finding the right information out of large and complex unstructured data is becoming an important issue. One is the Internet.

Another domain where data generation and processing is becoming increasingly complex is the Urban Traffic Systems and Intelligent Transport Systems field of study, which is facing the scalability and information processing issues in dealing with the demand for real-time information systems.

One of the main developments for the in-car devices in recent years has been the increase of the computational power of the devices to such a degree that they can now run any complex program designed to collect, generate and disseminate traffic information. In this process, the wireless communication facilities are always present, because it is the only way the in-car device can communicate with the external world. There are a number of large scale research initiatives in America, Japan and Europe. Assuming that very soon all vehicles will be equipped with a telematics platform, that will be able to supply traffic data collected on the move, the amount generated can be of vast proportions and this requires a special intelligent processing approach. Indeed, the abstraction process needs to be tuned to the needs of the application, and needs to be a dynamic system that responds to the real-time road situation.

Vehicles are being automated and computerized, and large amounts of data is being generated in vehicles, examples of which include: in car sensor data, temperature, emissions, vehicle speed, windscreen wiper on, lights are on or off, seatbelts are on or off, break usage, driving conditions, etc. This information is generated on the roads by vehicles, and in a large urban traffic system it is impossible to collect and process this data in real-time by the conventional traffic systems.

This project attempts to identify a layered hierarchical data processing generic infrastructure by utilising the latest advances in the field of intelligent (granular) knowledge generation and developments in the field of ad-hoc wireless communications. The project forms a pervasive and embedded ad hoc network-wide distributed intelligence for real time knowledge generation; bringing together the Vehicular Ad Hoc Networks (VANET) and Granular Computing (GrC) fields of study.

The project proposes a collaborative, hierarchical and intelligent information generation, dissemination and aggregation system with real-time characteristics, architected in a multidisciplinary domain, comprising of the fields of VANETS and Granular Computing. The aim is to achieve a pervasive, ubiquitous and embedded machine intelligence solution by taking a multidisciplinary approach.

The main components of the Urban Traffic System of interest are: roads, vehicles on the roads and VANET communication infrastructure in the form of vehicle –to-vehicle and vehicle-to-roadside.

VANETS are becoming increasingly popular for traffic systems. They are a very convenient way for communications on moving road conditions. Mobile ad hoc networks inherently do not need wired network infrastructure. They can be formed between peers anywhere. This project makes an interesting case for using VANETS for information generation.

The framework forms the architecture of a granular information generation mechanism by granulating the roads into road granules and forming ad-hoc networks on roads and collaboratively generating information in different granular levels.

The study divides the problem domain of Urban Traffic System into three major levels. This means that, there are three major granular views of the system. Those levels are: vehicle level, ad hoc network level, and inter-network level between ad hoc networks.

The study specifically concentrates on the ad-hoc network level as this level is the backbone of the distributed real-time information generation system that is developed. The study investigates the properties and the behaviour of this ad hoc network level both in terms of its networking aspect and information granulation aspect.

Further, a simulation framework is designed and developed to help with the evaluation and testing of the multidisciplinary make of the framework. The simulator has three major components, they are: Traffic simulation module, Network granulation engine, and Information Granulation Engine.

Traffic simulator is a component to simulate traffic on the NTF (National Transfer Format, records Ordnance Survey Map information) based Nottingham city map. Traffic generation and control engine is designed to cater for the problem at hand. The network granulation engine interacts with the vehicle objects generated at the traffic simulation module and forms networks between vehicles when a calculation is due. Networks are only formed when a calculation is needed. The Network granulation engine handles calculation based network formation and maintenance. The information granulation engine is invoked once the network is formed to collect data from vehicles and perform the information granulation process.

Traffic simulation is not an attempt to develop a traffic simulator but it provides enough logic to help with generation and movement of traffic to enable network formation. Also, Information Granulation Engine is a pluggable mechanism to use different algorithms to perform the calculations; the study has not been focusing on information granulation algorithms. Only linear set operations are used for calculations in the simulations. Information granulation algorithm optimization is subject to further study.

Some aspects of the framework are evaluated using the simulator and some parameters have been studied. Some properties of the system have provided some interesting insight to the proposed framework and those are discussed.

1.2 Aims of the Research

This project is a multidisciplinary approach to the data processing and information generation problem in large urban traffic systems. The project aims to address the challenge of real-time information generation and dissemination problem in large urban traffic systems by designing a hierarchical real-time framework, and an attempt is made to design and develop a simulator for such a system which provides a simulation model for the system model developed.

Following the above overview, the aims of this study are as follows:

1. To investigate and propose an architecture that incorporates the Vehicular Ad Hoc Networks and Granular Computing concepts and technologies for information generation and dissemination.
2. To identify and define the components of the multidisciplinary hierarchical architecture combining Vehicular Ad Hoc Networks and Granular Computing.
3. Study the defined components and identify some of their characteristics and properties.

4. Investigate distribution and scalability of information granulation in Urban Traffic Systems, utilizing the developments in the fields of Vehicular Ad Hoc Networks and Granular Computing.
5. Identify a mechanism of granulation of traffic information, defining the levels of data processing.
6. To propose a high level Vehicular Ad Hoc Networking mechanism to enable formation of Vehicular Ad Hoc Networks in a scalable manner and suitable for distributed information granulation.
7. Investigate the scalability of the system architecture.
8. To develop a simulation environment for the multidisciplinary distributed and scalable information granulation system and investigation of the system using it.
9. Study attributes of the proposed architecture through simulation, to validate the contributions of the thesis.

1.3 Original Contribution

During the course of this research study, the following original contributions to the body of research in computational support for transportation have been:

- Distributed, pervasive and scalable information granulation architecture for the Urban Traffic information systems, utilizing the developments in the fields of Vehicular Ad Hoc Networks and Granular Computing has been developed and proposed.

- An approach to the formation and operation of information granulation oriented and intelligent data calculation focused Vehicular Ad Hoc Network, based on geographically enforced physical topology with a node-head centring the geographical road interval network area has been proposed. This geographical interval road granules based topology provides a way for infinitely scalable adjacent Vehicular Ad Hoc Networks. The Vehicular Ad Hoc Networks are utilized for only information generation. They provide structures to perform information analysis.
- Simultaneous, clock triggered, short-lived Vehicular Ad Hoc Networks formation with universal scope to obtain a temporal system-wide view has been introduced as a new method for Vehicular Ad Hoc Networking. This new approach consists of adjacent network granules performing synchronized calculations to produce human centric information.
- A simulation tool has been designed and implemented for studying such a multidisciplinary system. Components of such a simulation tool that reflects the system architecture have been developed. The simulator design and development brings a new methodology and architecture for testing this multidisciplinary system.
- Investigation for identification of some attributes of the information granulation has been carried out with focus on Vehicular Ad Hoc Networks with geographically controlled topology.
- The consideration of road speeds is an important contribution of this research. VANET studies do not consider road speeds like 30, 40, 50, 60 mph as standard VANET speeds to change parameters according to current road speed. Current VANET research focuses on finding routing algorithms and

higher level communication tools for all the speeds together. This project considered those speeds as a major property and characteristic of VANETS and this project proposes this property to be part of any VANET studies. Upper speed limits on roads change the characteristics of the environment as the simulations demonstrated. As such, VANET studies for different speed limits become important. This study and simulations highlighted the issue. It may be that eventually there might be different VANET mechanisms for different speeds. This study has made a not of this issue.

1.4 Organization of the Thesis

This thesis contains 6 chapters. Each chapter contents are summarized below:

Chapter 1: This chapter gives an introduction to the research project. An overview of the study has been given. It also contains aims of the research and original contributions.

Chapter 2: In this chapter literature review has been given. It is re-iterated that this multidisciplinary project is unique in nature, and, literature review of the fields of Vehicular Ad Hoc Networks and Granular Computing are given. Vehicular Ad Hoc Networks and Granular Computing fields themselves are newly emerging fields of study, therefore; some of the findings and developments of those fields are highlighted. Vehicular Ad Hoc Networking studies are revised and some of the characteristics of the current research are noted. Then, Granular Computing has been introduced and useful principles are noted.

Chapter 3: This chapter presents the design of the system for real-time distributed information granulation. The system components are introduced and design decisions and challenges are discussed. From aims and objectives of the project a design is introduced to provide solution to the problems highlighted. The system components are explained and some showcase examples are given in this early design stage to solidify the design concepts.

Chapter 4: This chapter introduces the simulator designed and developed for this study. Given the nature of the study, which is multidisciplinary and has different layers and components, a new simulator with multidisciplinary components were found to be necessary. The simulator components are discussed and information on the implementation is provided.

Chapter 5: This chapter defines some simulations and displays results obtained from the simulations. Simulation results are presented, and the meaning of the results are discussed and interesting findings are highlighted.

Chapter 6: This chapter provides a conclusion remarks section and a section on future work suggestions.

Chapter 2

Literature Review

2.1 Introduction

This project covers a variety of technologies to introduce a framework for wireless real-time information granulation. A multidisciplinary solution is proposed. Vehicular Ad Hoc Networks (VANET) and Granular Computing concepts and technologies are utilized. This chapter will detail some of the existing literature on VANETS and Granular Computing.

Extensive feasibility studies have been carried out for a hierarchical, intelligent traffic data generation, dissemination and aggregation infrastructure with real-time characteristics. Latest developments in the fields of wireless communications, granular computing and vehicle communications have been studied.

Recent years have seen fast developments in infrastructure based wireless networks, like cellular networks and IEEE 802.11 b, g, a. However, scalability, coverage and latency issues inherent in this project as well as the ad hoc manner of the inter-vehicle communications directed this study towards the newly emerging wireless technologies of mobile ad hoc networks and vehicular ad hoc networks.

Given the multidisciplinary nature of the project, both the field of Vehicular Ad Hoc Networks and the field of Granular Computing have been studied.

For the Vehicular Ad Hoc Networks part of the study, current research projects and publications in the area of mobile ad hoc networks have been studied. Simulation and test results - which are preliminary in nature, given that the field is in its infancy – have been probed into and those early lessons learned from some of the most current projects have been considered with the view of the project. The very nature of mobile ad hoc networking together with its communication paradigm at levels of MAC layer, network and application layers and most pragmatic ways of interactions between them are yet to be established. However, studies in relation to scalability, communication protocols, mobility and node density have parallels to this project.

Developments in Vehicular Ad Hoc Networks - the recent specialised area of ad hoc communications – has been studied [1, 2, 3, 4, 5]. Latest projects and publications in the topic have been investigated. Different inter-vehicular ad hoc wireless communication strategies envisioned by those works have been evaluated and useful points are noted [42, 43, 44, 45, 101, 102].

From those projects and studies, a number of promising proposals for vehicle to vehicle and vehicle to roadside communication strategies and their simulation and test results have been studied.

For the information granulation part of the study, hierarchical processing and handling of data has been considered. Granular computing has been studied for inspiration in handling vast amounts of data at different levels [6, 7, 10, 11, 12, 13, 14, 15]. Techniques of the newly emerging Granular Computing have been found to be very promising for the data processing side of the project.

After detailed evaluation of the cutting edge developments in both fronts, an infrastructure for a collaborative wireless real-time information generation and distribution system has been proposed.

Below, some of the literature for Granular Computing and Vehicular Ad Hoc Networks has been surveyed.

2.2 Granular Computing and Granular Make of the System Architecture

Granular Computing is proposed for the information granulation component of the study. Granular Computing concepts are utilized for generating human-centric information granules in real-time.

Granular Computing is a newly emerging field of study. The field is drawing from different fields of study. As such, the field is at early stages of defining its borders. Current definitions and explanations are broad. Some of the popular explanations are as below:

"Granular Computing arose as a synthesis of insight into human-centred information processing by Zadeh [10] in the late 90's and the Granular Computing name was coined, at this early stage, by T.Y. Lin [60].

Granular Computing (GrC) as defined in the outline of the IEEE-GrC'2006 conference information, is a general computation theory for effectively using granules such as classes, clusters, subsets, groups and intervals to build an efficient computational model for complex applications with huge amounts of data, information and knowledge"[16]

Y.Y. Yao [11] divides the application of granular computing into two granular levels, as, structural thinking at the philosophical level and structured problem solving at the practical level.

Yao considers formal concept analysis as a concrete example of Granular Computing: "Formal concept analysis may be considered as a concrete model of granular computing. It deals with the characterization of a concept by a unit of thoughts consisting of two parts, the intension and extension of the concept. The intension of a concept consists of all properties or attributes that are valid for all those objects to which the concept applies. The extension of a concept is the set of objects or entities which are instances of the concept." [11]

"Among the basic concepts that underlie human cognition, three stand out in importance: granulation, organization, and causation. Informally, granulation involves a partitioning of a whole into parts; organization involves an integration of parts into a whole; and causation relates to an association of causes with effects. A granule may be viewed as a clump of points (objects) drawn together by indistinguishability, similarity, or functionality. Most of human reasoning and concept formation the granules are fuzzy. …Fuzzy Information Granulation [37, 38, 39, 46] plays a pivotal role in the remarkable human ability to make rational decisions in an environment of partial knowledge, partial certainty and partial truth. " [30]

"Granular computing is a newly emerging paradigm of using aggregations of data for closeness, similarity, indistinguishability, coherency, adjacency, size, etc to represent information as information granules for the purpose of solving, comprehending or reasoning about a specific problem." [6]

"Information granules do not exist as tangible, physical entities but they are conceptual entities that emerge in the ocean of information" [6]

Granularity of any universe is problem dependent. Granules are formed for needed abstractions. Qualitative Spatial Reasoning is used for determining granularity of the universe. It is to do with getting the right level of abstraction to generate the required knowledge or intelligence out of a universe. For different problems, different views of space can be considered. The project is an attempt to generate collaboratively processed knowledge as information granules, and to use this knowledge further in the upper hierarchies. Road and vehicles on the road take part in different aggregates, in different ways simultaneously to collaboratively generate different categories of knowledge granules.

One good example to granular computing is the work of Witold at al [18] on quantization. They give a good explanation of granular computing by using quantization as example: "Two things central to the design of the quantizer are distinguished first: the codebook (a collection of prototypes) needs to be constructed.

Second: one has to develop efficient decoding and encoding schemes. Using these, the compressed information is encoded (usually converted from numeric to symbolic form) and decoded. In a nutshell, the quantization is an example of information granulation. We create clumps of data that become encapsulated into a single symbol (entity) due to their similarity, close distance, or strong functional resemblance of the individual elements." [18]

Set theory is two valued logic. Fuzzy set [58, 59, 60, 61, 62] theory has a membership approach; each element in the universe has a membership value between 0 and 1. Shadowed sets are three valued constructs that have three values of full membership, full exclusion and uncertain.

Lotfi Zadeh draws attention to human cognition "The granules of age are fuzzy sets labelled young, middle-aged and old. The granules of height may be very short, short, medium, tall, and very tall. And the granules of truth may be not true, quite true, not very true, very true, etc. The concept of granularity underlies the concept of a linguistic variable—a concept which was introduced in my 1973 paper ''Outline of A New Approach to the Analysis of Complex Systems and Decision Processes. The concept of a linguistic variable plays a pivotal role in almost all applications of fuzzy logic"[31]

According to Zadeh, there are four basic rationales which underlie granulation of attributes and the use of linguistic variables. First one is the, the ability of the organs, and the brain, to identify detail and store information. Second one is, when numerical information may not be available. Zadeh gives an example to this and continues with the third rationale "For example, I may not know exactly how many Spanish restaurants there are in San Francisco, but my perception may be ‘‘not many.’’ Third, when an attribute is not quantifiable. For example, we describe degrees of honesty as: low, not high, high, very high, etc. because we do not have a numerical scale. And fourth, when there is a tolerance for imprecision which can be exploited through granulation to achieve tractability, robustness and economy of communication. For example, it may be sufficient to know that Monika is young; her exact age may be unimportant. What should be noted is that this is the principal rationale which underlies the extensive use of granulation, in the form of linguistic variables, in consumer products.” [31]

The fourth rationale gives us direction and insight to achieve robustness and economy of communication in the urban traffic systems where large amounts of data is generated in real time and ad hoc communication and networking is limited in many ways. To achieve a system with real-time characteristics, which is embarking on a mission of analyzing, observing and managing hundreds of thousands of roads and millions of vehicles in real-time, distributed intelligent data granulation in the settings of geographically bound local ad hoc networks, and bringing those ad hoc network level information granules temporally will provide the needed solution.

The original 0 or 1 set theory was invented by the nineteenth century German mathematician George Kantor. It was used as the basis of science for a long time until more human-centric logic was considered.

The German philosopher Ludwig Wittgenstein studied the ways in which a word can be used for several things that really have little in common, such as a game, which can be competitive or non-competitive. [29]

The first logic of vagueness was developed in 1920 by the Polish philosopher Jan Lucasiewicz. [29]

In 1960's, Lotfi Zadeh invented fuzzy logic [63, 64, 65, 66], which combines the concepts of crisp logic and the Lucasiewicz sets by defining graded membership. Many concepts are better defined by words than by mathematics, and fuzzy logic and its expression in fuzzy sets [67, 68, 69, 70, 71] provide a discipline that can construct better models of reality [29].

The project makes use of the concepts of GrC both in terms of the system architecture and the data processing within the system. The system is architected as different granular levels of data processing. Each granular level is semantically different and makes use of the previous granular level. For instance, the vehicle level information is fed into the ad-hoc network granular level which makes use of the data coming from the previous level to induce semantically new information granules by utilizing GrC formal methods and techniques. To form networks, vehicles on the road are granulated into ad-hoc networks. This is done by granulating the roads into network areas. Also temporal granulation is used for calculation cycles. Each network calculates at the same time intervals. Both the problem domain (vehicles and roads) and the time is granulated intuitively for real-time information/knowledge generation within the same granular processing level of the ad-hoc network level in the system architecture.

Roads are currently granulated into network area granules in a linear set based way in the simulator to model the system architecture, but the intention is to use fuzzy granulation to intuitively form network areas dynamically depending on the traffic conditions like speed, density and any other traffic parameters. In low speed and dense conditions network areas might be shorter then fast and sparse conditions. This will mean a dynamic topology formation using granular computing concepts to dynamically adopt the network topologies and optimize the system dynamics using fuzzy granulation concepts [72, 73, 74, 75] to make the system more suitable for the information granulation and knowledge induction process to follow.

The system takes a knowledge-oriented approach to information organization, processing and communication, as against a data-oriented approach. Communication between granular levels, are done at an abstracted level of information granules.

2.3 Vehicular Ad Hoc Networks

Vehicular Ad Hoc Networks provide the infrastructure to form constructs or information areas for information induction in real-time. Urban Traffic System is granulated into Vehicular Ad Hoc Network regions and local, Vehicular Ad Hoc Network level information processing is performed.

One generalized description of Vehicular Ad Hoc Networks (VANETs) is: "The Vehicular Ad-Hoc Network, or VANET, is a technology that uses moving cars as nodes in a network to create a mobile network. VANET turns every participating car into a wireless router or node, allowing cars approximately 100 to 300 meters of each other to connect and, in turn, create a network with a wide range. As cars fall out of the signal range and drop out of the network, other cars can join in, connecting vehicles to one another so that a mobile Internet is created"[22].

"A Vehicular Ad-Hoc Network, or VANET, is a form of Mobile ad-hoc network, to provide communications among nearby vehicles and between vehicles and nearby fixed equipment, usually described as roadside equipment. Most of the concerns of interest to MANets are of interest in VANETs, but the details differ. Rather than moving at random, vehicles tend to move in an organized fashion. The interactions with roadside equipment can likewise be characterized fairly accurately. And finally, most vehicles are restricted in their range of motion, for example by being constrained to follow a paved highway. In addition, in the year 2006 the term MANet mostly describes an academic area of research, and the term VANET perhaps its most promising area of application."[17]

The aim of vehicular ad hoc networks is to improve the Intelligent Transport Systems from a centralized to distributed way so that vehicles cooperatively solve traffic issues locally. VANET research focuses on safety and information applications, Electronic Toll Collection (ETC), car to home communications, travel and tourism information distribution, multimedia and game applications just to name a few. Initial projects considered adaptive traffic lights scenarios and vehicles being aware of their surroundings like vehicles around and also information about the area being broadcast.

"Crash prevention is the main motive behind ITS, therefore a number of applications have been specified. Crash prevention applications that rely on an infrastructure include road geometry warning to help drivers at steep or curved roads and warn overweight or over height vehicles, highway-rail crossing and intersection collision systems to help drivers cross safely, pedestrian, cyclist and animal warning systems to inform drivers of possible collisions, these systems become of vital importance at night or under low visibility conditions" [94]

There have been studies into wireless infrastructure. Wireless communication frequencies have been allocated for the purpose of VANET usage. In the United States, the band 5.9 GHz has been allocated as the Dedicated Short Range Communication (DSRC). With this, there is a physical layer development by the American Society for Testing and Material known as the ASTM E2213 standard. It utilizes Orthogonal Frequency Division Multiplexing (OFDM) for modulation and covers up to 1 KM range. The FleetNet project in Europe used UTRA-TDD. [94]

There are a number of vehicular ad hoc network study projects around the world like Californian Path [1], FleetNet Project [2], Cartalk Project [3], Network on Wheels (NOW)[96] , Car2Car[97], COMeSafety[100] The Vehicles on Wheels Project [86] being some of the earliest and most famous projects. Those projects and other similar projects deal with ad hoc networking among vehicles on the road. Current research is primarily concerned with network connectivity [87, 88, 89, 90, 91, 92, 93], network topology, and routing protocols [47, 48, 49, 50, 51, 52]. They aim to provide means of networking and they are not concerned with data processing [53, 54, 55, 56, 57].

The FleetNet project [1] investigates the aspects of vehicle communication on the road. FleetNet was setup by a consortium consisting of DaimlerChrysler AG, FhI FOKUS, NEC Europe Ltd, Robert Bosch GmbH, Siemens AG, and the Universities of Braunschweig, Mannheim, Hamburg-Harburg and Hannover [26].

FleetNet web site says: "FleetNet services and applications are divided into three categories: Cooperative driver-assistance applications (safety-related applications), Local floating car data applications, and User communication and information services. The applications belonging to each class pose their own particular requirements on the communication system in terms of delay, communication range, reliability, positioning accuracy, and bandwidth." [23]

Current VANET studies are mostly designed to research possibilities of infotainment and driver safety applications. Vehicle-to-Vehicle and Vehicle-to-Roadside communications are being evaluated to facilitate Internet or GIS based info and entertainment applications. Data processing is not considered much, as the focus is on getting the communications layer issues addressed, and standardizing ad hoc communications protocols. Recently work is focused on 802.11p WAVE as a protocol for VANETS [83, 84, 85] .

"VANETs (Vehicular Ad-hoc NETworks) are an emerging research area. Currently, most of the research is focused on the development of a suitable MAC layer, as well as potential applications ranging from collision avoidance to onboard infotainment services " [20].

This project envisages an Intelligent Transport System (ITS) utilizing vehicular ad hoc networks (VANET) techniques of inter vehicle communications (IVC) and Vehicle to Roadside Communications (VRC) to generate and distribute traffic information. A system is visualized with road-side gateways as backbone and ad hoc networks on roads having interaction with the roadside gateways in an ad hoc fashion, and gateway nodes tunnel information between the control centre and other vehicular ad hoc networks. This infrastructure of mixed and opportunistic make can enable distributed information generation and dissemination. Although the project focuses on bringing Vehicular Ad Hoc Networking and Granular Computing concepts together for information granulation, roadside gateway communications also form an important components of the system.

It is anticipated by the research community that some form of granular approach will need to be taken to VANETs as scalability is an issue. Raya, Hubaux say: “The scale of VANETs is another feature that sets them apart. With hundreds of millions of nodes distributed everywhere, VANETs are likely to be the largest real world mobile ad hoc network. But communication in this network will be mainly local, thus partitioning the network and making it scalable." [20]

FleetNet website describes data applications where vehicles broadcasting info and all the vehicles are receiving the data and making their own interpretations and then retransmitting all the data. "One typical application of this class is the distribution of traffic flow information. Each car is broadcasting data for example on its position, its driving direction and its velocity. Each application that receives such a data packet checks whether the content is of relevance for itself. If so, the received information is used to build up a picture on traffic flow on the anticipated route of the car. Each participating car periodically broadcasts data packets to other cars in reach. Beside its own traffic data, data received from other cars are included in these packets. Each application integrates the traffic data derived from other vehicles. For example old data are discarded, data about roads at larger distance is included less frequently, or missing data on roads ahead can be interrogated from cars within reach."[24]

FleetNet does have a gateway connected approach; the focus is on connecting multi-hop position based vehicular ad hoc network scatter nets through roadside gateways.

All this data receiving and retransmitting however do not provide any processing of the data. Large amounts of data generated keep getting retransmitted.

Fubler at al investigate characteristics of vehicular ad hoc networks in comparison to classical Waypoint ad hoc networks, and they test some routing protocols, and conclude that in multi-hop scenarios position based routing algorithms [76, 77, 78] are more advantageous for VANETS [25].

It must be noted that position based routing is not the same thing as the geographically constrained VANETS this study proposes. Position based routing is to do with forwarding packets, whereas, geographically constrained VANETS proposed is for controlling the network topology to provide enough granularity for problem at hand that is a concept of Granular Computing in return. Geographically constrained networks are a result of application of Granular Computing within VANET studies that this study proposes.

Network on Wheels (NOW) investigates communications protocols and data security algorithms. The study focuses on:

- Specification of position based routing and forwarding protocols;
- Adaption of wireless LAN under realistic radio conditions;
- Fundamental questions on vehicular antennas;
- Data security in vehicular ad hoc networks;
- Secure and fast communication between vehicles [96].

Another project is Car2Car. The manifesto of Car2Car[97] states:

The goal of the CAR 2 CAR Communication Consortium is to standardize interfaces and protocols of wireless communications between vehicles and their environment in order to make the vehicles of different manufacturers interoperable and also enable them to communicate with road-side units. The mission and the objectives of the CAR 2 CAR Communication Consortium are:

- to create and establish an open European (possibly worldwide) industry standard for CAR 2 CAR Communication Systems;
- to guarantee inter-vehicle operability;
- to enable the development of active safety applications by specifying, prototyping and demonstrating the CAR 2 CAR system;
- to promote the allocation of a royalty free European-wide exclusive frequency band for CAR 2 CAR applications;

- to push the harmonization of CAR 2 CAR Communication standards worldwide;
- to develop deployment strategies and business models to speed-up the market penetration.

“The Integrated Project PReVENT is a European automotive industry activity co-funded by the European Commission to contribute to road safety by developing and demonstrating preventive safety applications and technologies. “[98]

CHAUFFEUR in EU has studied platooning. “CHAUFFEUR has tackled the problem by developing systems which will increase the density of freight traffic while preserving safety and will use existing roads better. The systems involve a "Tow Bar" which links two trucks electronically. Traffic simulations have proved that this will increase throughput, permitting larger amounts of goods to be transported further in a normal working day. In feasibility studies, the concept has been extended to "Platooning" and "Automated Platooning", by which more than two trucks are linked electronically.” [99]

Preventive safety applications help drivers to avoid or mitigate an accident through the use of in-vehicle systems which sense the nature and significance of the danger, while taking the driver’s state into account.

Baumann and Rainer [21] study performance and usability of Vehicular Ad Hoc Networks. They concentrate on communication protocols and connectivity issues. They use Ad hoc On Demand Distance Vector routing protocol (AODV) [79, 80, 81, 82] for their simulations and they come up with some new approaches to protocols, they state: "we propose two new broadcasting mechanisms that try to minimize the number of broadcasting messages and to get more stable routes: the Secure Ring Broadcasting (SRB) and the Directed Route Node Selection (DRNS). SRB establishes routes over intermediate nodes that have a preferred distance between each other. This is beneficial for fast moving nodes with high density as in city scenarios during rush hours. DRNS has been developed for highway scenarios. It takes in account that nodes driving in opposite directions are a bad choice to be intermediate nodes in a route." [21]

Ouksel et al investigate resource discovery from the road. Vehicles find relative resources as they travel [27]. This type of studies consider discovery and of course dissemination of local information like restaurants and hotels in the area being broadcast.

C3 - Car-to-car cooperation for vehicular ad-hoc networks "envision a near to real time advisory system that is at once scalable, fault-tolerant and adaptable; it does not rely on any infrastructure installed on the roads, but adopts a cooperative model depending solely on the information collected by instrumented cars through their own sensors and via exchange with other vehicles they come across."[95]

The System Architecture proposed in this study, which is detailed below is designed and developed for the purpose of information granulation rather than infotainment purposes. In the projects mentioned in literature review, no data processing takes place neither any data is generated or communicated. The system architecture proposed is designed with the insights from Granular Computing field to generate human centric information granules using multiple levels of information granulation and the eventual application of fuzzy granulation to infinite amount of data generated by the Urban Traffic System is the main objective.

Spatial and temporal fuzzy information granulation at multiple granular levels is applied to the Urban Traffic System, and Vehicular Ad Hoc Networks are intuitively utilized for network level information granulation. Ad hoc networking topology and other parameters are superimposed to enable this objective.

2.4 Conclusion

All the studies show a trend to utilizing local and ubiquitous networking technologies in vehicles coupled with in-vehicle computing devices. This is becoming popular for new generation Intelligent Transport Studies, and as such it forms a strong base for this study. This study goes one step further from current research, which is generally into underlying technologies and network topology and routing protocols, to investigate scenarios of information generation. Current research on multi-hop scenarios where a limitless ad hoc network is assumed and vehicles keep passing information endlessly in a multi-hop fashion has provided a great deal of insight in forming the limited, geographically enforced ad hoc networks. The multi-hop vehicular ad hoc network studies have provided this project negative feedback in terms of controllability of such a network topology and semantic meaning of information obtained from such networks. As the proposed architecture focuses on information granulation at different granular levels, topology must have some amount of clarity, controllability and predictability to facilitate semantically right information granulation. Current topology studies are very useful in providing some answers to how to obtain meaningful information out of the system. By studying different studies it is possible to make observations to answer the question of what kind of a structure would be suitable for information granulation.

Location based routing studies like in FleetNet using GPS has parallels to this study in terms of utilizing GPS in urban traffic. Position based routing studies focus on routing algorithms for vehicular ad hoc networks.

FleetNet has provided some useful data on communication medium and the strength of communications. FleetNet has reported up to 1 KM communication range for their UltraTDD radio equipment. The FleetNet study concentrates on multi-hop vehicular ad hoc networks. In multi-hop vehicular ad hoc networks, vehicles are considered as network nodes and they forward information they receive to other nodes. This way, information is replicated well beyond the communication range of the communications medium from the initial source. Hence, network connectivity expands to wide areas as long as there are chain of vehicles within range to other vehicles from the source onwards. This study has provided a basis for considering real-time collaboration platform. To start with, FleetNet communication range has been taken as a realistic communication range. During simulations, communication range has been studied up to the reported range achieved from this study.

Similarly, the gateway approach where roadside gateways are utilized for information transfer has been helpful. FleetNet forms multi-hop networks that span in wide areas as long as there are vehicles within communication range to each other. This way, a single vehicular ad hoc network can span many miles. To connect disconnected networks in different areas or roads, roadside gateways are studied. This project has been designed to utilize roadside gateways for information transfer; and FleetNet approach has been supportive to the design.

As a whole, all the projects studied have provided some direction and assurance for this project. The studies in communication devices, communication protocols, networking topology studies and network maintenance studies have all provided assurance that VANET studies are here to stay and there is a common approval and support for their usage in the future. This project has taken encouragement and direction from the current research.

On the other hand, Granular Computing concepts have been utilized for information granulation. Problem solving approaches and fuzzy information granulation to obtain human centric information granules of Granular Computing have been noted.

This study is unique in the sense of using the disciplines of Vehicular Ad Hoc Networks and Granular Computing together. While vehicular Ad Hoc Networks provide the communication and networking mechanism, Granular Computing field is suggested for information granulation. Even, the architecture itself has taken a share from the Granular Computing in terms of approach and levels. This study uniquely attempts to bring together the accumulated experiences and knowledge of two fields.

The current literature on both Vehicular Ad Hoc Networks and Granular Computing are mostly on establishing main principles and tools of those two newly emerging fields. This study is an attempt to examine the findings of those two new fields of studies and apply them together to solve the problem of distributed, real-time collaborative information generation in urban traffic systems.

Chapter 3

System Architecture Design

3.1 System Architecture Considerations

The aim is to design an architecture to deal with the problem of very large amount of data generated in the urban traffic. The system will be utilising vehicular ad hoc networks to granulate the highly scalable information domain and the latest techniques of Granular Computing will be evaluated for generating human-centric information granules.

The architecture is going to attempt to address the problem of real-time local information generation in an environment that is infinitely scalable. Vehicular Ad Hoc Networks theoretically can span miles in a multi-hop fashion, can include tens of thousands of vehicles and cover entire cities and counties. This architecture will attempt to propose a solution to scalability of such a large system and utilize this architecture to facilitate real-time information granulation.

This architecture will attempt to propose a solution to the scalability of such a large system and utilize this architecture to facilitate real-time information granulation. The solution is provided by a geographically constrained Ad Hoc Network formation mechanism, which is detailed in section 3.2. According to this mechanism, vehicles only form networks in predefined geographical regions, the networks are enforced. Also, this mechanism uses a head node. Another attribute of this mechanism is it is short-lived only for the duration of one calculation. All these characteristics of Ad Hoc Networking are intuitively identified for this study. This mechanism will be designed to help with information generation with enough granularities. The architecture will also attempt to suggest a way of geographically constrained vehicular ad hoc networks. On top of such architecture an information granulation mechanism will be introduced.

Geographically constrained Ad Hoc Network formation algorithm:

1. Roads are divided into adjacent geographical ad hoc network regions.
2. Vehicles are loaded with data for each adjacent ad hoc network region and times for a calculation to occur on each such region.
3. Vehicles continuously check for current road ad hoc network region and check calculations registry to find our if there is a calculation request on the current ad hoc network region at the time
4. If a calculation is due, vehicles on the current ad hoc network region all know this and they all send network head claim messages simultaneously
5. Each vehicle will broadcast its location and each vehicle will receive those messages and calculate the middle node for them, and if any vehicle finds out that it is the middle vehicle, it will send a beacon to claim itself as the middle, and each vehicle will be expecting this. If more than one is received within a certain time, only the claimers will have a random wait and send claim again with a time stamp and the lowest timestamp will be accepted and all vehicles immediately sent information to the lowest one.
6. Head node will receive data from the vehicles and ad hoc network will end
7. Each time a calculation is due on a region, this short network formation mechanism will be repeated within the boundary of a geographically constrained adjacent ad hoc network road segment

3.2 System Architecture

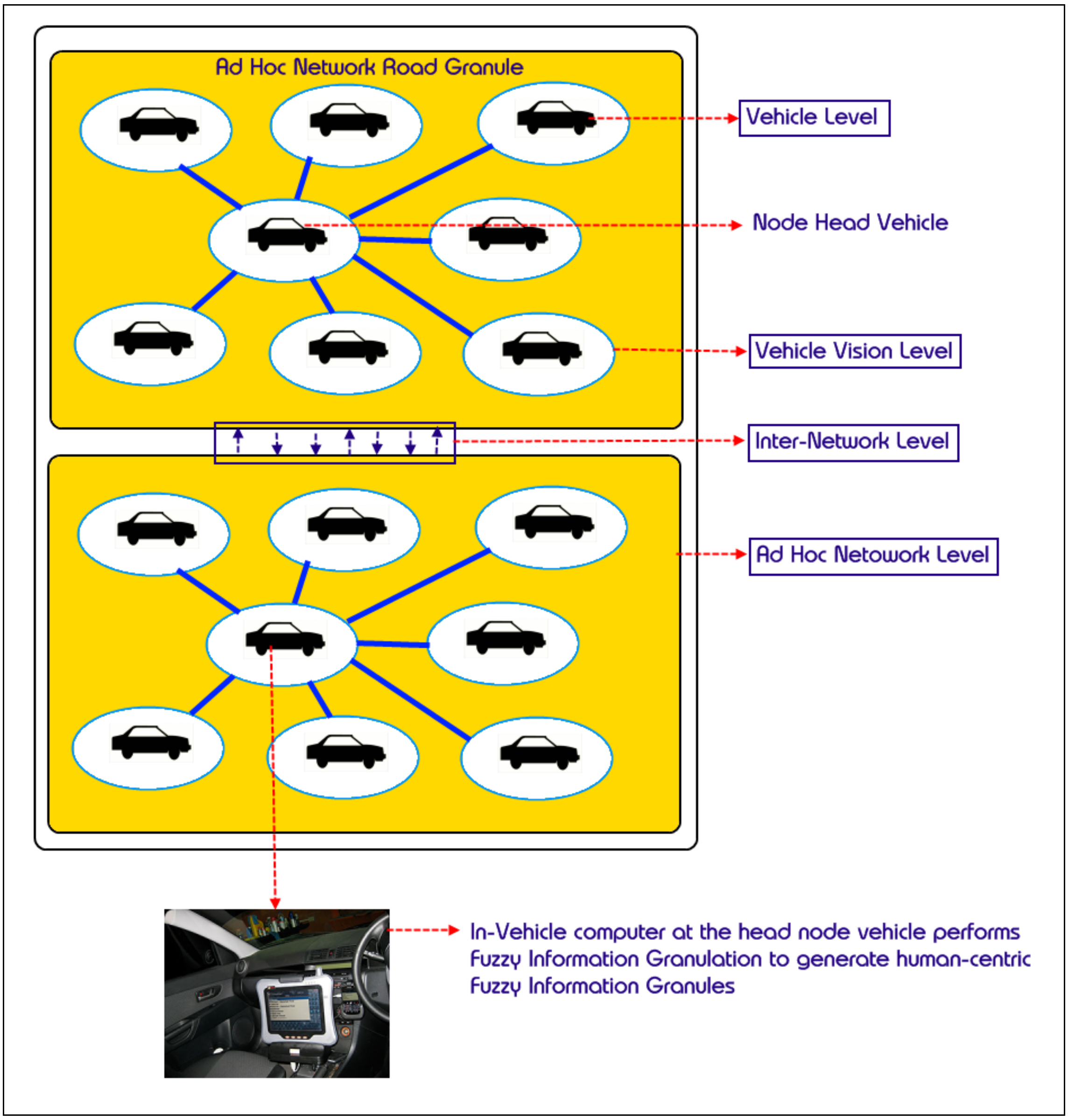


Figure 1 Vehicular Ad Hoc Networks on road

Figure 1 shows two separate adjacent ad hoc networks on a road. Each yellow region on the diagram represents an ad hoc network road granule. Within each road network granule vehicles are connected to a head node for calculation. Head node Information Granulation Engine then performs the information granulation.

Components:

Roads:

- Roads are granulated into ad hoc network road granules.

- Roads have wireless gateways.

Vehicles:

- Vehicles have wireless communication hardware. This may be in the form of two different radios in different frequencies, one to handle vehicle to vehicle communications at the vehicle level and the second one for ad hoc network level communications.

- Vehicles have inbuilt computing devices for processing.

- Vehicles have GPS equipment.

- Vehicles are loaded with map information. Vehicles are aware of roads and positions of road network region.

- Vehicles are loaded with information calculation times to be triggered on roads. (Vehicles check these calculation times against roads and form networks if a calculation is current on the current road)

- Vehicles are loaded with software for communications and calculations.

Operations:

- Vehicles keep checking their calculation maps against the current road they are on.

- If a calculation is due they check the current road pre-loaded tables for geographically enforced network regions on the road and send network formation and head node claim message.

- Head node is selected and vehicles broadcast information to head node vehicle.

- Vehicle networking software maintains the message exchange, sending and receiving is performed. Only the head node receives messages during an ad hoc network formation.

- Vehicle calculation software which is called Knowledge Granulation Engine processes information.
- Information granule is time-stamped and road and granule information is added and relayed to roadside gateways.

The system granulates roads into road network granules as spatial physical entities and enforces time triggered information granulation on those road intervals.

The architecture of the system concentrates on granulating the universe in an intuitive manner using the methodologies and formal underpinnings of Granular Computing. Granularity of traffic information has been identified in a progressive, iterative manner. Levels of data processing, as well as the underlying vehicular ad hoc networking, have been designed in a granular way to reflect the methodologies and philosophy of Granular computing. Intuitive approach, and enough granularity for the problem at hand principles of Granular computing can be mentioned as examples to be visible in the system architecture as a whole in both vehicular ad hoc network formation and granular information generation approach taken in the system.

Granularity of any universe is problem dependent. Granules are formed for the needed abstractions. Qualitative Spatial Reasoning approach is taken for determining granularity of the universe. It is to do with getting the right level of abstraction to generate the required knowledge or intelligence out of a universe.

In the case of this study, the issue was to generate local information granules in real-time using vehicular ad hoc networks. Granular Computing studies have identified an approach to consider the problem at hand, and then set the environment and abstraction according to the problem so that enough and needed amount of abstraction has been utilized to provide a solution to the problem at hand. This technique has directly contributed to the idea of having geographically enforced network topologies. This way, information granules can be generated for the locality of the geographic network granules. The conventional approach is to have multi-hop vehicular ad hoc networks in which vehicles are connected on a chain of network that has no limit to their boundaries. Local and specific enough information would be impossible to be obtained from such an environment.

The urban traffic system is a complex and large-scale system consisting of vehicles, roads, traffic management systems, pedestrians, drivers, etc. Traffic analysis and management is identified as one of the most challenging issues in the near future. Traffic management, emissions, jams, traffic infotainment systems, geographic location based services, driver safety and comfort, vehicle maintenance, vehicular ad hoc networking and route finding are some of the main areas of focus in current research.

The Urban Traffic System is generating large amounts of data at anytime. With the progress of technology the amount of data available is increasing fast. Currently, centralized Traffic Management Systems are not able to cope with the amount of data generated in real-time. Considering the scale of an Urban Traffic System spanning over a modern urban area and data generated in real time, it is simply impossible to feed such amounts of data into a central processing unit and have it processed.

Intelligent, decentralized ways of data processing, data mining, aggregation and intelligent information generation in local scope in real-time is the only way forward for any urban traffic system based real-time scenario.

Most applications of the future real-time systems will only be possible by solving the problems of intelligent information generation in a decentralized fashion and communicating it in a hierarchical fashion.

This project attempts to evaluate such a pervasive multidisciplinary system where large amounts of traffic data will be processed in real-time that utilize the latest developments in the fields of ad-hoc networking and Granular Computing.

The aim is to demonstrate a system that utilizes those technologies and suggest a multidisciplinary solution utilizing the ad hoc technology for intelligent knowledge generation.

So far, current research into vehicular ad hoc networks is about data communication only. This study is introducing pervasive and embedded ad hoc network-wide distributed intelligence for real time knowledge induction.

In a typical scenario, vehicles move around the urban environment. Each vehicle is expected to have Global Positioning Systems (GPS) in the near future and vehicles already have many embedded processors and sensors with expectation for more sophisticated systems in the near future.

The study envisages the usage of vehicle level data in local ad hoc networks to generate real-time local knowledge. Vehicles will form geographically localized ad hoc networks using their GPS systems and each ad hoc network will generate aggregated human-centric fuzzy information granules in real-time without the need for a centralized processing system and any infrastructure. Vehicles form temporally triggered simultaneous Vehicular Ad Hoc Networks on predefined road intervals and generate information granules. Vehicular Ad Hoc Networks are utilized to help with the information granulation process using a head-node chosen dynamically as the middle of the road network interval at the time of the triggering. This information will be calculated simultaneously on adjacent road intervals and roadside fixed gateways will be used to relay the information to central control office or other networks.

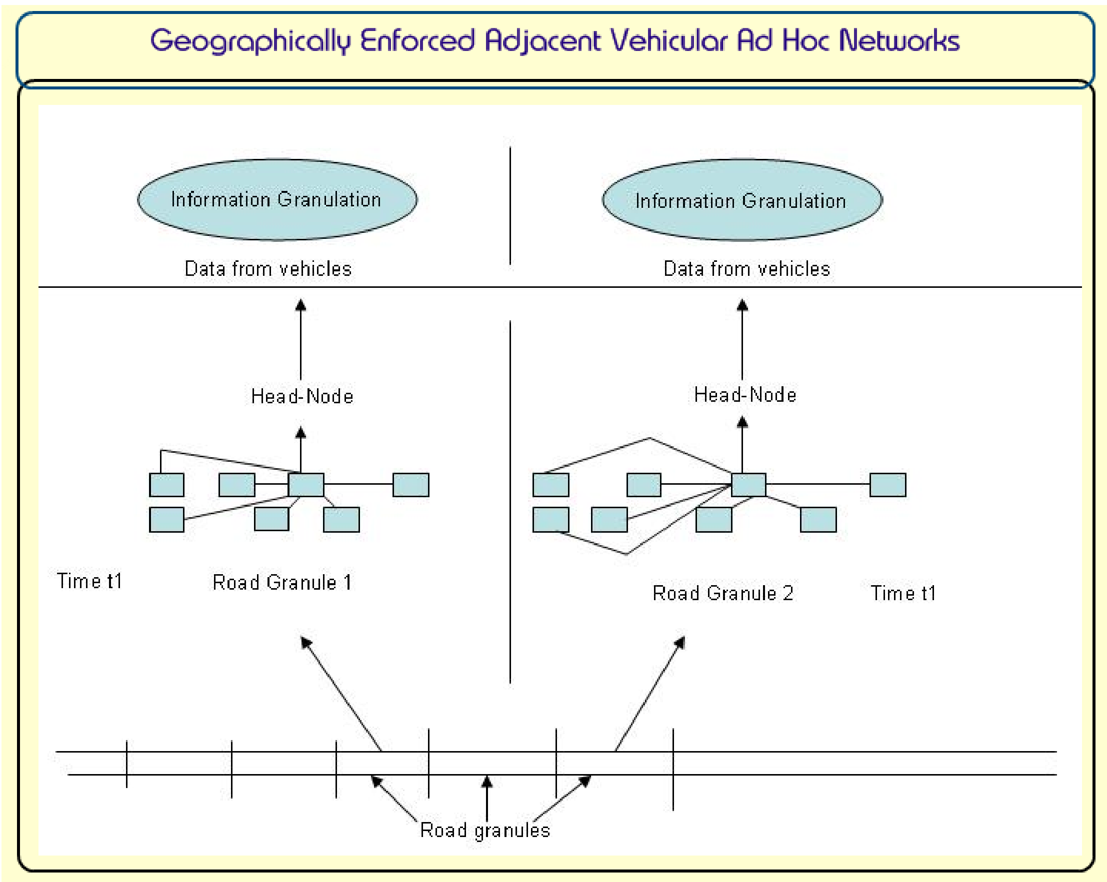


Figure 2 Geographically enforced vehicular ad hoc networks

Figure 2 shows geographically enforced vehicular ad hoc networks. There are two important software components residing on each vehicle that facilitates the information granulation proposed by this study. They are:

- Network Granulation Engine
- Information Granulation Engine

Those two components also represent the multidisciplinary nature of this study. Network Granulation Engine establishes and maintains ad hoc networks and Information Granulation Engine performs the information granulation.

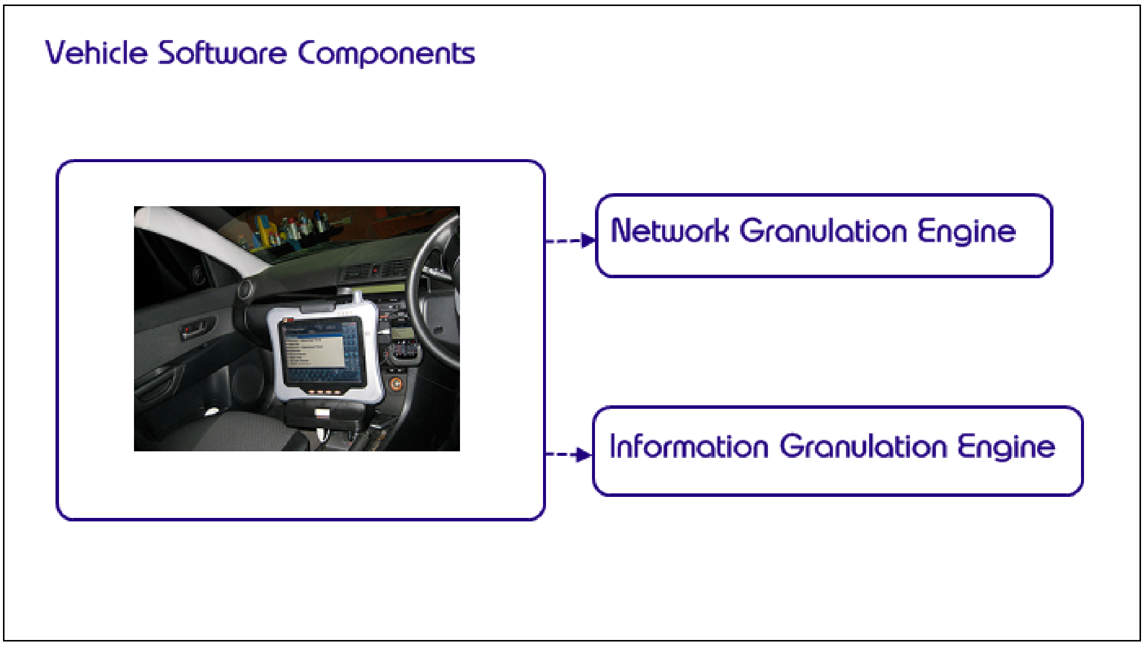


Figure 3 Network and information granulation engine components of the vehicle software

The information generated can be relayed to the control centre for a full view of the system or to perform further processing or can indeed also be used locally.

One interesting property of a road is its maximum speed limit. Each road has a maximum speed limit like 30, 40 or 60mph. This study identifies this property as being very significant for Vehicular Ad Hoc Networks. This property provides clarity as well as providing a degree of complexity into VANET studies. This study considers this property of the roads, and analyzes its impact on VANETS.

This study identifies and underlines the speed limit property of VANET environment, and demonstrates a number of studies relating to this property. Highlighting of this attribute of VANET environment can prove to be an important step in VANET studies.

After ad hoc network level information generation, vehicles then will be able to carry this information into other networks or pass them to roadside gateways which can eventually make their way to regional and central units for further aggregation with time stamps.

It is also possible to probe any area in the system from the centre asking for certain calculations using a broadcasting system to the area and receive a single information granule back summarizing the data from a large area.

This research project can provide a basis for a whole new way of urban traffic systems information generation, dissemination and usage.

3.3 Detailed Description of the Overall Architecture of the System

It has been a challenge to architecture a system with real-time characteristics given the scope of the problem domain and technologies involved. Ad Hoc networks, Vehicular Ad Hoc Networks and Granular Computing have been studied. Vehicles on the road are very unstable. Vehicles speed, slow down, change direction, stop, park, and stop at the lights, etc. Also, vehicles are considerably fast moving, any network involving vehicles as nodes will be very dynamic and complex.

The architecture includes roads, vehicles, intersections, and road-side nodes as elements. In a typical vehicular ad hoc network, vehicles are expected to have fairly powerful computing capability and radio communications platform together with GPS. Each vehicle is expected to hold in-built map of the Urban Traffic System. Each road on the map is split into virtual intervals. Those virtual intervals are predefined network regions on roads to facilitate a mechanism of geographically dependent ad-hoc networks to be formed simultaneously on all roads, and a road may have a number of such areas adjacent to each other. This way network topology is geographically controlled and area of a network is controlled for real-time calculation and information generation.

Roads are granulated into virtual geographically dependent road intervals. Each interval forms a virtual space for generating ad hoc networks between vehicles. Each road interval can only have one and only one ad hoc network and each vehicle can take part in one and only one ad hoc network. Figure 4 shows a road interval.

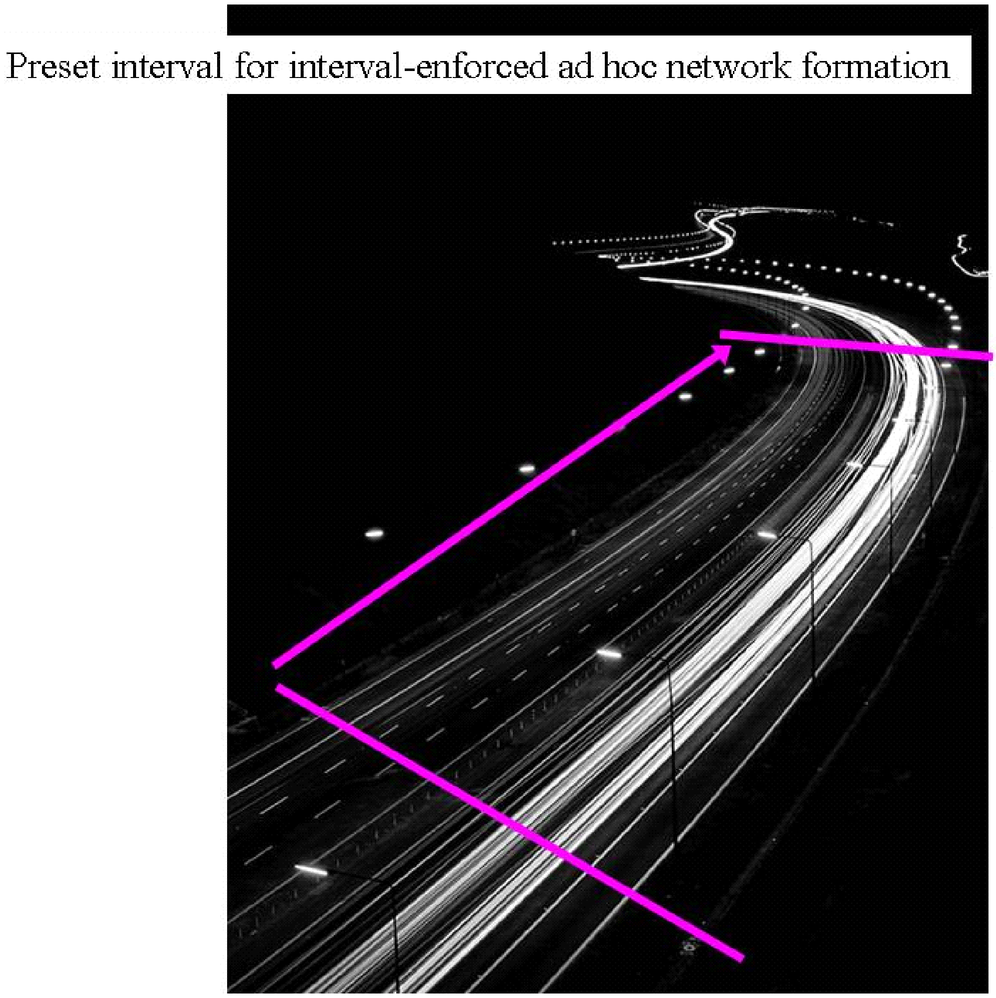


Figure 4 A road interval for ad hoc network

Initially, some studies have been made to discover the components of an urban traffic system, which can be utilized for this study. The initial studies of this project have led to some ideas about how a large traffic system can be formalized and granulated with a degree of uncertainty to allow information generation. These discoveries and formalization, leading to granular design and architecture, are new approaches opening doors to new properties of urban traffic systems that were not considered in such a formal granular way before.

The process of forming system architecture starts with vehicle level information generation and granulation. Only recently, inter-vehicle and vehicle-to-roadside communications became a reality, thus, not much attention has been paid to information to be generated by vehicles themselves and usage of such information. This has been taken into consideration. What is important is, this project is unique and revolutionary in considering generating human-centric information granules as knowledge granules which can be used at car level and network level immediately.

A three level approach has been taken. This means that there are three major granular views of the system.   Those levels are:

1 Vehicle level
2 Ad hoc network level
3 Inter-network level between ad hoc networks

This study specifically concentrates on ad-hoc network level as this level is the backbone of the distributed real-time information generation system this project is proposing. This study investigates the properties and behaviour of this ad hoc network level both in terms of its networking side and information granulation side.

Main components of the architecture are the network granulation engine and the information granulation engine. Network granulation engine is the name for the piece of software residing on each vehicle that deals with vehicular ad hoc network formation and maintenance. This component deals with the networking and also communications. Information is relayed and received at this component.

The information granulation engine is another component of the inbuilt vehicle software. The network granulation engine receives information at the communications level and passes this information to the information granulation engine to obtain human-centric information granules. Those two components are explained below.

3.3.1 Network Granulation Engine Module

The system is granulated using Granular Computing concepts. Roads are granulated into road intervals to form ad hoc networks. Vehicles on a road form ad hoc networks within the road intervals and they do periodic calculations and aggregations using the formal techniques of Granular Computing and Fuzzy Granulation. Fuzzy, Human form knowledge granules are generated as a result.

Each vehicle has an intelligent module called Network Granulation Engine. This module keeps an eye on the GPS location of the vehicle and matches the position to the in-built map of roads and road intervals.

The Network Granulation Engine, then establishes, maintains and re-establishes ad hoc network links in accordance with the network logic and the underlying protocols. This process will be explained further below.

3.3.1.1 Evaluation of the Need for a Master Node and Identification of Suitable Self-Organized Network Master Node Election Approach

A master node is proposed for each cycle of calculations. With the proposed architecture network level calculations depend on the master nodes and network formation and topology as well as maintenance depend on a master node. This point has been considered together with other mechanisms and found to be superior to other approaches like multi-hop ad hoc networking without network administration central point. Master node makes it more hierarchical and leads to centralized information granulation. This way; a human-centric information granule can be generated with a vehicle acting as the central point of processing.

3.3.1.2 Evaluation and Identification of a Suitable Routing Protocol in the Set of Disconnected Ad Hoc Networks

The granular approach with master node and cyclic calculations at set times clarifies the point of routing to some extent. As connectivity is set by the Network Granulation Engine module resident on each vehicle, following a clock and pre-set intervals to attempt to take part in a network connection and the network connection is only for the duration of the calculation and in the next cycle a new network with a new master node will be elected, this provides a good basis for the routing algorithm. This process is explained below.

3.3.1.3 Explanation of the Ad Hoc Network Formation

Vehicles form ad hoc networks on road intervals. Those intervals are geographically formed. Each vehicle is expected to carry a GPS equipment and a map of the area.

Also, vehicles will be loaded with physical road interval locations for ad hoc networks. Each vehicle will know its current location on the road and hence it will know the road interval it is on within the current road.

Here, it is expected that roads are granulated into ad hoc networking regions. Each road will have pre-set network interval regions, and vehicles will constantly keep track of their location using their GPS devices. This way, a vehicle knows what road network interval it is on at a given time.

A network granulation engine running in the car will keep track of this and network calculations. Each vehicle will be loaded a list of calculations. Calculations will be time dependent. Each vehicle will have a real-time clock to trigger calculations. Calculations will be triggered at the same time on each vehicle on the road for a road. Vehicles will keep their timers synchronized, so that each vehicle triggers a calculation at the same time. This way each vehicle knows when to attempt to form ad hoc network, and the type of calculation needed.

Time synchronization is an important issue. Vehicles normally will be in disconnected state and will only form ad hoc networks if they are triggered for a calculation. Other times cars will keep contacting to other vehicles on the same road interval and synchronizing their clock, also road-side gateway will provide a mechanism to make sure clocks are synchronized so that each car will know when exactly a calculation is due and seek to form a ad hoc network in its current road network granule. A satellite based time synchronization mechanism will also be suitable for time synchronization.

When a calculation is triggered, typically, an ad hoc network will be formed on each interval on the road at the same time. Calculations will be triggered on each road granule at the same time so that a temporal view of the system is formed by piecing the information granules together according to the timestamps as each information granule produces as a result of the calculation will have a time stamp and road name and road interval number information appended. Ad hoc networks are temporary and only for the duration of one calculation. An information granule will be produced at the end of the calculation.

After the calculation the ad hoc network will end. This is a truly ad hoc network. It was mentioned above that each vehicle will have a network granulation engine. This process will run in the vehicle keeping an eye on the calculation times and timer, and as soon as it is time for a calculation, it will check its current location from the GPS and send beacons to form an ad hoc network with the vehicles on the same road interval. A vehicle can only form ad hoc networks with the vehicles in the same road interval.

Network formation will be around a head node. This node will be the middle of the geographical road granule.

3.3.1.4 Head Node Selection Process

Each vehicle will broadcast its location and each vehicle will receive those messages and calculate the middle node for them, and if any vehicle finds out that it is the middle vehicle, it will send a beacon to claim itself as the middle, and each vehicle will be expecting this. If more than one is received within a certain time, only the claimers will have a random wait and send claim again with a time stamp and the lowest timestamp will be accepted and all vehicles immediately sent information to the lowest one.

In Summary, the characteristics of the system are:

- Each vehicle has a map of the area with roads and road speed information.
- Each vehicle has meta data loaded for the map that states locations of each geographic network interval.
- Each vehicle has GPS showing its current location, and vehicle keeps track of its location on the current road and the current network interval it is on.
- Each vehicle has information loaded for calculations to be triggered, this states calculation times for a road and exact time to trigger each calculation simultaneously on each and every interval.
- Vehicle has a module checking calculations for the current road interval and if one is due it tries to establish an ad hoc network.
- All the vehicles on the same road interval having the same calculation tables loaded are triggered to form an immediate ad hoc network, simultaneously.
- Vehicles form the network and do one and only one calculation and end the ad hoc network immediately.

Once a node-head vehicle performs the Information Granulation and obtains a human-centric information result, it will pass the information to the first road-side gateway it reaches. This way, all the temporal information granules from the adjacent Vehicular Ad Hoc Network road interval will reach to the centre. Information can also be passed to other roads for usage for example for other road vehicles to see how busy the current road is.

Also, roadside Gateways can have logic built in to form groups on roads to perform road-level calculations. All the gateways on a road can be grouped into a network, and all the road network interval level calculation result as information granules can be received by those roadside nodes, and all the gateway nodes can perform a further aggregation by using time stamp on data received to form a temporal aggregate of the information received. This way, a single human-centric road level information granule can be reached. This information can be passed directly to other roads through roadside gateways and can be used by other cars for decision making, journey planning or safety.

3.3.2 Knowledge Granulation Engine Module

On top of the Network Granulation Engine, resides the data processing and knowledge generation module called, Knowledge Granulation Engine.

While the underlying Network Granulation Engine establishes and maintains the network, and deals with data flow, the Knowledge Granulation Engine processes data.

Concepts of Granular Computing can be utilized for Knowledge Generation.

Granular Computing deals with Information Granules. It has firm formal foundations using Fuzzy Sets, Rough Sets, and Set Theory among other mathematical fields.

Ad Hoc Networks at each interval act as a coherent unit to perform one calculation at set periods, and produce a single Information Granule each time, using data received from vehicles. This knowledge is then relayed to the Control Centre and drivers in different ways through the roadside gateways.

The Knowledge Granulation Engine resides within each and every vehicle. Once vehicles are triggered to form a vehicular ad hoc network and perform a calculation, a temporary vehicular ad hoc network is formed for the duration of one calculation. The mechanism to form the network is explained above which uses a head node to eventually perform the calculation. The Knowledge Granulation Engine is utilised by the head node to actually perform the information granulation process on the data obtained from the vehicles in the temporary vehicular ad hoc network.

Knowledge Granulation Engine is concerned with algorithms for information granulation. Here Knowledge Granulation Engine is a term used to name the software component performing Information Granulation. This component has been named this way because it deals with the unprocessed knowledge received from the system. This is an area that is standing for future study. Knowledge granulation at this level can be using the classical set based or fuzzy algorithms. To provide human-centric information granules, concepts of granular computing and fuzzy information granulation would be most suitable.

Algorithms for the environment which has peculiar characteristics like time constraints can be subject to a separate study. Extensive research on the matter has not been possible during this study.

3.3.2.1 Fuzzy Information Granulation and Hierarchical Knowledge Construction

Fuzzy information granulation is a way of generating human-centric information granules. It is very suitable for the information granulation engine component of the vehicle software.

"Information granules such as high speed, warm weather, and fast car are examples of information granules falling into this category. We cannot specify a single well defined element that forms a solid border between full belongingness and full exclusion. Fuzzy sets, with their soft transition boundaries, are an ideal vehicle to capture the notion of partial membership."[19]

This architecture proposes to use VANET and Granular Computing methods collaboratively to achieve fuzzy information granulation as localized distributed information granules with the system having different granular levels.

The aim is to process traffic information data generated in a hierarchical way to mimic a human-like abstraction process using fuzzy set theory and granular computing. The real and essential focus of this study has been on the distributed manner of the system, and ad hoc network level local and distributed data processing and information generation has been the real aim, which deals with the problem of infinite and limitless data being generated at a given time and there is no way to collect and process such amounts of data. However, at the lower level, producing human-centric information granules helps to generate data in a distributed fashion.

Fuzzy information granulation makes it possible to generate human-centric information granules to be produced. Later a case study using the linguistic variables will extend this subject further.

Using the fuzzy granulation knowledge for different purposes in different granularities can be generated like:

Safety: Accident, Break Failure, Skidding, White Ice, Tyre Puncture, Low Break Fluid

Traffic Management: Vehicle Density (sparse), Speed Ratio to Max Speed (medium)

Other: CO2Level (low)

3.3.2.2 Levels of data processing

Granularity of any system is problem dependent. Granules are formed for the needed abstractions. It is to do with getting the right level of abstraction to generate the required knowledge or intelligence out of a universe. This project is an attempt to generate collaboratively processed knowledge as information granules, and to use this knowledge further in the upper hierarchies. Road and vehicles on the road take part in different aggregates, in different ways simultaneously to collaboratively generate different categories of knowledge granules.

There are three main granulated levels of information that have been identified for this study, those levels are:

- Vehicle level (Local) + Vehicle Vision level
- Ad hoc network level
- Inter-network level

Each one of these granularity levels is unidirectional. A construct of any kind of hierarchy is only formed by the vehicles travelling in the same direction on a road. However, there might be some kind of interaction between the opposite directions if a case is identified suggesting it would be useful. As hierarchical wireless framework is established for collaboratively generating data in real-time, the most significant portion of the collaborative knowledge generation scenarios that have been envisaged initially require granular constructs that have directional and temporal unity of some form.

These three granular levels will be connected with each other using different formal settings and physical means. Static road side nodes and free-moving vehicles will facilitate communications for some calculations while a lot of the calculations will be in real-time for many local processing problems.

3.3.2.2.1 Vehicle level

This is the local level. Some of the related parameters to a vehicle are current GPS location, current road and lane, Current Speed, Average Speed in last 5 minutes, Highest and lowest speeds in the last 5 minutes, break usage, windscreen wipers on/off, headlights are on/off, slowing and stopping distances, general flow of driving, etc.

3.3.2.2.2 Vehicle vision level

Vehicle vision level is an extension of the vehicle level. This ‘Vehicle Vision Level’ is not an ad hoc network; it is view or vision of each vehicle. The vehicle a, in front or vehicle b at the back would have different views as the clustering algorithm will take the vehicles a and b as the centre of their vision clusters respectively. This view is useful to generate some calculations which cannot be calculated at the car level without seeing vehicles around and getting some data back, but there is no need to form an ad hoc network for this scope. However, ad hoc wireless communication will be used for vehicles to form this vision. At this level only some message broadcasting of the vehicles is needed. No need to establish a two-way communication, or connectivity. Vehicles listen for incoming messages marked as ‘Vehicle Vision Level’ and process them.

It is important to note that this is only a level or a granular view among others. Ad hoc wireless capabilities are deployed to broadcast information. At this level, only the messages marked for this granular view will be processed. However, as there are other levels or granules existing in parallel to this level in space and time, there will be information being broadcasted simultaneously for those levels. A vehicle will be involved at these levels at the same time; broadcasting, processing, receiving data, and information.

To make this simultaneous communications possible, two different radios with different frequencies can be used.

Vehicle Vision Level is a virtual vehicle specific universe. Each vehicle is expected to have a view of its immediate environment. This environment is within a few vehicles to the front and back of the vehicle as well as any vehicles to the sides which are the adjacent lanes. This space is to be determined intuitively. Each vehicle has a kind of personal space around itself which is a fuzzy space rather than crisp. The vehicle will have a gradually fading view of its space which will be grey on the outer edges. As vehicles will be close to each other, inevitably they will be in each others vehicle spaces. This gives a cluster of the main universe into smaller fuzzy clusters taking each vehicle as the centre of the cluster/vehicle Vision. Clustering algorithm is to be formed intuitively by considering the proximity of the vehicles to the vehicle in question which is the middle of the cluster.

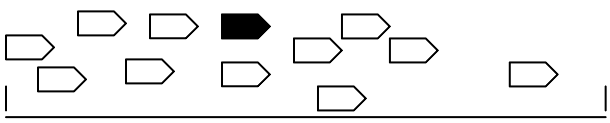


Figure 5 An interval containing vehicles within the Vehicle Vision Space of the vehicle V which is filled in black. This is the vision of the vehicle V. All the other vehicles also has their own vision intervals.

Each vehicle is to form a picture of its environment and calculate a fuzzy metric to indicate how free it is to move faster for showing vehicles' freedom degree from congestion. So, congestion may be considered differently for each vehicle in real-time depending on their freedom of movement and speed put together rather as being centrally calculated. This knowledge will be vehicle specific calculated using Vehicle Vision Level. This knowledge can be further processed collaboratively at the ad hoc network level between vehicles to generate a metric for a road interval A[x, y].

The Interval A[x, y] represents a road segment which is covered by the ad hoc network at a particular time and space. The calculation is done in real-time collaboratively by the vehicles, which form an ad hoc network according to the ad hoc network clustering algorithm.

Each vehicles' personal space in turn can be further clustered into four clusters which are Back, Front, Left and Right which feature other vehicles according to their place within the vehicle personal space.

3.3.2.2.3 Ad hoc network level

This is the network level. The network level is formed intuitively. This is the most important granular level of the system.

Ad hoc network level is at the heart of the system. Intelligent spatial and temporal calculations at this level, is the most important aspect of the system. Real-Time intelligent processing at this level is used to make the system information available in Real-Time as human-centric knowledge granules.

As the computing and communication technologies progress and provide better means for information generation and dissemination, the challenge is to semantically process the infinite amount of data, and generate information granules for a given context in which the summarized or processed data will make sense.

Ad Hoc network level fuzzy information granulation aspect of the system is proposed as a promising solution to Real-Time systems with large amounts of data and high complexity.

Also it is the most complicated layer. When forming the ad hoc network it should be formed intuitively. Physical constraints of the communication medium should not control the topology, for example, vehicle coming on the opposite direction might not be considered for a particular scenario. Ad hoc networking research has been concentrating on the network topology of such dynamic environments recently. In vehicular ad hoc networking studies the tendency is to consider network topology in terms of communication medium range and, in multi-hop scenarios network topology is considered to be as far as the network can reach. Using granular approach to problem solving, this project is suggesting a geographically bound network topology.

This project brings a new approach to vehicular ad hoc network topology by suggesting an architecture to control and manage network topology. Also, current research focuses on the issue of connectivity and network topology studies are mostly addressing connectivity and some scalability studies are being built on it. This project is utilizing ad hoc networking with the aim of obtaining real-time human-centric information generation in a distributed fashion. As such, the project intuitively suggests a new approach to network topology to suit such information generation and also the scalability necessary for such large systems.

Roads are granulated into spatial ad hoc network regions as road network granules. Geographically pre-defined virtual ad hoc network spaces are provisioned nationally and data relating to boundaries of those ad hoc network granules on maps are loaded into in-car devices with GPS capabilities. Vehicles are aware of their positions on the map at all times and vehicles also keep track of their current ad hoc network virtual granules. When triggered, vehicles form ad hoc networks within those virtual granules.

Each vehicle will have a calculation information module loaded. This will provide the vehicle with information times of calculation for certain information granules. This module will trigger calculations when the time is reached. When a calculation is triggered on a road granule virtual spatial interval, vehicles will send signals for connection, broadcast and receive messages with GPS position information. As vehicular ad hoc network formation will be triggered according to preset times that are loaded for all the vehicles, each vehicle on a road will be triggered at the same time by a universal clock. Vehicles will only consider communication within their road interval granule, as all the connection information will have GPS location.

Once discovery information is sent, vehicles check their location in the virtual network granule and compare other vehicle positions from the beacons and greedily claim to be the head node if they think they are the middle or nearest to the middle vehicle in that interval. If more than one vehicle claims to be the head node, only the claimants negotiate between them, and eventually one of them send a beacon for definite head node claim. Once definite head node claim is received from a vehicle, all the vehicles on the road send their data to that head node and end communication. Head node then granulates the information received as fuzzy information granule in human-centric form.

This calculation is done on all the roads at the same time and each road has virtual network granule spaces.

Communication range is superimposed. A vehicle might need to communicate with the immediate neighbour in a given context whereas the communication range physical medium might be 300 to 1000 meters depending on the communication medium used.

At the ad hoc network level, vehicles are considered as network nodes. They form a temporary network to perform some calculations.

A set of calculations are performed on some information granules coming from the lower level of the vehicle level.

Vehicles are seen as nodes, and the nodes are abstracted to be entities of the fuzzy set in the case of fuzzy information granulation.

The set of nodes each expose a set of parameters in the form of processed information granules.

Virtual Networks:

Virtual networks partition the population. Each network can be viewed as a cluster with a cluster head. This virtual network can either be connected to other virtual networks (clusters) or disconnected. Cluster head is re-calculated, and clusters (virtual networks) are re-calculated for each new calculation for the purpose of generating new information granules.

At the ad hoc network level, vehicles are considered as network nodes. They form a temporary network to perform some calculations. A set of calculations are performed on some information granules coming from the lower level of the vehicle level.

There are two major issues with this level:

- Granulation of the vehicles into ad hoc networks in a given road interval
- Granular information processing and generation of network level information granules

Vehicles are seen as nodes, and the nodes are abstracted to be entities of the set that is the ad hoc network. The set of nodes each expose a set of parameters in the form of processed information granules.

This research dealt with the definition of a couple of useful scenarios and definition of the characteristics of the information granulation process looking at the lower level information granules that are used in the ad hoc level to generate collaborative network level real-time information granules and possible usages of such knowledge granules.

There are many scenarios where ad hoc mobile network clusters might be utilized to generate useful information granules. Some of those are:

- Traffic density on a road interval
- Lane density for a given road or interval
- Road conditions (Bumpiness, breaking distance, visibility, weather…)
- Average Speed/Road Speed ratio
- Junction light management and road-side sign, even road speed maintenance in response to ad hoc network level information granules.

Finding out traffic conditions is an important issue for a given road or road interval at a given time. There are attempts to predict traffic patterns and also to obtain real-time traffic information but these systems are largely centralized. Such systems have to be brief and selective, they have to favour certain places, as it would be impossible to centrally process the infinite amount of data effectively.

3.3.2.2.4 Inter-network Level

This level is a combination of ad hoc networks in an Internet fashion. Ad hoc networks from the level before (*Ad hoc network level*) will connect together to make inter-network calculations.

This granularity can be implemented in two ways:

- Ad hoc networks can be superimposed by an algorithm to form the most intuitive setting by generating ad hoc networks at the lower level in such a way that their boundaries and sizes are most suitable to form inter-networks and knowledge generated at that level is best generated in that setting. In some cases there might be a need for a compromise, where two different knowledge granules will be generated independently and one favours a larger ad hoc level participation, i.e., longer interval of the road is considered but on the other hand, superimposing particular constraints on the lower level ad hoc networks best serve the needs of the inter-network connectivity and calculations.
- Secondly, vehicles might form networks with vehicles around them arbitrarily, with no superimposed constraints

Also, size and extent of inter-network might also be formalized to consider different situations. For example, if there is a situation where a busy motorway is running for miles and there is enough density to have a 100 mile long inter-network. Obviously, this would be an impossible and equally useless scenario, so a threshold may be used and this may be a fuzzy threshold.

Reverse Communications: Vehicles normally are expected to be forming directional granules. At some situations vehicles in different directions might need to be communicating. Ways of handling this seem to have different characteristics. It can be used for message/knowledge passing. No calculations or connectivity at this level is envisaged.

3.4 System Architecture Utilization through a Showcase Scenario

These are some preliminary settings to illustrate some initial ideas formed on the structure of the system. This section is included in the design chapter because this represents a brainstorming on the question of what exactly the system is going to do and how it will do it. This is a simplistic scenario approach to come up with a tangible example to capture the mechanisms of operation in such a system so that the framework design considers the elements to make this achievable.

This section also gives the nature of approach taken to model and understand the system and its components. Initially, an environment with 3 different domains of information generation is envisioned. This evaluation helps to logically solidify the design ideas and think through the conceptual model.

3.4.1 Level 1

This is the vehicle level. Data is generated by vehicle. Some data might be picked from outside like other vehicles and road side devices as well.

Initial thoughts were that, it was likely that data will be generated in independent domains. However, it could also be said that these domains would be totally independent of each other. It may be the case that there is a spiral DNA like structure where each domain is independent but there is a degree of interaction. It seems like there are domains that are in some way related. (These were initial feelings about the shape of such a system, it must be remembered that when this research started, there was no consideration of granular computing application in literature that is in the environment of ad hoc networks or more specifically vehicular ad hoc networks.) This relation is neither between the domain elements, nor the subsets of the domain, but rather it is likely to be the case that two subsets from two separate domains are put together like a kind of inter-domain t-norm relationship. This issue is open to be analyzed and formalized further.

Let X be a discrete domain for Lane Speed.

Fuzzy sets LowSpeed, HighSpeed, MediumSpeed : X -> [0, 1]

Each set will have a membership function for variable x in domain X.

LowSpeed(x), MediumSpeed(x), HighSpeed(x)

It will be the case that each road will have different speed rules, this will be obtained using the inbuilt map and satellite navigator. This information will be used to granulate the domain space. There will be a domain granulation function for domain X, using this information as input.

Xgranulator(variable) = LowSpeed, MediumSpeed, HighSpeed.

Xgranulator(50) = {0…….20} {18………..38} {30…….50}

At level two, these granules will be processed further to construct higher level granules for the temporary network.

3.4.2 Level 2: Car Slowing Fast Condition

Lets assume that each time a car slows down, it broadcasts an information granule for the kind of slowing it is doing.

SlowingVerySlowly, SlowingSlowly, SlowingQuickly, SlowingVeryQuickly, SlowingAtBreakLock.

Cars listen to each other's information granules, and judge them. They warn the driver when they receive the knowledge that the car in front is slowing at break lock if it is a car in "Very Close Proximity" and "In Front" from a SlowingAtBreakLock granule.

This usage is an example of how a fuzzy information granule can be used at that level in real-time.

So, "SlowingAtBreakLock" + "Very Close Proximity" = "Warn Driver"

The two granules of the two different domains are used to make a decision granule. There is no low level processing or central interference, the vehicle in front is broadcasting Fuzzy Information Granules as abstracted knowledge. The knowledge is in human form and used directly without any further processing. No raw data is coming out of vehicles, only processed high level granules.

If a few cars in close proximity give the same granule "WarningToDriver:TooFastSlowingOfCarInFront" then this might be recorder for the geographic location as the granule "DangerousSlowingInMass:InLocation".

DangerousSlowingInMass:InLocation" is a Level2 network level granule, induced by 3-4 cars giving the dangerous slowing for their slowing type. Some others might slow more sensibly, so information generated is ambiguous. This granule is to be constructed at the network level by all the cars (cluster head approach) and also send to the centre for further processing as well as being used temporally and may be in a location specific way.

Summarization of steps for congestion calculation:

Figure 6 shows typical steps for information granulation.

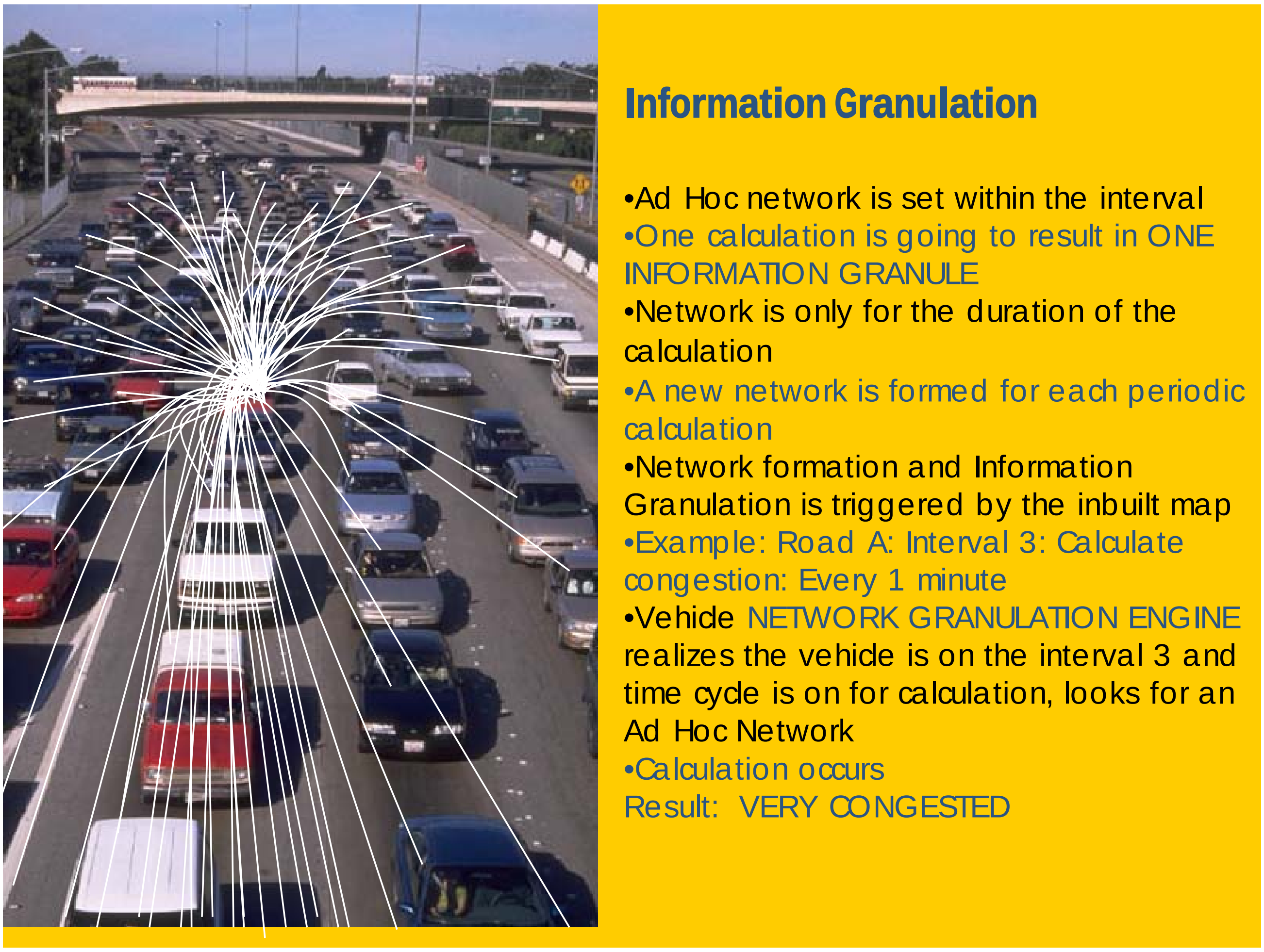


Figure 6 Demonstration of Information Granulation process where vehicles are relaying data to the selected head-node for one cycle

3.4.3 Level 3- Internetwork Level

Centre receives this level 2 granule and others. Centre might consider similar domain granules for all the system or for that particular geographic area or road.

Centre might use the granule as it is without further processing, as it is a fuzzy information granule in human-centric form knowledge. For example, centre might investigate the reason why so many cars were dangerously slowing at the same time in that spot.

Centre might look and see if the same granule is recorded for the region over a period, i.e. If more than 3 to 8 times a week, then the level 3 granule “Urgent Action” is produced. This might be due to some road condition like there is a hole in the middle of the road that is causing vehicles to break at that location.

“UrgentActionNeeded”, “Some AttentionNeeded”, “NoAttentionNeeded”…

These were some of the brief initial scenarios for the proposed system which has three granular views, helping to observe some patterns of operations to design a framework.

The next section exemplifies the operation of the scalable, collaborative, distributed real-time information generation system.

3.5 Explanation and Evaluation of the System through a Speed Showcase Scenario

This is another attempt to check and illustrate the framework set above. As well as logically putting the system components suggested above, the idea is to give a concrete speed related example to represent the system functioning.

One scenario identified previously is the “Average Speed/Road Speed ratio” for a given road or road interval. This can be an indicator of the traffic movement rate for the road interval concerned.

Lets say, Speed Limit for the road A234 is 60 miles per hour (MPH)
Average speed of the vehicles in a given road interval is 25 MPH.

This will logically indicate that those vehicles at the given location are slow; information granule generated would be something like “Badly Jammed”. Here we are slowly starting to define a model. What we want to know is what is the traffic jam or speed is like in the segment A[a, b] interval of the road A234. We want to go from point A to point B and want to evaluate two alternate routes if possible to find out the current traffic speed and density before selecting one.

We obviously need high level, human understandable knowledge granules. What kind of knowledge would we expect and find useful.

We will certainly expect to hear a measure of traffic situation to help us to choose between two or more alternatives and when we do choose one, we will have a more comfortable journey. This is not necessarily the fastest route as a route might have less jam but might be longer and the driver might prefer driving faster for longer time than sit in the traffic less.

A set of such measurements can be:

{normal, a bit slow, jammed, very jammed, critically jammed, standstill, closed}

Now, we want to get one of those indicative values for a given road interval A[a, b]. At a given time there might be a number of vehicles at that interval. What we are interested is an average value from those vehicles in the form of one of the above linguistic variable values.

The vehicles in the interval will form a temporary mobile ad hoc network for calculating this value. Considering the example above, let us say there are 5 vehicles at the given time within the interval A[a, b] of the road A123.

Max road speed is 60 MPH. Each vehicle is equipped with satellite navigation equipment, an inbuilt map and some other necessary data on the road and the particular interval to allow them to make the calculation.

Max road speed on its own can be misleading. Each road and intervals in roads are given realistic speed values are loaded into the vehicle system. For example roads have sharp bends in them, and speed in those bend areas can be very low. Vehicle considers this when generating its AVG Max speed/current speed ratio.

Let us say interval A[a, b] has a realistic speed of 50.

The vehicles in the interval establish an ad hoc network and chose a cluster head for the collaborative real-time calculation of the speed/jam indicator.

Here the cluster head can be chosen to be the one nearest to the middle for example using K-Means a clustering algorithm.

Once this is done each vehicle sends Realistic Speed – Current Vehicle speed.

Vehicle A = 50 – 30 = 20

Vehicle B = 50 – 20 = 30

Vehicle C= 50 – 25 = 25

Vehicle D = 50 – 25 = 25

Vehicle E = 50 – 25 = 25

Cluster head calculates an average speed difference from the Realistic MAX

(20 + 30 + 25 + 25 + 25) / 5 = 125 / 5 = 25

The result is: The vehicles in the interval A[a, b] of the road A123 at time T are moving 25 MPH less than the Realistic MAX speed.

Let us say this is very jammed.

The network releases the result as the road interval A [a, b] of road A123 is "Very Jammed" at time T.

This can further be used by the inter-network level to calculate a common value for adjacent road intervals.

A [a, b] = “Very Jammed” at time t1 = 12:30

B [b, c] = “Very Jammed” at time t 2 = 12:35

C[c, d] = “Very Jammed” at time t1 = 12:30

Let us say we can combine calculations made at different times to each other as long as they are all in the time interval T[t1, t2] = T[12:30, 12:35]

Situation between junction 23 and junction 24 of the road A123 is “Very Jammed” at the time interval T[12:30, 12:35]

As a result the driver gets a collaboratively generated high level information granule to help him to make a decision. Multiple levels of processing were carried out. First the Vehicle level granules are generated in the form of Realistic Speed – Current Vehicle speed, then Ad hoc network processed these granules further to generate higher level granules for the network within the interval at a given time.

Then in the 3rd level the network level information granules were put together for the adjacent interval to generate knowledge granules for a longer interval. When doing this only the ad hoc network level collaborative information granules within the time interval T[a, b] were accepted.

The result has been a human form information granule for a given short and sensible time interval to sufficiently and accurately show the road condition to the driver.

This was speed related. A density based calculation could be done in a similar manner.

This is a set based approach to information Granulation. Fuzzy Granulation and approximations would yield more human-centric information granules as fuzzy granulation makes the process more human-like. This exercise and similar exercises and problem analysis scenarios proved to be very useful in getting the network topology and the overall system architecture right. Other levels of granular processing also need to be in line with the expectations of the incoming data and the resulting information granules generated at this level for getting a coherent granular model.

The data coming from vehicle level above are stated as numeric data and internally represented as crisp sets. This vehicle level data can be granulated using the techniques of fuzzy granulation. For example each vehicle can disseminate information in the form of Human-centric fuzzy information granules like:

Stopping Distance: {normal, nearly normal, not normal, bad, dangerous}
Breaks: {normal, nearly normal, not normal, bad, dangerous}
Speed:{too fast, very fast, fast, slow, very slow, stationary}
Break Usage in last 2 minutes: {too much, a lot, considerable, some, a little, none}

In this case, as it is typical in fuzzy granulation, some data precision is lost for the benefit of convenience and human-centric knowledge granule generation.

3.6 Information Processing at Head Node

This section introduces the computations performed by the head node for information granulation by using an example scenario.

Linguistic variables are an important concept to represent information in human-centric terms. Information granulation at the vehicular ad hoc network level can be done using the linguistic variables as its formal basis. This is an addition to the illustration above. The illustration above was an attempt to clarify the way the system functions. This section now builds upon that by specifying a mechanism to do the formal information granulation itself, as such; this is a contribution to the design as it is further detailing how information granulation itself can be formalised.

Variables in the system can be thought as fuzzy variables with fuzzy values. One obvious such variable of the system defined above is speed.

Speed is a “Linguistic Variable” with “Fuzzy Values”. Let example fuzzy values for speed be; Slow, Normal and Fast.

The Universe of Discourse on which the Linguistic Variable Speed is defined depends on the road as each road has different max speed limits. The Universe of Discourse which provides the values for Speed is any legal speed value as mph. For a road that has 30mph max speed, the allowable speed values for the road will be 0 to 30 mph, hence the Universe of Discourse for Speed for this road will be 0-30 mph.

Each Road Granule on which an ad hoc network is to be formed will reveal a linguistic variable Speed among others, which will be calculated for each calculation cycle by the ad hoc network collaboratively. Speed will have Fuzzy Values as defined universally for all the roads. All the roads will have the same set of values for the same linguistic variable. In this case the linguistic variable Speed will have one of the fuzzy values of Slow, Normal and Fast. As the Universe of Discourse will vary according to max road speed, there will be a fuzzifier logic to fuzzify discrete values of the Universe of Discourse into those fuzzy values. Each fuzzy value is a fuzzy set defined over the Universe of Discourse. As each fuzzy set is defined as a membership function, the fuzzifier logic will use fuzzy membership functions to fuzzify discrete speed values into Fuzzy Values which will be the eventual value for the linguistic variable of Speed.

The Discrete Value Fuzzifier for Speed will take discrete values and return a Fuzy Value.

Typically, speed from each vehicle within a road segment as road granule will be aggregated in a node-head or the vehicle chosen as the master node for one calculation cycle. The aggregate speed will then be the speed value for that road granule in that particular granulation cycle. Speed values for each vehicle will come in as discrete values from the vehicles in the ad hoc network. Each vehicle will report its current speed value within the max speed limit. The master node will aggregate the incoming discrete values and obtain an aggregated road granule value. Each vehicle will be aware of the current max speed limit for the current road and the Universe of Discourse and each vehicle will have the fuzzifier logic inbuilt. These will be used by the chosen master node to fuzzify the aggregated speed value into one of the Fuzzy Values for the Linguistic Variable Speed. This will be the fuzzy value for that road segment for the calculation cycle.

Information Granulation Process to find the linguistic variable Speed fuzzy value:

- Vehicles are triggered by their inbuilt clock for a calculation.
- Vehicles in a road segment form a temporary ad hoc network for one collaborative calculation cycle.
- Discrete values of speed are sent to master node.
- Master node aggregates the values and finds out the membership functions for the current Universe of Discourse and fuzzifies the aggregation. A fuzzy value is reached for the linguistic variable.

As the fuzzy values of slow, normal and fast are defined as subsets of the universe of discourse, i.e. 0 – 30 mph, they are fuzzy sets themselves over the universe of discourse. Fuzzy sets are defined as membership functions over the entire universe of discourse. In crisp sets a value is either a member of the set or not, whereas, in a fuzzy set, every member in the universe is a member to a degree. For example for the fuzzy set of Fast in our case over the Universe of Discourse of 0 to 30 mph, both 0 and 30 are valid values for the fuzzy set but their membership values would be different. Figure 7 shows a graph representing the approximate membership function of the fuzzy set of fast vehicles.

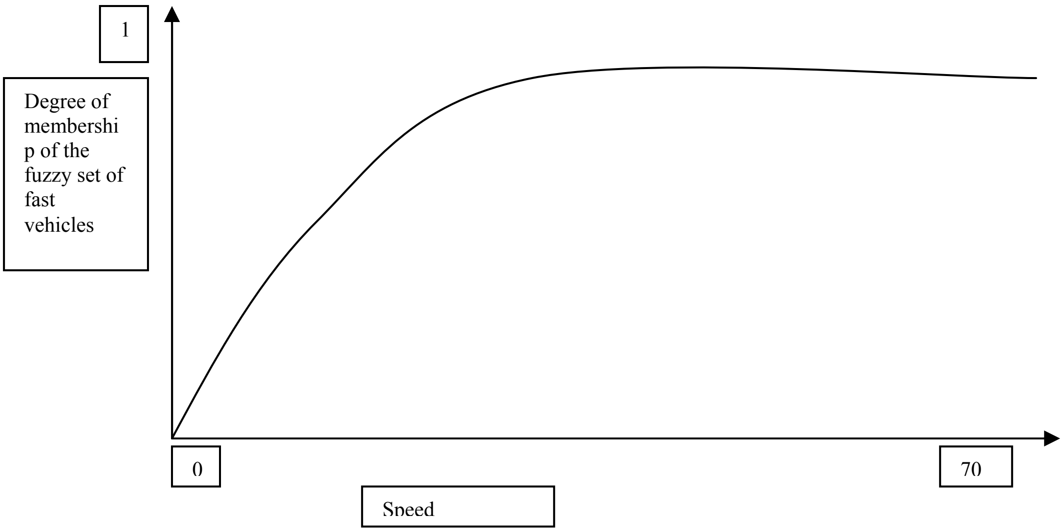


Figure 7 Chart showing the approximate membership function for the fuzzy set of fast vehicles

In this scenario, slow, normal and fast can be defined as 3 fuzzy sets over the universe of discourse. Those 3 sets will intersect with each other. Figure 8 shows a graph representing the membership functions of the 3 sets. The fuzzifier logic will calculate the membership values for given discrete values for all the 3 sets and get the appropriate fuzzy set as the fuzzy value.

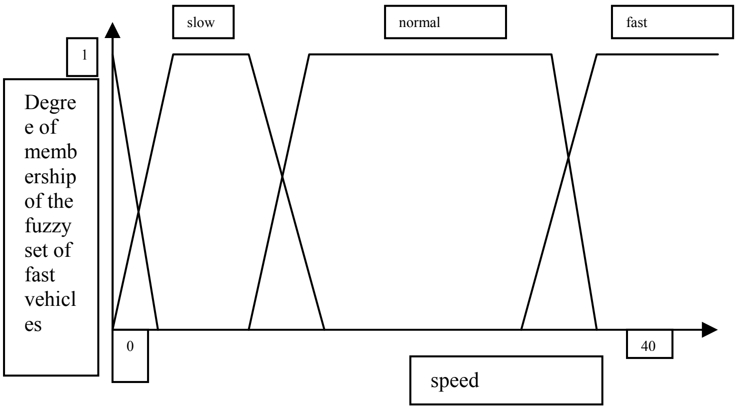


Figure 8 Graph showing the membership of fuzzy sets slow, normal and fast

Fuzzy membership functions for each road speed must be calibrated. What exactly Fast means on a road with max speed limit of 20 mph and 70 mph are very different. A membership function for Fast will mean different speed ranges for those two roads. Membership functions are Universe specific. There are as many universes as standard max road speeds and there are as many membership functions for fuzzy set Fast. Membership function for Fast changes for each road accordingly.

It is presumed that the inbuilt system in the vehicle will maintain a table of typical standard max speed values and membership functions for fuzzy values. A discrete value form the granulation will be fuzzified into a fuzzy value as fuzzy set according to universe of discourse specific membership functions.

3.7 Some Other Scenarios to Consider

- Calculate density
- Calculate average speed
- Calculate freedom to move
- Calculate average speed/road max speed ratio
- Calculate break usage in last X minutes in average
- Calculate average current emissions
- Calculate breaking distance
- Calculate visibility
- Calculate average space between vehicles
- Calculate average passenger number per vehicle
- Calculate number of vehicles
- Calculate average vehicle noise
- Calculate number of vehicles behind red light
- Calculate current average vehicle engine heat
- Calculate lane density by lane
- Calculate lane speed by lane
- Calculate average driver stress level
- Calculate necessary temporary max road speed needed for flow
- Calculate average private/public vehicles using the road
- Calculate average vehicle age
- Calculate the road surface condition from vehicle shaking and vehicle road balance
- Calculate current road condition according to weather to change max speed temporarily
- Calculate current rain or snow fall and change max road speed for the region
- Calculate current black ice or water on road surface
- Calculate current average vehicle weight

3.8 Conclusion

In this section, system architecture has been summarized to satisfy the requirements of a human-centric hierarchical wireless information system. Some explanations and basic examples are provided to clarify the model. The next chapter will describe the simulator designed to evaluate the multidisciplinary system proposed in this chapter.

Chapter 4

Simulator Design and Implementation

4.1 Architecture of the Simulator

Once an infrastructure design and architecture for the levels of data processing is in place, the next stage is to develop a simulator to test and optimize those models.

A simulator has been designed and developed to accompany the proposed system architecture.

It has been decided that, a new simulator would be developed, as there is no simulator fully suitable for the study, given the multidisciplinary nature of the study. There is traffic simulation software available but none has been designed for hierarchical data processing studies between vehicles. Given the fact that the study brings together the disciplines of the Vehicular Ad Hoc Networks and Granular Computing, a simulator to represent the architecture would be necessary. Simulator has been developed to have multidisciplinary components.

The simulator models the multidisciplinary components of the system design proposed and integrates them to enable simulations of multidisciplinary nature. The simulator provides a unique solution to component based multidisciplinary information-centric Vehicular ad Hoc Network simulation.

Microsoft .NET Framework 2.0, Microsoft Visual Studio 2005-2008 with C# 2.0, Windows Forms 2.0 have been used as technology. DirectX 9.0 has also been evaluated for performance related issues but was later dropped from the implementation as the operations on three strata's of the simulator; Traffic Simulator, Network Engine and Information Granulation Engine which run on each simulation cycle were the main holding point in the application, and User Interface latency was less important in comparison.

Microsoft Office Outlook framework release is used as UI framework, and A Microsoft Office Outlook look and feel has been developed as the UI.

HUTSIM [32, 33, 34, 35, 36] has been taken as basis for a reliable simulation framework. HUTSIM model has been analyzed and utilized for a simple Urban Traffic Simulator model.

An application has been designed and developed for a HUTSIM like simulator. Along with the traffic simulator, a Network Granulation engine for vehicular ad hoc networking and an upper level Knowledge Granulation module for information granulation are developed.

While the traffic simulator simulates realistic traffic patterns on Nottingham street maps, the Network Granulation Engine capabilities built into the vehicle objects form and maintain networks. Knowledge Granulation Module is developed on top of this infrastructure and plugged into the traffic simulator to perform and report information granulations.

It is envisaged that, the final software developed is a significant contribution to the Vehicular Ad Hoc Networks and Granular Computing communities.

There are three major aspects to the model which represent the upper level view of the system architecture. The proposed research topic is multidisciplinary, involving Ad-Hoc networking and Granular Computing. The study involves applying the principles of Granular Computing onto Vehicular Ad Hoc networks to generate Information Granules. To represent such a system four major components are developed. Those four main components are fundamental elements of the simulation model.

- GIS Map Data Processing
- Urban Traffic Simulator
- Ad Hoc Network Granulation Engine
- Information Granulation Engine

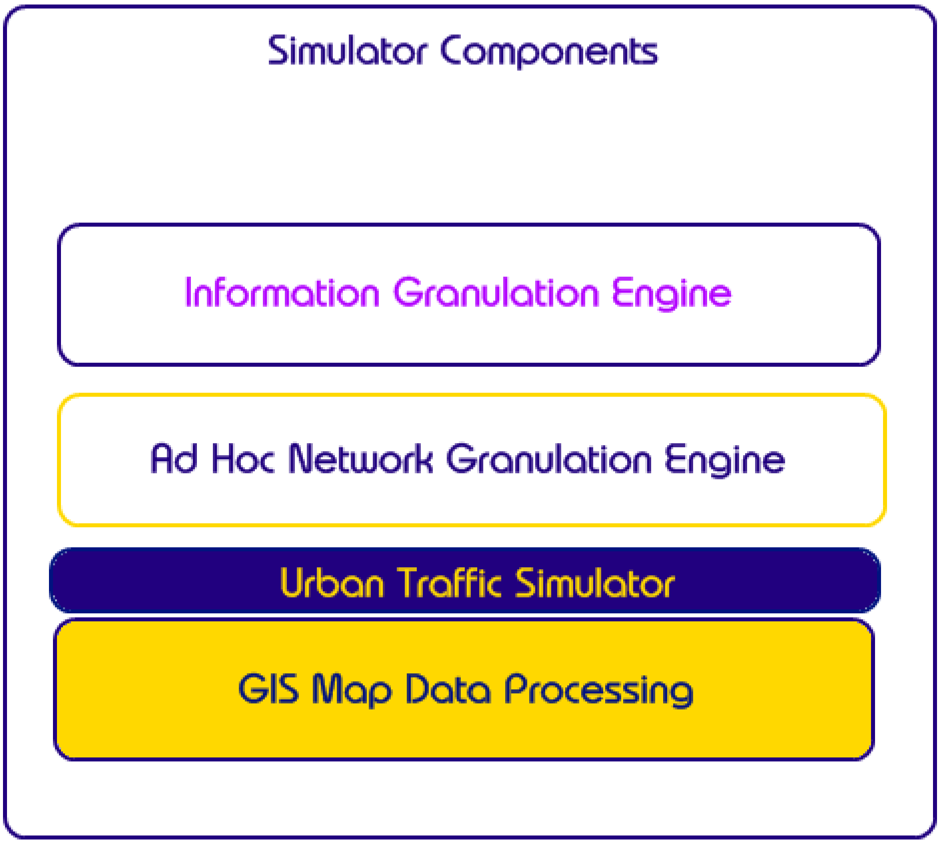


Figure 9 Four main components of the simulator

Figure 9 shows the four main components. Those four components come together to model the system architecture. GIS Map Data Processing and the Urban Traffic Simulator modules of the simulator establish a model of the Urban Traffic Environment. The GIS in the simulator scope is different to the GIS equipment of the vehicles in the Urban Traffic System which is an assumption in the proposed system architecture.

GIS + Urban Traffic Simulator Modules Network Granulation Engine	Vehicle traffic with each vehicle being equipped with necessary GIS and the Networking apparatus Network Granulation Engine
Information Granulation Engine	Information Granulation Engine

Table 1 Three major components of the simulator

As Table 1 shows, the first two components of GIS module and traffic simulator can be visualized as one to further abstract the architecture.

4.1.1 Simulator - GIS Map Data Processing

The GIS module is responsible for loading the Nottingham city map and processing the map data for usage by the Urban Traffic Simulator component. It parses and loads the NTF based data and holds the data in a structured way as nested objects for use by the simulator at different levels. An object entity model is developed to parse and represent the NTF entities. Other levels interact with this data as needed. Main functionality of the module is to load the Nottingham map and Ordnance Survey NTF based map data corresponding to it.

The object model for the GIS entities closely matches the NTF entity model. The parser parses the incoming data from a text file and structures it.

Once data is read and parsed, it is used to construct higher level objects to be used by the Urban Traffic Simulator component. For instance, the data is structured as Line objects, Attribute objects and Geometry objects. Each Line object is defined by Attribute and Geometry objects. There is no concept of Road, although each Line entity has an associated Attribute object and the Attribute object has a RoadName property. The GIS component constructs Road objects by collecting all the Line objects for the same Road under the same Road object. Each Line entity has a coordinate's collection. A Road object is practically a collection of all the Line entity coordinates collections. A Roads collection holds all the roads.

4.1.2 Simulator - Urban Traffic Simulator

The Urban Traffic Simulator uses the map information from the GIS module to generate and move vehicles on roads. HUTSIM Urban Traffic Simulator model has been studied for this component. Traffic Simulator is a complex bit of the application requiring a lot of decisions. HUTSIM model has been simplified to fit the domain specific requirements. The focus has been on generating, moving and discarding vehicles on the roads as required. Simulation parameters are simplified to fit the requirements.

The main reason why a new simulator was developed rather then using an existing one; was, due to the fact that the system is not merely a traffic simulator, rather, it is a network system and vehicles are just mobile nodes having Vehicular Ad Hoc network specific parameters and properties. Most of the functionalities and features in Traffic Simulators are not relevant in this context and network simulators on their own are not enough without proper traffic simulation features, especially considering that the proposed system architecture is concerned with information granulation and due to the very nature of Granular Computing itself the problem domain is best arranged intuitively for the required outcome. A granular data processing, fuzzy information granulation using purpose built ad hoc networks has a different outlook in terms of simulation environment and any related issues then a traffic Simulator.

The Urban Traffic Simulator generates and moves vehicle objects on road objects at each cycle. Vehicle movements are simplified. HUTSIM approach is used to move vehicles by a set movement constant at each simulation cycle. HUTSIM rule set has been simplified. As the system does not consider any system level traffic parameters, vehicle movements and vehicle life-cycle are road specific.

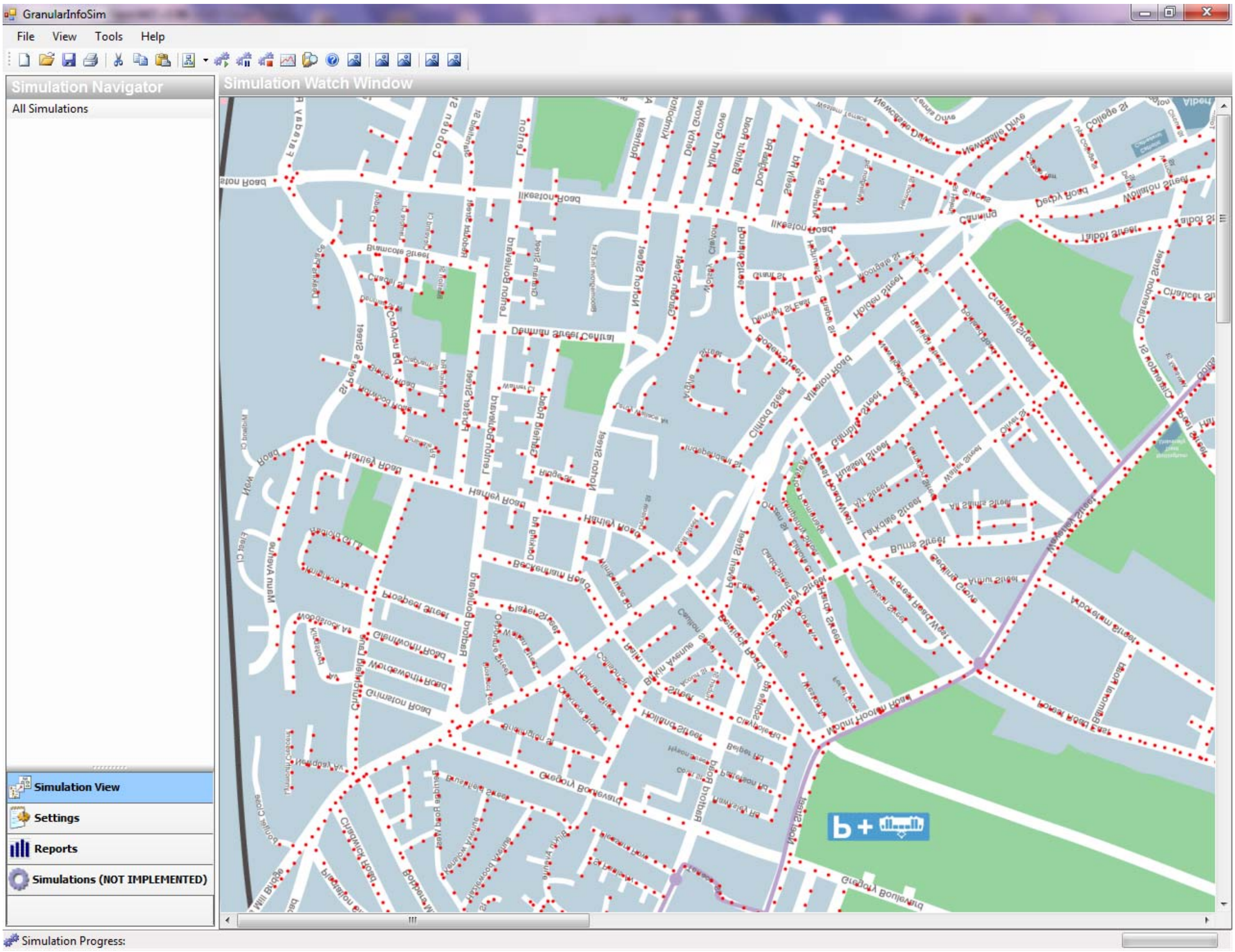
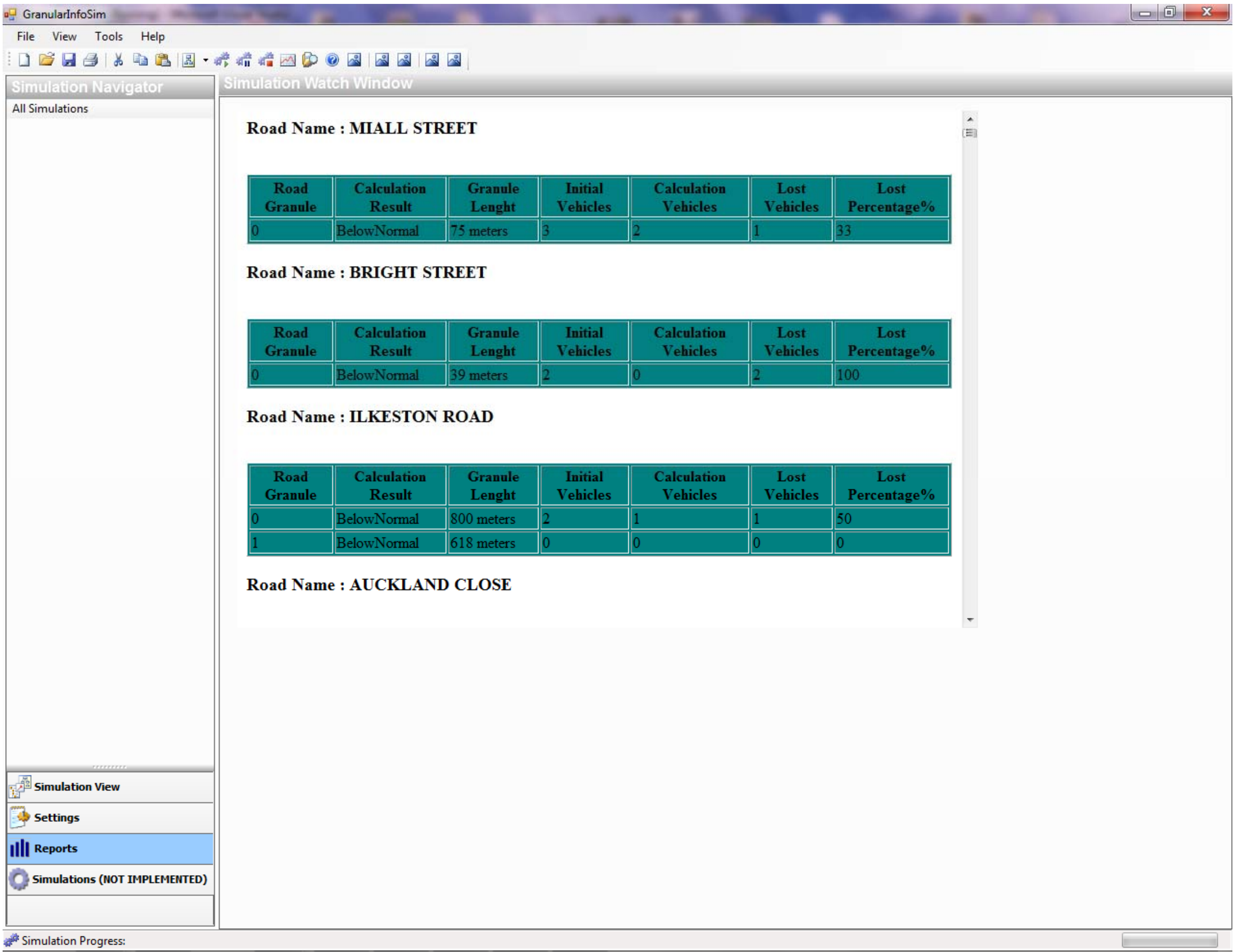

GranularInfoSim
File
View
Tools
Help
Simulation Navigator
All Simulations
Simulation Watch Window
Simulation View
Settings
Reports
Simulations (NOT IMPLEMENTED)
Simulation Progress:

Figure 10A



Road Name : MIALL STREET

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	75 meters	3	2	1	33

Road Name : BRIGHT STREET

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	39 meters	2	0	2	100

Road Name : ILKESTON ROAD

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	800 meters	2	1	1	50
1	BelowNormal	618 meters	0	0	0	0

Road Name : AUCKLAND CLOSE

Figure 10B

Figure 10A is a screen shot from the simulator in working. Red spots on the map represent the vehicle objects. Each vehicle object has related data associated to be used in analysis. 10B Simulation report view, report is generated after a simulation and can be viewed from the reports button.

Figure 10 shows screen shots from the simulator.

4.1.3 Simulator - Ad Hoc Network Granulation Engine

The Network Granulation Engine of the simulation model is a central component to ad hoc network formation and maintenance as well as data communications.

Roads are granulated into network granules and granules do not span into other roads.

The aim is to utilize vehicular ad hoc networks to form a decentralized real-time environment in which data will be granulated into knowledge, and used in real-time as it ripples through the network. In the revolutionary approach of this study data is relative to time and environment. Same data can be part of different information granules at different levels. Different information granules are also relative to their strata in the hierarchy and only meaningful in current context.

Network Granulation Engine is envisioned as a local process to vehicles to watch the timer and the calculations registered and trigger a calculation, send and receive beacons to establish a network.

In the simulator, each road object holds a collection of road granules which are the representations of road network intervals. This is done dynamically, depending on the set granule length. Road granule length setting determines the length of each ad hoc network on the road.

Calculations are registered by defining a cycle to start as this gives the chance to start a calculation after a saturation period, because, vehicles are generated on each cycle for the roads and it takes some time to fill the roads. After this a calculation is triggered. When a calculation is triggered, the simulation network granulation engine granulates vehicles on the road according to their current location into the ad hoc networks. This is achieved by putting the vehicles into different granule collections on the road.

After this, certain number of cycles later, simulator recalculates the vehicle granules depending on their current locations and compares it to the first one to find out if any vehicle moved out of the ad hoc network interval it was on, this is to find out what percentage of vehicles move out of the network during a calculation process, this is achieved by taking a snapshot of the current state and waiting so many cycles before taking another snapshot and comparing them. Then, a calculation is performed.

Once calculation is performed, a different calculation can be triggered. There is a calculations queue in which calculations can be queued. Vehicle connectivity is measured by taking snapshots and running the simulation a certain number of times and letting the vehicles to move according to their set speed which is again set by simulation settings and then checking out any vehicles moving out during this time. Any vehicle moving out is left out of the calculation. This may prove an interesting feature for future vehicular ad hoc network studies.

4.1.3.1 Road Granule and Information Granule dependent Vehicular Ad-hoc network formation

It is assumed that each vehicle is equipped with ad-hoc communications capabilities with necessary range and there is GPS and a telematics computing device on board. Each vehicle has a map of the urban area loaded in its GPS device and vehicle is aware of its position during its travel.

Vehicular ad hoc network (VANET) formation is superimposed by the telematics platform in the vehicles themselves by triggering ad hoc network formations in preset geographic locations and preset times. Vehicles will have this information preloaded in their telematics platforms. VANETs are used for the purpose of inter-vehicle calculations and information granules are obtained from those VANETs as a result. Network formation and persistence issues are built around this result. There are two aspects to formation of networks. First, roads on the inbuilt map are divided into road granules. Vehicle has the necessary calculation algorithm in its telematics system to granulate the road it is on into granules. Second element is information granulation schedule. This schedule is a map of roads to calculation times. Vehicles constantly know their current road and the granule they are on. When there is a calculation to be performed on the road vehicles form temporary VANETs only for the duration of the calculations on the road granules they currently are. Those road granules geographically restrict the network boundaries. A road may have many road granules and hence many VANETs independent of each other. Each VANET perform its own calculation and obtain its own information granule result for its road granule which is physically a road segment.

Information is granulated using Granular Computing concepts. The problem domain of collaborative generation of information is fuzzy in nature.

Vehicles on a road form ad hoc networks within road granules and they do periodic calculations and aggregations using the formal techniques of Granular Computing and Fuzzy Granulation. Fuzzy, Human form knowledge granules are generated as a result.

Each vehicle has an intelligent module called Network Granulation Engine. This module keeps an eye on the GPS location of the vehicle and matches the position to the in-built map roads and road intervals.

The Network Granulation Engine, then establishes, maintains and re-establishes ad hoc network links in accordance with the network logic and the underlying protocols.

The simulator has been developed to help with the design and evaluation process of the model. The simulator has provided a lot of insight into the model during development; it has helped to consider the model in different aspects. The development process of the simulator itself has acted as a brain storming exercise which helped to refine and shape the model.

Simulator has been designed to be modular to include the modules of GIS, urban traffic simulator, and on top of them the network granulation engine and the information granulation engine. The urban traffic simulator generates and simulates traffic while the network granulation engine generates geographically bound ad hoc networks, and arranges the infrastructure for data communications. The information granulation engine then makes use of the data within the ad hoc network to generate human-centric fuzzy information granules.

Each network is formed reactively to do periodical calculations and a network head is selected for the duration of one cycle of calculation.

The simulator consists of four major components. The first two components are the map parser and the traffic simulator which are closely coupled. As such, they can be treated as one component. This component includes a user Interface, loading and processing NTF based Ordnance Survey map data, synchronizing the data with the Nottingham City Map and simulating traffic movement on the map. A basic traffic simulation is produced for this to form the basis of VANET based information granulation.

On top of the traffic simulator module two more components are developed as the Network Granulation Engine and the Information Granulation. The network granulation engine utilizes the road and vehicle object in the underlying traffic simulation module and granulates the roads into network granules. Each network granule maps to a physical road segment. This road granule identifies a VANET. VANETs are geographically enforced. Each vehicle knows its current position and when a calculation is triggered vehicles form VANETs to perform the calculation triggered. The simulator places each vehicle from the underlying simulator into road segment objects and performs information granulation on this abstraction. Network delay is simulated as simulation cycle delay. The Information Granulator Engine takes a copy of the current state as vehicles on a road network granule, waits necessary number of cycles after which it checks vehicle positions and finds out the vehicles that have moved during this wait time and removes them from the initial state and performs the calculation on those vehicles that are still in the granule. This way network formation latency is considered for the connection timing in the granule.

With this component based granular structure different aspects of the system can be simulated independently.

Road granule length has been chosen to be optimal for the road speed of 40mph. This can be a fuzzy process too. Fuzzy road granulation into road segments on which calculations will take place can be useful to allow better road granulation. Also when granulating roads other factors can be taken into account and a number of different granulation techniques can be applied. For example, in a mountainous area where roads are going through tunnels and there are a lot of bends road granules can be made shorter.

4.1.4 Simulator - Information Granulation Engine

This is built on top of the Ad Hoc Network Granulation Engine and receives the data from the network. The data received then processed using either set based operations or the intelligent data processing methods of Granular Computing and Fuzzy Granulation. The aim is to generate human-centric information granules.

While the underlying Network Granulation Engine establishes and maintains the network and deals with data flow, the Knowledge Granulation Engine processes data.

Concepts of Granular Computing are utilized for Knowledge Generation.

Ad Hoc Networks at each interval act as a coherent unit, to perform one calculation at set periods and produce a single Information Granule each time, from data received from vehicles.

This knowledge is then relayed to the Control Centre and drivers in different ways. Road side gateways are assumed to be used to obtain and relay information granules.

Information granulation is performed after a network formation process detailed above. After snapshots are compared and vehicles are segregated into networks, data properties of vehicles are collected and Information Granulation Engine simulates a head-node vehicle by collecting data from vehicles and performing the calculation. Calculation results are then written to a html file.

4.2 Work on Simulation Model

Substantial amount of work has been done on the simulation software in terms of developing a User Interface, loading and processing NTF based Ordnance Survey map data, synchronizing the data with the Nottingham City Map and simulating traffic movement on the map. This makes for a well featured GIS system on its own right and a simple Urban Traffic Simulator. The GIS part of the system is a fully functional Ordnance Survey NTF based map processor. Traffic simulation part of the system is purpose built to cater for the problem domain and the architecture at hand.

Map data has been processed. Complex NTF Ordnance Survey data has been parsed and structured for the purpose. The NTF parser has been developed which is at the heart of many major GIS applications and is a complicated piece of application logic involving complex processed and modelling.

The Simulation Model has been developed to reflect the architecture. The calculation logic which is a component of the vehicles as the Information Granulation Engine has been abstracted as a simulator calculation module. Ad hoc network formation has been modelled to be bound to network granules. Road network granulation engine of the simulator granulates roads into network intervals and each of those network granules are represented as objects in the simulator. Each road network entity object holds a reference collection to vehicles on it. So, each road network granule is aware of its vehicles for ad hoc networking.

Calculation mechanism has been designed to be pluggable so that more calculations can be plugged with different calculation algorithms. The design allows many different calculations to be performed with different mechanisms. There is a queue system for calculations. Each calculation is performed once it is due. The queue represents the inbuilt vehicle calculation triggers.

4.3 Simulator Software Architecture

This section attempts to introduce the software architecture.

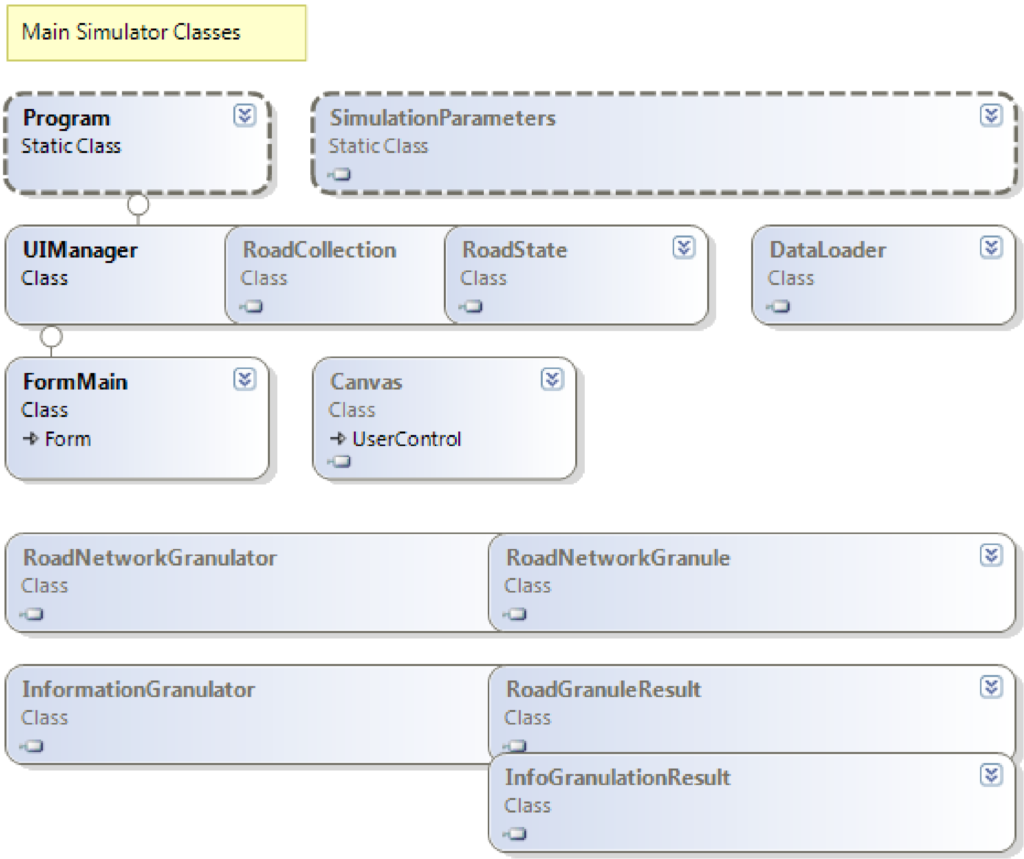


Figure 11 Main Classes in Simulator

GIS Module and Initialization:

The simulator uses an Ordnance Survey map for the city of Nottingham. Map data is in Ordnance Survey NTF format. NTF data is read and parsed. A NTF parser has been developed. The parser reads data and forms data structures to be used by the simulation. NTF data is read from a text file. The file is in the system root directory together with a map.

NTF Parser is the object `DataLoader`. It is instantiated by the UI Manager object which is called by the entry object of `Program.cs`. `UIManager` is the object that runs the simulator and provides the interface between the UI and the backend process objects. Full simulation cycle is managed by the `UIManager` object. The simulator is designed with a Model-View-Controller Design Pattern approach. `UIManager` acts as the controller.

`DataLoader` object has collections for the NTF objects

```
List<Entities.Attribute> attributes = new List<Entities.Attribute>();
List<Geometry> geometries = new List<Geometry>();
//reference to the output lists are added
List<Line> lines = new List<Line>();
List<Node> nodes = new List<Node>();
List<Entities.Point> points = new List<Entities.Point>();
RoadCollection roadCollection = new RoadCollection();
```

Parser logic is held in the LoadEntities() method which loops through the data from the text file and parses and constructs the road entities.

```
switch (id)
{
case 0: //continuation of the previous one
AddToPrevious(line, id, previousEntityID, previousEntityType);
break;
case 14: //AttRec
previousEntityID = int.Parse(line.Substring(2, 6));
previousEntityType = EntityType.Attribute;
AddAttributeEntity(line);
break;
case 15: //pointrec
previousEntityID = int.Parse(line.Substring(2, 6));
previousEntityType = EntityType.Point;
AddPointEntity(line);
break;
case 16: //NodeRec
previousEntityID = int.Parse(line.Substring(2, 6));
previousEntityType = EntityType.Node;
AddNodeEntity(line);
break;
case 21: //Geometry
previousEntityID = int.Parse(line.Substring(2, 6));
previousEntityType = EntityType.Geometry;
AddGeometryEntity(line);
break;
case 23: //LineRec
previousEntityID = int.Parse(line.Substring(2, 6));
previousEntityType = EntityType.Line;
AddLineEntity(line);
break;
default:
previousEntityID = 0;
previousEntityType = EntityType.None;
break;
}
```

Code fragment from the LoadEntities() method which parses NTF data:

NTF data is formed as lines and each road might be represented by many lines. After reading the lines the `UIManager` object calls the `DataLoader` ReconcileRoads method which combines lines to road objects. Each Road object has a list of lines collection.

After the reconciliation process, `UIManager` obtains a RoadCollection object which holds Road objects for all the roads from the data and each road object in return holds a collection of line objects. Simulator then makes use of this high level in-memory object collections.

Road data has spatial information for the map graphical interface. Road geometries are transformed to match the map. Vehicle objects are then generated and moved along the geometry data and drawn on the map accordingly. Vehicle generation is kept simple; this is an area that can be further improved to have different densities of vehicles generated in a fuzzy way. Currently, the vehicle generation is constant; settings come from the SimulationParameters file. Minimum distance between vehicles and road density constants are defined in this file and they are constant during the simulation. This constant vehicle generation has been implemented for simplicity so that real focus on higher level architectural real-time information granulation is not lost.

Density of vehicles generated can also be varified. The overall study was concerned with defining an architecture to bring together the fields of ad hoc vehicular networking and granular computing and designing a simulation framework for studying such an architecture. Existing traffic simulation tools are not designed to deal with networking and granular information generation studies and network simulators are lacking the ad hoc vehicular networking and also granular information generation components. So, the component oriented approach has been unique to the problem at hand, - granular computing also has such characteristic of being specific enough and pragmatic for the problem at hand - and designing such a system and a simulation architecture for it has been challenging in many respects. Due to complexity of the problem some lower level functionality has been kept simple. Those constants do provide enough realism to demonstrate that this architecture can be used as a blueprint for studies in generating real-time human centric information granules from the traffic data.

Vehicle simulation provides the basis for the study. However, the focus was forming ad hoc networks among vehicles and having information granulation performed in a real-time way. For this reason, a simple vehicle simulation would be most suitable for building the upper level components. When they reach the end of the road they are disposed. Simulation cycle keeps moving vehicles, doing necessary network formations and calculations as necessary.

This base component loads the NTF road objects and generates and moves vehicles on the map according to road geometries. Upper level components then utilize this functionality to form ad hoc vehicular networks and generate calculations of human-centric information granules.

UIManager.ReadData()

Program.cs instantiates a new instance of UIManager class. Then calls the ReadData(File) method of the UIManager.

ReadData(File) method reads and parses the data for map.

This method instantiates a DataLoader object and calls its LoadData() method. Then it calls ConstructRoads() method of the DataLoader object and then gets the RoadCollection of the DataLoader object.

Then the UIManager calls TransformGeometries() method.

Then SetInitialVehicles() method is called.

4.3.1 Road Network Granulation Process

Network granulation is performed as vehicle objects being added to network granules. RoadNetworkGranulator is the main object to achieve vehicular ad hoc networking on vehicle objects. Roads have RoadNetworkGranules collections, those RoadNetworkGranule objects will have empty vehicles collection, when a calculation is triggered all the vehicle objects on the road will be distributed between road granules and the state will be serialized, when the network delay time has elapsed the current state will be forming by repeating the process of redistributing the vehicles and matching the current state to the serialized state and forming a calculable state for the road.

The entry method to the RoadNetworkGranulator object is:

```
public void GranulateRoadsToNetworks(List<Road> roads)
```

This method takes the roads collection which includes all the roads and goes through each road. For each road, it granulates a RoadNetworkGranules list:

```
List<RoadNetworkGranule> roadNetworkGranules
```

Road is granulated into road network granules. This logic takes the SimulationParameters.roadGranuleLength parameter from the SimulationParameters object. This setting determines the road granule length for network granules on the road. Road is granulated into vehicular ad hoc network regions by this specified length and for each road interval calculated according to road lenghth a RoadNetworkGranule is instantiated. This way a list of RoadNetworkGranule objects will be formed covering the entire road. Each RoadNetworkGranule object has properties defining its start and end points on the road.

Code segment forming RoadNetworkGranule objects:

```
roadNetworkGranule = new RoadNetworkGranule();
roadNetworkGranule.SequenceNumber = sequenceNumber++;
roadNetworkGranule.StartLengthOnRoad = ++currentEndPos; //1 after the last one
float remaining = road.RoadLength - currentEndPos;
if (remaining > SimulationParameters.roadGranuleLength)
  {
   currentEndPos += SimulationParameters.roadGranuleLength;
   roadNetworkGranule.EndLengthOnRoad = currentEndPos;
  }
  else
  {
    roadNetworkGranule.EndLengthOnRoad = road.RoadLength;
    keepGoing = false;

  }
```

A collection of those RoadNetworkGranule objects is then added to the road.

Another method of the RoadNetworkGranulator is GetCurrentRoadStates.

```
public List<RoadState> GetCurrentRoadStates(List<Road> roads)
```

Before this, roads have lists of RoadNetworkGranule objects but they are empty. Vehicle objects keep moving on the roads on each simulation cycle without being associated to RoadNetworkGranule objects on the roads. Roads have a list of vehicles on them. When GetCurrentRoadStates is called to get the current road state, it associates vehicles with road network granule abojects. This is used when triggered to obtain current road state.

The way network delay is achieved is by capturing and serializing the current road state and waiting a number of cycles before taking another shot of the current road state and comparing the initial serialized state and the latest one and removing any vehicles from road granules that moved on by then. This way vehicles keep movng on each simulation cycle and some vehicles go onto other network granules on the road. When the secong shot is taken, each network granule on the road is checked for vehicles that appeared as a result of the delay and they are removed from the latest state and calculations are performed on this updated state.

So, GetCurrentRoadStates is used again to get the road state after the delay cycles and difference between two states is taken and the difference data of roads collection is assigned to the actual roads RoadNetworkGranules collection granule GranulesVehicles collection. Untill after the delay time and this difference is found the GranulesVehicles is empty or have invalid data.

Road states method code segment:

```
public List<RoadState> GetCurrentRoadStates(List<Road> roads)
{
List<RoadState> roadStates = new List<RoadState>();
RoadState roadState = null;
foreach (Road road in roads)
{
//set the roadstate and the dictionary collections
roadState = new RoadState();
roadState.RoadName = road.RoadName;
roadState.RoadID = road.id;
foreach (RoadNetworkGranule roadNetworkGranule in road.RoadNetworkGranules)
{
roadState.StateFromGranulesCollection[roadNetworkGranule.SequenceNumber] = new
List<Vehicle>(); //add a list for this granule
}
foreach (Vehicle vehicle in road.roadVehicles)
{
//get vehicles granule location
foreach (RoadNetworkGranule roadNetworkGranule in road.RoadNetworkGranules)
{
if (vehicle.VehicleDistanceFromRoadStart <= roadNetworkGranule.EndLengthOnRoad
&& vehicle.VehicleDistanceFromRoadStart >= roadNetworkGranule.StartLengthOnRoad)
{
//vehicle is in the current granule
(roadState.StateFromGranulesCollection[roadNetworkGranule.SequenceNumber]).Add(vehi
cle);
break;
}
}
}
roadStates.Add(roadState);
}
return roadStates;
}}}
```

4.3.2 Information Granulation Process

Calculations are entered into the calculations queue by simulation cycle to initiate calculation. Each calculation is triggered according to its simulation cycle. The system architecture relies on temprally triggered calculations by vehices and vehicles form a network to make one calculation of the triggered type and network disconnects. This is achieved by simulations being qued for certain simulation cycles. On each cycle the simulator manager logic checks for any simulation for the current cycle and triggers the simulation. The simulation being tirggered on a certain cycle does not mean that the calculation will be done on that cycle. When a simulation is triggered on a real-life traffic environment there would be a delay until the vehicular ad hoc network is formed and the calculation is peroformed. During this time some vehicles will get out of the network granule. This is handled by a delay mechanism in the simulator. Once a simulation is initiated a shot of the current state is taken and serialized. Then, the simulation number stated by the delay constant is waited and when the calculation is due, a new state is taken and vehicles are reconciled between the network granules as explained above, and calculation is performed on the vehicles.

When a calculation is due, a shot of the current state is taken by distributing vehicles into the road network granule objecs on the road and the state is serialized. A calculation object is instantiated and the serizlized road state is added to the calculation as a property. Then, the calculation is added to the calculation queue.

```
private void InitiateCalculation(CalculationTypes calculationType)
{
//form the calculations and add to calculations
Calculation calculation = new Calculation();
calculation.calculationType = calculationType;
calculation.roadStates =
this.roadNetworkGranulator.GetCurrentRoadStates(this.roadCollection.roads);
int cycleToPerform = SimulationParameters.simulationCycle +
SimulationParameters.numSimulationCyclesForNetworkDelay;
SimulationParameters.calculationQueue[cycleToPerform] = calculation;
}
```

On each cycle caculations queue is checked for the calculation due, at this stagem caclulation hac already been initiated, any calculation object is an initiated calculation in progress, they are simply waiting for the delay time to pass in the queue.

Code for performing calculations:

```
//check for calculations to be performed in this cycle, if so, perform and remove
them
List<int> calculationsPerformed = new List<int>();
foreach (KeyValuePair<int, Calculation> pair in
SimulationParameters.calculationQueue)
{
int key = (int)pair.Key;
if (key == SimulationParameters.simulationCycle)
{
                    performCalculation(SimulationParameters.calculationQueue[key]);
                    calculationsPerformed.Add(key);
}
}
```

performCalculation calls one of the appropriate calculation logic. One implemented calculation is density calculation by the method:

```
private void CalculateDensity(List<RoadState> initialRoadStates)
```

Code from the CalculateDensity method:

```
foreach (RoadNetworkGranule roadNetworkGranule in road.RoadNetworkGranules)
{
List<Vehicle> initialVehicles =
initialRoadState.StateFromGranulesCollection[roadNetworkGranule.SequenceNumber];
List<Vehicle> currentVehicles =
currentRoadState.StateFromGranulesCollection[roadNetworkGranule.SequenceNumber];
//only get the vehicles from initial vehicles that are still in range, not
interested in new comers
List<Vehicle> calculationVehicles = GetCalculationVehicles(initialVehicles,
currentVehicles);
float granuleLength = (float)System.Math.Abs(roadNetworkGranule.EndLengthOnRoad -
roadNetworkGranule.StartLengthOnRoad);
//calculate for granule
CalculationResult res =
this.informationGranulator.GetInformationGranuleForNetworkGranule(calculationVehicl
es, CalculationTypes.Density, granuleLength);
RoadGranuleResult roadGranuleResult = new RoadGranuleResult();
roadGranuleResult.calculationResult = res;
```

Results are than written out as HTML by calling:

```
WriteInfoGranulationResultsToHTML();
```

Information Granulator logic is separated into the InformationGranulator class. Above, the code calls a method of this class to perform the information granulation. Foreach road netowkr granule vehicles are passed to the GetInformationGranuleForNetworkGranule method of this class and information is taken from the vehicle objects to perform a calculation. This class acts as the place where calculation goes to.

The specific calculation algorithms of this class is an area for further investigation.

Chapter 5

Simulation Results and Analysis

5.1 Results and Analysis

A focused approach has been taken to simulation development. The aim was to develop an example granular simulation environment which will demonstrate some basics to design and development process of such an environment.

One study that can be done using the simulator is the percentage of connection maintained by granule length. As the model enforces geographically formed VANETs there are two major parameters of the system that comes to mind immediately. Those are: What would be the ideal speed to maintain the highest possible connectivity during a short VANET formation and information granulation process and secondly, what will be the ideal network granule length on the road. Different network granule lengths are studied by keeping the speed as 40 mph, 50 mph, 60 mph and 70 mph.

This speed limit is an important property of roads. Vehicular Ad Hoc Networks studies usually identify some useful properties like vehicles having roads as node distribution physical locations as opposed to classical Ad Hoc network topologies being a lot more unpredictable. Properties of roads also do affect the Vehicular Ad Hoc Networks. Roads have maximum speed limit constraints. One can more accurately predict the speed of vehicles on each road in the urban city environment. This property does give a great deal of clarity for studying VANETS.

This project has studied ad hoc network granule lengths of 200 meters to 800 meters. This decision has been made on the basis of current ad hoc network studies and communications hardware limitations. Range of communications can differ according to geographic conditions and obstructions as well as radio communications equipment used. In Vehicular Ad Hoc networks communications range is assumed to be maximum 1000 meters, for example European FleetNet study uses radio equipment with 1000 meters maximum range in line of sight conditions. If there are obstructions, this might vary. The project range of 200 to 800 meters to enable all the vehicles to be within range of the middle of the network as we select a vehicle in the middle of ad hoc network granule as node head for a calculation triggered simultaneously on all the vehicles in the same granule, is realistic. Considering that this project uses middle of granule as communication Hotpoint, it is even possible to extend these boundaries in both sides. However, this study has kept studies within range of so that some of the results and findings can be universally applied to VANET studies.

Simulation results are maintained in an object oriented way and published into html format. Those results are obtained and printed for all the roads.

Information Granulation Result

Road Granule Lenght: 800meters
Each cycle a vehicle moves: 7.5meters
Delay between initiation and calculation completion: 5simulation cycles.
Vehicle generation density: 5 meters apart
EXPECTED STATE FOR NORMAL:
2 vehicles per 20 meters.
Calculation Type: Density

---

* Initial Vehicles: Number of vehicles in the road granule when the calculation was triggered.
* Calculation Vehicles: Number of vehicles in the road granule when the calculation was performed after delay.
* Lost Vehicles: Number of vehicles lost from the road granule when the calculation was being performed, they moved into the next granule.

Total number of road granules: 1608
Total number of vehicles: 13518
Total number of vehicles lost during process (this means vehicles moved out of range): 2751

Total percentage: 0

Road Name : MIALL STREET

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	75 meters	3	2	1	33

Road Name : BRIGHT STREET

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	39 meters	2	0	2	100

Road Name : ILKESTON ROAD

Road Granule	Calculation Result	Granule Lenght	Initial Vehicles	Calculation Vehicles	Lost Vehicles	Lost Percentage%
0	BelowNormal	800 meters	2	1	1	50
1	BelowNormal	618 meters	0	0	0	0

Table 2 Example report

Table 2 shows an example report from the output for three roads. Each road is represented as a table with 0 based ad hoc network granule numbers. Each granule is one ad hoc network granule on the road. Each granule has a granule length, road is granulated into ad hoc network granules according to specified granule length, in this case it is 800 meters. Some roads in this example are not populated at this stage yet, as calculation are made at later stages road vehicle density change.

Those results are then calculated to find average lost vehicles during the calculations. The way calculations are performed is, there is a constant to define network delay to simulate connection time and network package loss and communication physical layer issues. This is done as simulation cycles.

Calculations are triggered by the Information Granulation layer, this is done by registering calculations of certain type as network level calculations against a simulation cycle. In this case calculation type is density. This is triggered for all the ad hoc networks on roads at the same simulation cycle. Once a calculation is triggered, vehicle locations on each road ad hoc network granule which is represented as "Road Granule" in the table of results are noted. Road Granules in the table are treated as vehicular ad hoc network entities in the system with peculiar properties like road the granule is on, the geographical position of the ad hoc network granule on the road, vehicles on the ad hoc network granule, etc. These properties make an ad hoc network granule object a true information granule with intuitive properties. A vehicular ad hoc network granule object as a Road Granule object in the system has information about its road position and its own vehicles. Road also has a collection of vehicular ad hoc network collection.

Calculations of percentage of lost vehicles in relation to granule length variable changing while road speed staying as for example 40 mph.

After simulating connectivity for the entire grid, one thing that became obvious was the fact that road lengths in a city did not always allow for road granule lengths specified. After certain granule length, increase in granule length started to have less effect on connectivity as many roads did not have enough length for the specified granule lengths and also many of the roads would have some short granules left at the end. Combination of road end short granules and short roads, granule length increases do not affect the connectivity in the overall system that much after certain values of granule lengths.

Total number of vehicle objects involved in simulation is approximately: 13200
Vehicle objects are generated periodically, based on road saturation constant and vehicles coming to the end of a road are discarded. Vehicle speed is initially set as 40 mph; this is simulated by simulation cycles and movement on each cycle.

Below are the results for a set of simulations run by keeping the speed to 40 mph and increasing the road interval lengths, on which geographically constrained vehicular ad hoc networks are formed. Speed is kept 40 mph on each simulation and road granule lengths are varied between 200 meters and 800 meters.

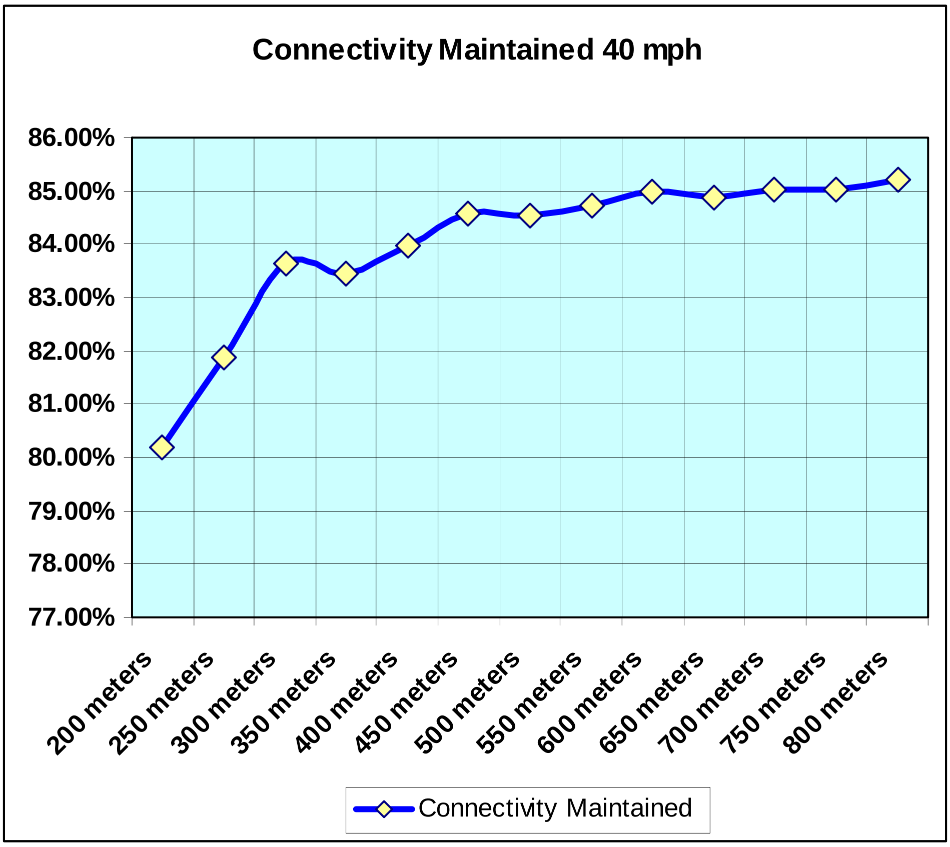


Figure 12Speed is 40mph and Road Granule length between 200 and 800

Figure 11 shows a set of simulations for connectivity maintained, where speed is kept 40 mph and road granule length on which geographically constrained vehicular ad hoc networks are formed varies between 200meters and 800 meters.

Connectivity – Granule Length graph for 40 mph road speed. Connectivity is as percentage. This is the connectivity maintained for the duration of the network calculation.

Granule Length	Connectivity Maintained
200 meters	80.18 %
250 meters	81.86 %
300 meters	83.62 %
350 meters	83.45 %
400 meters	83.99 %
450 meters	84.59 %
500 meters	84.53 %
550 meters	84.71 %
600 meters	85.00 %
650 meters	84.86 %
700 meters	85.02 %
750 meters	85.01 %
800 meters	85.23 %

Table 3 *Granule Length – Connectivity for 40mph values*

It is clearly visible from the graph that, increasing the road granule sizes does not result in equivalent linear increase in connectivity in the overall urban system.

The study repeated tests for 30 mph and 60 mph. 30 mph results show higher level of connectivity as expected:

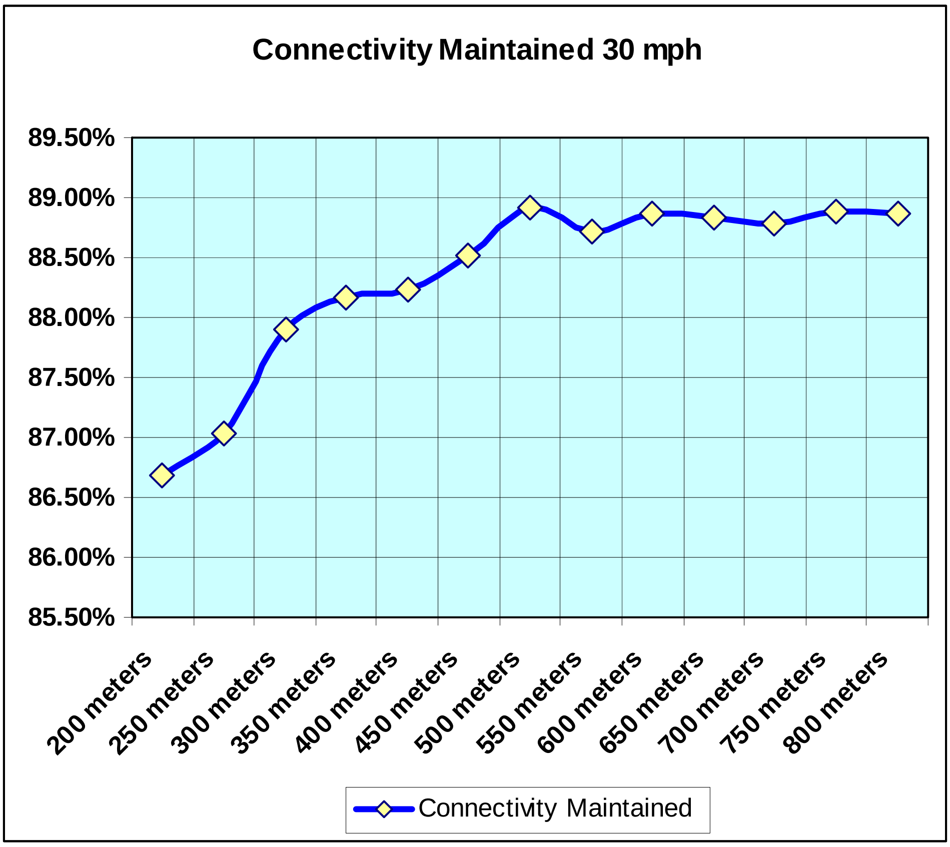


Figure 13 Speed is 30mph and Road Granule length between 200 and 800

Granule Length	**Connectivity Maintained**
200 meters	86.68%
250 meters	87.04%
300 meters	87.90%
350 meters	88.16%
400 meters	88.24%
450 meters	88.52%
500 meters	88.92%
550 meters	88.71%
600 meters	88.87%
650 meters	88.83%
700 meters	88.79%
750 meters	88.89%
800 meters	88.87%

Table 4 *Granule Length – Connectivity for 30mph*

Figure 12 shows a set of simulations for connectivity maintained, where speed is kept 30 mph and road granule length on which geographically constrained vehicular ad hoc networks are formed varies between 200meters and 800 meters.

The 30 mph results show significant improvement in connectivity over 40mph results. While there is a linear increase up to 500 meters in ad hoc network size, results show similarity and some degree of arbitrary change after this point. This study is granulating roads into road intervals by a constant but as each road is taken and granulated by the length, and road is not equally divisible by the constant, then a surplus at the end of the road is left and considered as a granule. For example if road is 1000 meters and granule length is 300 meters, then road is divided into 3 X 300 granules and a 100 meter granule. We end up with 4 granules one of which is 100 meters. Considering there will be different number of surplus granules in different granule lengths with different surplus lengths, eventually, vehicles are more likely to go out of those small networks very quickly resulting connectivity loss. The somewhat non-linear behaviour in connectivity is a result of this granulation mechanics. This can be improved by checking the surplus granules and if they are under certain length they may be divided into other granules on the road and road can be re-granulated with non-standard lengths. This approach might impact on results as well as many granules will then be different length to intended length. So, this current surplus mechanism might be more suitable for study. However, it is also possible to decide to leave surplus networks out all together.

Connectivity studies are also done for high speed of 60mph. Results show degradation in connectivity:

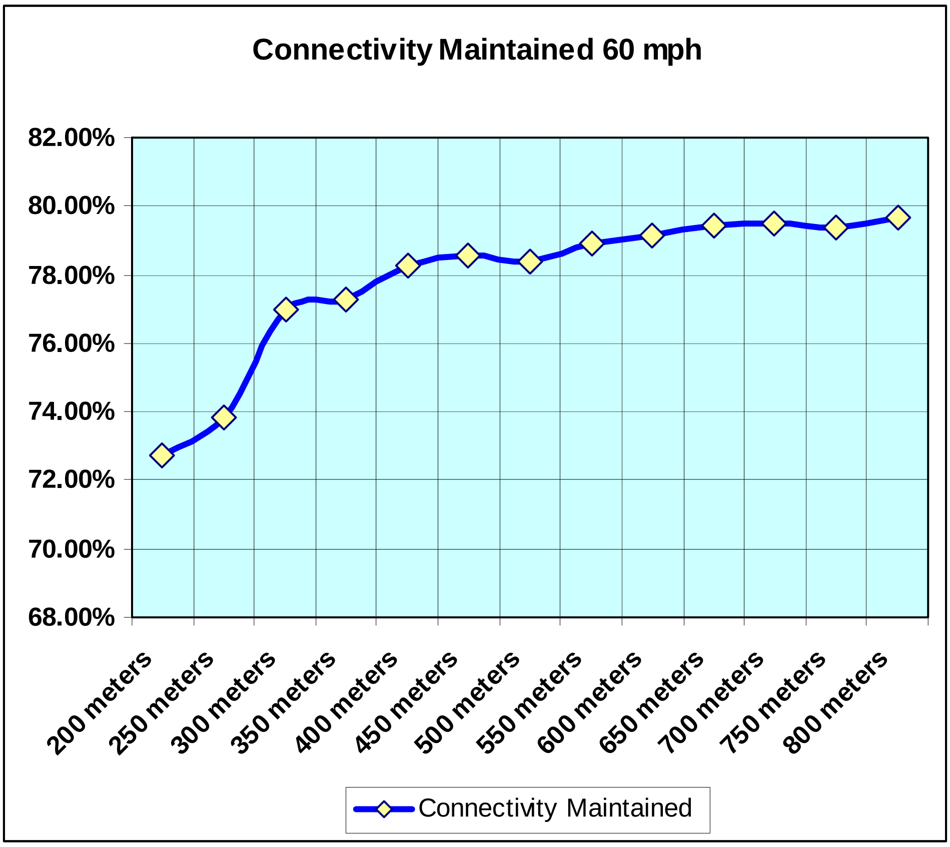


Figure 14 Speed is 60mph and Road Granule length between 200 and 800

Granule Length33	**Connectivity Maintained**
200 meters	72.70%
250 meters	73.83%
300 meters	76.99%
350 meters	77.29%
400 meters	78.27%
450 meters	78.56%
500 meters	78.40%
550 meters	78.92%
600 meters	79.12%
650 meters	79.41%
700 meters	79.51%
750 meters	79.37%
800 meters	79.65%

Table 5 *Granule Length – Connectivity for 60mph*

Figure 13 shows a set of simulations for connectivity maintained, where speed is kept 60 mph and road granule length on which geographically constrained vehicular ad hoc networks are formed varies between 200meters and 800 meters.

Results for 60mph get higher for connectivity beyond 500 meters for ad hoc network granules. Studying roads with average speed properties gives the impression that, different strategies of network formation and network granule length might be considered for VANETS in the future. Also, in high speed highway scenarios, roadside gateways might act as head-node to form calculations.

In highways there are help telephones on the roadsides for emergency use. These help phones are all connected to data communication networks. Most of the UK network is high speed Ethernet with large portions of highways having fiber-optic cables. The Highways agency has plans to upgrade entire Highway network with fiber-optics in the coming years for high-speed roadside data communications. This will provide a great infrastructure for this projects vision of roads with gateways.

By having roadside gateways as head nodes for calculations, negotiation process will be a lot shorter and gateways will be able to relay information regularly. This will scale the calculation process to high speed Highway scenarios a lot easier.

Some interesting comparative observations also emerge from these studies in terms of how speed affect connectivity maintenance as well as how much of an impact speed has on connectivity in VANETS. 30mph speed constant has produced connectivity results that in the range of between 86.68 per cent for ad hoc network granule of 200 meters and 88.87 per cent for 800 meters in ad hoc network granule length. 40 mph results for same ad hoc granule lengths are: 80.18 per cent for 200 meters and 85.23 per cent for 800 meters. Connectivity comparison chart below shows the full comparison. From this demonstrates how much an impact 10 mph speed variation has on connectivity. This can be an important metric for VANET studies. Results might vary according to vehicle density and road conditions as well as physical communications issues but it must be noted that this project has identified a very important metric for VANET studies. A speed based connection and communication quality for VANETS can be a useful area to investigate and solidify for VANET researchers. Granular study of this project has highlighted this as an important direction.

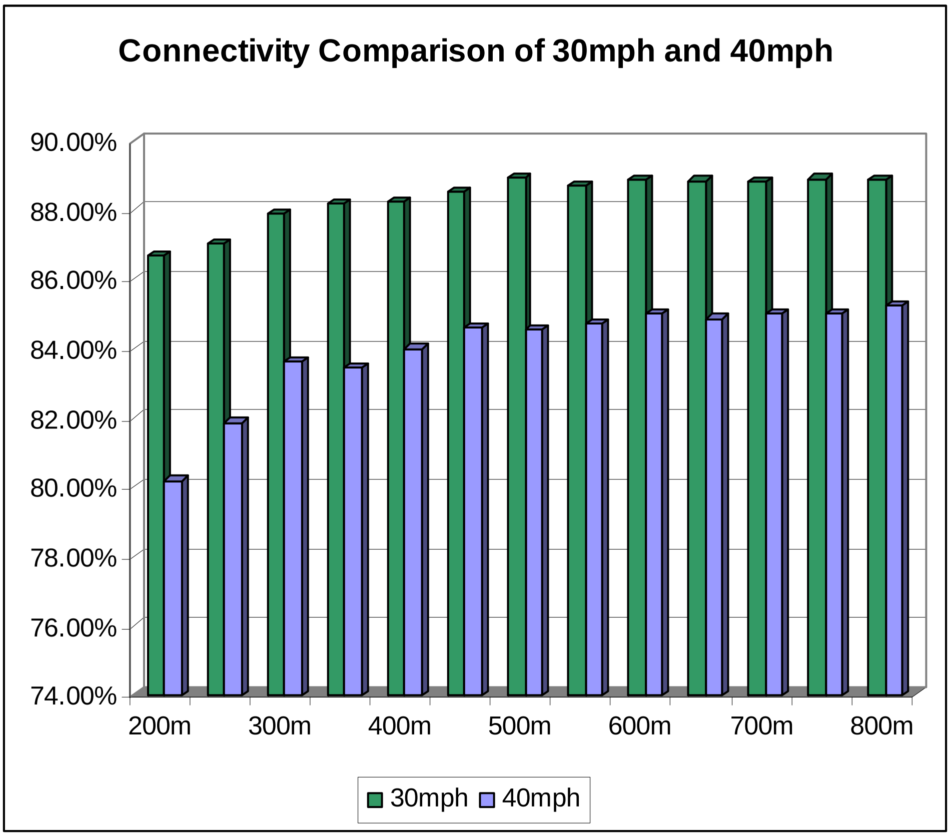


Figure 15 Connectivity comparison of 30mph and 40mph

Connectivity Comparison values:

30 mph	**40 mph**
86.68%	**80.18%**
87.04%	**81.86%**
87.90%	**83.62%**
88.16%	**83.45%**
88.24%	**83.99%**
88.52%	**84.59%**
88.92%	**84.53%**
88.71%	**84.71%**
88.87%	**85.00%**
88.83%	**84.86%**
88.79%	**85.02%**
88.89%	**85.01%**
88.87%	**85.23%**

Table 6 Connectivity comparison values for 30mph and 40 mph

Another variable studied was the number of the road network granules in the system and how they changed with road granule length enforced. This shows a much sharper decrease initially but slows later. Longer granule lengths mean larger ad hoc network areas and more vehicles getting involved but loss of vehicles do not decrease as such. Loss of vehicles during calculation cycle happens when vehicles exits the current road network granule and enters into the next one during the calculation process. Vehicles close to the exit edge will get out of the granule during a calculation. Increasing granule length gets more vehicles involved and less percentage gets out of the edge. When the two graphs are compared this correlation can be observed.

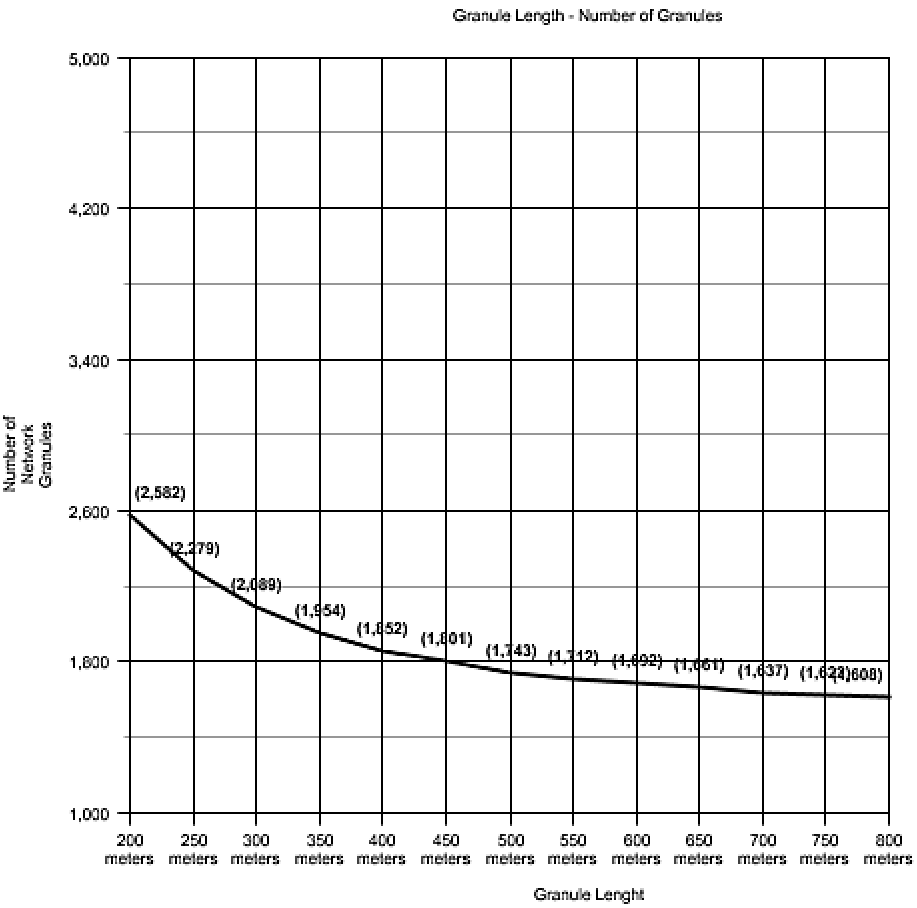


Figure 16 Granule Length – Number of Granules

Number of Granules	
200 meters	2582
250 meters	2279
300 meters	2089
350 meters	1954
400 meters	1852
450 meters	1801
500 meters	1743
550 meters	1712
600 meters	1692
650 meters	1661
700 meters	1637
750 meters	1622
800 meters	1608

Table 7 Granule Length – Number of Granules

5.2 Conclusion

This initial study into the proposed architecture has produced some interesting results. It definitely seems like it would be possible to find optimized road segment lengths for temporary Vehicular Ad Hoc Network formation on different speeds. Increase of road granule lengths so that vehicles don't go out of networks before calculations provided interesting values for different road speeds. Interestingly, there seems to be a threshold value of granule length at each road speed that after this value increasing the granule length did not result in increase in connectivity. Connectivity means vehicles not going out of ad hoc network region before the calculation.

Results have shown that it is possible to perform calculations on geographically constrained vehicular ad hoc networks. Connectivity seemed acceptable for such calculations. The results suggest that even at the top speed of 60 mph studied, the connectivity is acceptable with existing technologies.

Another interesting aspect of the proposed architecture was the road segmentation process produced surplus values. When roads are discretely granulated like a road of 1000 meters being granulated into 300 meters granules produces 100 meters surplus which has impacted on results. Simulator might be improved to deal with this.

From the study into the two developing fields of study, Granular Computing and Vehicular Ad Hoc Networks, this project has come across credible amount of features in support of the initial vision. The project has architected a hierarchical real-time information system of imprecise data form the Urban Traffic System. The study has established an original data processing system utilizing both fields of study.

Principles of a Vehicular Ad Hoc network level communications protocol is envisioned which will cater for the aim of inter-vehicle intelligent knowledge generation.

Utilizing the techniques of intelligent information processing in the field of Granular Computing, the imprecise and dynamic conditions of the Urban Traffic System can be dealt with in the way of forming a truly scalable, real-time and useful Urban Traffic Information generation and processing system. The architecture that has been developed is very promising to overcome the underlying difficulties of the imprecise and dynamic nature of the Urban Traffic System.

The proposed system architecture has been developed as a prototype solution scenario for real-time handling of infinite amount of data. This is provides a roadmap and project plan for a futuristic Urban Traffic System capable of dealing with complex and infinitely scalable capacity for real-time human-centric information generation and dissemination.

From this study into the two developing fields of study, Granular Computing and Vehicular Ad Hoc Networks the researchers working on this project have come across credible amount of features in support of the vision of this project. This project has architected a hierarchical real-time information system of imprecise data from the Urban Traffic System. The study has established an original data processing system utilizing both fields of study.

A Vehicular Ad Hoc network level communications protocol is envisioned and some basic principles of such a truly ad hoc network protocol is summarized; which will cater for the aim of inter-vehicle intelligent knowledge generation.

Utilizing the techniques of intelligent information processing in the field Of Granular Computing, the imprecise and dynamic conditions of the Urban Traffic System can be dealt with in the way of forming a truly scalable, real-time and useful Urban Traffic Information generation and processing system. The architecture that has been developed is very promising to overcome the underlying difficulties of the imprecise and dynamic nature of the Urban Traffic System.

The proposed system architecture has been developed as a prototype solution scenario for real-time handling of infinite amount of data. This is also a roadmap and project plan for future work. The system can be further evaluated and improved and eventually a prototype can be field test as a solution as proposed in the future work section.

It must be highlighted that the consideration of road speeds is very important which came out of this study. VANET studies do not consider road speeds of 30, 40, 50, 60 mph as standard VANET speeds. This project has considered those speeds as a major property and characteristic of VANETS and the project proposes this property to be part of any VANET studies.

The study has considered the highway gateway scenario for solution to local data processing. Currently, highway roadside networking infrastructure is being upgraded with the aim of exploring ways of bringing the Internet to the highways [40][41]. The study has drawn attention to the potential of using this network infrastructure to enable local distributed data processing and information relay scenarios as a solution to the problem of extremely large amounts data being generated on roads.

5.3 Simulator Evaluation

Vehicle generation is kept simple; this is an area that can be further improved to have different densities of vehicles generated in a fuzzy way. Currently, the vehicle generation is constant; settings come from the Simulation Parameters file. Minimum distance between vehicles and road density constants are defined in this file and they are constant during the simulation. This constant vehicle generation has been implemented for simplicity so that real focus on higher level architectural real-time information granulation is not lost.

Density of vehicles generated can also be made variable. As the overall study was concerned with defining an architecture to bring together the fields of ad hoc vehicular networking and granular computing and designing a simulation framework for studying such an architecture; the vehicle patterns were not studied. Existing traffic simulation tools are not designed to deal with networking and granular information generation studies and network simulators are lacking the ad hoc vehicular networking and also granular information generation components. So, the component oriented approach has been unique to the problem at hand, - granular computing also has such characteristic of being specific enough and pragmatic for the problem at hand - and designing such a system and a simulation architecture for it has been challenging in many respects. Due to complexity of the problem some lower level functionality has been kept simple. Those constants do provide enough realism to demonstrate that this architecture can be used as a blueprint for studies in generating real-time human centric information granules from the traffic data.

Vehicle simulation provides the basis for the study. However, the focus was forming ad hoc networks among vehicles and having information granulation performed in a real-time way. For this reason, a simple vehicle simulation would be most suitable for building the upper level components. When vehicles reach the end of the road they are disposed. Simulation cycle keeps moving vehicles, and doing necessary network formations and calculations as necessary.

Ad hoc network formation in literature is usually spontaneous; ad hoc networking is not triggered periodically. The approach taken by this study is simultaneously triggering the system to form adjacent ad hoc networks to perform local and real-time information granulation. To simulate this there is a job based approach. Each calculation is registered as a job against a simulation cycle count. Network delay in the simulator is also implemented this way. After triggering the calculation, network formation and delay is simulated by further delay. This delay is taken as estimated time. Each simulation cycle causes vehicles to move certain distance. This is in comparison to speed. There is a system level simulation cycle counter static variable that counts cycles. There is also a static constant for moment which is in meters, so on each cycle vehicles are moved by that constant meters. This provides basis to set a simple constant road speed like 40 miles per hour so that simulation can be carried out in a constant road speed. These simplistic scenarios are very important and useful in these early studies. Later a system with more dynamic characteristics like vehicle speeds responsive to road conditions and varied road speed for different roads might be studied. But first look into this unique environment and system does require as much simplicity as possible.

Simulators with thousands of vehicles and thousands of roads involved all with constant speed are repeated in the study. As road speed is constant, this has meant improving simulation movement constant in meters to increase vehicle movement speed. This study has given some valuable results. Also, same goes with ad hoc network granule lengths. They are also kept constant and studies have been made to understand how exactly granule lengths will impact on connectivity and information quality. Those two variables are essential for the system and understanding those two parameters and their effects is a very valuable work on its own. This project has for example established after many simulation runs with many different constants that increasing granule length does not mean reducing granule numbers, as the Table 8 from the study results show:

Granule Length	Number of Granules
200 meters	2582
250 meters	2279
300 meters	2089
350 meters	1954
400 meters	1852
450 meters	1801
500 meters	1743
550 meters	1712
600 meters	1692
650 meters	1661
700 meters	1637
750 meters	1622
800 meters	1608

Table 8 Granule Length – Number of Granules

This is because road lengths are variable.

When simulations were run by keeping speed constant to 40 mph it was possible to be able to establish granule length changes across the entire system and once again some interesting results were obtained. Granule length variation did not mean higher connectivity, in fact by increasing the network granule length which means the network communication range and vehicular network topology area there was not much difference in terms of percentage of vehicles lost connection during the network formation delay. The way this was established is, a granule length like 500 meters is set then vehicles moved along the roads and a calculation is set to certain cycle to trigger. After triggering the calculation, a network formation delay is simulated by waiting the amount of cycles for delay. During this time vehicles are observed.

Typically, some simulations are triggered after system is populated with enough density of vehicles. This achieved by waiting for certain amount of cycles like 100 cycles. This is because vehicle generation logic generates vehicles at the start of roads and places them on the road. Each road object has its own vehicles collection and each vehicle knows its place on the road. This way vehicle generation logic checks the density constant. As well as having vehicle speed constant like 40 miles per hour, there is also a density constant which specifies the minimum distance between two vehicles. Generation logic checks road vehicles and waits as many cycles as needed before generating a new vehicle to be placed at the beginning of the road so that vehicles are never closer than the minimum distance constant. It takes a while before enough saturation is reached on the system for calculations to take place.

All the vehicle movement is taken care of by the simulation component, the network granulation component at this point does nothing until a calculation is triggered. Once a calculation is triggered on the cycle, Network granulation logic granulates vehicles on roads to ad hoc networks according to granule length constant. Vehicles are all placed into a granule on the road as Figure 16 represents.

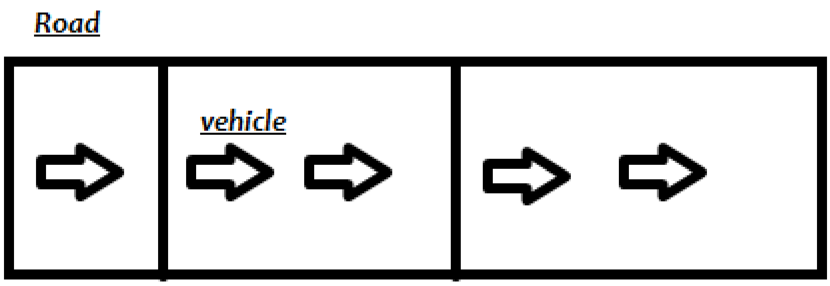


Figure 17 Road Granules

All the vehicles are placed into granule objects and on each simulation cycle after this, vehicles are checked for their current ad hoc network granule by their position on the road and if they move into another ad hoc network area on the road they are placed into the next granule and they are moved from the previous road network granule.

Now this is the network granulation and maintenance component. Once calculation is triggered, a view of the current state is noted. Then, network delay is simulated by waiting a number of cycles. At the end of the network formation and negotiation delay, a new view of the system is taken. By this time some vehicles would have moved onto the next road granule. So, all those vehicles that moved out of a granule during this time lapse are registered as losses and connectivity maintenance of the ad hoc network is recorded as percentage of vehicles that are left in the granule. The connectivity - granule length graph utilizes this technique:

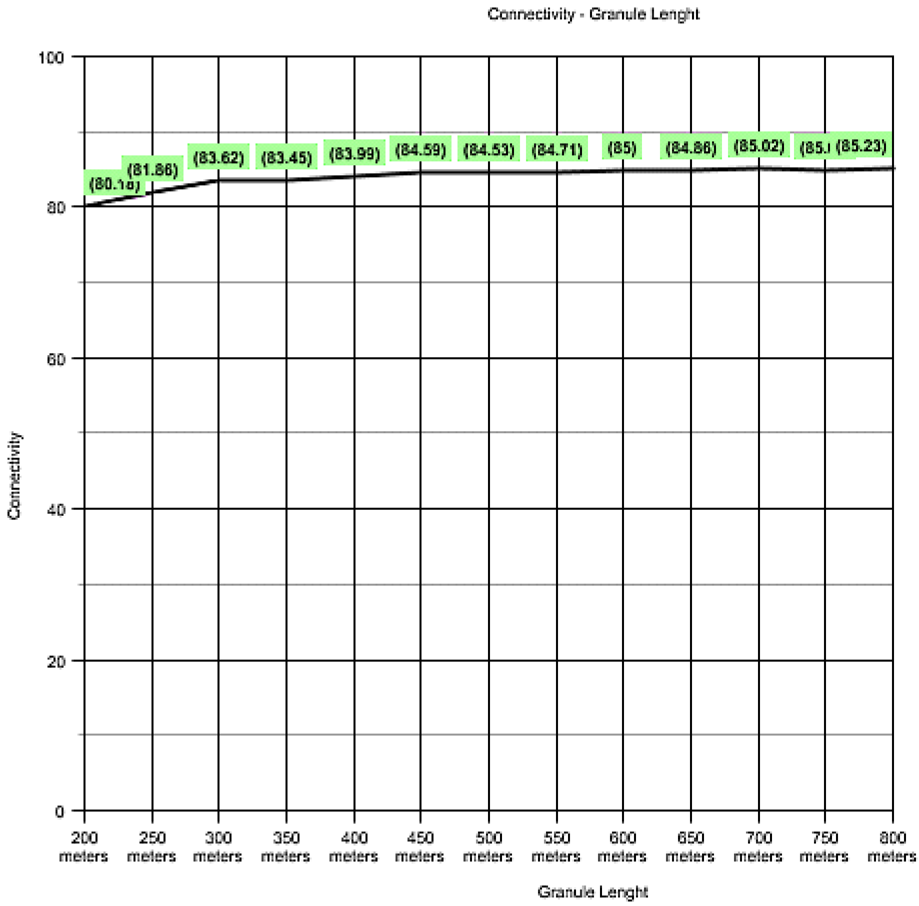


Figure 18 Connectivity – Granule Length graph

This delay constant for allowing the negotiation and connection for the nodes is useful to view how system will behave with network physical constraints. Of course, the network granule lengths also can be thought of physical connectivity constraints as radio ranges. This are of the system can be evaluated further. The intention was to lay the foundation for real-time granular information generation in a large urban system with infinite scope to scalability. It has been demonstrated that many thousands of adjacent networks can be formed simultaneously and totally independent of each other to take a real-time picture of the system. It is more than a picture. Not only that, at that moment one is looking at data, one is constructing human-centric information granules. This distributed approach is scalable and maintainable. This was the main point that the project has embarked on to investigate and so the focus was kept on abstracting this point out. The system and simulation results in scale are promising.

Vehicles can be considered as granules and their interaction with system components can be viewed in a granular level architecture. Vehicles have different interactions with different components. This is a concept of granular computing. Vehicles in a vehicular ad hoc network can be thought of as information granules. There are three different levels that vehicles participate as granules. First one is the simulation granular level. These granular levels can be considered as different stratas having different usage and views of granules.

At the simulator level vehicles are seen as simulation objects, their properties like current location on a road, distance from the vehicle in front and coming to end of the road are important.

At the Network Granulation level vehicles are seen as entities in granule objects. This components look at vehicles as entities in different network granules.

The Information Granulation level is concerned with the information obtained form vehicle like current speed variation, break usage, fuel consumption, etc.

Currently, vehicles only have lifetime for the length of a road. Vehicles are generated on one end of the road, moved along the road each simulation cycle and when they reach the end of the road, they are discarded. This simplicity was enough for this study to display the real-time distributed information granulation in a very high scalability of thousands of adjacent ad hoc networks and was enough to study some fundamental characteristics of such system. Further studies can be thought of to improve this to study different characteristics of the system more closely.

Although the focus has been on real-time information granulation, having road network granules as vehicular ad hoc network topology constraints which relate ad hoc networks to geographic location, this would give historical dimension to ad hoc network granule information. Information can be collated to have a weekly or monthly view of a road segment for example or certain times of the day for each day can be viewed historically after information is related to traffic system through roadside gateway. Networks are ad hoc in nature but granules being geographically mapped to a road segment enables physical coupling of information generated. This information results can be related a number of ways, because information granules generated will be an aggregation making them very small in size.

Simulations can be improved to generate road level and area level information granules for study purposes.

Vehicular ad hoc network (VANET) studies usually focus on connectivity, continuity, maintainability typically with no time constraints and extensibility of the networking infrastructure. The approach taken by this study is truly ad hoc fashion, this study envisages triggered ad hoc short connectivity for a single purpose only and as soon as that aim is achieved the ad hoc network is broken. A lot of studies in literature focus on multi-hop scenarios. This study only considers communication range networks as ad hoc networks are adjacently scalable. Ad hoc networks are triggered only for the duration of a calculation. Simulator only establishes networks for the duration of calculations.

One area that can be visible as an area to improve is how simultaneous calculations are triggered. This is part of a communications protocol for the system. Multiple radio approach is one way to handle this.

Only one way traffic is simulated, vehicles are all assumed to be in the same direction. Simulation also simulates traffic in a one way fashion. Although the simulator is only handling one way traffic; this can be improved, and two way traffic can be simulated. To implement this, best advice would be to have a different vehicles collection on each road to hold vehicles moving in the opposite direction and calculations to consider two calculations for each granule in each direction. Vehicle objects themselves to include direction information. For the purpose of this study this one way granularity was enough and to point. In fact, it could be argued that one way model gave more clarity and was more suitable to study some high level attributes and properties of the system.

The approach to protocol design for ad hoc networking has been different to most of current literature which consider protocol design for universal purposes rather than being problem specific. A lot of current work follows a pattern of developing a protocol for the environment before a problem is applied. In the case of this study, the focus is on the problem first and clarifies the needs.

Another important observation that can be made from the results obtained is the fact that, due to network delay and vehicles moving with a speed, vehicles are going out of the network granules during the calculation. The mechanism for calculations can be improved to include the moving vehicles into the calculations.

Chapter 6
Conclusion and Future Work

6.1 Conclusion

This research has made a strong case that the imprecise and dynamic conditions of the Urban Traffic System can be dealt with by utilizing the techniques of intelligent information processing in the field of Granular Computing and Vehicular Ad Hoc Networks and help with forming a truly scalable, real-time and useful Urban Traffic Information generation and processing system. The architecture that has been developed is a promising new approach to overcome the underlying difficulties of the imprecise, dynamic and infinitely scalable nature of the Urban Traffic System.

The main aim of the project was to investigate the possible ways of building scalable Urban Traffic Information Systems, utilizing the developments in the fields of Vehicular Ad Hoc Networks and Granular Computing. A hierarchical real-time information system of imprecise data for Urban Traffic Information Systems has been architected and investigated. A simulator has been developed for evaluation of such systems utilizing both fields of study.

A novel Vehicular Ad Hoc network level communications and information granulation model is envisioned which promises cater for the aim of inter-vehicle intelligent knowledge generation.

The proposed system architecture has been developed as a prototype solution scenario for real-time handling of large amount of data in a large system. This provides a basis and project plan for a futuristic Urban Traffic System capable of dealing with complex and infinitely scalable capacity for real-time human-centric information generation and dissemination.

The aim of identifying and defining the components of the multidisciplinary hierarchical architecture has been achieved. The proposed system architecture introduces the components of a geographically constrained Vehicular Ad Hoc Networking component and a real-time human-centric information granulation component utilizing the concepts of Granular Computing.

The aim of studying the newly identified components has been achieved to a level where it was possible to demonstrate that the proposed architecture is viable. Geographically enforced Vehicular Ad Hoc Networks have revealed some interesting results during simulation. For instance, it has been established that road speed and granule lengths on which vehicular ad hoc networks are enforced are two of the most important properties of the architecture.

Identification of a mechanism to granulate traffic information and levels of data processing has been established. A three level system view is proposed and ad hoc network level has been the focal point of the study. However, further tests and evaluation can be made. Field studies for example on the ad hoc network level would be very interesting in proving the concepts.

The aim of identifying an ad hoc networking mechanism has been achieved. The study has suggested geographically dependent short-lived vehicular ad hoc networks with a node head for information generation. This is a whole new approach to vehicular ad hoc networking that has been introduced for the purpose of real-time distributed information generation.

The aim of investigating the scalability of solution and providing a scalable solution has been achieved successfully. Geographical ad hoc network areas make it possible to have infinite amount of adjacent networks, disconnected form each other. This was the entire urban network can be granulated into those small geographical networks and real-time information generation can be performed simultaneously.

The aim of designing and developing a simulator has been achieved successfully. A component based simulator has been designed to reflect the proposed architecture. The simulator successfully represents the multidisciplinary make of the system architecture introduced. The general architecture and components have been designed. Of course, this architecture can be improved in areas like traffic movement, vehicle generation, network formation, and information granulation.

The aim of running simulations and reporting results has also been achieved. Some preliminary tests have been performed and some very interesting findings have been reported. The simulation results have given an insight into the architecture. The simulator has been demonstrated to serve its purpose. The design and development of the simulator has been successful.

From study into the two developing fields of, Granular Computing and Vehicular Ad Hoc Networks, research have come across credible amount of features in support of the vision of establishing a geographically controlled topology based Vehicular Ad Hoc Networks and Granular Computing which promises to handle the topology and scalability issues as well as latency of information retrieval.

A Vehicular Ad Hoc network level communications architecture with geographically enforced topology is envisioned and some basic principles of such a truly ad hoc network environment are summarized; which will cater for the aim of inter-vehicle intelligent knowledge generation. Although the communication protocol for the envisaged geographically enforced Vehicular Ad Hoc Networks has not been given a lot of focus, a mechanism is suggested in forms of head-node selection and network formation which would serve as a basis.

The project has also considered the highway gateway scenario for solution to local data processing and dissemination. Currently, highway roadside networking infrastructures are being upgraded with the aim of exploring ways of bringing the Internet to the highways [40][41]. The project has drawn attention to the potential of using this network infrastructure to enable local distributed data processing and information relay scenarios as a solution to the problem of extremely large amounts data being generated on roads.

As a result of the study; components of a multidisciplinary hierarchical architecture combining Vehicular Ad Hoc Networks and Granular Computing has been identified and a promising architecture has been developed.

Identified components for the system have been evaluated and studied and some important properties of the components are considered. Focus has been on the Ad Hoc Network Level. Future study might consider the remaining components identified in this project.

The ad hoc networking topology enforced geographically and the approach of independent adjacent networks forming a scalable network has been suggested as the networking basis for the information granulation. This is a promising way of scalability and dealing with infinite data generated in the Urban Traffic.

A simulation system for the multidisciplinary architecture proposed has been designed and developed. The simulator is a significant contribution both in terms of how to architecture a simulator for such a system, and how to manage the complexity test and evaluate the system. Simulation results have provided some interesting findings on the properties of the system model developed. Simulator can be advanced and developed further. The simulator developed has achieved to demonstrate the approach and gave some important preliminary results.

Information processing or reasoning algorithms have not been considered at the Information Granulation Level. Evaluation of different and efficient algorithms for Information Granulation ad calibration of such algorithms would have required a focused study and extensive evaluations for which the project did not have time for given the scope of the project. The Information Granulation architecture with multidisciplinary approach was a challenging task and as such micro level component based studies have been kept simple for the sake of keeping focus on the architecture.

6.2 Future Work

Architectural:

- Architecturally, the system can be extended to include a mechanism for ad hoc querying of a road interval or entire road from the control centre using the gateway or mobile communications. Currently, calculations are triggered internally by vehicle using inbuilt calculation schedules.
- Current architecture assumes that each vehicle would have a calculation schedule for all the roads and road segments and a Network Granulation Engine triggers calculations if there are any current calculations for the current road segment. This mechanism can be changed so that vehicles dynamically load calculation schedules from roadside gateways for roads or areas.
- Calculation schedule synchronizing can be done using the mobile telephone network infrastructure. A study into using and integrating the mobile telephone networks to Vehicular Ad Hoc Networks can be done.
- A communications interface bringing together the current Wi-Fi and WiMax public mobile network infrastructures into the domain would be an interesting study. The system can perform information granulation as suggested by this infrastructure and human-centric fuzzy information granules can be fed into public Wi-Fi network and to the Internet and made available to public through the means of the Internet.

- An Internet based information system can be developed using the proposed system architecture as backbone to make the information available. The interface to public Internet Wi-Fi facilities through the roadside gateways must be developed and information must be presented on the Internet through a website.
- Further to Internet website, the information generated by the system can be fed into the Internet domain through the gateways and facilities and ways of making this information available through devices like handheld computers or mobile phones, etc can be studied.
- Although, this study utilized other studies like FleetNet to suggest reasonable communication ranges and mechanisms, a study into physical infrastructure like in-vehicle devices and communication devices to achieve the objectives of this study or even improve it can be made.
- A mechanism can be designed so that a police vehicle can request certain calculations on a road. A mechanism to trigger ad hoc immediate calculations on roads or regions can be designed.
- Interface to existing traffic systems is an outstanding issue. How this information can interact with the existing systems is to be investigated.
- A mechanism by the traffic management centres to interact with the system is to be investigated. Ideally, a study should capture what expectations and uses this system can have for the traffic management centres and how the interface for such requirements can be established.
- Road granulation and optimization for communications can be an interesting study. As the system makes use of physical geographical network topology, different roads and areas can have different communication ranges and

density. A mechanism can be developed to dynamically do road network granulation or a self-learning central system can granulate roads into network intervals by probing roads for network parameters an checking communication parameters.

- Inter-network calculations are to be designed and implemented.
- Currently, vehicles go out of network granules during network delay time. Architecture can be improved to include new coming vehicles in adjacent granules.

Simulator:

- Simulator currently uses a one way simple traffic movement mechanism. This can be improved, a two way traffic simulation can be developed.
- Traffic movement is currently kept constant for the system to make system wide studies. Road specific speed can be implemented and road speeds can be fed into the simulator to only allow the max speed on that road. This way more granular studies can be performed.
- Speed can also be varied on roads, and also, current vehicle generation engine can be fuzzified to produce different traffic patterns.
- One interesting study would be to be able to feed in realistic traffic density patterns and study the system.
- Network granulation can be fuzzifed to handle different road speeds. Geographical network topology depends on road network granules, those granules can be fuzzified .

- Information granulation engine should be studied further. Currently, this level was kept simple to provide a mechanism for higher system level studies, algorithms and methods of information granulation can be studied further.
- Inter-network information granulation component is to be developed.

Other:

Network Granulation Engine part of the simulator can be improved. This study has kept it simple to contribute to the higher architecture as a component. This component involves granulating roads into road granules which are geographically constant and vehicles form ad-hoc networks with other vehicles within the same granule. Network topology is defined and restricted by those road granules. Although the model envisages each vehicle to have an inbuilt map and a GPS apparatus and have preset road network granules or an algorithm to granulate the roads using Granular Computing concepts, simulator simplifies this by segmenting the roads into granules and holding a roads collection with algorithms to calculate exact location for a vehicle and the granule it belongs. Road granulation is mostly developed. Second part of this component is to form networks and maintain them. This is the next and ongoing work. Object model and processes for such network formation has been developed.

This Network Granulation Engine is developed as the second strata to sit on top of the first layer which is composed of the GIS component and the Urban Traffic Simulator subcomponents.

This is followed by the third and last level which is the Information Granulation Engine. This component is at the heart of the optimization of fuzzification of knowledge from uncertain environment. This component does the necessary information/knowledge generation from the ad-hoc networks which will have been formed by the second strata. This component will generate ad-hoc network level information granules utilizing the Granular Computing concepts.

This simulation architecture with its ad hoc granulation engine and the information granulation engine is designed to model and study the ad hoc networking level of the overall system architecture as ad hoc network generation, maintenance and information granulation. Vehicle Level which is a lower level view from the ad hoc network level, and the Inter-network level parts of the system have been left for future study.

Vehicle Vision Level might provide an interesting base for vehicle level decision making as well as generation of information granules to be passed onto upper levels for further processing. Some data assumed to be coming into the ad hoc network from vehicles might well be Vehicle Vision level granules like movement constant.

Movement Constant is a parameter indicating the degree of freedom to move onto other lanes a vehicle enjoys which can be temporally aggregated like for the last 5 minutes. A vehicle can use its vehicle space to observe how free it is at a given time to be able to change lane to both sides. It might be that a vehicle on the lane to its right is fast approaching at a given time t, speed difference is in its favour and it is within 5 meters behind. In this scenario it will virtually be impossible to move out to the right lane until this vehicle passes and there is a suitable gap on the right lane. This parameter can be very useful in planning how free vehicles are to change lanes and ultimately speed the flow of the traffic.

Vehicle level also might be considered more carefully in the future to identify current and developing technologies to see what kind of information is likely to be available from this level that might be of interest to ad hoc network level calculations. A study into this area might be a good report to base some network level calculations on.

Another area that is interesting to look at is the geographical road network granules. Roads can be granulated into physical network areas dynamically using fuzzy logic. Also, fuzzy neural networks approach can be used to improve road network granule segmentation for a given region.

Moving forward from the ad hoc network level, inter-network level information processing will be considered to establish spatial and temporal information granulation at a higher level and usage scenarios. Ad hoc network level calculations are to take place in set periods and each network will match these times. Ideally every ad hoc network within a road will do information generation simultaneously at exactly same time and it will be possible to bring information granules together at a higher level and do further granulation to obtain higher level information granules.

Another piece of the control jigsaw is the algorithm for localized data processing and its interaction with the in car devices. The initial granules of traffic information knowledge will appear at this level.

One very important issue is the collaborative generation of information which is not available within one single car taken separately - e.g. wind-screen-wipers on for several cars – therefore it is raining at this specific location. The ad-hoc networks formed during the movements of the cars in the city seem to be the ideal approach to making the cars communicate with each other and share information on car level with the aim to obtain new level of traffic information. The project is aiming to identify the in set-of-cars data process algorithm for such scenarios.

Further to the in-set-of cars algorithm the next level in the hierarchy is the identification of the in set-of-local-nodes data process algorithm. This level is necessary for data processing purely for reducing the amount of transferred data purposes. It can also help with traffic data distribution within the nodes and cars currently in the range of the set of local nodes.

Having gathered processed on at least two levels real-time information the central location data processing algorithm should be able to cope with the vastly reduced and intelligently processed data to generate in real-time an up-to-date picture of the traffic in the city.

Another task is improving the set of tools available to the Traffic Managers - identifying the real-time traffic control data required by Traffic Managers.
Existing data sources provide information at a relatively coarse temporal and geographical level. When all vehicles are able to provide floating vehicle data, the capability to monitor network performance in detail will be transformed. Future studies will take this project forward to provide the means to process that data and an overview of what will be needed by traffic managers.

Also, equally significant task will be improving the set of tools available to the Traffic Managers - investigation of the possibility of presenting some of the generated data in visual form to the Traffic Managers and identification of appropriate traffic control operator screen designs. This task requires the processed data to be presented to the control room operator in appropriate form so that the granules of processed information carry maximum information about the traffic thus improving the set of tools available to the Traffic Managers.

A prototype implementation will also be helpful in evaluating the system model. The prototype implementation will be built on the existing test site that was implemented for the Traffimatics project. The prototype implementation will involve the necessary equipment and software to be developed and mounted on cars or busses and run in Nottingham alongside predefined routes covered also by SCOTT inductive loops for comparison purposes.

Field trials of the prototype will be performed. All field trials will be also carried out on the basis of the equipment installed for the Traffimatics project in Nottingham. Several crossroads will be subject to testing and the results will be suitably reported in papers and reports.

7. REFERENCES

1. Californian Path Project - http://www.path.berkeley.edu, (Accessed 12 April 2011)

2. FleetNet project http://www.neclab.eu/Projects/fleetnet.htm, (Accessed 12 April 2011)

3. Cartalk Project - www.cartalk2000.net, (Accessed 12 April 2011)

4. T. Michael, E. Peytchev And D. Al-Dabass, "Auto-Sensing And Distribution Of Traffic Information In Vehicular Ad Hoc Networks",UKSIM2004, Conf. Proc. of the UK Simulation Society, St Catherine's College, Oxford, 29 - 31 March 2004, pp124-128

5. S. Zhi, M. Thomas, E. Peytchev, T. Osman And D. Al-Dabass, "Embedded Communication and Java Technologies for Traffic Information in Vehicular Ad Hoc Networks", paper 464-026, Int. conference on Networks and Communication Systems (NCS2005), Editors: M.H. Hamza, P. Prapinmonkolkarn, T. Angkaew, Krabi, Thailand, April 18-20, 2005.

6. A. Bargiela And W. Pedrycz, Granular Computing - An Introduction, Kluwer Academic Publishers, 2002, p-4

7. W. Pedrycz And A. Bargiela, Granular clustering: a granular signature of data, IEEE Trans. on Systems Man and Cybernetics, 32, 2, April 2002, pp. 212-224.

8. C. Claramunt, B. Jiang And A. Bargiela, A new framework for the visualisation of very dynamic traffic data. In: Geographic Information Systems in Transportation, J.C. Thill (ed.), Elsevier Science Pub., 2001.

9. E. Peytchev and C. Claramunt. 2001. Experiences in building decision support systems for traffic and transportation GIS. In Proceedings of the 9th ACM international symposium on Advances in geographic information systems (GIS '01). ACM, New York, NY, USA, 154-159.

10. L.A. Zadeh, "Toward a theory of Fuzzy Information Granulation and its centrality in Human Reasoning and Fuzzy Logic", Fuzzy Sets and Systems, 90, 111-27, 1997.

11. Y.Y. Yao, and J.T. Yao, Granular computing as a basis for consistent classification problems, in PAKDD 2002 Workshop entitled "Towards Foundation of Data Mining", Communications of Institute of Information and Computing Machinery, Vol. 5, No.2, 2002, pp.101-106.

12. Y. Y. Yao, Perspectives of Granular Computing , Proceedings of 2005 IEEE International Conference on Granular Computing, Vol. 1, pp. 85-90, 2005.

13. Y.Y. Yao A partition model of granular computing LNCS Transactions on Rough Sets, Vol. 1, 232-253, 2004.

14. Y.Y. Yao, Information granulation and rough set approximation, International Journal of Intelligent Systems, Vol. 16, No. 1, 87-104, 2001.

15. Y. Y. Yao, Stratified rough sets and granular computing, Proceedings of the 18th International Conference of the North American Fuzzy Information Processing Society, New York, USA, June 10-12, 1999, Dave, R.N. and Sudkamp. T. (Eds.), IEEE Press, pp. 800-804.

16. A. Bargiela, W. Pedrycz. The roots of Granular Computing. In: IEEE Conference on Granular Computing (GrC2006), Atlanta, USA, 2006.

17. VANET http://en.wikipedia.org/wiki/VANET, (Accessed 12 April 2011)

18. W. Pedrycz, A. Gacek, Kybernetes, Information granulation and signal quantization, Volume: 30, Issue: 2, 2001, pp: 179 – 192.

19. P. Witold, Knowledge-Based Clustering: From Data to Information Granules, Wiley-Interscience, 2005, pp-31

20. M. Raya and J.-P. Hubaux, Securing Vehicular Ad Hoc Networks, Journal of Computer Security, Special Issue on Security of Ad Hoc and Sensor Networks, Vol. 15, Nr. 1, pp. 39 - 68, 2007, p-41

21. R. Baumann, “Vehicular ad hoc networks (VANET). (engineering and simulation of mobile ad hoc routing protocols for VANET on highways and in cities)”, ETH,

Swiss Federal Institute of Technology Zurich, Department of Computer Science, Computer Systems Institute (2004).

22. http://emergingtechnology.wordpress.com/2007/10/03/VANET-the-vehicular-ad hoc-network, (Accessed 1 January 2008)

23. http://www.et2.tu-harburg.de/fleetnet/english/vision.html, (Accessed 1 January 2008)

24. http://www.et2.tu-harburg.de/fleetnet/english/floating-car.html, (Accessed 1 January 2008)

25. H. Füßler, M. Käsemann, D. Vollmer "A Comparison of Strategies for Vehicular Ad-Hoc Networks", Technical Report TR-3-2002, Department of Computer Science, University of Mannheim, July 2002

26. Kutzner K., Tchouto J.-J., Bechler M., Wolf L., Bochow B., Luckenbach L. "Connecting Vehicle Scatternets by Internet-Connected Gateways", Workshop on Multiradio Multimedia Communications MMC 2003, University of Dortmund, Germany, February 14, 2003.

27. B. Xu, A. Ouksel, O. Wolfson, "Opportunistic Resource Exchange in Inter-Vehicle Ad-Hoc Networks," mdm, p.4, 2004 IEEE International Conference on Mobile Data Management (MDM'04), 2004

28. GMT Abdalla, M Ali Abu-Rgheff, and S-M Senouci, "Current Trends in Vehicular Ad Hoc Networks", International Workshop on ITS for Ubiquitous Roads (UBIROADS), IEEE GIIS,Marrakech, Morocco July 2007

29. F. Martin McNeill - Ellen Thro, Fuzzy Logic a Practical Approach, Morgan Kaufmann Pub, 1994, pp 10-11

30. Witold Pedrycz, Fernando Gomide, An Introduction To Fuzzy Sets: Analysis and design (Complex Adaptive Systems), The MIT Press, 1998

31. L.A. Zadeh, Toward a generalized theory of uncertainty (GTU)—an outline, Inform. Sci. 172 (2005) (1), pp. 1–40

32. A. Etches, C. Claramunt, A. Bargiela, and I. Kosonen, (1998) "An integrated temporal GIS model for traffic systems", GIS Research UK VI National Conference, March 31-April 2, 1998. University of Edinburgh.

33. I. Kosonen, (1996) HUTSIM - Simulation tool for traffic signal control planning. Helsinki University of Technology, Transportation Engineering, Publication 89. Otaniemi.

34. I. Kosonen, (1998) HUTSIM - Urban traffic simulation model: Principles and applications, Manuscript of D.Sc. (Tech.) thesis, Helsinki University of Technology, Transportation Engineering. Otaniemi.

35. http://publish.uwo.ca/~jmalczew/gida_5/Pursula/Pursula.html, (Last Accessed 17 April 2011)

36. A. Argile, E. Peytchev, A. Bargiela, I. Kosonen (1996). DIME: A shared memory environment for distributed simulation, monitoring and control of urban areas Nottingham-Trent University, Department of Computing, Laboratory of Real-time Telemetry Systems. Paper submitted for European Simulation Multiconference ESM'96, Genua, 1996. 5.

37. L. A. Zadeh, "Fuzzy sets and information granularity", In: M. Gupta, R. Ragade, and R. Yager (eds.), Advances in Fuzzy Set Theory and Application, North Holland, Amsterdam, 1979, pp. 3--18.

38. Keun-Chang KWAK Dong-Hwa KIM, Adaptive Neuro-Fuzzy Networks with the Aid of Fuzzy Granulation, IEICE TRANSACTIONS on Information and Systems, Vol.E88-D No.9, 2005/09/01, pp.2189-2196.

39. Euntai Kim, Witold Pedrycz, Information granulation as a basis of fuzzy modeling. Journal of Intelligent and Fuzzy Systems 18(2): 123-148 (2007)

40. Draft Standard for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages, November 2005, IEEE P1609.2/D2,persistent-link:
http://ieeexplore.ieee.org/servlet/opac?punumber=5551097, (Last Accessed 17 April 2011)

41. H. Hartenstein, H. F¨ußler, M. Mauve, and W. Franz, "Simulation Results and Proof-of-Concept Implementation of the FleetNet Position-Based Router," in Proc. of Eighth Inter- national Conference on Personal Wireless Communications (PWC '03), Venice, Italy, 09 2003, pp. 192–197.

42. A. Boukerche. 2004. Performance evaluation of routing protocols for ad hoc wireless networks. Mob. Netw. Appl. 9, 4 (August 2004), 333-342

43. D. L. Lough, T. Keith Blankenship, K. J. Krizman, A Short Tutorial on Wireless LANs and IEEE 802.11, The Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University

44. C. E. Perkins, E. M. Royer, Ad hoc On Demand Distance Vector Routing, Sun Microsystems Laboratories, University of California

45. Matheus, K., Morich, R., & Lübke, A. (2004). Economic Background of Car-to-Car Communication. Proceedings of the 2 Braunschweiger Symposium Informationssysteme fuer mobile Anwendungen IMA 2004.

46. L. A. Zadeh, Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic, Fuzzy Sets and Systems, Volume 90, Issue 2, 1 September 1997, Pages 111-127.

47. J. A. Stott, "The Effects of Frequency Errors in OFDM," BBC Reseearch Department Report No RD 1995/15 1995.

48. T. Wang, J. G. Proakis, E. Masry, and J. R. Zeidler, "Performance Degradation of OFDM Systems Due to Doppler Spreading," IEEE Transactions On Wireless Communications, vol. 5, pp. 14221432, June 2006.

49. C. E. Perkins, E. M. Royer, Ad hoc On Demand Distance Vector Routing, Sun Microsystems Laboratories, University of California

50. J. Salmi, AODV Multicast Features, Helsinki University of Technology, April 2000, http://www.cse.tkk.fi/fi/opinnot/T-110.5190/2000/AODV_features/index.html, (Last Accessed 17 April 2011)

52. C. E. Perkins and E. M. Royer, Ad-hoc On-Demand Distance Vector Routing, In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, pages 90–100, New Orleans, LA, February 1999.

53. M. TorrentMoreno, F. SchmidtEisenlohr, H. Füßler, and H. Hartenstein, "Packet Forwarding in VANETs, the Complete Set of Results," Dept. of Computer Science Universität Karlsruhe (TH) 2006.

54. M. Meincke, P. Tondl, M. Dolores, P. Guirao, and K. Jobmann, "Wireless Adhoc Networks for InterVehicle Communication," in Zukunft der Netze Die Verlezbarkeit meistern, 16. DFNArbeitstagung, über Kommunikationsnetze: GI, 2002. Ubiquitous Computing and Communication Journal 9

55. M. Jerbi, S.M. Senouci, and Y. GhamriDoudane, "Towards Efficient Routing in Vehicular Ad Hoc Networks," in UBIROADS 2007 workshop, GIIS Marrakech, Morocco: IEEE, July 2007.

56. M. Mabiala, A. Busson, and V. e. V`eque, "On the capacity of Vehicular Ad Hoc Networks," in UBIROADS 2007 workshop, GIIS Marrakech, Morocco: IEEE, July 2007.

57. (Engineering and simulation of mobile ad hoc routing protocols for VANET on highways and in cities) Master's Thesis - Master's Thesis in Computer Science
Rainer Baumann, ETH Zurich 2004

58. W Pedrycz, Granular Computing - The Emerging Paradigm, Journal of Uncertain Systems Vol.1, No.1, pp.38-61, 2007

59. Y. Yao, Perspectives of Granular Computing, Proceedings of 2005 IEEE International Conference on Granular Computing, Vol. 1, pp. 85-90, 2005.

60. T.Y. Lin, From rough sets and neighborhood systems to information granulation and computing in words, European Congress on Intelligent Techniques and Soft Computing, 1602- 1607, 1997.

61. Z. Pawlak, Rough sets, International Journal of Computer and Information Sciences, 11, 341 356, 1982.

62. A. Skowron, and J. Stepaniuk, Information granules: towards foundations of granular computing, International Journal of Intelligent Systems, 16, pp.57-85, 2001.

63. Vilém Novák Ostrava, What is Fuzzy Logic, Fuzzy Sets and Systems Volume 157, Issue 5, 1 March 2006, pp. 595-596.

64. Chih-Hsun Chou, Hung-Ching Lu, A heuristic self-tuning fuzzy controller Fuzzy Sets and Systems, Volume 61, Issue 3, 10 February 1994, pp. 249-264.

65. U. Höhle, L. Neff Stout, Foundations of fuzzy sets Fuzzy Sets and Systems, Volume 40, Issue 2, 25 March 1991, pp. 257-296.

66. M. Delgado, A. F. Gómez-Skarmeta, F. Martín, A methodology to model fuzzy systems using fuzzy clustering in a rapid-prototyping approach Fuzzy Sets and Systems, Volume 97, Issue 3, 1 August 1998, pp. 287-301.

67. D. Dubois, H. Prade, Twofold fuzzy sets and rough sets—Some issues in knowledge representation Fuzzy Sets and Systems, Volume 23, Issue 1, July 1987, pp. 3-18.

68. Wenyi Zeng, Hongxing Li, Relationship between similarity measure and entropy of interval valued fuzzy sets Fuzzy Sets and Systems, Volume 157, Issue 11, 1 June 2006, pp. 1477-1484.

69. J. A. Drakopoulos, Probabilities, possibilities, and fuzzy sets Fuzzy Sets and Systems, Volume 75, Issue 1, 13 October 1995, pp. 1-15.

70. S. Gottwald, Mathematical aspects of fuzzy sets and fuzzy logic: Some reflections after 40 years Fuzzy Sets and Systems, Volume 156, Issue 3, 16 December 2005, pp. 357-364.

71. D. Teodorović, Fuzzy sets theory applications in traffic and transportation European Journal of Operational Research, Volume 74, Issue 3, 5 May 1994, pp. 379-390.

72. Mu-Chen Chen, Long-Sheng Chen, Chun-Chin Hsu, Wei-Rong Zeng, An information granulation based data mining approach for classifying imbalanced data Information Sciences, Volume 178, Issue 16, 15 August 2008, pp. 3214-3227.

73. W. Pedrycz, A. Gacek, Temporal granulation and its application to signal analysis Information Sciences, Volume 143, Issues 1-4, June 2002, pp. 47-71.

74. L. A. Zadeh, Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic Fuzzy Sets and Systems, Volume 90, Issue 2, 1 September 1997, pp. 111-127.

75. W. Pedrycz, G. Vukovich, Feature analysis through information granulation and fuzzy sets Pattern Recognition, Volume 35, Issue 4, April 2002, pp. 825-834.

76. Joo-Han Song, Vincent W.S. Wong, Victor C.M. Leung, Secure position-based routing protocol for mobile ad hoc networks Ad Hoc Networks, Volume 5, Issue 1, January 2007, pp. 76-86.

77. Kousha Moaveninejad, Wen Zhan Song, Xiang-Yang Li, Robust position-based routing for wireless ad hoc networks Ad Hoc Networks, Volume 3, Issue 5, September 2005, pp. 546-559.

78. Alejandro Quintero, Da Yu Li, Harold Castro, A location routing protocol based on smart antennas for ad hoc networks Journal of Network and Computer Applications, Volume 30, Issue 2, April 2007, pp. 614 636.

79. Elizabeth M. Belding-Royer, Charles E. Perkins, Evolution and future directions of the ad hoc on-demand distance-vector routing protocol Ad Hoc Networks, Volume 1, Issue 1, July 2003, pp 125-150.

80. Ting LI, Rui-bo TANG, Hong JI, Status adaptive routing with delayed rebroadcast scheme in AODV-based MANETs The Journal of China Universities of Posts and Telecommunications, Volume 15, Issue 3, September 2008, pp. 82-86.

81. A. A. Pirzada, M. Portmann, J. Indulska, Performance analysis of multi-radio AODV in hybrid wireless mesh networks Computer Communications, Volume 31, Issue 5, 25 March 2008, pp. 885-895.

82. W. Al Mobaideen, H. M. Mimi, F. A. Masoud, E. Qaddoura, Performance evaluation of multicast ad hoc on-demand distance vector protocol Computer Communications, Volume 30, Issue 9, 30 June 2007, pp. 1931-1941.

83. Committee SCC32, IEEE P1609.4 Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation, draft standard ed., IEEE Intelligent Transportation Systems Council, 2006.

84. Task Group p, IEEE P802.11p: Wireless Access in Vehicular Environments (WAVE), draft standard ed., IEEE Computer Society, 2006.

85. Standards Committee, Wireless LAN Medium Access Control (MAC) and Physical layer (PHY) specifications: Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements, IEEE Computer Society, 2005.

86. The Network on Wheels Project. http://www.network-on-wheels.de , (Last Accessed 17 April 2011)

87. O. Dousse, P. Thiran, and M. Hasler, “Connectivity in ad–hoc and hybrid networks,” in Proc. of IEEE INFOCOM, New York, USA, 2002.

88. M. Desai and D. Manjunath, “On the connectivity in finite ad hoc networks,” IEEE Comm. Lett., vol. 6, no. 10, pp. 437–439, Oct 2002.

89. D.Miorandi, E. Altman, "Connectivity in one-dimensional ad hoc networks: A queuing theoretical approach", Wireless Networks, Volume 12 Issue 5, September 2006.

90. P. Santi and D. M. Blough, “The critical transmitting range for connectivity in sparse wireless ad hoc networks,” IEEE Trans. On Mob. Comp., vol. 2, no. 1, pp. 25 39, Jan–Mar 2003

91. M. M. Artimy, W. Robertson, W. J. Phillips, "Connectivity with Static Transmission Range in Vehicular Ad Hoc Networks", 3rd Annual Communication Networks and Services Research Conference, 2005.

92. M. M. Artimy, W. Robertson, W. J. Phillips, "Connectivity with Static Transmission Range in Vehicular Ad Hoc Networks", 3rd Annual Communication Networks and Services Research Conference, 2005.

93. S. Tsugawa S. Kato, "Evaluation of incident information transmission on highways over inter-vehicle communications", IEEE Intelligent Vehicles Symposium, 2003, pp. 12-16.

94. G. M. T. Abdalla, M. A. Abu-Rgheff, and S. M. Senouci. "Current Trends in Vehicular Ad Hoc Networks", IEEE Global Information Infrastructure Symposium, Morocco July 2007.

95. http://www.aqualab.cs.northwestern.edu/projects/C3.html, (Last Accessed 17 April 2011)

96. A. Festag, G. Noecker, M. Strassberger, A. Lübke, B. Bochow, M. Torrent Moreno, S. Schnaufer, R. Eigner, C. Catrinescu, J. Kunisch, NoW - Network on Wheels: Project Objectives, Technology and Achievements, In proceedings of 6th International Workshop on Intelligent Transportation (WIT), Hamburg, Germany, March 2008

97. Car2Car, http://www.car-2-car.org/, (Last Accessed 17 April 2011)

98. PReVENT, http://www.prevent-ip.org/, (Last Accessed 17 April 2011)

99. http://cordis.europa.eu/telematics/tap_transport/research/projects/chauffeur.html, (Last Accessed 17 April 2011)

100. COMeSafety, http://www.comesafety.org/, (Last Accessed 17 April 2011)

101. Y.-C. Hu, A. Perrig and D. Johnson, Ariadne: a secure on-demand routing protocol for ad hoc networks, in: Proceedings of Mobicom'02, 2002, pp. 12–23.

102. M. Lott, R. Halfmann, E. Schultz and M. Radimirsch, Medium access and radio resource management for ad hoc networks based on UTRA TDD, in: Proceedings of Mobihoc'01, 2001, pp. 76–86.

103. http://www.guardian.co.uk/media/2007/mar/06/newmedia.business, (Last Accessed 17 April 2011)

104. L. A. Zadeh, From Search Engines to Question Answering Systems—The Problems of World Knowledge, Relevance, Deduction and Precisiation, Computer Science Division, Department of EECS, UC Berkeley, August 15, 2005, http://www.cis.fiu.edu/conferences/IRI05/html/IRI05keynotes/IRI05_Keynote_Zadeh.pdf, (Last Accessed 17 April 2011)

Appendix

Publications, Papers and Presentations

As part of this study one Presentation and two Conference Papers have been submitted.

They are:

- The Governments Department of Transport has called for presentations to coincide with the ITS World Congress in London. A presentation has been entered for the Department of Transport s Best ITS Vision competition. *ITS World Congress 2006*
- ECMS 2009 23rd European Conference on Modelling and Simulation, Paper: Modelling Granule Dependent Information In Vehicular Ad Hoc Networks. Paper: *E. Peytchev, I. Kucukdurgut, "Modelling Granule Dependent Information In Vehicular Ad Hoc Networks", ECMS 23rd European Conference on Modelling and Simulation, 2009, pp.135*
- 2008 Second Asia International Conference on Modelling and Simulation, Paper: Collaborative Wireless Information Granulation Architecture. Paper: *E. Peytchev, I. Kucukdurgut, "Collaborative Wireless Information Granulation Architecture", Second Asia International Conference on Modelling and Simulation, 2008, pp.83-88*

Presentation for the Department of Transport s Best ITS Vision Competition

Department for Transport's ITS Visions Competition Acknowledgement Letter

Dear Ismail

Many thanks for entering the Department for Transport's ITS Visions Competition. We were very pleased to receive many high quality entries from academic institutions around the world. The international panel of judges, chaired by Professor Eric Sampson, Head of Transport and Technology Division, Department for Transport, had a very difficult task to complete in judging all the entries.

The judges were impressed by your entry but unfortunately I have to inform you that that your entry has not been nominated for an Award on this occasion. I am sorry to have to give you this disappointing news and thank you for taking the time to put forward an entry. However, I hope that you will still be able to join the ITS community at this year's Congress here in London where we will be displaying of all the winning entries at the DfT exhibition stand.

Kind regards,

Cathy Jenkins

ITS World Congress 2006 Co-ordinator

Transport Technology and Standards Division

Department for Transport

Zone 2/03

Great Minster House

76 Marsham Street, London, SW1P 4DR

Tel 020 7944 4851

Fax 020 7944 2196

email: cathy.jenkins@dft.gsi.gov.uk

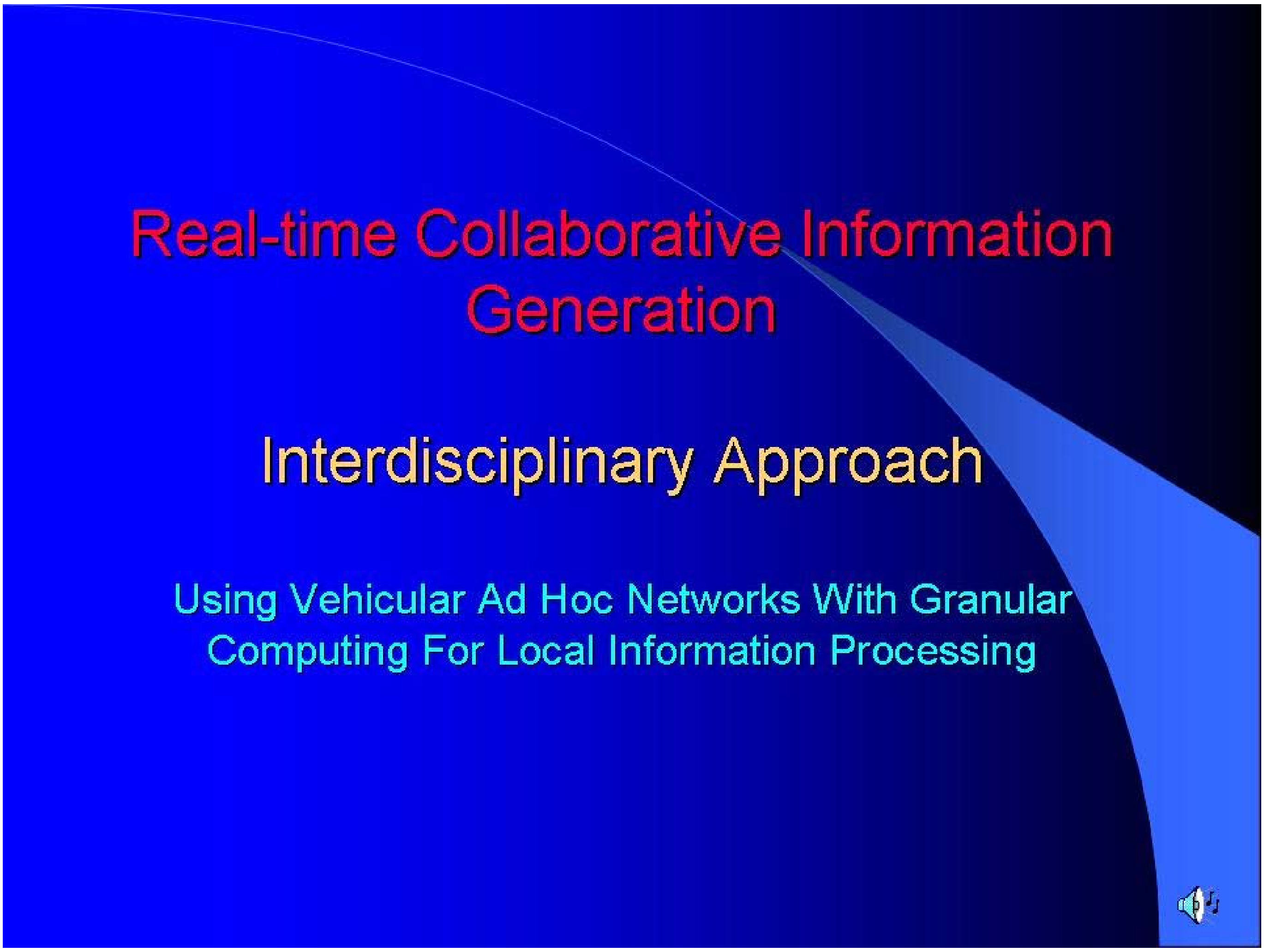


Figure 19 A screen shot from the presentation entered for the Department of Transports Best ITS Vision competition.

Paper for ECMS 2009 23rd European Conference on Modeling and Simulation

Paper:

E. Peytchev, I. Kucukdurgut, "Modelling Granule Dependent Information In Vehicular Ad Hoc Networks", ECMS 23rd European Conference on Modelling and Simulation, 2009, pp.135

This paper presents a novel simulation model which incorporates traffic simulation model and a Vehicular Ad Hoc networking model to achieve temporal and geo-spatial information granules formations simulation for the vehicles in the urban traffic networks in real-time using the concepts and techniques of Granular Computing theory.

Paper for 2008 Second Asia International Conference on Modeling and Simulation

Paper:

E. Peytchev, I. Kucukdurgut, “Collaborative Wireless Information Granulation Architecture”, Second Asia International Conference on Modelling and Simulation, 2008, pp.83-88

Abstract:

As we move further into the age of machine intelligence and automated reasoning, one daunting problem becomes harder and harder to master. The problem is - how can we cope with the explosive growth in data, information, and knowledge. How can we locate and infer from decision-relevant information that is embedded in a large database that is unstructured, imprecise, and not totally reliable. [Zadeh] This paper introduces an architecture which is design to start offering solutions to some of these problems. The architecture is based on wireless connectivity mobile network where the participants collaboratively.