Cooperative & cost-effective network selection: a novel approach to support location-dependent & context-aware service migration in VANETs

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DEDICATION

This Dissertation is dedicated to my family

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Declaration

I declare that, to the best of my knowledge, the research described herein is original except where the work of others is indicated and acknowledged, and that the thesis has not, in whole or in part, been submitted for any other degree at this or any other university.

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Abbreviations

CCWS	Cooperative Collision Warning System
GPS	Global Positioning System
HDNS	Hazard Detection and Notification Service
ITS	Intelligent Transportation System
MANETs	Mobile Ad hoc Networks
RSU	Road Side Units
TJPAS	Traffic Jam Prediction and Avoidance Service
UMTS	Universal Mobile Telecommunication System
VANET	Vehicular Ad hoc Networks
HTTP	Hyper Text Transfer Protocol
SMTP	Simple Mail Transfer Protocol
LDCAMS	This dissertation uses 'location dependent context aware services', location dependent context aware applications' and 'location dependent context aware migratory services' words interchangeably as they refer to the same class of VANET Non safety applications.
CENSA	It refers to cost effective network selection algorithm.
CACENSA	It refers to cooperative & cost effective network selection algorithm. CACENSA and CENSA refers to same algorithm that is contributed in this thesis.
NFP	Network Failure Points
N/S	Network Switching

Abstract

Vehicular networking has gained considerable interest within the research community and industry. This class of mobile *ad hoc* network expects to play a vital role in the design and deployment of intelligent transportation systems. The research community expects to launch several innovative applications over Vehicular Ad hoc Networks (VANETs). The automotive industry is supporting the notion of pervasive connectivity by agreeing to equip vehicles with devices required for vehicular *ad hoc* networking. Equipped with these devices, mobile nodes in VANETs are capable of hosting many types of applications as services for other nodes in the network. These applications or services are classified as safety-critical (failure or unavailability of which may lead to a life threat) and non-safety-critical (failure of which do not lead to a life threat). Safety-critical and non-safety-critical applications need to be supported concurrently within VANETs. This research covers non-safety-critical applications since the research community has overlooked this class of applications. More specifically, this research focuses on VANETs services that are location-dependent. Due to high speed mobility, VANETs are prone to intermittent network connectivity. It is therefore envisioned that location-dependence and intermittent network connectivity are the two major challenges for VANETs to host and operate non-safety-critical VANETs services. The challenges are further exacerbated when the area where the services are to be deployed is unplanned i.e. lacks communication infrastructure and planning. Unplanned areas show irregular vehicular traffic on the road. Either network traffic flows produced by irregular vehicular traffic may lead to VANETs communication channel congestion, or it may leave the communication channel under-utilized. In both cases, this leads to communication bottlenecks within VANETs. This dissertation investigates the shortcomings of location-dependence, intermittent network connectivity and irregular network traffic flows and addresses them by exploiting location-dependent service migration over an integrated network in an efficient and cost-effective manner.

CHAPTER 1. INTRODUCTION

A Vehicular Ad-hoc Network (VANET) is a special type of Mobile Ad-hoc Network (MANET) where vehicles act as mobile nodes [1-3]. The mobile nodes in a VANET are capable of hosting many types of services for other nodes in the network. These services may include, but are not limited to, safety-critical services (failure or unavailability of which may lead to a life threat) - for example, an emergency braking notification service, and non-safety-critical services (failure of which does not threaten lives) may also be supported - such as a service for measuring and monitoring vehicular traffic on the road[4, 5]. One common aspect of VANET services is their location-dependence. Due to high speed mobility, VANETs are prone to intermittent network connectivity [6-8]. It is therefore envisioned that location-dependence and intermittent network connectivity are the two major challenges for VANETs to host and operate VANET services. The challenges are further exacerbated when the area where the services are to be deployed is unplanned i.e. lacks communication infrastructure and planning. Lack of infrastructure and planning not only complicates driving, but it also limits the ability for vehicles to communicate. Moreover, it is assumed that unplanned areas show irregular vehicular traffic flows. The assumption is realistic as due to lack of planning, vehicles can come across traffic jams, etc. Frequent Irregular vehicular traffic flows add communication bottlenecks to VANETs. More specifically, they play a vital role in the intermittent connectivity nature of VANETs. This dissertation investigates the shortcomings of location-dependence and intermittent network connectivity and addresses them by exploiting location-dependent service migration over an integrated network in an efficient and cost-effective manner.

1.1 Assumptions and Motivations

Failure of safety-critical applications in terms of time or reliability poses life risks which cannot be compromised. Moreover, safety-critical applications need to be available freely in terms of cost. Cost-free service availability motivates vehicle operators to participate actively in communication. Having this in view, communication bandwidth that has been allocated for VANETs communication is divided into several channels[9, 10] . This research assumes a separate channel allocated for safety-critical applications. It is also assumed that the channel allocated for safety-critical applications is sufficient to meet the requirements to address issues raised by scalability and congestion challenges of worst-case safety-critical applications. This assumption is supported by the significant body of research that has already focussed on this class of applications. Given these assumptions, this research focuses on other applications, i.e. traffic, security and comfort-related applications. These non-safety-critical applications are important in VANETs as they support revenue generation as well as participate in efficient (in terms of usefulness) bandwidth utilization.

For the success of VANET deployments, it is important to consider the geographical area in which the VANET services are deployed. Geographical areas may be categorized as planned and unplanned areas. Planned-geographical-areas are either equipped or can cost-effectively be equipped with fixed dedicated road-side communication infrastructure (e.g. road-side-units). Unplanned areas lack road-side-units, hence pose challenges to vehicular communication. This research investigates vehicular communication challenges in unplanned areas and addresses the issues by integrating multiple network technologies in the vehicular environment.

In the current pervasive connectivity era, the automobile industry has agreed to provide multiple network technologies, such as Wireless Access in Vehicular Environment (WAVE) [10]and Universal Mobile Telecommunication System (UMTS)[11] technologies in vehicles. This has fuelled efforts to improve service availability in unplanned areas without deploying expensive, fixed, roadside units.

It is important that vehicle operators actively participate in VANET communications. Another assumption made in this research is that the vehicle operators agree to such participation. This assumption is supported by the fact that VANETs provide safety and comfort to vehicle operators.

1.2 Real-life Motivational Scenarios

There are several real-life scenarios to support this research motivation. One such scenario consists of police surveillance applications to track suspicious vehicles using cameras installed on police patrol vehicles, policemen's helmets or other vehicles[12]**.** This service becomes more important in scenarios such as a terrorism incident in an urban area. An example of such an incident is the attack on the Sri Lankan cricket team on 3 March, 2009 in Lahore, Pakistan[13-15]**.** In such a scenario, the police not only want to monitor the site, but also track and identify criminals by collecting important images and video recordings. These images and video streams help in tracking the criminals. Moreover, different police vehicles may also need to share live camera streams with each other before taking necessary measures. One service on police vehicles may also direct the vehicle operators to route around the incident area.

In another scenario, when a vehicle is involved in an accident, information about the accident needs to be transmitted to relevant emergency-service departments. Each emergency service, such as police, ambulance, and fire brigade, may start monitoring the site for service-specific information. Overall coordination of the accident site may entail sharing of this monitored information.

Another scenario is a group of vehicles going to a common destination, such as to attend a marriage ceremony; this is common in the south Asian region. These vehicles communicate and coordinate with each other through out their journey. Usually, very few people know the route to the destination. Moreover, these vehicles determine the route to take while driving on the road. Different possible services in such situations include live video sharing, text messaging, voice communication, file transfer services, tourist information services, petroleum or CNG price services, and traffic congestion, notification services.

In addition to the applications described above, there are two other important applications envisioned particularly by this research for unplanned areas. One such application is to provide data evidence to the police for supporting the process of identification of vehicles responsible for an accident. The goal of the second application is to provide users with processed data of how the vehicle is been driven. Here the term processed explicitly means the extracted relevant data for a particular user's vehicle.

1.3 Thesis statement

Vehicular Ad-hoc Networks (VANETs) are expected to have great potential to support safety, security, traffic and comfort related services. However, the provision of such services in an unplanned area is a challenge.

Intermittent network connectivity in VANET may limit the availability of VANET services. Moreover, the quantity of network traffic produced from vehicles in unplanned area varies to a large extent. The variations in the network traffic can lead to network congestion and, as a result, can degrade VANET services. The problem is further exacerbated when services are location-dependent i.e. they have to be provided in a designated proximity.

To address the issues of intermittent network connectivity, network congestion due to irregular traffic flows and location-dependence, the automobile industry has agreed to provide multiple network technologies, such as Wireless Access in Vehicular Environment (WAVE) and Universal Mobile Telecommunication System (UMTS) in vehicles. The significant challenge, however, is to provide availability-efficient (here availability-efficient explicitly means better availability i.e. increased availability of VANET services yields better VANET service efficiency) and cost-effective, location-dependent services over these networks. Existing VANET strategies are not adequate to provide availability-efficient and cost-effective location-dependent VANET services in unplanned areas.

I assert that the provision of availability-efficient and cost-effective, location-dependent VANET services in an unplanned geographical area is possible. However, this depends upon the migration of location dependent context aware migratory services (LDCAMS). I will prove this assertion by:

1. Detecting network congestion in an unplanned area using a novel approach.
2. Providing a cost-effective network selection algorithm to support an integrated network for reliable LDCAMS migration.

1.4 Aims and Objectives

The provision of location-dependent VANET services in an unplanned geographical area is possible. One approach for such provision is via deploying location dependent context aware migratory services; however, the deployment of such services largely depends upon the performance of the underlying network. This research attributes the performance of the underlying network through an additional backup network to support the service migration process. However, to keep control over the cost incurred by using an additional network, this research presents cooperative and cost-effective network selection algorithm. However, it requires first to detect if the underlying network is congested or unavailable. Thus, it is the first objective of this research to detect network congestion or availability using some simpler approach. The critical analysis of existing single network (WAVE) to support LDCAMS presents an improvement capacity of about 30 percent. Thus, another objective is to improve the network performance by 20 to 30 percent by providing additional network support. Provision of additional network support requires several amendments at system design level. This leads to another objective for this research to propose several necessary amendments to the system design to support location-dependent VANET services. Finally, a thorough validation of the system design supporting location-dependent VANET services in unplanned areas through additional network support is required.

1.5 Research Contributions

This research classifies VANET applications as safety-critical and non-safety-critical. Safety and non-safety critical applications need to be available concurrently. Such concurrent applications and services introduce significant network traffic, leading to channel congestion and thus degradation of quality of VANET services. This situation may cause failure of certain safety and non-safety applications. To avoid this situation, it is important to allocate separate communication channels (and bandwidth) for the two said categories. This research assumes a separate communication channel for safety-critical applications.

Non-safety-critical applications are important to be considered. Due to high-speed mobility, a service may become unavailable, as the node hosting a service may become unsuitable to host that service. Moreover, network congestion can degrade VANET services. To cope with these issues, services need to be sensitive and responsive and should be able to adapt to changes in the network. This research contributes a novel mechanism to detect network congestion. Based on network congestion, it provides efficient and cost-effective location-dependent services through service migration exploiting a cooperative, policy-based, network handoff mechanism.

The roadmap of this dissertation is as follows. Chapter 2 introduces VANETs, their potential applications and their classification in more detail. Furthermore, it presents an exemplar application for each class. Chapter 3 presents a subclass of non-safety-critical applications called context-aware migratory services. It analyses how these services can address location-dependence and determines the existence of bottlenecks. Chapter 4 reviews the literature related to wireless network technologies, specifically Wireless Access in Vehicular Environment (WAVE) and Universal Mobile Telecommunication System (UMTS). It elaborates several communication advantages that can be achieved through integration of networks. Chapter 5 presents the system design and system assumptions made to clearly address the problems identified and presented in preceding chapters. Chapter 6 discusses the results of simulations performed for different scenarios throughout this research. Finally, Chapter 7 presents future work and open issues identified in this research.

CHAPTER 2. BACKGROUND

Wireless networks are gaining popularity because they offer several useful features, such as mobility and less complexity than wired networks. Wireless networks can be categorised into two types:

- Infrastructure-based Networks
- Infrastructure-less Networks

An infrastructure-based network comprises of wireless mobile nodes and an infrastructure that provides interface/connectivity between wireless and wired networks. Mobile communication systems that are widely used for voice communication as well as data communication, such as *Universal Mobile Telecommunications System* (*UMTS)* , 3G and 4G networks, are examples of these networks.

On the other hand, infrastructure-less networks comprise of wireless mobile nodes and wireless mobile routers/bridges for node to node communication. These networks lack any fixed infrastructure for node to node communication. Any node may act as a source or a destination of data as well as a mobile router to enable multi-hop communication. Mobile *Ad hoc* Networks (MANETs) are examples of such networks. The deployment of such networks can be realised in unplanned areas that lacks fixed communication infrastructure. Unplanned areas are assumed as the areas that lacks fixed communication infrastructure.

This chapter introduces Mobile Ad hoc Networks (MANETs), in general, and Vehicular Ad hoc Networks (VANETs), in particular. This chapter defines the two primary types of geographical areas and describes the unplanned area that is taken into account in this research. Then, it elaborates the characteristics that distinguish VANETs from other MANETs and describes several challenges faced while implementing and deploying VANETs in an unplanned geographical area. It subsequently illustrates potential applications of VANETs. Taxonomy of VANET applications is presented in this chapter to demonstrate the importance of existence of these applications. More specifically, a particular type of non-safety-critical application, location-dependent context-aware migratory services, is introduced. Finally, it presents several motivational scenarios for the research documented in this dissertation.

2.1 Introduction to Unplanned Areas

Unplanned areas are defined as the areas that are characterized by being developed in contradiction to planning regulations of concerned authorities. Thus such areas, in essence, lack services and infrastructures. With economic growth in developing countries, unplanned land development is likely to take place. As a result, spatial unplanned distribution of cities, towns and villages will be found in developing countries. The urban network of cities, towns, and villages encompass all aspects of the environment within which societies' economic and social interactions take place. This research assumes unplanned areas as the areas that are not equipped with road-side communication infrastructure for vehicle to vehicle communication. In developing countries such areas are required to be monitored in several security-related and emergency related scenarios. VANET services provide cost-effective means to serve these objectives.

Provision of VANET services in unplanned areas is important, however, the deployment of VANET services in such areas lacking dedicated fixed road-side communication infrastructure, poses several communication challenges, such as

1. Vehicles communication range: Vehicles may go out of each other's communication range.
2. Vehicle's distribution on the road may be irregular. There might be very few vehicles on the road so vehicle to vehicle connectivity can be an issue.
3. Because of lack of vehicular traffic planning, there can be high vehicle traffic and/or low vehicle traffic scenarios. In case of high vehicle traffic scenarios, high network traffic or network congestion is likely to be observed.
4. Sharp road turns, hilly areas, unplanned buildings on the roadside offer vehicle to vehicle communication hurdles.
5. In unplanned areas it is hard to predict vehicular traffic and network traffic thus, the advantage that can be obtained by early predictions of traffic is hard to obtain.
6. It requires high cost to install fixed road-side communication infrastructure for vehicle to vehicle communication.

All these situations involve either degrading the performance of the communication network for vehicles or raising the deployment cost of such networks. Thus, the deployment of VANET services, in general, is a challenge.

2.2 VANET, a subclass of MANET

Wireless communication continues to expand as the research community is continuously expanding the capabilities, applications, flexibility and ease of use that it offers. The growing use of wireless communication demands new wireless communication technologies and devices. Mobile devices communicate with each other via two mechanisms: either through a pre-established centralised infrastructure (e.g. mobile telephony) or in the absence of a pre-established infrastructure. Mobile devices communicating with each other without relying on any infrastructure form a mobile *ad hoc* network (MANET). A MANET is a wireless, self-organizing and self-healing network that is comprised of self-governing mobile nodes. MANETs plays a particular role when the geographical area in which communication is to take place lacks centralised communication infrastructure. Vehicular *Ad hoc* Networks (VANETs) are a subclass of MANET where the vehicles act as mobile nodes[16]. VANETs are one of the promising areas for the creation of Intelligent Transportation Systems (ITS) in order to provide safety and comfort to vehicle operators. A transportation system is the process of moving the people and goods from place to the place; ITS refers to application of information and communication technology to the transportation infrastructure or vehicles [17]. Intelligent transportation comprises of following components:

- Infrastructure: In ITS, infrastructure refers to the roads, road side communication units, traffic signals etc.
- Vehicles and other resources: ITS include vehicles and other equipment integrated in vehicles required to meet the challenges of an advanced transportation system.
- Process of transportation and management: refers to different processes in road transportation and administration, for example driving, parking management, and toll collection.

By equipping vehicles with several resources, a communication system is constructed in order to provide safe and enjoyable journeys to vehicle operators. Vehicles can be equipped with sensors, processing units, Global Positioning System (GPS) receivers[18], cameras and other devices. The capability of vehicles to gather information and process it while moving enables a number of useful applications [3, 5, 12, 19]. These applications can play a vital role in reducing the number of road accidents and enhancing the safety and comfort of vehicle operators.

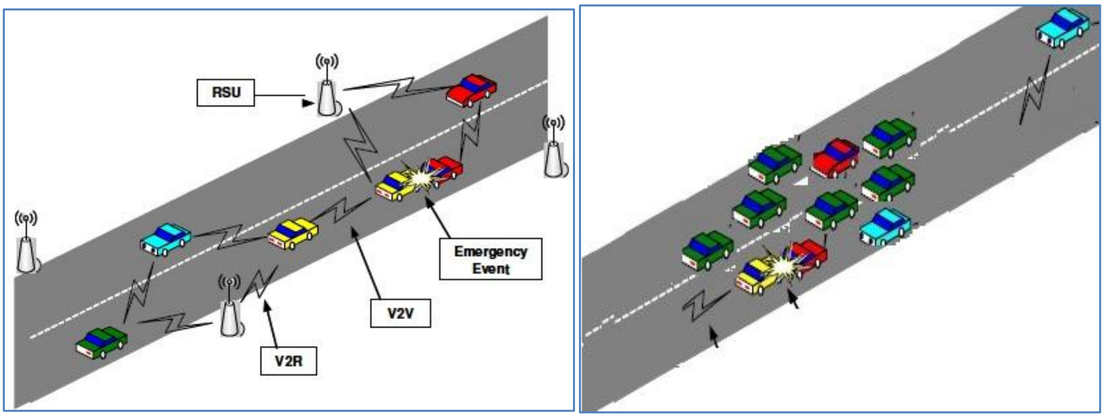

Figure 2-1 VANET in Planned and Unplanned Areas

The geographical areas where VANETs can operate are categorized as planned and unplanned areas. Planned geographical areas are those which are either equipped or can cost-effectively be equipped with fixed, dedicated, roadside communication infrastructure (e.g. road side units). Another feature of such an area is that the vehicular traffic exhibits regular and predictable flow patterns. These areas can be termed as smart areas. Un-planned areas lack road-side units to assist vehicular communication. Vehicular traffic in such areas exhibits irregular and hard to predict traffic flow patterns i.e. traffic density in such areas may vary frequently to a large extent. Variation in vehicular traffic flows (changing vehicular congestion) leads to variations in the communication network traffic flows. These variations impart degraded network performance and so affect VANET service availability. It may be observed that deployment of VANET services in unplanned areas requires efforts beyond the efforts that are required to deploy services in planned areas. These efforts include efficient network congestion detection, support of backup networks and support for service migrations etc.

2.3 VANET vs MANET

Deployment of services in MANETs is not a new research issue[20-23], However, VANETs exhibits unique characteristics that may make deployment of services different to deployment of services in MANETs. Wireless telephony systems use fixed infrastructure to support effective connectivity to mobile telephones and smart-phones; this approach prevents a wireless system's deployment into geographical areas lacking such a fixed infrastructure. Mobile ad hoc networks consist of autonomous nodes that are free to move and are connected through wireless links. Each node of ad hoc network acts as a user as well as a router for all other nodes in the network. MANETs do not rely on fixed infrastructure so they enable network deployment into unplanned areas. VANET are mobile ad hoc networks for which network nodes are attached to vehicles.

Unlike other mobile *ad hoc* networks, vehicles acting as network nodes in VANETs are highly mobile. Vehicular mobility can be classified as micro-mobility and macro-mobility. Micro-mobility captures variations in a vehicle's speed and acceleration. Moreover, it accounts for traffic events like traffic queues and lane changing etc. Macro-mobility keeps track of road topologies, traffic signals and road features like multi lane etc. Vehicle movements are constrained by road topologies [24-31]. It makes node positions predictable. On one hand, this information is useful for tracking any misbehaving vehicle; on the other hand, it violates node privacy. Privacy violation can limit the number of vehicle operators willing to participate actively in VANETs[1, 32]. Because of vehicular mobility, VANETs experience rapidly changing network topologies. In the face of such dynamically changing topologies, VANET service availability can face considerable degradation in performance. Other characteristics which make VANETs a distinguished network are listed below:

- Unlike MANETs, VANETs are considered as open networks i.e. any vehicle can join it anytime and anywhere, so scalability is one of the major issues for VANET deployments.
- Another important difference of VANETs is the time-criticality of the information being transferred from one node (vehicle) to another. In particular, safety-critical applications deal with extremely critical dissemination and reception of information related to events occurring on the road or in the network.

- VANETs nodes are heterogeneous in terms of resources they possess. These resources can be communication resources, processing and data storage resources or other accessories like cameras etc. VANETs nodes do not suffer power shortages which is characteristic of classic MANETs nodes. This unique capability helps in service deployment and implementation phases [1, 16, 24, 33].

2.4 VANETs Application Types

VANETs applications collect, process, relay, store and forward information to other network nodes. Information can be seen as time critical information and reliability critical information. The applications which consider time criticality as well as reliability criticality are grouped as safety-critical applications. Safety-critical applications are applications where the correct information must be processed and forwarded in a specific amount of time. Any delay or discrepancy in the correctness of information leads to an accident or threatens life. The applications where incorrectness of information or time delay in message dissemination, does not threaten life, are grouped as non-safety critical applications. Non-safety-critical applications are further categorized as security-related services, traffic-related services and comfort-related services. The classification of VANET applications is shown in the following figure[2-2]:-

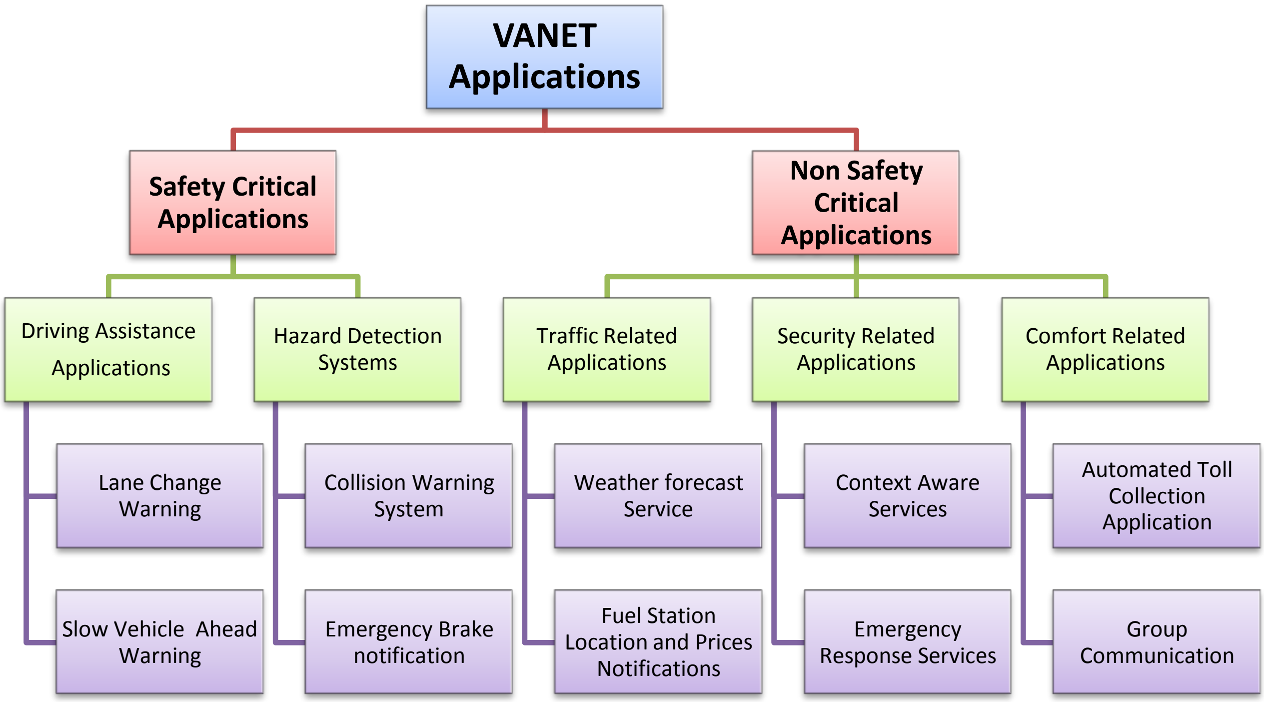

Figure 2-2 VANET Applications

2.4.1 Safety-critical applications

Safety-critical applications are applications which may cause accidents if they fail. In other words, failure of these applications can seriously threaten the life of motorists and passengers. An application for emergency braking, which broadcasts the vehicle's current position and state of action in the event of emergency braking, is one of the primary safety-critical applications. A collision warning application that detects a potential collision and warns the driver, such that the driver can act accordingly to avoid the collision, is another example of a safety-critical application. Failure of safety-critical applications poses risks to life, and as a result, cannot be compromised. Moreover, safety-critical applications, if deployed, should be free to use for all vehicles so that all the vehicles can actively participate and cooperate in the communication. These applications are divided into two categories:

1. Driving Assistance Applications(DAA)
2. Hazard Detection Applications(HDA)

2.4.1.1 Driving Assistance Applications(DAA)

Driving assistance applications assist a driver in the driving process. An exemplar is a Lane Change Warning Application.

2.4.1.1.1 Lane Change Warning Application

There are several scenarios on the road when a vehicle needs to change its lane on the road. There can be several scenarios when the vehicle's signal light is not visible to the following vehicles. Unobserved lane changes may cause accidents. To avoid these accidents, Lane change warning applications are exploited to ensure that any following vehicles know the driver's intention to change lanes. This application notifies the following vehicles that the driver of the vehicle intends to change lanes.

2.4.1.1.2 Slow Vehicle Ahead Warning Application

Another potential application for safety critical scenarios is required to inform the drivers on the road if there are any slow moving vehicles in the fast lane of the road. This application notifies the drivers of following vehicles with location, direction and other relevant information of a slow moving vehicle so that they can take necessary measures to avoid any accident.

2.4.1.2 Hazard Detection Applications (HDA)

Vehicles are assumed to be equipped with several sensors such as slippery road detection sensors, collision detection sensors etc. Hazard detection applications use these sensors to predict hazards and notify the driver and any following vehicles during driving. A hazard can be a location attribute that can lead to an accident; examples include a pothole, a stopped or very slow moving vehicle in the middle of the road or a pedestrian or cyclist crossing the main road in violation of the traffic signal. A vehicle using HDA detects such a situation and shares this information with vehicles in close proximity[34, 35]. This application is very useful in unplanned areas where there are not enough roadside traffic signals. Such applications include cooperative collision warning system and emergency brake notification services. The further details of these applications are presented in the next section.

2.4.1.2.1 Cooperative Collision Warning System (CCWS)

It is a common observation that sudden braking by vehicles can cause accidents. The reason behind such accidents is lack of information. If relevant information is provided to drivers, there are significant chances of reducing the number of accidents by predicting potential collisions and taking necessary measures to avoid them. In order to predict a collision, vehicles share information relevant to their position, speed and direction with neighbouring vehicles. This information is used by a Cooperative Collision Warning System (CCWS) [31, 36-38] application to predict a collision and suggest necessary actions to be taken by the drivers to avoid the collision. Successful deployment and implementation of CCWS depends upon several factors:

- Scale of vehicle cooperation involved in the communication: It is very important that vehicles cooperate with each other by taking an active part in the timely dissemination of information in the network. People may oppose such participation assuming it a privacy violation to share position, speed and direction information with people they don't know. An efficient communication model is needed that not only preserves user privacy but also enhances their trust so that vehicle operators will actively participate in communication.
- Access to relevant information: The CCWS application must have accurate relative position information concerning neighbouring vehicles. Furthermore, vehicles should be able to propagate their own position to neighbouring vehicles. Here a vehicle's ability explicitly means that vehicles are equipped with all communication devices and a mechanism or protocol for dissemination of information.
- Number of users: For the successful deployment of a CCWS application in a VANET, it is important that vehicle operators participate in communication. If the vehicles participating in communication are few and are distributed sparsely on the road, there is a high likelihood that vehicles are outside of each other's communication range. Hence, single-hop communication and multi-hop communication among vehicles becomes more difficult to achieve. Vehicles unable to communicate in a VANET results in failure of the application in question.
- Data type compatibility: The CCWS application uses text messages for notification purposes. It is essential that vehicles follow a standard, unified data format.

2.4.1.2.2 Emergency Brake Notification Service (EBNS)

Another potential safety-critical application is an emergency brake notification service. A vehicle driver slamming the emergency brake can notify any following vehicles of this action so that the drivers of the following vehicles can take necessary measures to avoid an accident.

2.4.2 Non-safety-critical applications

These are applications whose failure does not carry risk to life and limb. Non-safety-critical applications play a vital role in achieving several goals. More specifically, non-safety-critical applications are used for driving assistance, administrative roles, and information or infotainment purposes. Infotainment applications can provide significant revenue generation, which helps to fund the operation of the system.

2.4.2.1 Traffic-Related Applications

The primary objective of these applications is to make driving easier and more comfortable. Moreover, these applications keep the vehicular traffic in flow while minimizing traffic jams etc. An efficient transportation system offers a safe and enjoyable journey. Planned urban areas having larger vehicle density than the vehicle capacity defined in the city-plan, and unplanned geographical areas, are liable to traffic jams. Traffic jams not only waste the time of vehicle operators; they also increase fuel consumption and pollute the environment. A traffic jam prediction application is thus required; on the basis of the current volume of traffic heading towards a destination and road capacity information, it predicts the likelihood of a traffic jam and broadcasts this information to other vehicles[39, 40]. A find-best-route application can use this information to determine the best route that a driver should take to avoid the traffic jam. One such potential application in this category is Traffic Jam Prediction and Avoidance Service (TJPAS). TJPAS is an application that predicts traffic jam situations on the basis of information that it gathers from vehicle operators [12]. After the prediction, it broadcasts a traffic jam warning to vehicles in the particular proximity. Vehicle operators use this information to take alternate routes. This application can gather and generate data in the form of text, visual still images and live traffic streams. Another potential application is a slow vehicle warning application which, on the detection of a slow moving vehicle, broadcasts this information to any vehicles that will overtake the slow vehicle.

Traffic-related applications also include administrative applications. Such applications are used for distributing and collecting information regarding administrative uses. Examples of such applications include a toll collection application that collects tolls without requiring the vehicle to stop; a road administration application can inform commuters about any scheduled events that may interrupt the normal driving routine, such as VIP movements on the route the driver was going to follow; and an accident reporting application can gather information from the scene of an accident to provide important information about the accident to relevant departments [5, 17].

2.4.2.2 Security-Related Applications

Another important set of non-safety-critical applications is security-related applications. These applications can be designed to deploy over VANETs specifically in unplanned areas to monitor security measures on the road. Such applications are more useful in special circumstances where security is an issue for people travelling on the road. In other words, these applications are used for surveillance purpose. These applications collect relevant information and disseminate it to the security agencies. For these applications, vehicle operators cooperate and compromise their privacy to a certain extent to secure themselves as well as the surroundings around them. One such application performs surveillance through a policeman's helmet[12]. It accepts data only from predefined devices i.e. (i.e. policeman's helmet) rather than accepting data from any public vehicle. If the information is to be taken from public vehicles, it is highly desirable to hide the identity of the vehicle as well as to ensure the vehicle operator's privacy is not violated. In developing countries like Pakistan, it may be required to monitor several geographical unplanned areas. Location-dependent, context aware migratory services are one of the security related application to serve such scenario. These applications may be hosted on the vehicles and are capable to migrate to other vehicles if required. However, the inconsistent and unreliable performance of VANETs in unplanned areas poses several challenges to the deployment of these applications. The detailed discussion of context aware migratory services is presented in chapter 3 of this dissertation.

2.4.2.3 Comfort-Related Applications

This class of applications includes a variety of services such as a service for tourist information about a specific region, services providing information regarding hotels, restaurants, petrol and diesel prices, weather forecasts, internet services, and games for kids. These applications also include interactive games, internet access, chat, file sharing and music sharing applications. These applications play a vital role in motivating vehicle operators to cooperate and participate in the communication.

2.5 VANET Application Deployment

Non-safety-critical applications can also be classified with respect to their deployment, falling into location-dependent and location-independent applications. Location-dependent applications are deployed on nodes present in specific, targeted locations. When such a node moves outside the boundaries of its specific, targeted location, it becomes unsuitable to host this application. For example, a vehicle with a camera can take pictures of an accident scene but, due to its mobility, it will leave the location and become unable to host the accident reporting application. Location-independent applications can be deployed upon any mobile node, which possesses the required resources for hosting the services. Different types of resources are described later in this chapter. Location-dependent, non-safety-critical applications can be implemented and deployed using several approaches. One common aspect of these approaches is that they employ and share their location awareness technique. One such approach is context-aware migratory services [12]. Unlike a regular service that always executes on the same node, a context-aware migratory service can migrate to different nodes in the network in order to accomplish its task. Further details about context-aware migratory services are discussed in chapter 3.

Vehicles can collect information and forward this information to neighbouring vehicles. There are many possible sources of such information. For example, vehicles can be provided with sensors to collect information, such as road grip, temperature and hazard detection. Vehicles can also be equipped with GPS devices to know their position and direction. The other primary source of information is the driver, who can provide information such as the destination and intended route for reaching the destination. Applications can be deployed on vehicles to gather such information and use it to support the driver as well as to enable cooperation with other vehicles so as to reduce the number of accidents. Before describing the research motivation, the next section of this chapter presents and classifies resources that are required to deploy VANET services in an unplanned area.

2.5.1 Data collection resources

Newly manufactured vehicles are equipped with many sensors and other equipment like cameras etc. Vehicles collect data directly using such equipment. Examples of such equipments include temperature sensors, road status sensors which can detect if roads are slippery, visibility sensors and special purpose cameras for capturing live videos and images.

2.5.2 Communication resources

The vehicle industry has shown an interest to equip vehicles with communication resources. These resources include several types of network cards and antennas with transmitters and receivers. The automobile industry has agreed to equip new vehicles with multiple communication capabilities. This research focuses on two major network technologies i.e. UMTS and WAVE. Further details about WAVE and UMTS are provided in chapter 4 in this dissertation.

2.5.3 Computational and data storage resources

In VANETs there is no hard power limitation, thus vehicles can be equipped with computational and data storage resources[16, 41]. This capability enables a number of useful applications in VANETs.

2.6 Existing VANET Projects

This section presents a brief overview of some of the research projects that have previously investigated VANETs communication and deployment.

2.6.1 FleetNet

The Project FleetNet (2000-2003) was supported by academia and the vehicular industry in Europe. This project investigated requirements, design decisions, and challenges of vehicular networks. It considers provisioning of safety-critical and non safety-critical applications. This project motivates the use of UMTS as the communication network among vehicles as well as providing integration of VANETs with the Internet. To achieve this communication and integration, this project investigates the challenges that are involved at the MAC and Routing levels. The major areas that are investigated in this project includes new routing and MAC level protocols for VANET communication[42, 43].

The Fleetnet project promoted the choice of UTRA-TDD to be used as communication hardware. However, the time criticality of VANET safety-critical applications makes it a poor choice as it hardly meets the critical time requirements of safety critical applications. [44]

2.6.2 Car-to-Car Communications Consortium (C2C):

This project started in 2001. The major objectives of this project was the development of an open standard for cooperative vehicular communication to support development of safety and non safety critical applications[45]. This project is investing its efforts to develop a European standard for regulating vehicle to vehicle and vehicle to infrastructure communication in Europe. This project is particularly focussing on validation of vehicle to vehicle communications and its integration with vehicle to infrastructure communication to provide non-safety critical applications. This project also considered investigating the deployment strategies and development of business models to increase market penetration of vehicular communications. Moreover, this project considered a planned area for the deployment of VANETs and provisioning of safety and non-safety applications. In particular, the deployment of location dependent services seems to be an ignored area in this project.

2.6.3 Vehicle Infrastructure Integration (VII)

The project VII (2004-2009) is a collaborative effort of academia, manufacturing industry and IT service providers. This project considers issues involved in deployment of infrastructure to support vehicle to infrastructure communication. This project also explores some of the issues that are involved in vehicle to vehicle communication for a variety of safety-critical and non-safety-critical applications. In particular, this project explores development of VANET applications which can contribute to gaining the interest of vehicle manufacturers[46, 47].

2.6.4 Vehicle Safety Communications(VSC)

This project has been supported by the U.S department of transportation in two phases i.e. VSC (2002-2004) and VSC-2(2006-2009). This project explored experimentation with safety related applications so as to improve automobile commuting by using DSRC (Dedicated Short Range Communication) and other supporting technologies. This project considers several driving scenarios and on the basis of impact of driving events on road safety, it classifies applications in several categories. This project is focussed on issues that are involved in provisioning of safety-critical applications. For achieving significant safety, this project exploits vehicle to vehicle communications. This project claims to reduce the number of accidents and injuries by 76% per annum. This project does not consider the issues that are involved in provisioning of non-safety-critical applications[48].

2.6.5 Intelligent Vehicle Initiative (IVI)

This project intended to reduce the number of road accidents exploiting vehicle to vehicle communication to avoid various driving mistakes[49, 50]. This project considers identifying driving distraction events by examining crash data. Various types of crash events were selected to study. Identification of root causes of these distractions helps in determination of crash avoidance systems to reduce the number of such accidents. This research considers safety critical applications and again the provision of non-safety-critical applications are ignored[50].

2.6.6 Network-on-Wheels(NOW)

NOW is a project supported by the German government, industry and academia. The major contribution of this project is to investigate optimal performance of message communication among vehicles on the road. Additionally, security mechanisms for data transfer among vehicles has also been researched[51].

2.6.7 PRESERVE (2010-2014}:

This project is aimed at provisioning of a complete security system that should provide protection to the entire vehicular communication system. A vehicular communication system includes all communication components ranging from sensors attached to the vehicles, on-board networking units, V2V/V2I communication components, and the receiving application. PRESERVE is an effort to provide a complete, scalable, and cost-efficient V2X security subsystem that can be integrated with other, ongoing VANET projects to provide Cooperative ITS and V2X communication for a new age of safer, more efficient, and more comfortable road traffic. The PRESERVE project is not very closely related to this research, as its much more focussed on security issues involved in VANET projects, however, in the future, the PRESERVE project may be integrated with this research to secure deployment of location dependent migrating services [52-54].

2.6.8 Sim TD (2008-2013)

This project intends to provide increased road safety and an improved traffic system by exploiting vehicle to fixed infrastructure communication. This project provides real test beds to perform experiments at large scale to test deployment scenarios of VANETs in Europe. This project considers the availability of road side infrastructure so as to deploy the safety and non-safety applications in Europe; however, in unplanned areas this assumption is not realistic. Particularly, the deployment of security related applications in unplanned area is a challenge that cannot be met by the assumptions taken in this project[55].

2.6.9 SAFESPOT(2006-2010)

SAFESPOT is another European project that considers issues involved in several areas of intelligent transportation systems that uses vehicular communication. The project is subdivided into sub-projects to address safety and non-safety-critical applications. This project considers the availability of road side infrastructure for vehicle to infrastructure communication for provisioning of non safety critical applications. However, parameters that characterize unplanned areas are not taken into account. Furthermore, this project does not investigate the cost-effective provision of communication for availability of safety and non-safety-critical applications[56, 57].

2.6.10 Drive C2X 2011-2014

DRIVE C2X focuses on communication among vehicles (C2C) and a roadside and backend infrastructure system (C2I). Previous projects such as PReVENT, CVIS, SAFESPOT, COOPERS, and PRE-DRIVE C2X have proven the feasibility of safety and traffic efficiency applications based on C2X communication. DRIVE C2X goes beyond the proof of concept and addresses large-scale field trials under real-world conditions at multiple national test sites across Europe. The systems to be tested are built according to the common European architecture for cooperative driving systems defined by COMeSafety, thus guaranteeing the compliance with the upcoming European ITS standards. This approach also ensures that the results of DRIVE C2X have long-term validity at the European level, giving system developers as well as decision makers in the industry and authority sides the necessary decision confidence.

For the first time in Europe, DRIVE C2X is also implementing and testing a concept for the integration of a data backend, therefore enabling commercial services based on C2X communication data to private and commercial customers. Such services are expected to become a major revenue source for cooperative driving systems and can be the key for successful implementation of this technology on European roads[58].

From the review of European projects, it is evident that the research community is actively pursuing safety-critical projects; however, there are few projects that considers provision of non-safety-critical applications as revenue generating applications. Provision of safety-critical and non-safety-critical applications has been proposed in two ways.

1. On a single communication channel with a single radio transmitter/receivers
2. On separate communication channel with multiple radio transmitters/receivers.

Both approaches have their pros and cons. Provision of safety-critical and non-safety-critical applications with a single radio transmitter and receiver is a cost-effective solution. Moreover, it offers better utilization of bandwidth. However, this approach requires a complex priority mechanism to ensure network availability for safety-critical applications. Another drawback is that non-safety-critical applications may face the situation of starvation as if there are always safety-critical applications running and utilizing the complete bandwidth. Finally, switching a single radio from one channel to another requires time, so it may affect the performance of VANET applications in terms of time-delay. Provision of safety-critical and non-safety-critical applications with multiple radio transmitters and receivers is not a cost-effective solution. However, it provides better performance in terms of reliability. It is important to note that no work has considered provisioning of safety-critical and non-safety-critical applications in unplanned areas. Particularly provision of location dependent context aware migratory services in unplanned areas is not investigated. This research investigated the provision of these security-related applications in unplanned areas.

2.7 Concluding remarks

A significant amount of research is being carried out to investigate how communication services can be useful in improving the road transportation system. Several applications are envisioned to be available in vehicles on the roads. This chapter presents classification of VANET applications. Availability of both safety- and non-safety-critical applications is important. Provision of safety-critical and non-safety-critical applications has already been proposed on a single communication channel with a single radio transmitter/receiver and on a separate communication channels with multiple radio transmitters/receivers. Both the approaches have their pros and cons. This research assumed investigation of provision of non-safety-critical applications on separate communication channel with dedicated transmitters and receivers. VANETs show intermittent network connectivity, thus it is hard to achieve satisfactory performance of VANETs services. Several efforts are made to improve VANET connectivity in planned areas. Deployment of VANETs services in unplanned geographical areas requires more efforts. This chapter introduced unplanned areas. Unplanned areas exhibit characteristics that make VANETs communication even more unreliable. Furthermore, in developing countries, unplanned areas are required to be monitored in several security related situations. Location-dependent, context-aware migratory-services have already been proposed for planned areas. However, deployment of such services in unplanned areas requires more reliable VANETs communication. The next chapter discusses location-dependent, context-aware migratory services and further presents issues that must be addressed for successful deployment of these services in unplanned areas.

CHAPTER 3. LOCATION-DEPENDENT, CONTEXT-AWARE MIGRATORY SERVICES(LDCAMS)

There are several, potential safety-critical and non-safety-critical applications that can be deployed in a pre-defined proximity over VANETs. This dissertation assumes the proximity as a part of an unplanned area. Major challenges in deployment of a large number of non-safety-related applications include their location-dependence and the mobility of nodes hosting location-dependent services. Both issues i.e. location-dependence, and the host node mobility in unplanned areas need to be addressed simultaneously. Location-Dependent Context-Aware Migratory Services (LDCAMS) belong to the non-safety-critical class of VANET applications. Location-dependent, context-aware migratory services provide a method for developing and deploying location-dependent services over high speed mobile *ad hoc* networks. LDCAMS attempt to address the challenge of location-dependence and high speed mobility through migration of services from one node to another. This research particularly underlines the communication issues that may cause failure to the deployment of LDCAMS.

This chapter analyses the related work that has been conducted to address issues of host-mobility and location-dependence in unplanned areas and elaborates the system requirements for deploying LDCAMS. In particular, it enumerates network support requirements for LDCAMS service migration and, finally, it concludes and lists the network-related challenges upon which this research focuses.

Several real-life scenarios are envisioned to drive this research. An exemplar scenario is a road accident in an unplanned-environment. In case of a road-accident, fire-event or hazard on the road, the administrative authorities (e.g., police, ambulance and fire brigade) not only want to monitor the site but also track those involved in the accident by collecting accident-site images and video-recordings. Moreover, life-saving services, such as ambulance and fire control, may also want to share live camera streams with each other while taking necessary measures. Other road users may also need information about the resulting road blockage.

3.1 Location Dependent Context Aware Migratory Services (LDCAMS):

LDCAMS are based on the concept of service-oriented computing [59]. Service oriented computing relies on a service oriented architecture (SOA) to support the development and deployment of applications as services. SOA provides capability to adapt service behaviour such as migrating services from one host to another, in a frequently changing operational environment. Furthermore, SOA supports service interactions in a ubiquitous computing environment that may be required for service adaptation due to changes in service context. This thesis considers the deployment of LDCAMS over a highly dynamic ad hoc network characterized by intermittent network connectivity and proposes the provision of multiple network support availability for successful deployment of services that requires live migration from one host to another. The ultimate goal of service migration is to enable continuous provision of location-dependent service hosted on a vehicle. In such a scenario, context awareness is one of the major requirements not only for the selection of the next host but also to decide at what time the service migration triggers.

There are several approaches presented in the literature to address the issue of how to develop such context aware services. Although the development process of LDCAMS is out of the scope of this thesis, a brief review of context aware service development approaches is presented in the next section.

The development of context-aware mobile services (such as LDCAMS) for mobile ad hoc environments needs to consider several potential capabilities of these services such as:

1- Ubiquitous device-independent access

   Mobile services are assumed to be accessible from anywhere and on any device. Thus the mobile service should be designed in way to address the issues posed to incorporate such capabilities.

2- Provision of particular information such as resource information

Design of mobile services accommodates the capability to provide specific information such as information related to available resources at a particular location or particular device.

3- Provision of location information for resolving location dependence.

To support the ubiquitous access of context-aware mobile services, it is important to ensure the availability of location information to these services. Furthermore, the availability of location information provides support to resolve location dependence of location-dependent, context-aware services.

4- Provision of network related information for adaptation of services and their behaviour.

   It is also important that network related information is available to up and running mobile services. Network related information is of vital importance for service adaptation and migration process. Hence, a reliable mechanism to gather network information is required.

Furthermore, the development of LDCAMS requires considering fundamental distributed system issues such as modularity, scalability, and openness. The development approaches to location-dependent, context-aware services can be categorized as agent-based and non-agent-based approaches.

3.1.1 Agent based approaches:

This approach for the development of context aware services relies on middleware that takes the responsibility of providing abstraction to the low level interactions of services. Furthermore, it facilitates the development of context-aware mobile agents that may roam across different nodes to acquire specific information. The middleware supports mobile agents to perform two important tasks:

- Collect context information
- Interact with other agents in the system

The agent-based approach is discussed in several research articles [22, 59-64] by the research community for the development of context-aware services.

3.1.2 Non-Agent-based approaches:

Non-agent-based approaches do not employ agents for the development of context-aware services. Projects such as DOM[65], LOVEUS[66] and Smart Messages[67] provide platforms to develop context aware services without exploiting agent-based approaches. A context-aware migratory service platform for the development of services to operate in an ad hoc environment has been presented in [12].

Generally, the architecture to support development of mobile services consists of middleware at the top of the operating systems layer. On one hand, the middleware layer provides abstractions for the development of applications/services, whereas, on the other hand, it coordinates with the operating system for accessing system resources such as execution of services, etc. Thus, addresses the underlying heterogeneity, either at the hardware or operating system level, for development of mobile services in ad hoc networks. A brief review of context-aware, migratory services approach [12] is presented as follows:

There are several functions that are needed to be performed for a successful service operation. The middleware incorporates components to meet such functional requirements. Some of the functions are presented as below:

- Monitoring and Management of Contextual information.

The middleware provides an abstraction of several underlying functional details to service components by offering several functions. One such function is to gather context information and manage it. Context-aware mobile services craft their behaviour depending upon changes in context, so it is important to provide an effective mechanism of monitoring and management of contextual information, thus improving the performance of service in terms of quality and availability.

- Mobility management of service components

Service may be composed of several distributed components such as in multi-agent systems; multiple agents act as service components that interact with each other to perform service tasks. Moreover, a service may require migrating from one host to another. These mobility decisions may be based on different criteria such as change in context, location information, etc. The service design needs to consider such criteria and the service mobility mechanism.

- Management of the communication mechanism among service components and nodes to host the services.

Service components need to communicate and coordinate with each other; hence, service design must consider incorporating an efficient communication mechanism for service communication and coordination.

- The migration mechanism if services are designed to be migrate-able.

Location-dependent, context-aware migratory services incorporate a mechanism for service migration from one host to another host. This mechanism comprises of several input parameters. These parameters are presented in chapter 5 of this dissertation.

- Neighbour discovery

LDCAMS may also require neighbour information in several scenarios, thus a reliable mechanism must be employed for performing neighbour discovery.

The authors of paper [12] presented a middleware-based approach to develop context-aware migrate-able mobile services. Several components are designed to perform the above mentioned functionalities. It is realized that for a successful mobile service model, the provision of programming method is important. Hence, a content-based message passing API[67] is exploited to serve as a programming method. The choice of using a content based message passing API is justified by considering the acceptability of a message passing distributed programming model. The content-based message passing API enables client applications to send requests and to receive responses. Client applications and services are required to register themselves with the middleware. The implementation of this mobile service development model is implemented using Smart Messages[67]. Smart Message refer to an application whose deployment can be achieved by distributing its execution over several nodes dynamically. Such nodes are termed as nodes of interests. It is assumed that nodes of interests agree to participate in service execution and service migration.

There are several limitations of this approach. Given that a high number of frequent disconnections characterizes VANETs, the current design of service provisioning considering single network connectivity isolates it to un-reliable service design. The other limitations involve privacy, security, and scale of supported service issues that need to be addressed.

LDCAMS contributes a variety of traffic in the network. The communication among VANET nodes can be seen in the form of messages where a message is defined as a chunk of data to be exchanged among source and destination. Based on the classification of VANET application types, the messages generated by the applications can also be classified in several categories.

- Safety-Related Messages
- Other (Non-Safety-Related Messages)

Safety-related messages are critical messages and need to be disseminated while considering latency and reliability. Based on how these messages are generated, these messages may further be categorized as

- Periodic Messages
- Event Driven Messages

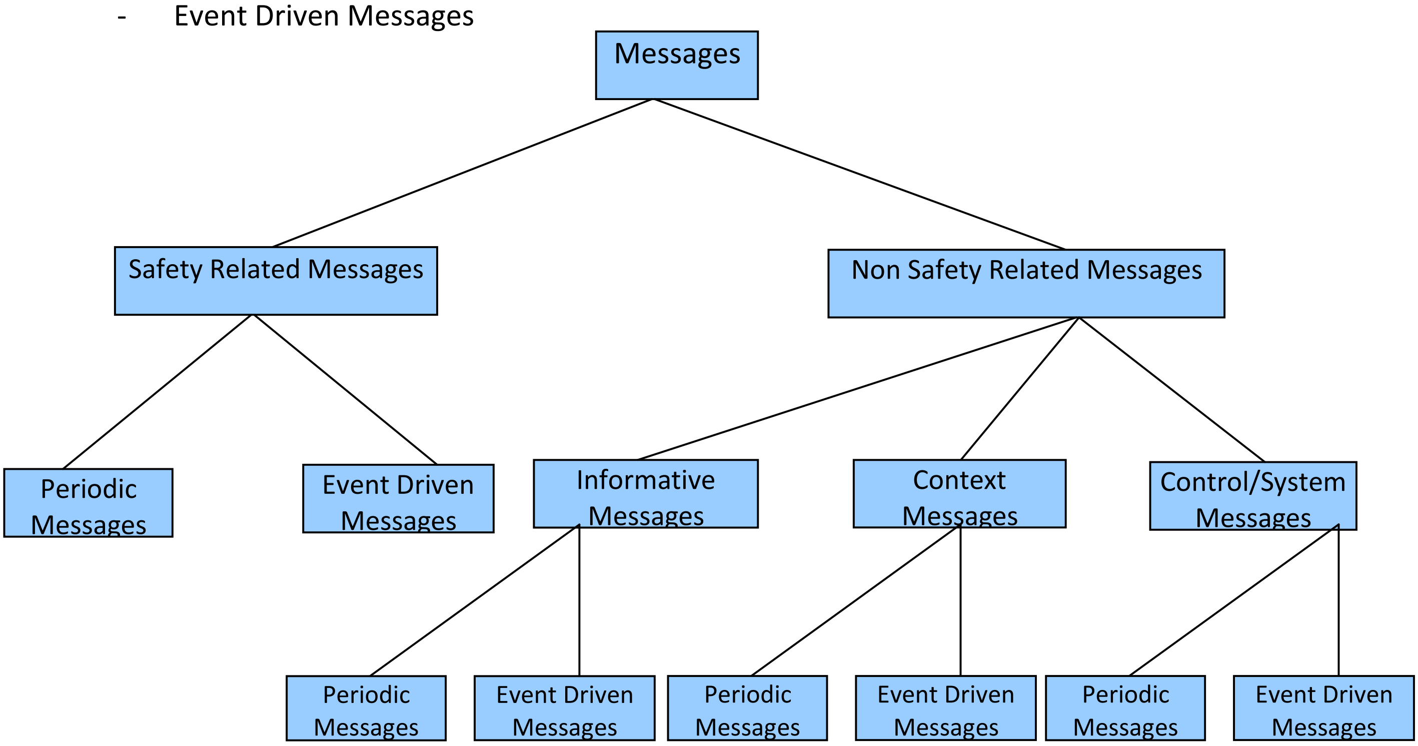

Figure 3-1 Classification of VANET Messages

3.1.3 **Safety Related Messages**

Safety-related messages are generated by safety-related applications. These messages may be generated periodically, which means regularly after specified duration of time, or on occurrence of an event such as a change of network quality or availability. Further discussion of these messages is presented in the next section of this chapter.

3.1.3.1 Periodic Messages

Periodically disseminated messages, such as beacons, include information related to the state of vehicle like position, speed, and direction of travel. These messages may contain aggregated information of two or more vehicles. These messages are disseminated after fixed and predetermined time and are usually broadcasted or geo-casted. Each vehicle reads its position, either using GPS or Location Service, and broadcasts this information periodically. Along with this information, the direction of motion, speed of vehicle, coordinates of vehicle size and weight of the vehicle are also aggregated in the message. Each message is given a lifetime and area of applicability i.e. proximity. Moreover, each message is assigned a sequence number and the vehicle-id which generated it. Each vehicle, after receiving this message, interprets it and decides its reaction based on the information provided in the message. Based on standards such as SAE J1746 and MS/ETMCC and additional security fields and information encoded in the message, the message size is estimated to range from 100 Bytes to 500 Bytes. The traffic load added by this application depends upon message size (payload), packet generation technique, packet generation rate, coverage area, vehicle density, and number of road lanes.

3.1.3.2 Event Driven Messages

Event driven messages are disseminated as a result of some event occurrence, such as emergency brake signals, lane changing signal, approaching emergency vehicle signal.

These messages are also used to broadcast if an incident occurs. Communication range requirement for these types of messages may vary from 300m to 20 km. The message size may vary from 100 bytes to a few Kilo Bytes, depending upon the information that is encoded in the message.

3.1.4 Non-Safety-Related Messages

Non-safety-related messages are generated by non-safety applications. These messages show less criticality in terms of time and reliability as compared to safety-related messages; however, achieving higher quality of service for dissemination of these messages is also required in VANETs.

3.1.4.1 Informative Messages

Informative messages are sent to provide driving assistance to drivers. These messages contain information like weather, road status and traffic congestion; the size of these messages may be as large as a few kilobytes. If the message is transmitted when a receiver request, it is called PULL-based message dissemination; if a sender transmits such information periodically, without any request, it is called PUSH-based information propagation. PULL-based mechanism helps to minimize congestion, but receivers need explicit knowledge of senders and services provided. In addition, receivers may also need service lookups. PUSH-based mechanisms usually broadcast information to the whole network.

3.1.4.2 Context Information Messages

These messages contain context information and are disseminated to share context information among vehicles. The services that are context aware makes use of these message types to disseminate the relevant contextual information. Exemplar services distribute on-demand information describing road conditions and available facilities in some geographical areas. Furthermore, these services disseminate information such as traffic conditions, congestion, and traffic alerts that result from on-road emergencies.

Informative messages and context information messages are further classified into periodic messages and event-driven messages depending upon when these messages are sent.

The network traffic load generated by VANETs applications, in general, and LDCAMS in particular, requires to be managed in a way to meet the required QoS demanded by applications. Particularly, to support successful deployment of an efficient communication mechanism is thus required to support LDCAMS successful deployment in an unplanned area.

Unplanned environments complicate communication as they lack roadside infrastructure for communication. Moreover, in developing countries that are economically poor, it is very hard to fund such infrastructures[68, 69]. As a result, VANET communication models making use of fixed roadside infrastructure are excluded from the solution options for VANET communication in unplanned areas.

To achieve successful deployment of several VANET services in an unplanned area, it is possible to host the location-dependent, context-aware migratory services on vehicles present in the area of interest. Due to high-speed mobility, it is not possible for a single vehicle to remain for a long time in a particular location, to capture the scene and send images or video streams to client vehicles. Consequently, due to high-speed mobility, a vehicle may no longer be suitable to host the service[12]. Here relevant clients refer to the vehicles of public service departments like the police, ambulance, and fire brigade. The services are assumed location-dependent. To maintain the service in the target location, the service must migrate to another vehicle in the area of interest. Location-dependent, context-aware, migratory services provide a method for developing and deploying a number of services over high-speed, mobile *ad hoc* networks. This approach has several challenges underlined in this chapter. Some of these research challenges are related to the development of LDCAMS; the others are related to the deployment of LDCAMS in unplanned areas. Although this chapter introduces some research literature related to the development of location-dependent, context-aware migratory services, the development of these services is out of the scope of this dissertation. The purpose of introducing the LDCAMS development issues in this dissertation is to better analyse the background and system requirements for communication, context-awareness, location-dependence and service-adaptability for deployment of LDCAMS. Contributions of this research include the provision of a high-level policy meeting the system requirements for deployment of LDCAMS. This dissertation uses the phrases 'location-dependent context-aware services', location–dependent, context-aware applications' and 'location-dependent, context-aware migratory services' interchangeably as they refer to the same class of VANET non-safety-critical applications.

The deployment of LDCAMS in unplanned area is challenging. Depending upon the motivational scenarios, deployment of LDCAMS can be categorized as follows:

1- Deployment in general public and private vehicles

This deployment is executed in general public and private vehicles to perform general tasks such as dynamic prediction of traffic jams. For performing these tasks, migratory code can be introduced by a vehicle that migrates from one vehicle to another while collecting relevant information such as direction and destination; the concluded response can be brought back to the originating vehicle. Security-related institutions might also exploit these deployments to dynamically monitor specific areas. Vehicles may capture images and video streams. Specific codes for processing images and videos to extract particular information can be introduced dynamically to identify incidents or cause of incidents. For successful general deployment, it is assumed that public and private vehicles agree to participate in communication and hosting the services. However, it is realised that vehicles may vary in terms of resources such as network capabilities and cameras they possess.

2- Deployment in Security-Related vehicles

This deployment considers enabling security-related vehicles that perform specific operations such as rescue operations in a disaster situation. These services support the security command and control to collect relevant information and to disseminate relevant actions to be performed in different situations more specifically in unplanned areas.

3.2 Challenges to the Deployment of LDCAMS

Deployment of LDCAMS in unplanned areas faces several challenges. Systems offering LDCAMS deployment need to address the following issues:

Context-awareness: LDCAMS are required to be capable of dissemination and collection of context information of host and client nodes [12, 17, 19, 31, 39, 70]. Here the host node is the vehicle that hosts the service and client nodes are vehicles using the services offered. To support ubiquitous computing and address the service design characteristics, context-awareness is one of the vital parameters. By collecting the relevant information, it supports the decision making process- for example, in deciding if the currently hosting node will be suitable to host the service for a given amount of time or in deciding which node should be selected as the next hosting node.

Service adaptation: LDCAMS are adaptive to changes in the context. In VANET, context information changes frequently due to high-speed mobility so it is vital for a service to adapt its behaviour accordingly. An example of such service adaptation is a service hosted on a vehicle detects a change in the context (e.g., a highly congested network environment) and adapts its behaviour by not offering video streams for a while.

Resources discovery: LDCAMS faces a major challenge in the form of performing resource discovery [12, 19, 71, 72]. Before the service migrates from one vehicle to another, it is vital to find out if the resources available at the target vehicle are sufficient to host the service successfully. One of the major factors involved in the selection of the next host vehicle is the list of resources with which the candidate vehicle is equipped. In addition, it is important to consider if available network resources are sufficient to perform service migration.

Service state capture and transfer: LDCAMS reduces the number of service discoveries. LDCAMS achieve this advantage through migrating the services as well as the list of client vehicles (addresses) from one node to another. LDCAMS proactively contacts clients and, hence, there is a substantial decrease in the number of service discoveries. For seamless relocation, the state of the service at the host vehicle is captured, and preserved, while migrating the service from one vehicle to another vehicle [70, 73].

LDCAMS are assumed able to share location, speed, direction, and available resource information with neighbouring nodes. In order to share the information to support migration of location-dependent, context-aware migratory services over VANETs, there are several requirements described in the following subsections.

3.3 Communication requirements:

Communication requirements of VANETs services may vary depending upon the nature of application. Some services need to disseminate information that is needed by all nodes in the network, whereas, other applications may have a target node to which the information is to be sent. Other services may look for target nodes in a specific geographical region for communication. Given this variation in the service requirements, VANETs in an unplanned geographical area must offer the following communication techniques.

3.3.1 Unicast communication:

Unicast is the traditional point-to-point communication between exactly one sender and one receiver. In figure [3-1], the vehicle A is communicating with vehicle B.

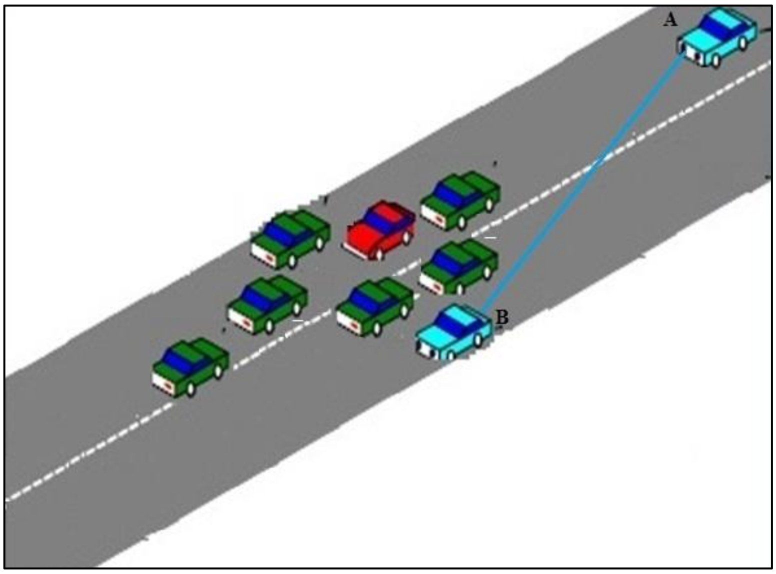

Figure 3-2 Unicast Communications

The mode of communication can be simplex, where one of the two vehicles is sender and the other is receiver, or it can be duplex where both the vehicles can send and receive data[74]. There are several exemplar services designed based on LDCAMS that requires Unicast communication. In convoy movement, the commander may communicate to particular node for access to site images. Similarly, services can be designed to serve disaster management teams to coordinate with each other. Another potential service is instant message exchange among vehicles. All such services require simplex or duplex communication among nodes. The data that needs to be transferred from source to destination, can be in the form of still images, textual data, video and audio streams. Unicast communication can be achieved using single hop communication or via multi-hop communication. The authors of paper [74] determined the level of QoS required for such communication in VANETs.

3.3.2 Multicast Communication

Multicast communication involves a set of vehicles as receivers. There are several potential applications of VANETs in unplanned areas that require use of multicast communication. One such application is a communication service for the ceremony caravan of vehicles that involves video streaming, shared plan-board, and multi-user games.[75, 76]

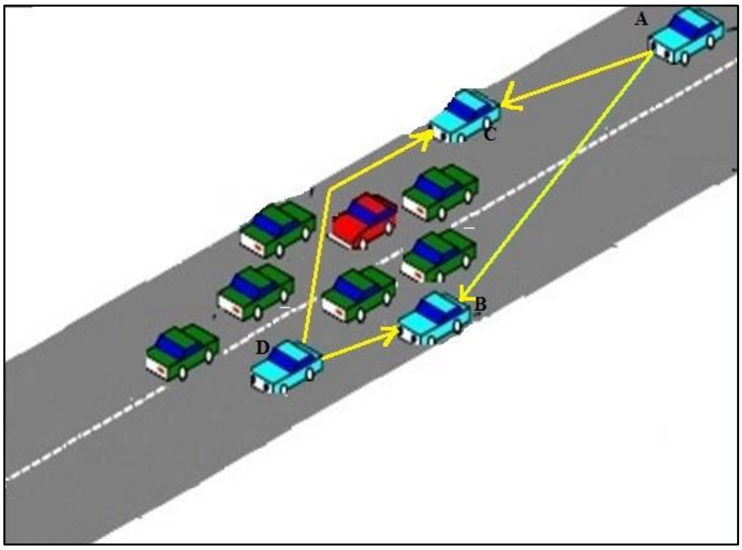

Figure 3-3 Multicast Communications

Multicast communication is also called multicasting. It is a cost-effective technique to communicate over any network technology providing support for Transmission Control Protocol/Internet Protocol (TCP/IP). Figure 3.2 shows two vehicles multicasting their data i.e. vehicle A is sending data to vehicle B and vehicle C. Similarly, vehicle D is also sending data to vehicle B and vehicle C. Video multicast is an example application that makes use of multicasting. A multicasting video application sends the same video to multiple receivers. Exemplar applications using Multicasting video are group video, conferencing, distance learning and video-on-demand.[77]

3.3.3 Concast Communication

Concast communication involves unidirectional communication between multiple senders and the single receiver. In such a communication, sender and receiver vehicles have an m:1 communication relationship. In VANETs, several applications make use of the Concast communication model. For example, a police vehicle travels through the road collecting security related information from other vehicles.

3.3.4 Anycast Communication

Anycast is a communication approach that was first introduced in Internet Protocols version 6 [IPv6]. In Anycast, which is also referred to as a one-to-any communication model, the message is sent to any member of a network. The receiver is selected from a group of potential candidates. In VANETs, Anycast can provide the communication service in several scenarios. For instance, in a situation where vehicles are grouped on the basis of their location, direction of mobility and destinations, Anycast can be used for message forwarding between the groups [78, 79]

3.3.5 Broadcast Communication

Broadcast communication involves dissemination of messages from a source to all the network nodes without any restriction [35, 80-82]. In VANETs, broadcast communication has vital significance. Numerous applications make use of broadcast communication. For instance, a fuel station may advertise petrol and gas prices to road users. Similarly, in safety-critical applications, a vehicle applying the emergency brake broadcasts this information to the entire network. In another scenario, an ambulance or a police vehicle can broadcasts its location and direction of travel. A vehicle can detect a hazard (e.g. a pot hole in the road or slippery road), and alert any following vehicles by broadcasting the hazard information. Broadcast communication is shown in figure [3.3] where the source vehicle detects a hazard and alerts the following vehicles through broadcast messages.

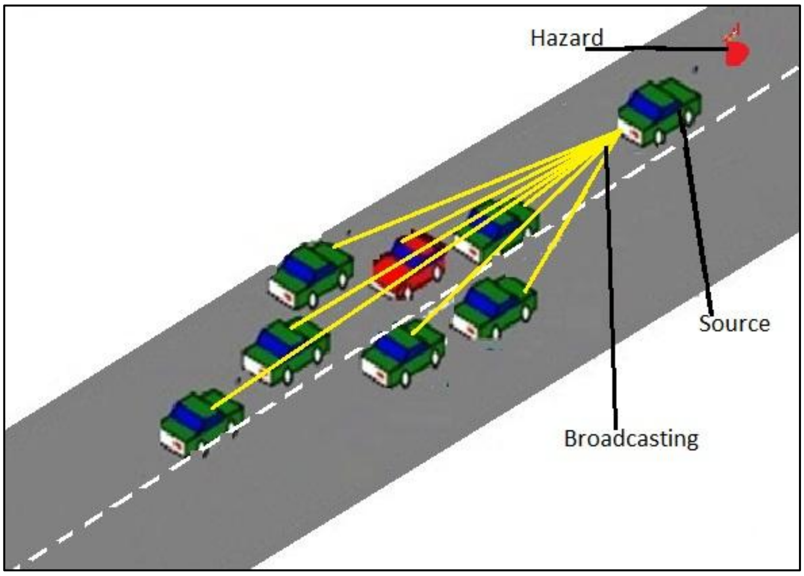

Figure 3-4 Broadcast Communication in VANET

3.3.6 Geocast Communication

Geocast communication is also termed Geocasting. It is type of communication through which a service can disseminate its messages to the vehicles present in a specific geographic area [83-85]. Geocasting is an important communication technique used by several VANETs applications. A vehicle hosting a traffic jam prediction and detection service can disseminate its messages to vehicles in a specific region, enabling them to re-route to avoid the traffic jams.

3.4 Context-awareness requirements

LDCAMS operate depending upon their current geographical location information. In addition to the location, LDCAMS require additional context information for successful operations. In other words, the VANETs application (in this research) are assumed to be context-aware, where context refers to location, speed, direction, destination, available resources and other related information. Context-aware services self adapt to changes in the context. It is an important requirement of such services that there exist a mechanism through which context information can be gathered and disseminated.

3.5 Location-dependence requirements

LDCAMS are characterised by the fact that they operate in a specific region of interest. In a road accident scenario, the region of interest refers to the area where the accident has taken place. For a service to operate in a specific geographic region, the node on which the service is hosted must be present in the region of interest. This node can be a roadside static unit or any vehicle. The possibility of deploying the service on a roadside unit (RSU) is excluded, as the environment chosen for this research is an unplanned environment, which is characterised by a lack of such infrastructure. The other possibility of service deployment is to deploy over the vehicles currently present in the area of interest. Here the area of interest refers to the geographical region where the VANETs services are to be provided. Deploying such services over vehicles however raises several issues:

- **Mobility of the vehicles:** Vehicles are mobile entities. Due to their mobility, they can go out of the region of interest. In order to keep a service alive, the service should be able to monitor the proximity and neighbourhood of the node that is currently hosting it. Monitoring the neighbourhood explicitly means that a LDCAMS record and track its current host node location, the area of interest, and the other candidate vehicles that are present or will be present in the area of interest in time to take responsibility for hosting the service before the current host vehicle becomes unsuitable to host the service.
- **State of the service:** State-full services are services which need to maintain their execution state [70, 73, 86]. If services are state-full, it is not sufficient to choose a new vehicle and start a new service on the target vehicle. To maintain the service state, there is need for communication between the current host i.e. the vehicle currently hosting the service and the candidate vehicle i.e. the vehicle that has agreed to host the service next. This interaction ensures:
  - The candidate vehicle has agreed to host the service.
  - The candidate vehicle is present in the region of interest.
  - The candidate vehicle has all the required resources.

3.6 Adaptability Requirements

LDCAMS are hosted by vehicles. Different vehicles can be equipped with different levels of resources. The nature of resource in each vehicle may also vary. To respond and minimize the effect of heterogeneity, it is essential that LDCAMS are designed to support adaptability. VANETs are highly dynamic in nature with respect to mobility and changing environments. Unplanned environments also add their complexity in the form of irregular network traffic flows. To be able to perform over such a network environment, the services should be adaptive in nature, which means they should be able to adapt themselves according to the available resources.

LDCAMS obtain and share their context and location information. Processing this information, they decide if their host will become unsuitable to host them any longer. Moreover, based on this information, they can choose new node that can host them for further processing. Furthermore, after the selection of the new host, these services can migrate to the new node. Making the service migrate-able has a number of advantages:

- Not all the vehicles need to carry the application code for execution.
- Service state can be maintained.
- LDCAMS provide a single virtual end point to a client, regardless of their different physical locations; the client continues communication to a single endpoint. Hence, no interruptions occur and continuous client server interaction is maintained.
- The total number of service rediscoveries is reduced. Here the term service rediscovery is defined as a process in which a service-user attempts to find the service in a network whenever the service he is using becomes unavailable on a host. [12, 86]

There are several advantages for having LDCAMS migrate from one node to another to resolve location dependence and node mobility in unplanned regions; yet for service migration, it is highly important to ensure network availability for LDCAMS communication and migration. Better network availability shows remarkable contribution to keep VANETs services alive. However, lack of infrastructure and planning makes VANETs intermittent and unreliable. Without efficient and cost-effective network availability, it is almost impossible to migrate a service from one node to another. Moreover, vehicles in VANETs possess heterogeneous resources. There is a high probability that vehicles possess multiple network capabilities[87]. Having multiple network capabilities raises several challenges for service migration including:

- Determine if there is a need to switch to a different network. The Cooperative and Cost-Effective Network Selection Algorithm (CACENSA) determines such need: Vehicles require at least one network available for service migration. In case of multiple network capabilities, the current node hosting the service and the next host node are required to agree and cooperate to decide what network they will use for service migration. Current network selection policies in MANETs particularly VANETs do not consider the neighbour's network capabilities.
- Next Host Selection: Next host selection is an important aspect for successful deployment of LDCAMS. The next host selection algorithm selects the next host for service based on several parameters such as network capabilities, resources required by the application service that has to be migrated, etc.

To address these challenges, it is essential to provide the LDCAMS over a cost-effective, cooperative, and integrated network. This research provides a cost-effective, cooperative, algorithm for network selection to achieve service migration from one vehicle to another in an unplanned area. The next section of this chapter provides an in-depth review of VANETs related literature and lists the network problems that occur while VANETs operates in unplanned areas.

3.7 Concluding remarks:

In VANETs, there are several potential scenarios where classical mobile applications may not perform due to high-speed mobility, network volatility and location-dependence of applications. Location-dependent, context-aware migratory services (LDCAMS) are services that are designed to resolve location-dependence of applications. LDCAMS are deployed over mobile nodes (vehicles in VANETs). For resolving location-dependence, LDCAMS migrate from one node to another. This chapter reviewed literature to present a brief introduction of how LDCAMS can be developed, and the challenges for deploying such services over mobile networks. LDCAMS can potentially resolve location dependence by service migration; however, the challenge is to migrate over a network that is highly volatile. For successful service migration over mobile *ad hoc* networks, efficient network performance in terms of connectivity is required. Service migration from one node to another over a single network characterized by intermittent network connectivity is hardly possible. Existing approaches in the literature do not provide sufficient network support for successful service migration over VANETs in the unplanned areas.

CHAPTER 4. INTEGRATED NETWORK TECHNOLOGY FOR VANETS

Wireless Access in Vehicular Environment (WAVE) arms new generation transportation systems with technology aimed at improved transportation environments. This chapter provides an introduction to WAVE technology, WAVE's emergence from IEEE 802.11, a brief overview of spectrum allocation for WAVE networks to support several classes of network traffic and the challenges for WAVE's successful deployment in an unplanned geographical area. More specifically, this chapter discusses the choice of a UMTS (Universal Mobile Telecommunication System) network as a supporting network to overcome the challenge of frequent disconnections faced in VANETs using WAVE while migrating an LDCAM service from one vehicle to another. Finally, it discusses the requirement of an algorithm for triggering hand-off between the WAVE network and the UMTS network to provide efficient and cost-effective context-aware service migration performance in an unplanned geographical area.

4.1 Communication standard for VANET

The process of standardization of IEEE 802.11p WAVE started with the proposal for Dedicated Short Range Communication (DSRC)[88, 89]. DSRC was proposed to operate in the United States of America**.** DSRC presents a stack of protocols arranged in different layers for communication. DSRC proposes to use a modified form of IEEE802.11 called IEEE802.11p i.e. WAVE (Wireless Access in Vehicular Environments) at Physical and Medium Access Control layers of OSI model, the WAVE protocol stack; DSRC employs the IEEE 1609 standards [90-93]. All the operational concepts and knowledge are defined by IEEE 1609 standards. IEEE 1609.1 addresses resource management issues, IEEE 1609.2 regulates security issues, IEEE 1609.3 address connection management issues and IEEE 1609.4 resolves issues involved in multichannel operations without physical layer knowledge [90-93]. Initially, trial-use versions of these standards were published; however, with the support of lessons learned from field trials, the "full use" standards are being published to replace the "trial-use" ones. In 2010, new versions of IEEE 1609.3 and IEEE 1609.4 standards were published. Furthermore, new standards such as IEEE 1609.11 (for electronic fee collection) and IEEE 1609.12 (provider service identifier allocations) have been published. Two more standards, IEEE 1609.0 (for architecture) and IEEE 1609.6 (for remote management), are in progress. Lessons learned from field results for support of IEEE 1609.1

concluded not to maintain it anymore. Thus, developments of alternate standards are in progress. The technical details of these all standards are out of the scope of this dissertation. However, for general understanding the Protocol stack for DSRC is presented in figure [4-1]

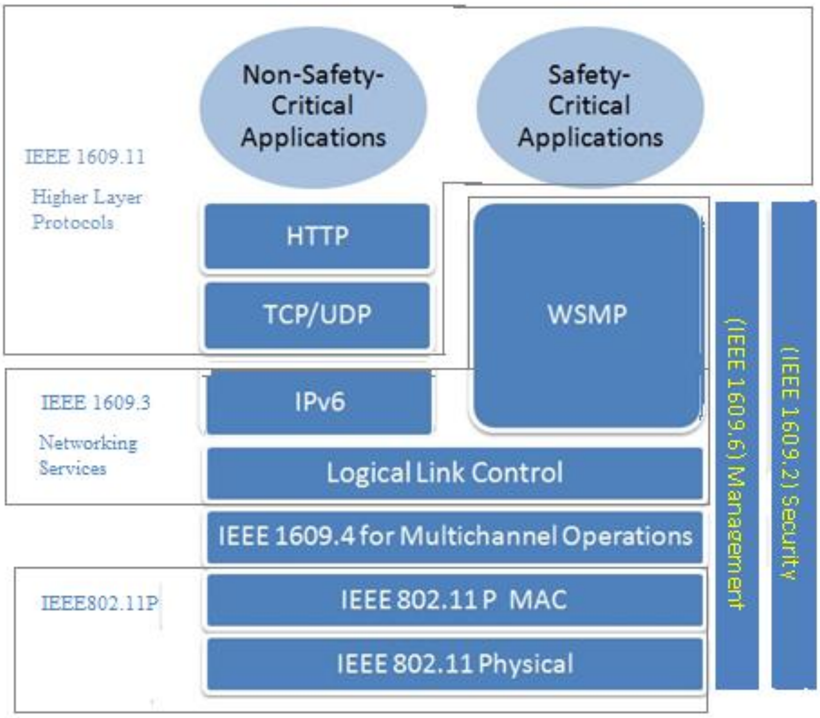

Figure 4-1 Block Diagram of WAVE Architecture

The lowest layer represents the physical layer protocol stack. The WAVE architecture uses the IEEE 802.11 Physical layer protocol at its physical layer. The Data link layer can be further divided into two sub layers: Medium Access Control comprises of protocols to regulate access and utilization of medium; and Logical link Control (LLC). It is important to understand that the IEEE 802.11a is specifically designed for multimedia communication in indoor environments with low user mobility so it, as it is, is not appropriate for VANETs applications. The IEEE 802.11a also takes significant amounts of time in association and re-association functions that is not affordable in VANETs applications with time and reliability-related critical requirements. Considering these facts, several amendments are made at the physical and MAC layer of IEEE 802.11 to meet the requirements of VANETs applications yielding IEEE 802.11p[94]. The lowest layer of WAVE proposed for VANETs communication, as shown in figure [4-1], is the IEEE 802.11 Physical layer.

4.1.1 Physical Layer Aspects of IEEE 802.11p

Before presenting the physical layer aspects of IEEE802.11p, it is important to review the original IEEE802.11 standard. The original IEEE 802.11 standard provides two spread spectrum radio techniques to operate in the 2.4 GHz band defined by Industrial Scientific Medical (ISM) and one diffuse infrared specification. In this band, IEEE 802.11 does not require any user license or training. Spread spectrum techniques offer better reliability, greater throughput, and openness to share spectrum without making explicit cooperation agreements. Original IEEE 802.11 offers data rates of 1 Mbps and 2 Mbps via radio waves using Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS), respectively.

In the original IEEE 802.11 standard, the total band of 2.4 GHz band is divided into 75 sub channels of 1-MHz each. This division is based on FHSS. Sender and receiver both agree on hopping patterns. Following the hopping patterns, data is transmitted over a sequence of sub-channels. Each conversation in IEEE 802.11 follows different hopping patterns. The design of hopping patterns attempts to minimize the chance of multiple senders using the same channel. This design is limited to offer data rates of not more than 2 Mbps. The reason behind this limitation is that the Federal Communication Commission (FCC) has restricted of sub-channel bandwidth to 1 MHz; this forces the usage of the whole 2.4 GHz band, which leads to high hopping overhead.

Using the alternate spread spectrum technique DSSS, the frequency band of 2.4 GHz is divided into 14 channels of 22-MHz each. Adjacent channels of 22-MHz each partially overlap. There are three completely non-overlapping channels. Using DSSS, no hopping is required to send the data over 22-MHz channels; hence, there is no hopping overhead as compared to FHSS. To compensate for the imposition of noise by this technique, Chipping methods are employed. Chips are redundant bit patterns. The Original IEEE 802.11 standard specifies 11 bit chipping called the Barker sequence. Chips are converted into symbols. These symbols are transmitted at 1 MSPS (Million Symbols per Seconds) using Binary Shift Keying to give 1 Mbps. To give 2 Mbps, Quadrature Phase Shift Key is used.

IEEE 802.11b made changes in the physical layer to obtain better rates of 5.5 Mbps and 11 Mbps. At physical layer, DSSS is employed as the only spread spectrum technique given that

FHSS cannot achieve better rates without violating FCC regulations. To achieve new and better data rates IEEE 802.11b introduced the use of Complementary Code Keying (CCK) that consists of 64 8-bit code words. CCK encodes 4 bits per carrier to produce a data rate of 5.5 Mbps and 8 bits per carrier for 11 Mbps. IEEE 802.11 b uses dynamic rate shifting in case of noise. The implication with IEEE 802.11b is that it does not work with 1-Mbps and 2-Mbps IEEE 802.11 FHSS. One significant disadvantage is that it uses the 2.4 GHz band that may be crowded with other networking technologies, such as cordless phones; some other drawbacks include lack of interoperability with voice devices and lack of QoS provisioning for multimedia contents.

IEEE 802.11a offers 54Mbps in the 5 GHz band using eight simultaneous non-overlapping channels of 20MHz. This standard uses a new spectrum usage scheme termed Orthogonal Frequency Division Multiplexing (OFDM) instead of spread spectrum. This encoding scheme offers better channel availability and improved data rates. This standard is not compatible with IEEE 802.11b due to frequency difference[95].

IEEE 802.11g can offer data rates up to 54 Mbps while operating in the 2.4 GHz band. It can operate in different modes. These modes are complementary code keying (CCK), offering 11 Mbps, and OFDM, supporting 54 Mbps of data rate. The other two modes are Packet Binary Convolution Coding (PBCC-22), offering 22 Mbps, and CCK-OFDM mode, offering 33 Mbps. This standard also uses the same number of non-overlapping channels as IEEE 802.11b. This standard uses dynamic rate shifting hence, if any node has IEEE 802.11 b on network card, then the rate for whole network will be shifted to it[95].

IEEE 802.11b enjoys international acceptance with a data rate offer of 11Mbps at 2.4 GHz radio frequency with no license. IEEE 802.11g also operates in the same frequency band as 802.11b, and hence provides backward compatibility. IEEE 802.11a operates around 5 GHz frequency band, and offers clear-channel operation in the United States and Japan. In other areas, such as the EU and Switzerland, the 5 GHz band is mostly assigned to the military and to radar applications. At the beginning of 2004, Switzerland granted in-building use of the 5.2GHz band. 802.11a also provides for up to 54Mbps throughput, but is not interoperable with 802.11b[95].

IEEE 802.11p uses physical layer specifications of 802.11a with a few amendments. It uses one control channel to setup transmission over the other six channels. Physically, a 75 MHz frequency bandwidth is reserved in the 5.9 GHz band in the USA. This frequency band has been divided into seven channels, each of 10 MHz, with one channel used for control and the remainder used as service channels. Allocation of bandwidth to different channels is shown in figure [4-2] [9, 10, 35, 95, 96].

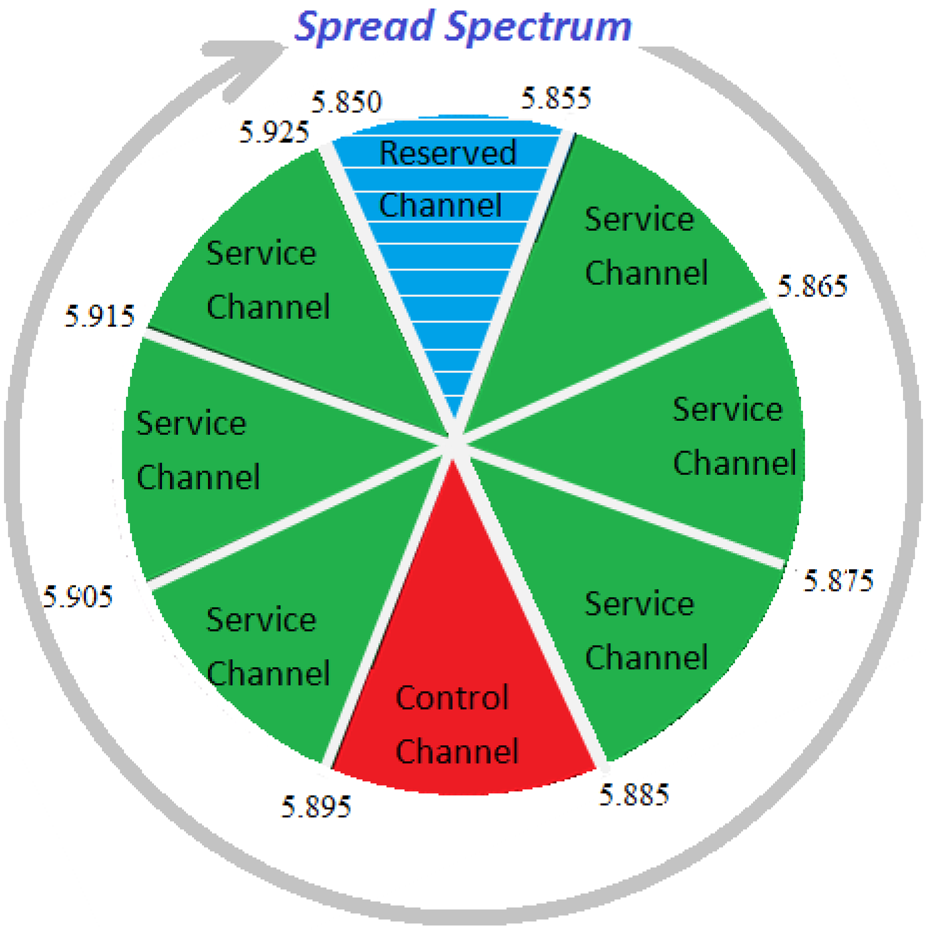

Figure 4-2 Spectrum Allocation for WAVE

5 MHz bandwidth in DSRC is allocated as a reserved channel that supports the operations of seven channels.

WAVE radio devices are able to demodulate one channel at a time, and are half-duplex. As a result, these radio devices operate on a period comprising of CCH (Control Channel) interval and (Service Channel) SCH interval and in an alternating pattern. All the devices must listen to CCH in their respective intervals. Devices that use services or are being used as service providers, switch to the service channel in SCH times. This approach of switching to several channels in alternate fashion introduces significant delay and hence degrades the non-safety-critical applications[97]

The primary objective of DSRC is to support safety-critical applications. Moreover, it is envisioned to provide communication between vehicular devices and fixed infrastructure to enable non-safety-critical applications. However, providing roadside fixed infrastructure everywhere, particularly in unplanned areas, is rarely possible. Unavailability of roadside infrastructure in unplanned areas degrades the quality of communication. Safety-critical applications are characterised by the requirements of fast network access, low latency, and high reliability. At the same time, the non-safety-critical applications are important because of their role in revenue generation and the interest of users. Classification of such potential applications has already been presented in chapter 2 of this dissertation.

Threat to the safety of life due to under performance of safety-critical networks cannot be compromised, to better improve the safety- and non-safety-critical services, this work assumes entirely separated and independent systems that are equipped with multiple radios working at separately allocated bandwidth. Furthermore, another assumption made in this thesis is that safety-critical applications are deployed and run with satisfactory performance over separate dedicated bandwidth. The assumption is supported by the argument that sufficient network bandwidth must be allocated for running these applications to avoid any emergency. Moreover, a huge number of research projects are already aiming at reliable safety-critical applications.

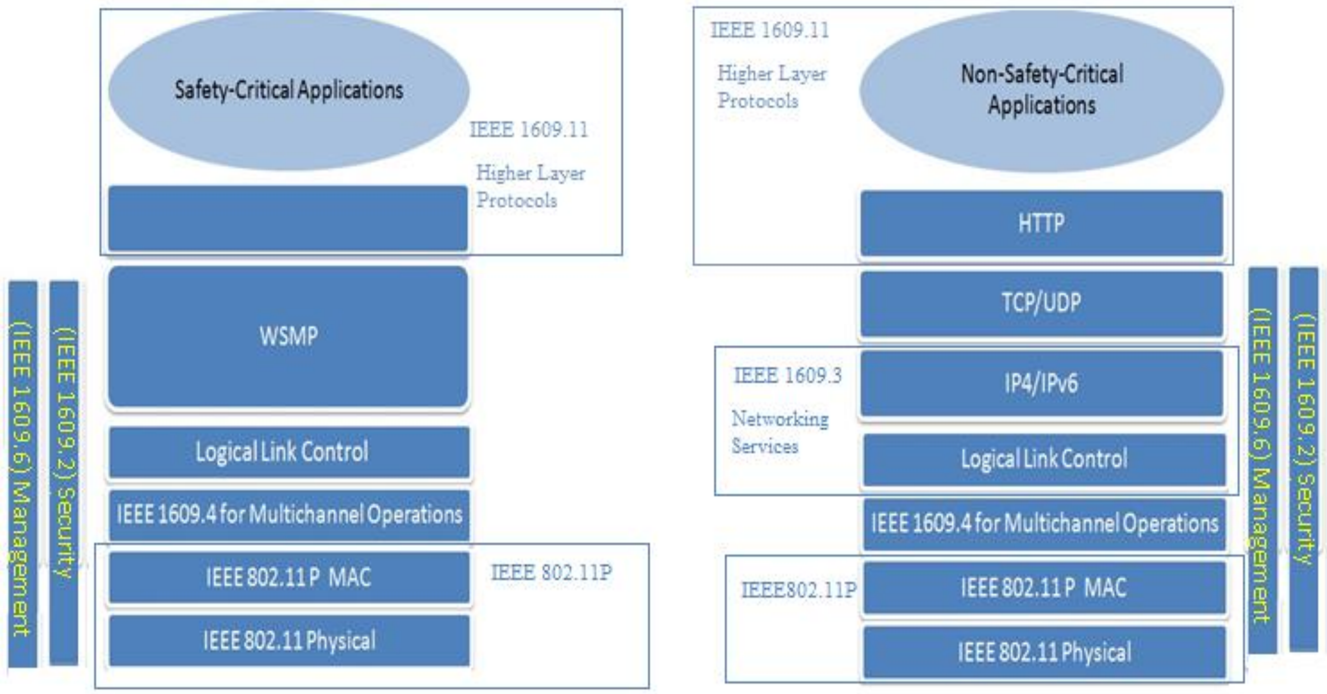

Figure 4-3 Block Diagram for Separate Allocation of Spectrum

Figure 4-3 presents separate protocol stacks for safety- and non-safety-critical communication. At physical layer both the systems for safety-critical applications and non-safety-critical applications use IEEE 802.11p specifications.

4.1.2 MAC Layer Aspects for IEEE 802.11p

Layer 2 of the WAVE stack presented in figure 4-1 and 4-2 is the MAC layer. This layer is responsible for managing medium access in such a way as to minimize packet loss and to maximize medium utilization. A brief introduction to MAC layer protocols is presented in the next section.

The purpose of IEEE 802.11 MAC includes devising methods to establish and maintain cooperating groups called the basic service set (BSS) by orchestrating the radios transmitting over the medium. Within the groups, these radios communicate freely, however, transmission outside the BSS is filtered. Amendments to the IEEE 802.11p MAC specification enable efficient group setup without much of the overhead that is typically present in the IEEE 802.11 MAC specifications. In other words, simplifying the BSS operations in a truly *ad* *hoc* manner is required. There are several MAC layer protocols to choose from for IEEE 802.11p to operate[98].

ALOHA is the first Medium Access Control (MAC) protocol based on random access used in packet radio networks. The ALOHA protocol determines if a channel for transmission is available or not by detecting a packet collision.[99]

Improvement to the ALOHA protocol is proposed by dividing the medium into time slots in Slotted ALOHA or S-ALOHA. A sender attempts to send at the start of a time slot, hence reducing vulnerable time and doubling the throughput. However, in dense environments, where there are multiple sources and destinations, the performance of ALOHA and S-ALOHA remains unsatisfactory when compared to the performance of Carrier Sense Multiple Access (CSMA)[99].

CSMA is another probabilistic MAC layer protocol widely accepted in the research community and industry. In CSMA, a sender verifies that the medium is free before transmission. Although this approach introduces additional overheads, it gives better results in terms of reduced number of collisions.

Multiple Access with Collision Avoidance (MACA), Multiple Access with Collision Avoidance for Wireless (MACAW) resolves hidden and exposed terminal problems through use of data sending (DS) – Acknowledgement (ACK) in addition to RTS and CTS packets; however, due to the time-critical nature of VANET applications, they are not considered for IEEE 802.11p.

Busy Tone Multiple Access (BTMA) presented another solution for the hidden terminal problem by splitting each channel into a data and a control channel. Double Busy Tone Multiple Access(DBTMA) uses two tones, one for the transmitter and one for the receiver[99]. Due to the wide acceptability of CSMA/CA by researchers and industry, BTMA and DBTMA are not considered as a MAC for IEEE 802.11p. IEEE 802.11p is a CSMA/CA (Career Sense Multiple Access/ Collision Avoidance) based standard. It makes use of two processes to determine whether the medium is in use or free. Firstly, it senses carrier physically by listening to the physical medium. This is called physical carrier sense. Secondly, it observes a network allocation vector (NAV) which is a timer representing the duration of a transmission [100].

4.1.3 IEEE 1609.x Protocols

There are several protocols of the IEEE 1609 standards family that can be seen in figure [4-1] and figure [4-3]. The IEEE 1609 family of standards for WAVE defines several aspects including architecture, network communications, security-related aspects, provision of network services and regulations for multichannel operation in the vehicular environment. Furthermore, these standards for WAVE provide two options (WAVE short message protocol (WSMP) and IPv4/IPV6) for communication among nodes (such as vehicles). IEEE 1609 standards support application design for seamless interaction with the WAVE environment regardless of heterogeneity in terms of device manufacturers, data storage access mechanisms, device management, and secure message-passing mechanisms. The IEEE 1609 family of standards consists of several published (final for use) and unpublished (trial-use) standards. Technical details of all the standards are out of the scope of this dissertation, however a brief introduction to the functions of these standards is provided here:

- **IEEE P1609.0** describes the specifications for the WAVE architecture. It describes working mechanisms among several IEEE 1609 standards to support services necessary for multi-channel communication among devices in a mobile vehicular environment.
- **IEEE 1609.2™** describes specifications for provision of security services to applications and management messages. For achieving such provision this standard defines ways to secure message formats and processing techniques. In addition, this standard also defines the situation for using and processing of such secure message exchange.
- **IEEE 1609.3™** defines network and transport layer services such as addressing, routing, etc. Furthermore, it defines WSMP for provision of an efficient WAVE-specific alternative to IPv6 to support safety-critical applications.
- **IEEE 1609.**4**™** provides enhancements to the IEEE 802.11 Media Access Control (MAC) to support multichannel WAVE operations.
- **IEEE P1609.6** provides remote management services. It enables regulation of inter-operable services to manage WAVE devices over the air. This standard consists

primarily of a remote management service. Furthermore, it includes the WAVE device identification services, the WAVE management services defined by IEEE 1609.3, and the WAVE short message protocol defined by IEEE 1609.3.

- **IEEE 1609.11™** defines the message formats for services that are necessary to support secure electronic transactions.
- **IEEE 1609.12™** This standard defines identifier values, such as service provider identifier allocated for use by WAVE systems. Such identifiers are harmonized with International Standards Organization (ISO), Comité Européen de Normalisation (French: European Committee for Standardization) (CEN), and European Telecommunications Standards Institute (ETSI).

4.1.4 WAVE Short Message Protocol (WSMP)

WSMP is a unique protocol to support critical applications. Primarily, it is designed to avoid connectivity and association delay that is caused when using other network layer protocols, such as IPV6. WSMP supports high priority and time sensitive communication. A WAVE short message (WSM) (i.e. data from upper layers) is passed to the WSMP for delivery to the destination. Upon reception, WSMP generates and concatenates a header to the WSM and forwards to a lower layer(i.e. Logical Link Control (LLC)) for further processing.

For a single system to accommodate safety-critical applications and non-safety-critical applications (Figure 4-1), LLC receives the packet and extracts relevant information to decide whether information has to be forwarded to WSMP or IPV6 for further processing. This process also causes delay and may affect the performance of safety-critical applications particularly emergency braking warning systems. Thus, dedicated systems are assumed in this dissertation to support safety-critical and non safety-critical applications. WSMP is only presented to support safety critical applications for non-IP traffic.

Several non-safety-critical services need to be available concurrently on a single service channel. These services, in vehicular environments, have different QoS requirements. Researchers have been working to foster an efficient mechanism for prioritization of these applications. One approach for prioritization is facilitated at the MAC level by exploiting the IEEE 802.11e (Enhanced Distributed Channel Access) QoS extension with application messages in four Access Categories (ACs) of different priority, varying from 0 to 3, with 3 representing maximum priority. However, due to the frequent disconnections faced by

VANETs using the WAVE network, it becomes difficult to meet the required QoS for several VANET non-safety-critical applications. Frequent disconnections in VANETs are due to the high-speed vehicle mobility, dynamically changing topology of vehicles on the road and non-uniform distribution of vehicles on the road. To improve the availability of VANETs services in the environment characterised by frequent disconnections, an existing road-side network infrastructure can be exploited[101].

UMTS provides an efficient means of cellular services in unplanned areas. UMTS infrastructure already exists in most geographical areas, so it can be exploited to realize the majority of VANET applications. However, it is observed that there exists diversity in VANET non-safety-critical applications and hence the latency and the system capacity of current UMTS networks cannot fulfil the requirements of all the VANET non-safety-critical applications. In addition to the facts mentioned above, the cost of using the UMTS network is also considered when deploying a service over the UMTS network. The next section of this chapter presents an introduction to the UMTS network and its comparison with WAVE in the context of support of LDCAMS applications.

4.2 UMTS

The first generation mobile communication systems were introduced in the mid 1980's. These systems were based mainly on analogue radio communications; however, digital switches were used in 1st Generation (1st G) mobile communication systems. 1st G systems offered basic voice and related services. The Nordic Mobile Telephone system (NMT) and the American Mobile Phone System (AMPS) are two examples of such 1st G mobile communication systems.

The increasing needs of industry to scale mobile communication at global or greater regional level in the early 1990's motivated the research community and telecom industry to address the issues of transparency at international level and compatibility of Mobile communication in 2nd Generation(2G) mobile systems. The Global Systems for Mobile communication (GSM) was outcome of such efforts; however, due to more region-specific standardizations, 2G could not offer the expected globalization scale.

4.2.1 Evolution of 3G/UMTS:

To overcome the limitations of 2G systems (i.e. it operates in narrow band, support for multimedia contents, dependence on radio access technology); and to offer worldwide acceptable standardized interfaces, a 3rd generation system as 3G was evolved. One major goal of 3G system was to ensure the adaptation of any change in the network transparently to the existing services using network structures. In Europe, the regional synonym for 3G is the Universal Mobile Telecommunication System (UMTS).

To provide an umbrella for activities undertaken to scale UMTS standards at global level, the 3rd Generation Partnership Project (3GPP) and 3GPP2 were established. UMTS incorporated mostly of the GSM functionalities; however, initially the major contribution that distinguished UMTS from GSM was consideration of a new access technology called wideband code division multiple access (WCDMA). WCDMA is an evolved form of CDMA that had been used for military purposes by the US army. "UMTS was aimed to provide the users with data rates up to 144kbps in macro cellular environments, up to 384kbps in microcellular environments and up to 2Mbps in indoor or Pico cellular environments" [102]. 3G is an evolved form of 2G from both data rates and term of services perspectives.

4.2.2 Moving from GSM to UMTS:

GSM is a widely implemented form of 2G, although many other standards are also used globally. To meet the globalization requirements as discussed previously, there are three different aspects of the system that are required for transition from GSM to UMTS, i.e. Infrastructure, architecture, and services. It is important to define “open” standard interfaces so that interoperability can be ensured among systems from different vendors and cost of infrastructure and system can be accumulated.

4.2.3 UMTS Services

UMTS offers provision of teleservices such as voice and text, and bearer services to offer the capability for exchange of information among nodes. This thesis particularly looks at bearer services for exchange of information among vehicles. Connection-oriented and connectionless services are offered for Point-to-Point and Point-to-Multipoint communication.

UMTS Bearer services may have different Quality of Service requirements in terms of maximum transfer delay, delay variation, and bit error rate. The data rate offered by UMTS bearer services are:

- 144 Kbps satellite and rural outdoor
- 384 kbps urban outdoor
- 2048 kbps indoor and low range outdoor

4.2.4 UMTS Architecture

The general UMTS architecture is shown in figure 4-4. As can be seen in figure, UMTS architecture can be divided into three major components:

4.2.4.1 Core Network:

The core network is the backbone of the UMTS architecture. It provides processing capabilities and central management for UMTS. In GSM, the Network Switching Subsystem (NSS) supported these functionalities. The core network interfaces to external networks, such as the public phone network and other cellular networks.

The Core Network is divided into a connection-oriented system i.e. circuit-switched domain) and a connectionless system (i.e. packet switched domain). The circuit-switched domain includes components such as Mobile services Switching Centre (MSC), Visitor location register (VLR) and Gateway MSC. The packet-switched domain components include Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). Other UMTS network components such as EIR, HLR and AUC are shared by both systems. MSC, VLR and SGSN can merge to become a UMTS MSC.
The core network is responsible to provide mechanism for switching, routing, and transit for user traffic. Additionally it manages system databases and regulates network management functions.

4.2.4.2 Radio Network Subsystem (RNS):

The Base Station Subsystem (BSS) of GSM technology is upgraded to Radio Network Subsystems (RNS) in UMTS. The RNS is responsible for provision of network and air-interface management of system.

4.2.4.3 User Equipment (UE):

The User Equipment (UE) is same as mobile or cell phone with considerably greater functionalities. These functionalities include capabilities for data processing, exchange etc.

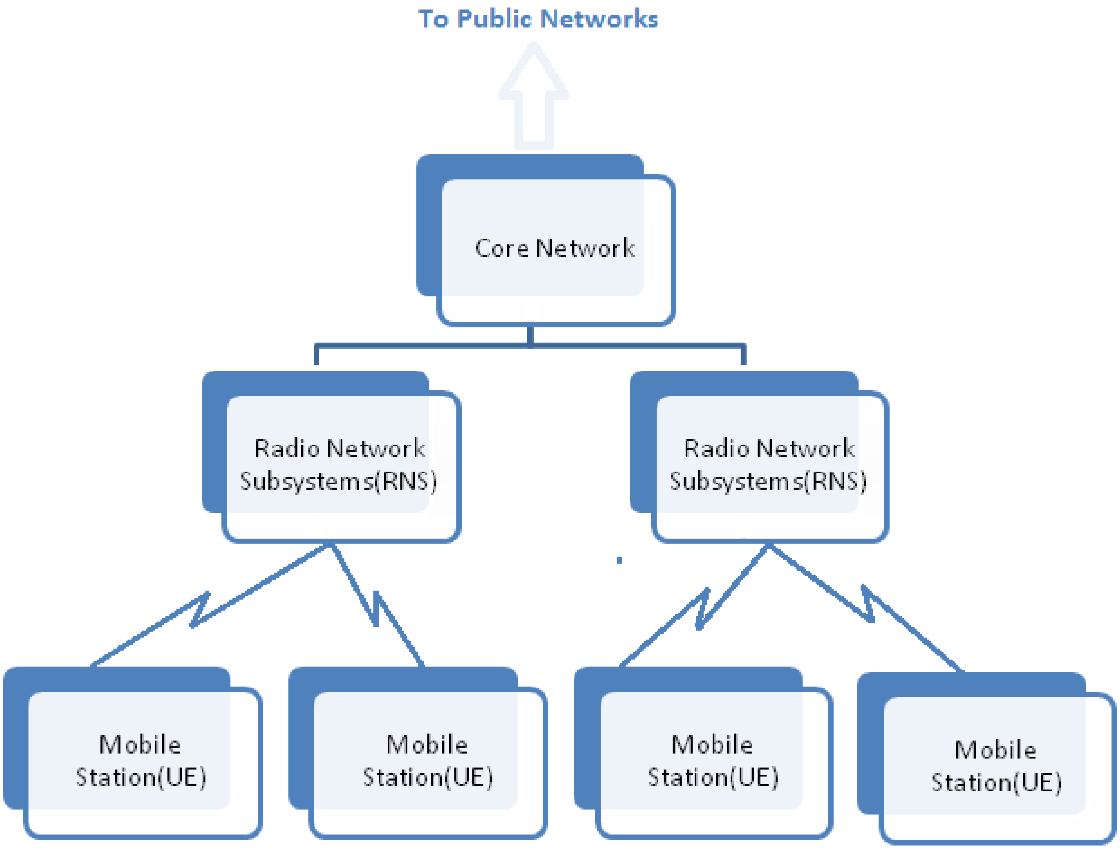

Figure 4-4 UMTS general Architecture

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One of the UMTS elements is Virtual Home Environment (VHE). The VHE is an environment that offers user with a common unified service interface regardless of the heterogeneity in terms of location, network, and other resource types. The VHE is based on the standardised service capabilities and offers portability across network boundaries and between terminals. This environment ensures that users are consistently presented with the same personalised features, User Interface customisation, and services in whatever network or terminal, wherever the user may be located. UMTS also has improved network security and location based services.

Network nodes equipped with UMTS devices communicate to each other via a fixed central infrastructure. These network nodes in VANET scenarios are vehicles. The common communication pattern of vehicular applications using UMTS relies on uplink and downlink messages. A vehicle transmits a message using the uplink option whereas a central server attached to the network processes the message and forward it to the target vehicles using the downlink option.

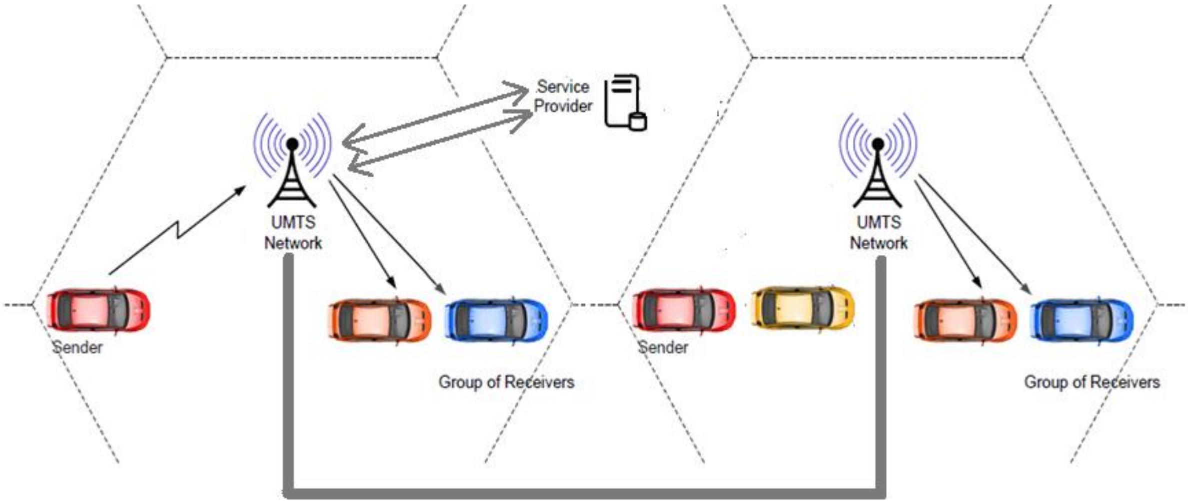

Figure 4-5 Vehicular Communication using UMTS

4.2.5 Communication Pattern of Vehicle Applications Using UMTS

There are many vehicular applications, e.g. traffic jam warning, weather forecast, and the bad road condition warning, that uses point-to-multi-point communication, i.e., the information addresses a group of vehicles in a specific geographical area. Many of these applications can be realized with today's UMTS networks already; however, the cost of using the UMTS network is high. In addition, to avoid network congestion assuming large numbers of users, an effective way to offer such services is to use geo-scalable and geo-specific broadcast services that are available in the cellular systems for message dissemination. The Cell Broadcast Service (CBS) and the advanced Multimedia Broadcast Multicast Service (MBMS) are the two broadcast services that are standardized in UMTS.[103] Using CBS and MBMS, network operators broadcast application messages to user equipment in a given geographical area. In comparison with CBS, MBMS offers more sophisticated broadcast and multicast services with significantly lower transmission delay. Therefore, MBMS is preferred for vehicular non-safety-critical applications particularly LDCAMS[103, 104]. According to a technical feasibility study[105] , traffic warnings with UMTS achieve an average transmission delay of about 300ms. Furthermore, employing MBMS for message dissemination leads to vehicle-to-vehicle delays of about 500ms.

4.3 Existing Approaches for decision making process for network selection

The decision making process for network selection is an important research issue. In several situations, vehicles may need to decide what network is best suited for communications among vehicles and for location-based context-aware service migrations. As academia and the automotive industry agrees to equip vehicles with multiple interfaces to access a wide range of applications, as well as reliable network availability. The usual mode of connection uses an Always Best Connected (ABC) approach for communication. However, the definition of the word 'Best' may vary in different scenarios. As the industry has agreed to provide a variety of network capabilities in vehicular nodes, it is important to compare the different networks against the requirements of system under consideration. In the following table, several features are presented that are offered by different network technologies- in particular, network coverage, data rate, mobility, and cost of using the network.

Network	Coverage	Data Rate	Mobility	Cost
Satellite	World	155 Mbit/s	Very High	High
GSM/GPRS	35 Kilometres	30-40 Kbit/s	High	High
GSM/EDGE	20 Kilo meters	160-200 Kbit/s	High	High
UMTS	20 Kilo meters	384Kbps to 2Mbps with CDMA	High	High
WiMax	30-50 Kilometres with line of sight; 3-10 Kilometres with non line of sight	72 Mbit/s	Medium/High	Medium
IEEE 802.11a	Approx. 10 kilo meters	54Mbit /s	Medium	Medium
IEEE 802.11b	200 -500 meters outdoor 50-100 meters indoor	1 Mbit/s to 11 Mbit/s	Low	Low
HiperLAN 2	30 – 150 meters	54 Mbit/s (over the air-rate)	Low	Low
IEEE 802.11g	30-130 meters	20 Mbit/s	Low	Low

IEEE 802.11P	250 meters	2Mbps-54Mbps	Low to High	Low

Table 4-1 General comparison different Networks

The table shows a comparison of several technologies in terms of parameters that are important for LDCAMS deployment and migration. These parameters represent features such as network coverage, data rate, mobility and cost of using the network. The preference for successful LDCAMS deployment and migration is a network exhibiting low cost, good network coverage, data rate and low to high speed mobility of network nodes i.e. vehicles. Particularly in unplanned areas, it is important to consider that sufficient infrastructure for networking is not available throughout the city. From the given table it can be seen IEEE 802.11p may provide network availability at low cost and high mobility covering 250meter from each node. Thus, if the nodes are distributed in the area within a 250 meter range, a well-connected network can be created using IEEE 802.11p. However, uneven distribution of vehicles on the road and high speed mobility may cause a frequent disconnections. Thus, it complicates the process of LDCAMS service migration. To support LDCAMS deployment and migration, this research focuses on the availability of infrastructure-based networks such as UMTS, as a backup network to improve network availability for security-related applications such as LDCAMS. Although, UMTS is a costly solution with limited bandwidth, it may be exploited to support network availability when IEEE 802.11p underperforms. This triggers the need for an efficient, cost-effective algorithm to support network selection.

Numerous wireless networks, such as Bluetooth, Wi-Fi, Wi-Max, and GPRS, have emerged offering different features. These networks differ in access technologies, network architectures, and protocols for transport, routing strategies, and mobility management techniques. To resolve these variations in order to provide wide range of services to mobile users, there is a need to handover the communication channel from one network to another by considering network features and user requirements.

With respect to the network types involved in handoffs, handoffs can be categorized into Horizontal handoff and Vertical handoff. If the channel handoff involves two identical types of networks, the handoff is said to be a horizontal handoff, whereas, if the handoff involves two different network technologies, the handoff is said to be a vertical handoff. A general classification of handoffs is shown in the figure below:

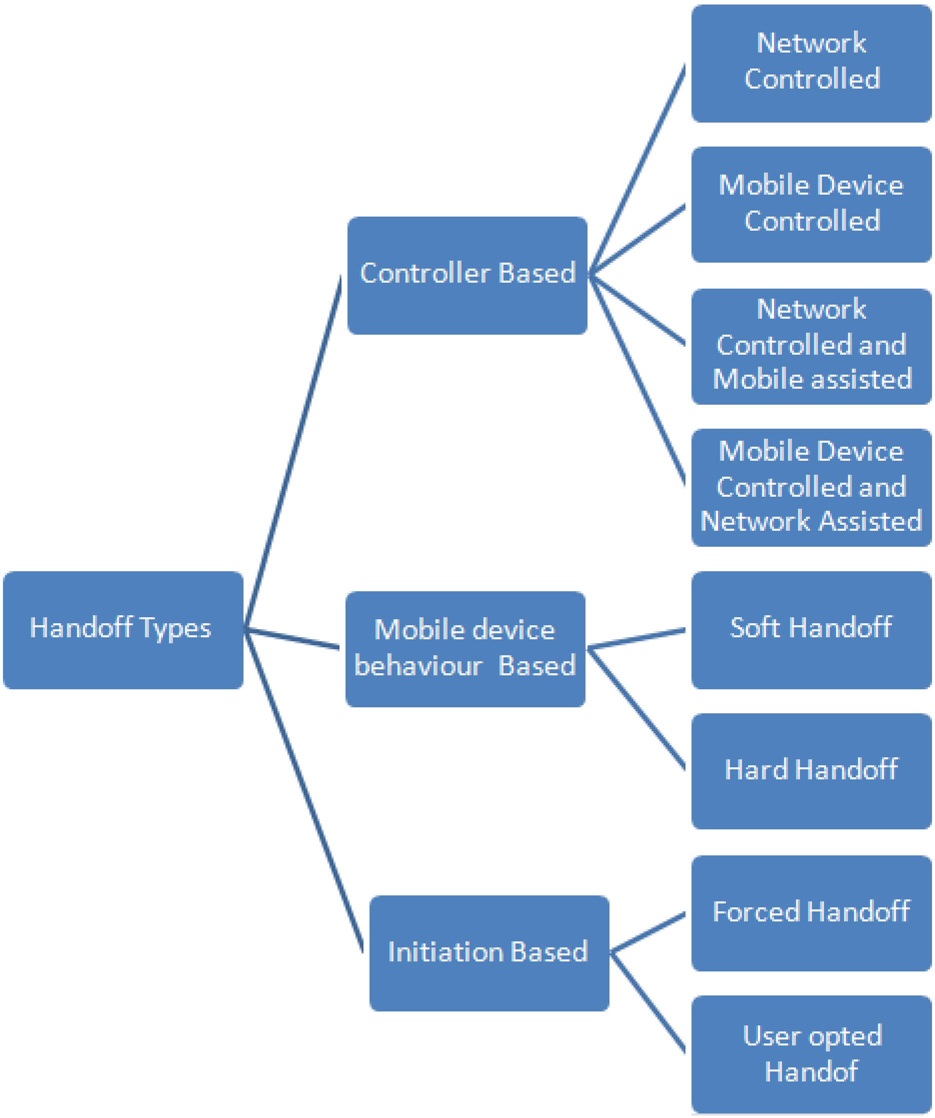

Figure: 4-6 Classification of handoffs

This research considers handoff issues that are involved in channel handover between different types of network technologies i.e. WAVE and UMTS. Thus vertical handoff is investigated for better availability of network services to support location-based. context-aware migratory services. The important issue that is considered for network handoff in this research is the handoff decision-making process. The decision criteria for vertical handoff are further elaborated in chapter 5. However, the handoff management process followed by a brief review of different approaches presented by the research community to facilitate network handoff, is discussed next in this chapter.

4.3.1 Handoff Management Process

The Network handoff process can be subdivided into three phases.

1. Handoff initialization process

   This process provides measurements against several parameters that may be required in handoff decision process for determining suitable network and if there is a need for handoff execution. Such information may include network-related parameters as well as user-related parameters. This information can be collected at different layers of the network, such as the data link layer, transport layer and application layer. Based on the information collected at different layers of network, the handoff decision process determines a suitable network for communication.
2. Handoff decision process

   This process works based on inputs provided by the handoff initialization process. The measurements of different parameters are forwarded to the handoff decision process so that the system can decide on a suitable network for communication. The suitability is further elaborated by decision strategies provided by the user, system or a combination of both.
3. Handoff execution process.

   The handoff execution process triggers a handoff based on the decision made in the handoff decision process. This process re-routes the communication channel to the selected network in a seamless manner. The selection of a suitable network is made by the handoff decision process. These three processes for handoff execution are shown in figure [4-7].

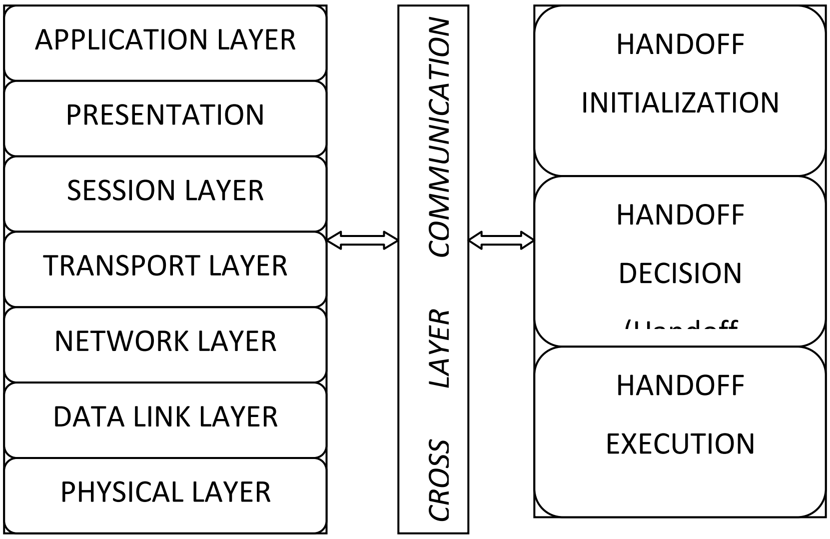

Figure: 4-7 Handoff communication Activities in relation to OSI layers.

It shows a block diagram of handoff process communication with respect to the OSI Model. The intermediate component shows the communication of handoff processes with different layers. Moreover Cross layer communication component facilitates cross layer communication in OSI.

This research focuses on the handoff decision process for selection of a suitable network for migration of location-based, context-aware services. In this research, for better elaboration of the handoff decision-making process, it can be further divided into two components:-

a. Decision making strategies
b. Decision criteria

Decision making strategy can be seen as approach to integrate multiple networks. Several decision-making strategies are presented in the next section of this chapter.

4.3.1.1 Handoff Decision Making Strategies

For deployment of location-based and context-aware services in an unplanned area, it is an important and necessary process to decide and select the best network that should provide high performance not only in terms of time but also in terms of reliability between the two vehicles. Furthermore, the objectives defined to achieve high performance consider minimizing overhead, minimizing packet loss, minimizing transfer delay, and maximizing throughput. There are several strategies presented by the research community to select the suitable network for achieving high performance. These strategies are presented below in next section of this chapter along with drawbacks of each strategy.

4.3.1.1.1 Received Signal Strength Based Strategies (RSSBS)

These strategies are based on RSS values of available networks[106, 107]. The flow chart as shown in figure [4-8] presents rules for handoff decision. Comparison of RSS values of competing networks results in the selection of a network for channel communication. The threshold value of RSS is set to minimize frequent network handoffs that are also termed as bouncing ball effect. However, RSS-based strategies do not consider user preferences, context information of the mobile node and application requirements. Thus, any handoff strategy that only considers RSS as the base of the network selection decision is not appropriate to support this scenario.

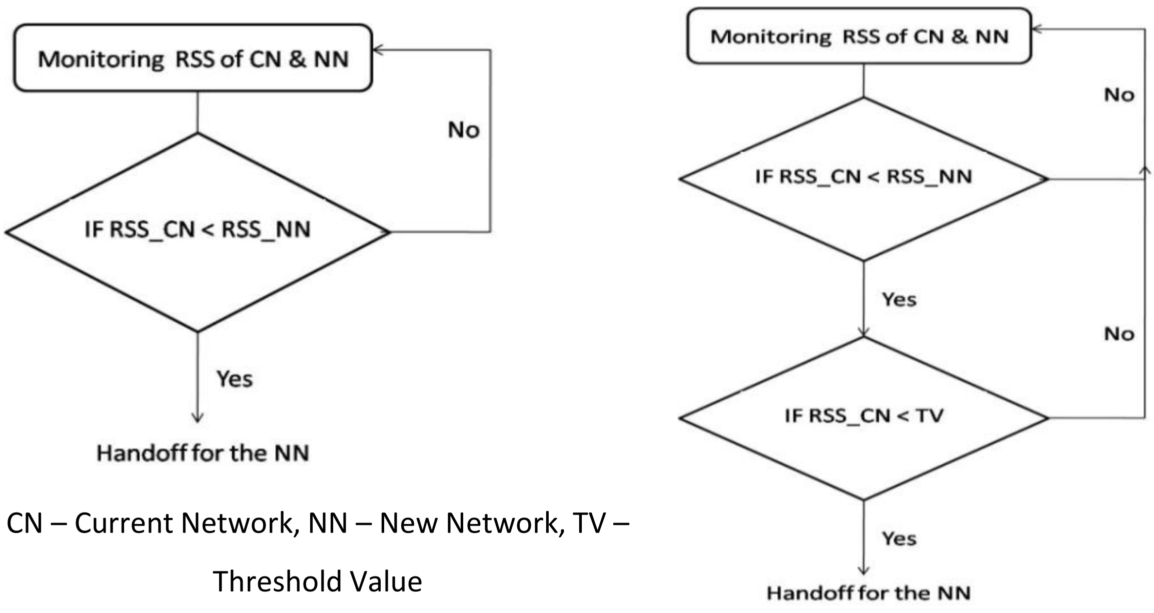

Figure: [4-8] Taken From: [108]: Two simple RSS centered handoff strategies

4.3.1.1.2 User Preferences Based Strategies (UPBS)

These handoff algorithms consider user preferences such as cost and required QoS as the basis for the handoff decision process. To integrate GPRS and WI-FI networks, while considering cost or QoS as user preferences, a two threshold value based algorithm is presented[108, 109]. This approach focuses on user satisfaction, however, in addition to having low context awareness, it is also less adaptive and less scalable. Thus, to achieve better QoS, an elegant selection criteria needs to be employed for selection of an efficient network while maximizing user satisfaction [108, 109].

4.3.1.1.3 Decision Functions (DFs)

Decision functions are based on measuring the value of the benefit attained by triggering a handoff. This strategy considers assigning weights to the parameters that are involved in the decision-making process, and the sum of all weights represents the criteria for handoff. There are numerous decision functions presented by research community such as the utility function based model proposed in [110] and two adaptive handoff decision methods proposed in [110, 111] These functions attempt to speed-up the handoff process in addition to reducing the number of handoffs; however, these methods are also not scalable. Moreover, the capabilities of the mobile node and requirements of applications are not considered.

4.3.1.1.4 Multiple Attribute Decision Making Process (MADMP)

The handoff decision process resembles a multiple attribute decision making process (MADM)[112], which is a combination of two steps:

1- Identify the objectives of each task.
2- Measuring the effectiveness of the selected objectives.

A few of the famous MADM models are given below.

1. Simple Additive Weights (SAW):

   In these methods, all the attributes that are considered to contribute in network selection are assigned specific weights. The network score is calculated by adding up all the weights associated with attributes contributing to specific network[113].

2. Technique for order preference by similarity to ideal solution (TOPSIS):

   SAW method simply adds the weights associated to all the attributes whereas TOPSIS attempts to classify the relevant attributes into three classes to calculate qualitative and quantitative benefits and cost benefits.

3. Analytic Hierarchy Process (AHP): Another method to resolve the handoff decision is AHP in which the attributes related to the network are classified into a hierarchy of choices and criteria. The organized hierarchy computes the ranking of candidate

networks.

4. Gray Relational Analysis (GRA): This process declares best case and worst case system with complete information as highest value system and system with no information with lowest value system. Every system in between these systems is defined as a grey system. Furthermore, all the networks are ranked accordingly. Network with the highest rank is chosen for the handoff process.

In the literature there are several approaches that use the above-mentioned models for the handoff decision making process. In [113], E. Stevens-Navarro et al. show that weights associated to the decision-making process play a vital role in influencing the performance of the handoff process. Simulation results presented in [114] show the effectiveness of an integrated model of AHP and GRA in a scenario of UMTS – WLAN integrated platforms.

AHP[115] is a well known and well established multi-criteria method for the handoff decision making process that allows evaluation of qualitative and quantitative criteria for the handoff decision. However, the complexity associated with this approach questions its performance while using it to make handoff decisions. Another issue with this approach is the time to rank the available networks that is also comparatively high due to the complex computation involved in the process.

4.3.1.1.5 Context Aware Strategies (CAS)

While considering the case of location-based, context-aware service migration, it is important to understand that the choice of network is highly dependent on the communication capabilities of vehicles, context of vehicles, as well as the requirements posed by types of applications. The aim of CAS is to select the best network among the available networks while considering the context of the mobile node and that of the network. The contexts that may be used for decision-making process are classified as static and dynamic. There are several context-aware proposals presented for the handoff decision making process such as in [116], T.Ahmed et al. propose a context-aware decision model by considering mobile initiated and mobile controlled vertical handoff decision processes.

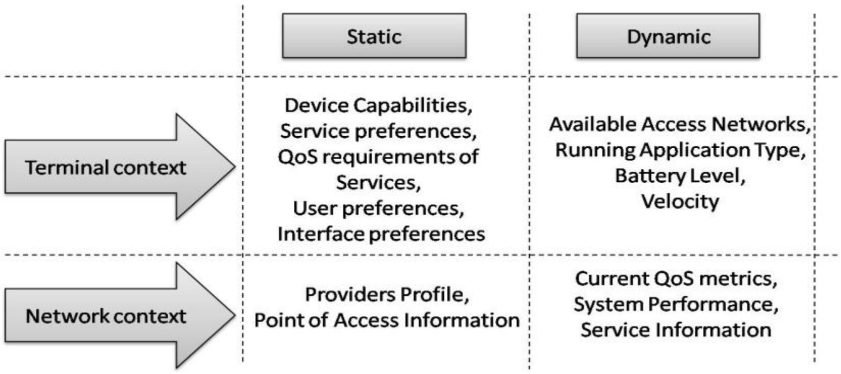

Figure: 4-9 Taken from:[108] Context models for the decision Algorithms

Another context-aware handoff decision making model is presented in [117] by S. Balasubramaniam et al. This model classifies context as static and dynamic context profiles. Moreover, it assumes application QoS specified as user-perceived QoS. If the model is implemented using a single context repository, it may cause a single point of failure.

4.3.1.2 Vertical Hand Off DECISION MAKING PARAMETERS

A decision-making algorithm may consider several parameters as the basis for the handoff decision. These parameters can be classified into several categories as presented below:

- Network – Related: This category includes parameters whose values are measured and provided by the network, such as Bandwidth, Latency, RSS, and Cost.
- Mobile Node – Related: This category includes parameters whose values are measured or provided by mobile nodes such as Velocity, Battery power, Location Information.
- User Preference -Related - This category includes parameters whose values are provided by the user e.g. user profile and other preferences.
- Application / Service Related - This category includes parameters whose values are taken from services or applications that are deployed over the network. Service capabilities, requirements, and QoS demands are few examples of this category.

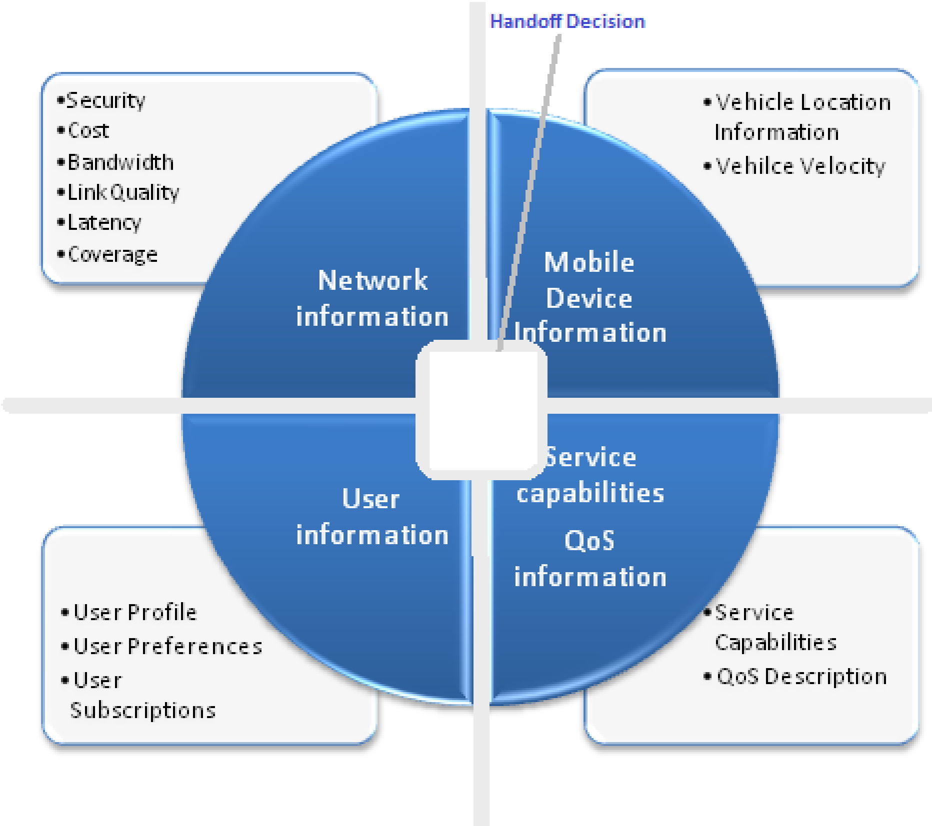

Figure: [4-10] Taken from[108]: Handoff decision attribute classification

Some of the established parameters used in the handoff decision-making process are presented below:

1. *Network Bandwidth*

Network bandwidth is a measure of the width of a range of frequencies. A network offering higher bandwidth is considered a better choice for communication.

2. *Handoff Latency*

It is measure of the time that elapses between the last packet received over a communication channel using the previous network and the arrival of the first packet over a communication channel using the new network. Handoff Latency is an effective parameter as a handoff decision making attribute.

3. *Network Cost*

Network cost is also an essential attribute that is considered in most of the algorithms for handoff.

4. *User Preferences*

Different users have different application requirements. Hence, the type of network traffic and QoS requirements of this traffic generated by numerous applications varies from user to user. Based on these values, an user may prefer different networks to attain the benefit of heterogeneous networks.

5. *Network Throughput*

Network throughput is defined as the average of successful data or message delivery over a specific communications link over time. The network that offers higher throughput is ranked higher and so is more desirable.

6. *Network congestion*

   Network congestion is a state of a communication link that shows that the communication channel is overloaded with network traffic. Network congestion causes increased packet loss as well as increases the average end-to-end packet delivery time delay (latency). The network that is less congested is ranked higher and so is more desirable.

7. *Packet loss*

   It is the measure of packets that are transmitted by transmitter however could not reach the destination successfully in acceptable form. The network that offers lower packet loss with high throughput is ranked higher and so is more desirable.

8. *Received Signal strength (RSS)*

In addition, an important attribute is considered while measuring the quality of communication channel offered by a network. The RSS should not be below a certain threshold in a network during handoff otherwise handoff would be initiated in traditional approaches.

9. *Velocity*

Velocity of nodes is also considered as an important factor for making handoff decision.

10. *Cooperation level*

In addition, an important issue is to consider cooperation level as an attribute to decision-making process. This research considers cooperation level as an important attribute that needs to be considered while assigning weights to the other attributes.

4.3.2 WAVE, UMTS and Hybrid Network for deployment of LDCAMS APPLICATIONS

The choice of network used for deploying LDCAMS is made considering the following characteristics of available networks.

a) Network structure
b) Communication range
c) Transmission delay
d) Network capacity

4.3.2.1 Network Structure

As a typical ad-hoc network, the WAVE system provides support for vehicular communication without a pre-established infrastructure. The flexible network structure and the limited communication range makes WAVE technology preferable for LDCAMS communications in an ad-hoc mode, e.g. for the wireless local hazard warning application. However, infrastructure is still needed when the WAVE network fails to provide communication range or satisfactory performance for vehicular communication or the migration of LDCAMS from one vehicle to another vehicle. Due to the lack of roadside infrastructure in unplanned areas, migration of LDCAMS using WAVE technology is hard to achieve , since it must exploit a network that is characterised by frequently changing network topology.

An infrastructure-based approach, such as UMTS, can be used as a network to support LDCAMS deployment and migration. The UMTS network is based on a well-developed infrastructure with significant coverage. The infrastructure-based network provides efficient information dissemination over a large distance, owing to the core network infrastructure. In addition to the support for traditional applications, UMTS network infrastructure can be exploited to support two main types of network traffic.

- LDCAMS Application traffic
- LDCAMS service migration network traffic

The UMTS network also supports high mobility, however, all the communications go through the core network. Direct communication is not possible among mobile terminals.

This lack of direct communication among mobile terminals limits performance to a certain extent. e.g. today's UMTS network offer round trip times around 100 ms, whereas the transmission delay between two WLAN ad-hoc terminals is typically below 10 ms for one single hop. Although UMTS can be thought of as a reliable network for LDCAMS migration, the cost of the network in addition to the limited bandwidth must be addressed.

4.3.2.2 Communication Range

An important parameter for considering what network should be adopted for LDCAMS deployment and migration is communication range offered by a network technology. Furthermore, in VANET scenario using DSRC the distance between vehicles may become greater than the communication range of DSRC compliant radios provided in the vehicles. This may cause disconnections and hence affects the communication. Greater number of disconnections and higher frequency of disconnection characterizes unreliable network. Therefore, it is important to measure the number of disconnections to measure network performance.

4.3.2.3 Transmission Delay

In a WAVE system, the end-to-end delay consists of the communication delay and the information processing delay. The information processing delay is considered as constant at each hop, whereas, the communication delay may vary dramatically according to the network density and the traffic load on the wireless channel. The study in [118] reveals that in a crowded WAVE system, the communication delay increases when the wireless channel gets busy because of interference. In case of low market penetration, WAVE communication suffers from a network disconnection problem that induces unacceptable communication delays [119]. From this point of view, the market penetration heavily affects the performance of WAVE based C2C communication network. The performance of WAVE based communication may fall to a certain value that does not meet LDCAMS communication and migration requirements. Therefore, a solution is needed to support VANET for the deployment of LDCAMS applications. As summarized in [104], to implement the hazard warning applications in today's UMTS networks, the approach using common transport channels is preferred. This enables an average vehicle-to-vehicle transmission delay about 300 ms for a hazard warning introduction scenario. For higher service penetrations, MBMS is a more resource efficient way to distribute the warning message because it can address a group of receivers at the same time. MBMS with UMTS can provide an average vehicle-to-vehicle transmission delay of 500m. Contrary to the WAVE system, as long as the coverage of UMTS networks is available, the delay performance of an UMTS network is more or less independent from the penetration of user terminals because of the wired backbone infrastructure. The problems with UMTS networks include the operational cost and limited system capacity. Thus, an efficient, cost-effective, cooperative algorithm is required to exploit the use of UMTS for LDCAMS communication and migration.

4.3.2.4 Network Capacity

In the WAVE system, multiple users share the given bandwidth. With an increasing number of users that contend for channel access, the probability of packet collisions increases accordingly. Therefore, the WAVE system is a collision-limited system, and in an overloaded situation, which is considered as the worst case of the system, the performance of the WAVE system depends very much on the number of users[120]. Nevertheless, the studies in[121] show that by differentiating and managing the priority of messages being transmitted, we can prevent the system being overloaded, and therefore, to guarantee the QoS of the WAVE system.

The capacity limitation of UMTS systems has been studied in [122]. E.g. for UMTS, it is stated that for the vehicular safety applications like traffic warnings, inducing only small (< 100 B) and rather rare transmissions, the WCDMA system will be code limited, which means that the maximum number of users that can be served depends on the number of available codes in the network. This means that in UMTS Release 99 a maximum of 251 vehicle terminals per cell can be served with a dedicated network connection, given no code resource is allocated to any other UMTS services. In case of transmissions that are more frequent, additional services or larger data packets, the interference will limit the system capacity to even fewer communicating vehicles. This constrains the ability of UMTS in supporting a vehicle manoeuvring service, which needs dedicated data communication to every vehicle. One conclusion of the evaluation in [122] is that today's UMTS networks allow the introduction of warning services. However, for a large-scale deployment of cooperative applications, the use of broadcast services, e.g. MBMS, is proposed to enhance system capacity addressing multiple terminals simultaneously.

	UMTS	WAVE
Network Infrastructure	Infrastructure based system	Infrastructure-less system. but some services require infrastructure support
	Infrastructure available	No infrastructure available in Europe
Communication Range	Large network coverage range	Ad-hoc network with single hop distance of 300 m to 1 km
Processing and Network Delay	Minimum end-to-end delay around 100 ms for local hazard warning service, but not guaranteed	Guaranteed minimum end-to-end delay < 100 ms for local hazard warning
	Delay performance of long distance communication is independent of penetration rate	Delay performance of long distance communication depends on the penetration rate
System Capacity	Interference limited system with constrained number of codes in each cell	Contention-based system: The system saturation throughput is limited by the number of active users
Cost	Licensed spectrum	License-free spectrum
	Well-developed network reduces the cost of developing and maintaining the infrastructure	Huge investment is expected in deploying and maintainin2 the roadside infrastructure
Security and Anonymity	Centralized	Distributed infrastructure protocol relying on infrastructure

Table 4-2 Comparison between UMTS and WAVE for Vehicular Applications

Through the analysis, it is observed that WAVE-based networks are characterized by a high number of disconnections, and so does not provide a reliable means for migration of LDCAMS applications. In addition, in extremely dense scenarios, a WAVE network becomes unable to accommodate the traffic generated in the network.

It is also noticed that VANETs with WAVE only and the infrastructure-based UMTS networks are complementary to each other in many aspects. This research investigates the integration of both technologies into a hybrid solution to support LDCAMS migration and communication. Thus, benefits from the advantages of one technology can address the drawbacks of the other. An important aspect to cover here is to employ the algorithm for cost-effective migration of service from one node to another.

Following are the assumptions made for integrating the two technologies i.e. WAVE and UMTS.

- Sufficient guard bandwidth is provided to separate the two frequencies of the chosen network technologies. This assumption makes coexistence of WAVE and UMTS in a single user device feasible.
- The cost of a WAVE radio device is cheap and WAVE is accepted in the market as mature network support.
- Capacity of UMTS network is enhanced to accommodate both conventional and vehicular applications.

Furthermore, to investigate the effectiveness of such an integrated network for LDCAMS migration, the following parameters are considered.

FACTORS	WAVE	UMTS
Data Rate	2Mbps	DL=2Mbps UL=384Kbps
Bandwidth	10MHz	5MHz
Multiple Access	CSMA/ CA	CDMA
Coverage	250m	Wider
Mobility	Low to High	High

Table 4-3 Assumptions of data rates offered by WAVE and UMTS for this research

The analysis of the given comparison of WAVE and UMTS reveals that a single network, i.e. WAVE or UMTS, cannot achieve successful LDCAMS deployment and migration. Hence it is realised there is need of a system architecture to support the integration of both the networks to achieve required network performance. The next chapter presents a system architecture to support cost-effective network selection for LDCAMS deployment and migration.

4.4 Concluding Remarks:

This chapter reviewed and presented literature related to four major areas addressed in this dissertation. It presented an introduction to the WAVE architecture. In addition, to support safety-critical and non-safety-critical applications, the chapter presented the assumption to consider separate systems available in vehicles. The chapter introduced the spectrum allocation for VANET communication. In addition to the spectrum allocation, a system architecture to support safety-critical applications and non-safety-critical applications separately is presented. The chapter provided a brief review of several standards and protocols at different layers of the system architecture. For successful deployment of services, particularly location-dependent, context-aware migratory services over VANETs, this chapter presented three approaches. Firstly, it discussed the use of WAVE as the only available network, and concluded that it is not able to meet the challenges for communication and service migration due to its intermittent nature of network connectivity. Secondly, this chapter provided a brief introduction to UMTS networks. UMTS alone is also not the best choice for vehicular communication and LDCAMS migration due to its cost and low system capacity. Thirdly, this chapter discusses the integration of WAVE and UMTS networks to support service migration. This chapter presented requirement of an integrated approach to support LDCAMS deployment. It discussed the requirements of an algorithm for triggering hand-offs between the WAVE network and the UMTS network to provide efficient and cost-effective, context-aware service migration in an unplanned geographical area. Finally, after a review of several network handover policies and functions, different parameters are identified and presented for the handoff decision-making process between WAVE and UMTS.

CHAPTER 5. SYSTEM ARCHITECTURE

This chapter presents the system architecture to support LDCAMS deployment and migration. The architecture presented in this chapter is divided into three sections. The first section elaborates how the system incorporates WAVE and UMTS radio modules into a single system to achieve the integration. The second part presents the framework of interacting components required to perform several functionalities such as to collect contextual information, to monitor resources, and to manage and execute the decision-making process. It discusses how depending upon the cost and availability of the networks, information generated by LDCAMS can be disseminated via either or both the technologies i.e. WAVE and UMTS. Finally, it presents and elaborates a cost-effective network selection algorithm to support LDCAMS deployment and migration.

5.1 Integration of UMTS and WAVE networks

A WAVE network is characterized by intermittent network connectivity, particularly in medium and high-speed mobility scenarios in unplanned areas; the performance of network is hardly sufficient to support deployment of applications such as LDCAMS. UMTS is network that has existing infrastructure in unplanned areas in developing countries; however, its operational, and the usage cost for LDCAMS communication is significant. Furthermore, UMTS has capacity limitations. Thus, there is need to integrate the two technologies to provide improved network availability in cost-effective way. These requirements for an algorithm to integrate networks, to support LDCAMS in particular, have been presented in the previous chapter i.e. chapter 4. This chapter presents the system architecture to integrate WAVE and UMTS networks for the provision of efficient and cost-effective, context-aware service migration in an unplanned geographical area. Figure 5-1 shows the block diagram of integration of UMTS and WAVE networks. In addition, figure 5-1 also shows the provision of a GPS unit to provide vehicular geographical position for the communication framework.

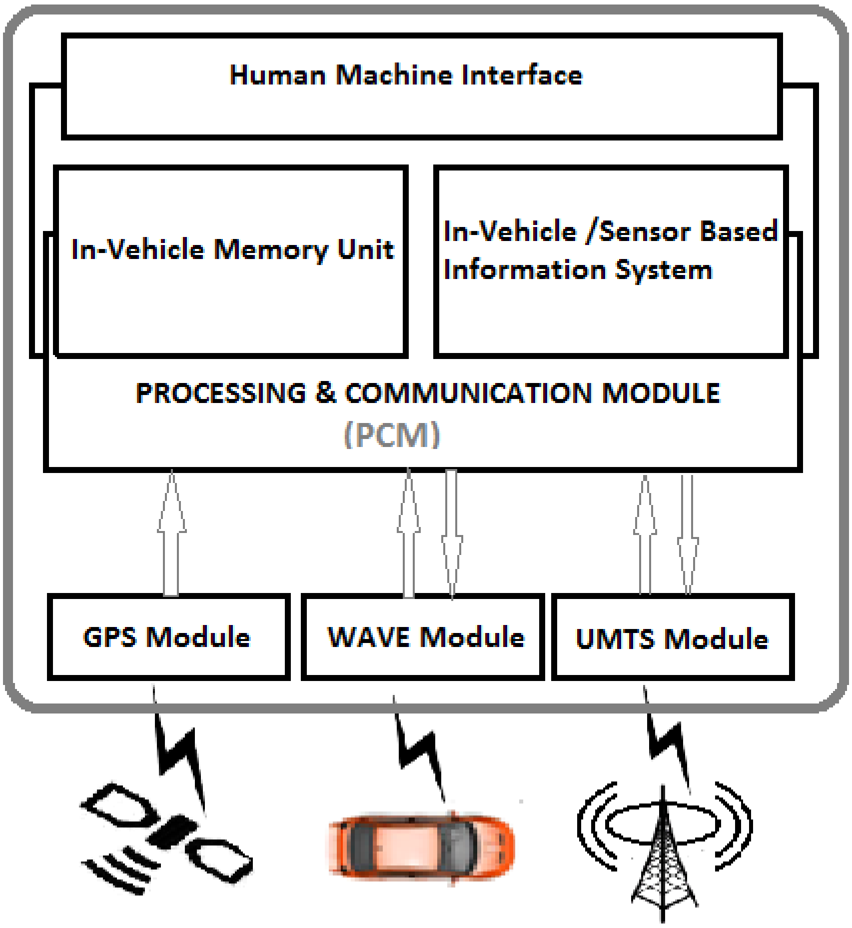

Figure 5-1 the Block Diagram of User Device for Integrated Network Solution for Deployment of LDCAMS

The lowest layer in figure [5-1] shows the technological components for communication such as satellite for providing location information to vehicles through a GPS module integrated in vehicle. Furthermore, it shows a WAVE module integrated in the vehicle communicating to WAVE module integrated into another vehicle. Thus, vehicle-to-vehicle communication using WAVE modules can be achieved without any external infrastructure. The third module for communication presented in this architecture is a UMTS module. The figure [5-1] shows a UMTS base station that may support communication among vehicles. However, the decision to choose UMTS or WAVE network for LDCAMS communication is made through execution of a cost-effective network selection algorithm presented later in this chapter. A central framework shown in this figure is processing and communication module (PCM). PCM has responsibility for collecting the required information, such as neighbour information, vehicle location, speed, road condition, weather condition, vehicle destination and network related information based on information collected, PCM is responsible for executing the network selection algorithm. The PCM Framework to support LDCAMS is presented in figure [5-2] and is discussed later in this chapter. Two more modules that may be seen in figure[5-1] are an in-vehicle memory unit and in-vehicle sensor based information. The in-vehicle memory unit is responsible to keep data that is either generated by running applications or received from another vehicle. The second module i.e. in-vehicle sensor based information module, takes the responsibility to collect relevant information using sensors within the vehicle. Examples include temperature sensors, and road grip sensors. The top module shown in this figure is the human machine interface. This enables a user to give inputs and receive outputs. For example, a user may see as collision warning on the screen that is integrated in this module. The PCM is interfaced with rest of the modules to help obtain vehicle dynamic data, interacting with drivers, the GPS unit to obtain geographic location and timing reference, as well as any application logic. The cost-effective network selection algorithm is implemented in the communication framework in order to reach the optimal complementary effect of both technologies i.e. WAVE and UMTS. Further details of the PCM framework are discussed later in this chapter.

5.2 Processing and Communication Module (PCM)

Context-aware service migration with single network support has been proposed in [123]. LDCAMS are capable of migrating to different nodes in the network while preserving and maintaining the state of communication with clients. Such a service migrates from one node to another, reducing the number of service rediscoveries. When the service migrates from one hosting node to another node, the state information of the service may also need to be migrated. Although service-migration has these advantages, a single network (i.e. WAVE) is highly dynamic in nature; furthermore, the high-speed mobility of vehicles, particularly in unplanned areas contributes a high number of frequent disconnections. Thus, for successful migration of LDCAMS, multiple integrated networks in integration may be used. UMTS is one of the choices for secondary network support for LDCAMS migration and communication. However, the cost to use UMTS may be significant. Thus, an efficient and cost-effective network-availability algorithm is required. This dissertation presents an integrated network solution to support LDCAMS deployment over VANETs operating in unplanned areas. The simulation results that are presented in chapter-6 show how this system architecture with the proposed algorithm (CACENSA) performs better in real life scenario particularly in unplanned geographic areas.

The Block diagram of user device for the integrated network architecture for deployment of LDCAMS is presented in figure [5-1]. One of the important elements shown in figure [5-1] is PCM. The proposed system architecture of PCM to support LDCAMS in unplanned areas is shown below in figure [5-2].

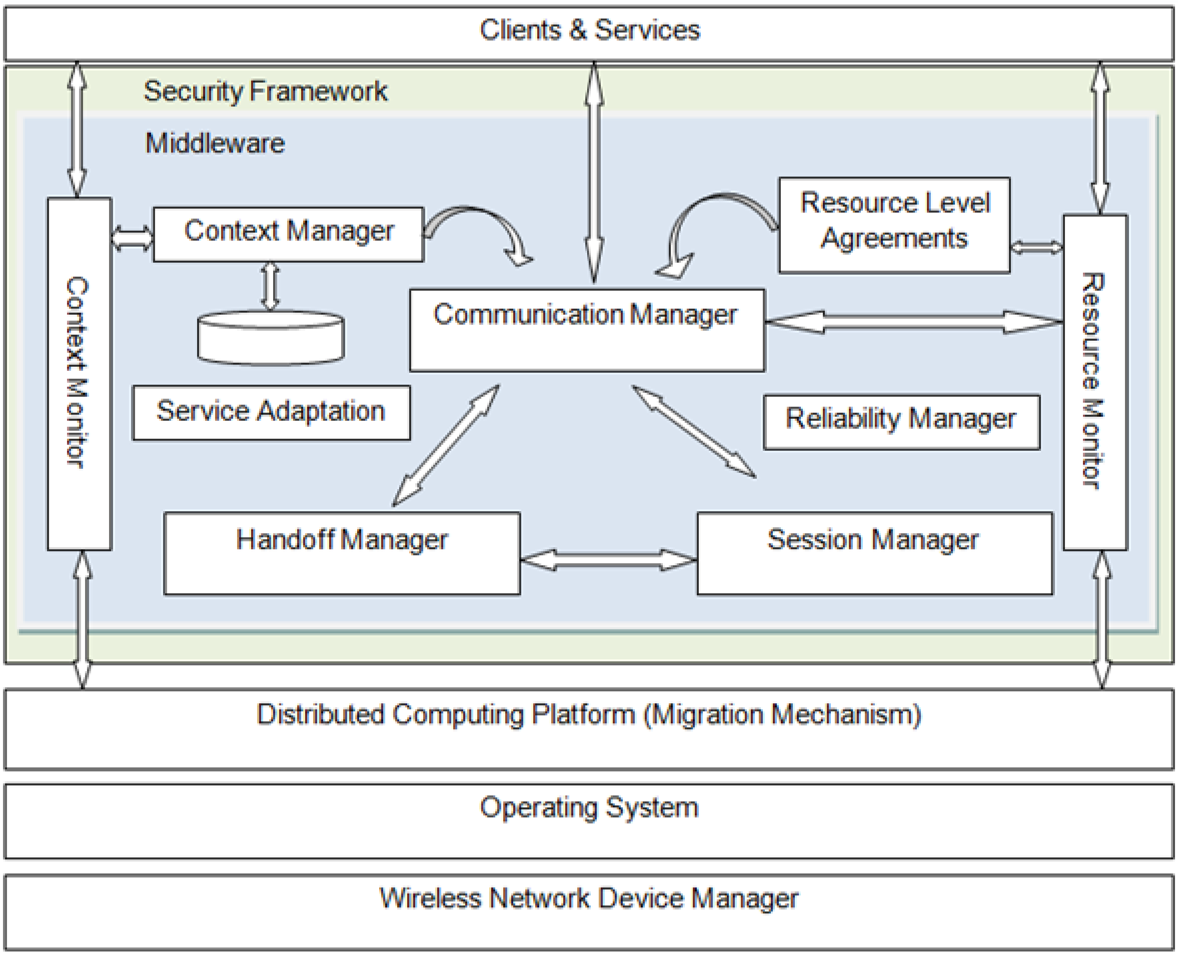

Figure 5-2 proposed system architecture of PCM to support LDCAMS (Source: adapted from [124])

The proposed architecture to support deployment of LDCAMS shown above is multilayered. Lower layers of the framework provide management of multi-homed devices. The upper middleware collects and provides decision capabilities for service adaptations, migration, and switching of the network. This thesis is restricted in scope to cover the integration of WAVE and UMTS networks to support LDCAMS migration. In addition, this thesis incorporates an approach to detect network congestion as an example parameter for collecting information via the Resource Monitor as shown in figure [5-2]. In the next section, a brief description of the proposed architecture is presented; the implementation of modules for integrated network support and network congestion detection that are covered later in this thesis are presented in chapter 6 section 6.1.1.7 and figure [6-2]. The scope of this thesis does not provide development and validation of all the components shown in this architecture; however, it proposes the presence of several modules as shown in the architecture in figure [5-2]. Functional descriptions of such components of the framework are described in the next section of this chapter.

5.2.1 Wireless Network Device Manager

Wireless network device manager is a module in the proposed PCM framework to support multiple wireless networks. This thesis considers WAVE and UMTS networks to support LDCAMS. The Wireless network device manager is responsible for selecting one network at a time. The network selected for LDCAMS depends upon decisions made by communication manager.

Communication among modules located at different layers shown in figure [5-2] takes place via Service Access Point (SAPs). The concept of SAP is taken from OSI reference model.

5.2.2 Operating system

The operating system layer shows the availability of operating system level functionality to support LDCAMS migration and communication.

5.2.3 Distributed Computing Platform

Distributed computing platforms support the development and execution of LDCAMS. DCP generally is located at upper layer of operating system as middleware. It provides abstraction for the development of applications/services such as LDCAMS. In addition, DCP coordinates with operating systems for accessing system resources such as execution of services etc. As a middleware, DCP addresses the underlying heterogeneity, either at hardware or at operating system level, for development of mobile services in ad hoc networks. There are several approaches of how DCP functions. These approaches have already been presented in chapter-3, section-3.1, of this thesis. In this proposed architecture, the choice of DCP also offers a location-dependent, context-aware service migration mechanism from one node to another node.

5.2.4 Communication Manager:

The communication manager acts as the brain of the system. The Communication Manager module is responsible for making decisions based on context and resource information that is gathered through the context and resource monitors.

5.2.4.1 Communication Manager's Functionalities

Within the scope of this thesis, the communication manager is designed to implement two functionalities.

1- Collecting network congestion information using a simpler approach presented in this thesis.

2- Making network selection based on a cooperative and cost-effective network selection algorithm contributed in this thesis for LDCAMS migration.

In addition to the functionalities implemented in this thesis, it is proposed to implement communication manager as set of sub modules, each of the sub modules performing its part.

The other tasks that the communication manager performs are:

- It is responsible to consider resource level agreements that are made among different nodes.
- The communication manager tracks available resources and resource demands of running services. Based on this information, the communication manager can initiate service adaptation, service migration and network handover.

The Communication manager takes the decision if the service needs to adapt its behaviour to avoid complete service failure in case of limited available resources. The Communication manager has the capability to command the service to migrate to some other node. During communication, if the WAVE network is unable to meet the QoS challenges, communication manager calls the handoff manager to perform the network handoff.

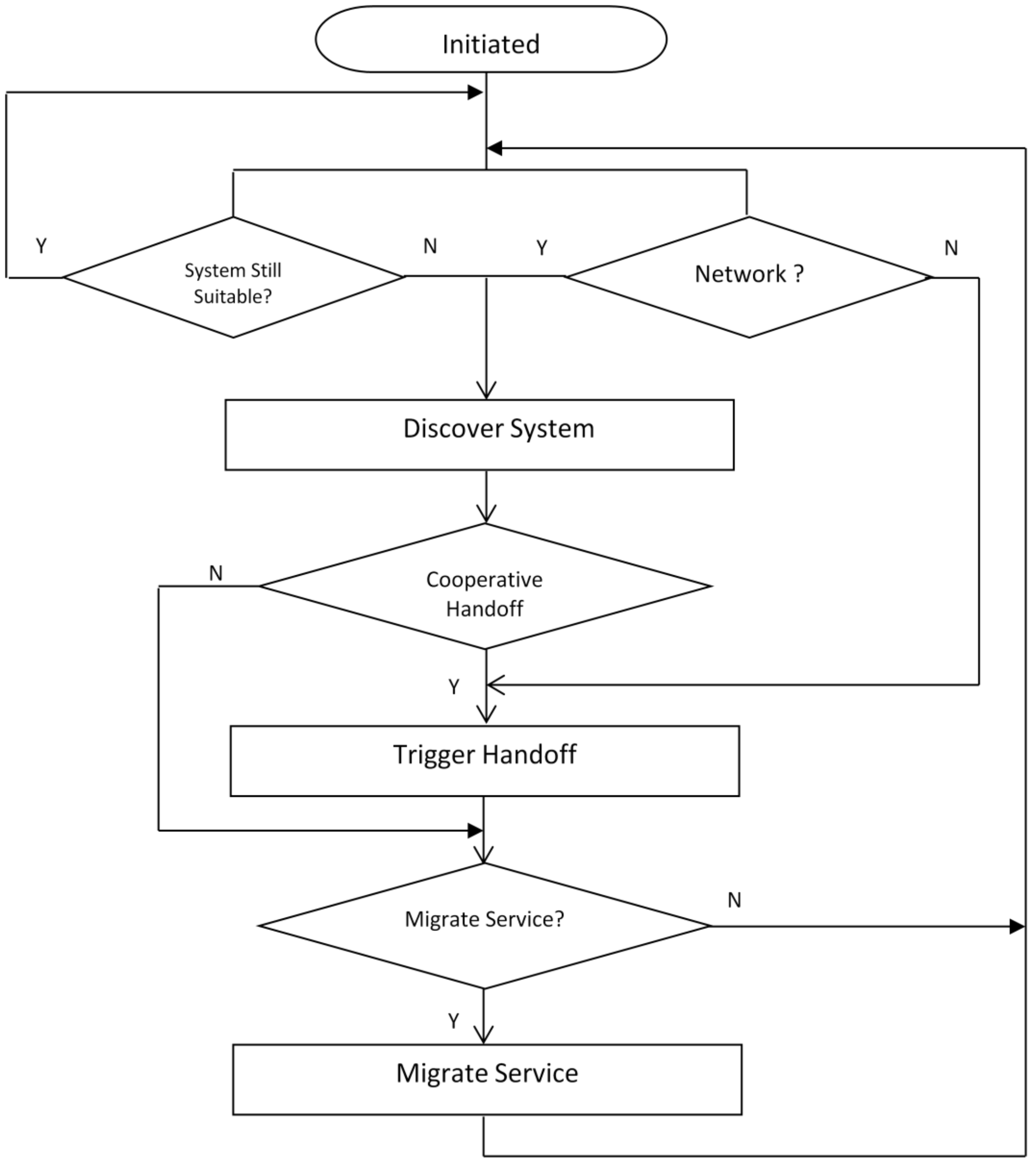

Figure 5-3 Flow chart of Network Selection and Service Migration

The communication manager that has already been described previously runs three processes.

- Process System (PS): This process is responsible to check if the current host is able to host the service for a minimum duration of time that is defined depending upon type and size of the service. Based on information that is collected from system, this process may reach one of two possible conclusions:
    a. Yes, the system is able to host the service
    b. No, the system will not be able to host the service due to changes the location and other context parameters.

If the system concludes (a), then system will continue to host the service until the next check is run. However, if the system concludes (b), then system needs to select next node (vehicle) to host the service for a defined minimum duration of time. The detailed selection algorithm of the next hop is assumed to be out of scope of this research. However, it is considered that next hop selection involves the availability of network resources as one of the major parameters. In this thesis, selection of the next node is executed manually by creating a node at specific geographic location. The process of next hop selection is shown as “Discover System” in the flow chart.

- Process Network (PN): This process is responsible to check if the current network is able to discover a new host or to support service migration to the next host. In addition, PN periodically checks the available network status to ensure the current network meets minimal QoS requirements to support LDCAMS migration and other management processes, such as the next host selection process. Based on information that is collected from the system, this process may reach one of the two possible conclusions:
    a. Yes, the Network is fine to support service migration
    b. No, the network will not be able to support next host selection or service migration. Furthermore, this process may conclude that the network is not even meeting QoS requirements for currently running services.

    If the system concludes (a), then the next process of ‘discover the new system’ is executed. After the selection of the next host, the system decides if there is a need of handoff to consider the cost of network. However, if the system concludes (b), then the system needs to select an alternative network.

- Process Management (PM): The process takes the values from the two processes defined previously and manages the execution of functionalities, like triggering handoff and triggering service migration.

The flow chart in figure 5-3 shows that the communication manager continues to process the context information gathered by the context manager and decides if the node hosting the LDCAMS is still suitable to host the service for a defined minimum time. In addition to the suitability of location, the communication manager reviews the network conditions and capabilities of neighbouring communicating vehicles. If network conditions of the WAVE network falls below a minimum threshold value predefined by the system, the communication manager can trigger the handoff and switch to the UMTS network for more reliable communication. If the communication manager finds out that the node hosting the service is going to be out of the specified location of the service, it discovers a new node to host the service. The communication manager uses information gathered through the context monitor and resource monitor to decide what node is in the best position to host the service. An important assumption made here is that vehicles that agree to cooperate in communication makes resource level agreements. From resource level agreements, the Communication manager decides which node has sufficient resources to host the particular LDCAMS. After the node is selected for hosting the LDCAMS, service migration is initiated by triggering service migration. To manage state-full service migration, the session manager is invoked. The communication manager guarantees the use of WAVE when it is available and meets the minimum predefined quality of service parameters.

Network switching also depends upon the network capabilities of neighbouring vehicles. Neighbouring vehicles may have different network capabilities. Depending upon the cost and criticality of information being provided by LDCAMS, network-switching decisions are taken. A few exemplar scenarios are shown in figure [5-4] as follows.

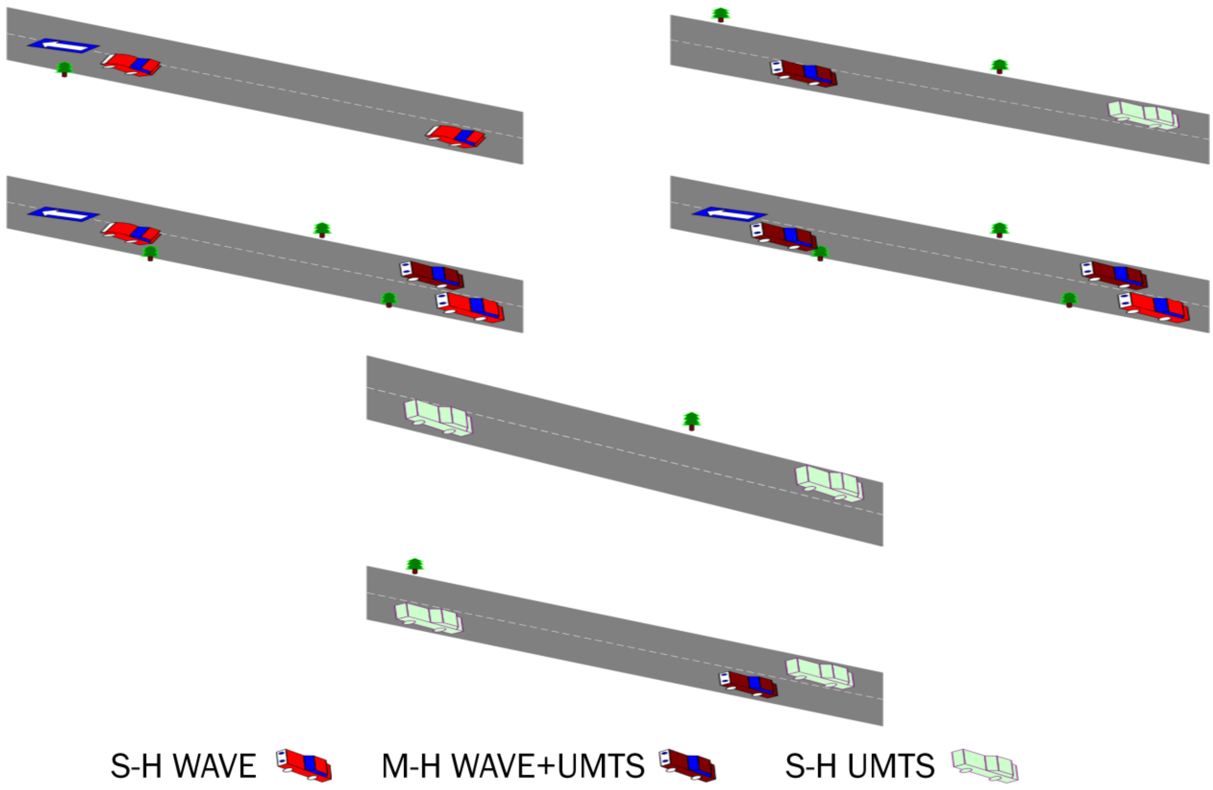

Figure 5-4 Vehicles with Multiple Types of Communication Devices

In figure[5-4], it is observed that there are single-homed vehicles with single network technology radios like WAVE or UMTS and there are multi-homed vehicles that contain both the network technology capabilities. The cost of the communication and LDCAMS migration from one vehicle to another vehicle depends upon the types of vehicles taking part in communication. Ultimately, the CACENSA algorithm ensures cooperative and cost-effective network selection for reliable LDCAMS communication.

5.2.5 Context Manager:

Vehicles on the road gather context information continuously through the context monitor that forwards the information to the context manager. The context manager validates the information and stores it. This information provides the basis for the communication manager to ensure the service acts accordingly.

5.2.6 Service Adaptation Manager:

The service adaptation manager is responsible to perform service adaptation when the communication manager triggers service adaptation. Adaptations define the behaviour of services under different circumstances. E.g. how to perform in a highly congested environment or resource-constrained environment etc.

5.2.7 Handoff Manager

The handoff manager is the module that is responsible for performing handoff among different available network devices. It performs this handoff on the basis of policy defined by the communication manager.

5.2.8 Session Manager:

The session manager performs the management of session for service communications. When a service needs to migrate from one node to another node, the session manager ensures the migration of state information of the service along with service code.

5.2.9 Resource Monitor

The resource monitor monitors the currently available resources like location, speed, network-availability, etc.

5.2.10 Resource level Agreements

As different nodes communicate and use each other's resources, so before use, they must reach resource level agreements. These resources level agreements also provide the basis for service migration decisions.
Collectively, there are numerous modules presented that participate in LDCAMS deployment, particularly in unplanned areas.

Another interesting aspect that the proposed LDCAMS architecture presents, is, its code size and complexity. The code has to be executed and stored in the vehicle. Thus, a vehicle's capability to execute the code affects the overall system performance. Although there are several approaches to design and develop LDCAMS, however, this dissertation assumes LDCAMS is designed using the Smart Message Platform. Furthermore, the Smart Message Platform is based on the Java Virtual Machine. Literature shows in exemplary scenario (TJam: taken from [124]) that heap size for running the JVM and a small LDCAMS (TJam) is 172 Kb; however, vehicles are going to be providing a diverse range of application including JVM-based entertainment applications, therefore, the heap size may range from 16Mb to

512Mb. To cope with requirements raised by such applications, It is also evident from literature that automotive industry has agreed to equip vehicles with rich computation and communicational resources[125-127]. However, management of network traffic introduced by such applications in a cost-effective way is a challenge. This thesis contributes CACENSA-based algorithm to support LDCAMS migration over an integrated network. The next section of this chapter presents the implementation in NS-Miracle, naming the newer version as NS-Miracle-V, to validate the performance gain by CACENSA.

5.3 Implementation of LDCAMS Architecture in NS-Miracle-V

NS-Miracle supports back end functionality for cross layer communication that is one of the prime requirements of this design. However, NS-Miracle lacks the definitions of IEEE802.11p for vehicular communication. To simulate scenarios provided in this research, NS-Miracle has been adapted to support IEEE 802.11p communication. The NS-Miracle structure is shown in figure[5-5] [128].

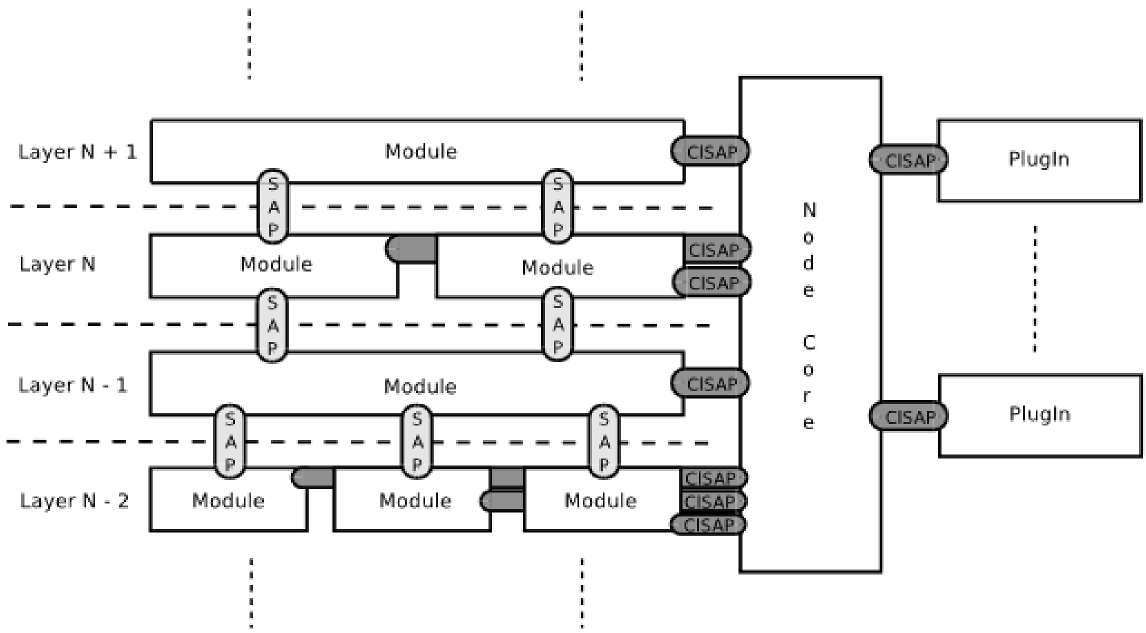

Figure 5-5 Block Diagram of NS-Miracle

A brief description of the basic components of NS-Miracle is provided as follows.

5.3.1.1.1 Module

The Module class is one of the basic building blocks in NS-Miracle that represents an entity that can be placed in the stack. A Module can represent an entity involved in communication. It can be an application, and it can also represent a wireless interface at the physical layer of OSI model [128].

5.3.1.1.2 SAP

SAP concepts are presented in the OSI model. To connect several modules in NS-Miracle, an SAP is defined. Since all the traffic passes through an SAP, it is the right point to trace traffic. SAPs are used in three different ways.

- Firstly, SAPs are used to interconnect different modules in the neighbouring layers of NS-Miracle. These connections are manually defined using OTcl not only to regulate the data traffic travelling up and down the stack but also to be able to define multiple interfaces connected to single link layer.
- Secondly, using a specific class, ChSAP, SAPs connect nodes to the channel. ChSAP interconnects a Module and a ChannelModule.
- Finally, SAPs enables cross layer communication by making use of ClSAP subclass to connect every Module to the NodeCore[128].

5.3.1.1.3 Cross Layer Messages

NS-Miracle provides cross layer module communication with the help of cross layer messages. NodeCore, as shown in the figure [5-5], contains the logic to receive and forward cross layer messages and hence works as a cross layer message bus. A cross layer message is derived from the base class ClMessage. By using cross layer messages, nodes are able to pass any kind of data between them. Cross layer communication, using these messages, can be executed in the following modes.

- Synchronous mode (the sender Module blocks until it receives a reply).
- Asynchronous mode (the sender Module does not wait for a reply).

The NodeCore supports Unicast and broadcast communications. Cross layer communication can also be executed exploiting SAPs connecting Modules in a stack. This communication is particularly important to performing control operations on the stack[128].

5.3.1.1.4 Plug-in

A Plug-in provides the functionalities that are node specific or that are not appropriate in stack. The Plug-in Module operates as the base class of module defining a ClSAP connection to the NodeCore. An exemplar application of Plug-in module is resource monitor (network monitor). In this research, for context monitoring and resource monitoring, separate plug-ins are installed with some amendments; for example the congestion detection mechanism has been implemented to monitor congestion in the network traffic.

The system architecture presented in figure [5-2] is implemented in NS-Miracle-V as the Cross Layer Adaptation and Information Manager as shown in figure [5-6].

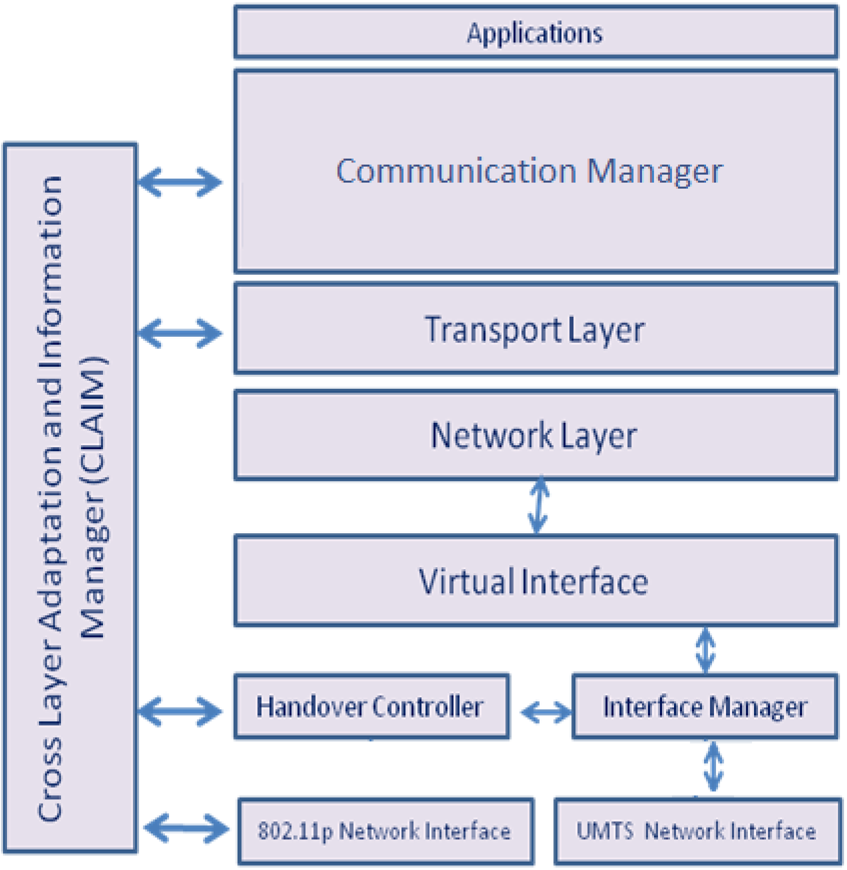

Figure 5-6 System Design implemented as NS-Miracle-V

1. **Multiple Network interfaces**

The lowest layer presents multiple network cards, i.e. IEEE 802.11p and UMTS network cards, that are created as physical layer modules.

2. **Cross Layer Adaptation and Information Manager (CLAIM)**

An Interface facilitate cross layer information flow, management and adaptation information. In NS-Miracle, it is implemented using cross layer messages through SAPs to the Node Core. CLAIM is based on a library of functions to support cross layer communication. The functions include checkstatus(ifid) (to check status of specific interface) , setup(ifid) to activate a network interface, setdown(ifid) to deactivate a network interface, detectnc() detects network congestion based on average delay of RTS-CTS. Furthermore, it is important to mention that CLAIM is implemented based on NodeCore in NS-Miracle as shown in figure[5-2]. In particular, the cross layer communication is based on the ClMessage class. By using cross layer messages, nodes are able to exchange relevant data. Cross layer communication among different layers, such as communication manager and handover controller can be executed in Synchronous mode or Asynchronous mode. In addition to the basic cross layer communication, CLAIM supports Unicast and broadcast communications through Nodecore.

3. **Interface Manager**

It contains a mapping between virtual interface IP and the IP of the active network interface.

4. **Handover Controller**

It performs the handoff when triggered by the communication manager through CLAIM

5. **Virtual Interface:** VI provides transparency of network handovers to the upper layers.
6. **Communication Manager:** The communication manager is the core component of this architecture. It runs the algorithm described earlier in this chapter. The communication manager collects network-related information through CLAIM and

makes the network handover decision. The decision is executed by calling relevant functions provided in the CLAIM library. The communication manager communicates to the handover controller through CLAIM message to execute the handover. Communication manager also calls the interface manager to update the mapping database.

Pseudo code

1. *Main()*
2. *Start*
3. *Action=Calls(Proc Syscheck(), 10) # calls syscheck procedure periodically in every t seconds*
4. *Switch (action)*
5. *Case (Fine):*
6. *Exit()*
7. *Case(Bad):*
8. *Calls (Take(NextNodeID), CheckNetworkstatus(NextNodeID) #claim.checkstatus(ifid)*
9. *If Networkstatus =fine # the next host has similar network capability*
10. *Calls(Migrate(NextnodeID)*
11. *Else*
12. *update=Calls (CLAIM.Handovermanager.interfacemanager.setupifid()) #Network #switches #to alternate supporting network interface i.e. UMTS*
13. *if update=1 then #if success in setting up new interfaceid*
14. *Calls(Migrate(NextnodeID) #start migratingservice to new host*
15. *Else Goto 8*
16. *Proc Migrate(NN)*
17. *Start*
18. *While claim.detectnf(t)=false #check WAVE network in every t seconds*
19. *Continue data transfer / service migration*
20. *If claim.detectnf(WAVE)=true then*
21. *Calls(networkswitch(UMTS))*
22. *End*
23. *Goto 1*
24. *End*

Tcl code(source: [129] used to set IEEE802.11p Parameters:

```
Phy/WirelessPhyExt set CSThresh_              3.162e-12    ;# =-85 dBm

Phy/WirelessPhyExt set Pt_                    0.001
Phy/WirelessPhyExt set freq_                  5.9e+9
Phy/WirelessPhyExt set noise_floor_           1.26e-13     ;#-99 dBm for 10MHz bandwidth
Phy/WirelessPhyExt set L_                     1.0
Phy/WirelessPhyExt set PowerMonitorThresh_  6.310e-14   ;#-102dBm

Phy/WirelessPhyExt set HeaderDuration_        0.000040    ;#40 us
Phy/WirelessPhyExt set BasicModulationScheme_   0
```

```
Phy/WirelessPhyExt set PreambleCaptureSwitch_   1
Phy/WirelessPhyExt set DataCaptureSwitch_        0
Phy/WirelessPhyExt set SINR_PreambleCapture_    2.5118;     ;# 4 dB
Phy/WirelessPhyExt set SINR_DataCapture_         100.0;      ;# 10 dB
Phy/WirelessPhyExt set trace_dist_             1e6      ;# trace distance of 1 km
Phy/WirelessPhyExt set PHY_DBG_                0
Mac/802_11Ext set CWMin_                   15
Mac/802_11Ext set CWMax_                   1023
Mac/802_11Ext set SlotTime_                0.000013
Mac/802_11Ext set SIFS_                    0.000032
Mac/802_11Ext set ShortRetryLimit_          7
Mac/802_11Ext set LongRetryLimit_           4
Mac/802_11Ext set HeaderDuration_           0.000040
Mac/802_11Ext set SymbolDuration_           0.000008
Mac/802_11Ext set BasicModulationScheme_      0
Mac/802_11Ext set use_802_11a_flag_          true
Mac/802_11Ext set RTSThreshold_             2346
Mac/802_11Ext set MAC_DBG                  0
```

However, for using this script in NS-Miracle-V, this research made following amendments to NS-Miracle. In the NS-Miracle library, I added the following files that were developed for NS-2 by a team from Mercedes-Benz Research and Development North America and from the University of Karlsruhe:

1. apps/pbc.{cc,h}
2. mac/mac-802_11Ext.{cc,h}
3. mac/wireless-phyExt.{cc,h}
4. mobile/nakagami.{cc,h}

These files included amendment to basic IEEE 802.11 related parameters advised by the IEEE 802.11P standard. The validation of these amendments are performed and presented in the next chapter of this thesis.

5.4 Concluding Remarks

Depending upon the cost and availability of the networks, information is disseminated in unplanned areas via either or both technologies, i.e. WAVE and UMTS. This chapter presented an approach to integrate WAVE and UMTS networks to support LDCAMS migration. It presented the basic architecture to integrate both network units. More importantly, this chapter proposed a system architecture to support LDCAMS deployment and migration. Furthermore, it presented a cooperative and cost-effective network selection algorithm for LDCAMS migration. Finally, this chapter presented some amendments made to NS-Miracle to support IEEE 802.11p.

CHAPTER 6. EXPERIMENTAL SETUP, RESULTS & DISCUSSION

This research investigates the integration of WAVE and UMTS to support location-dependent, context-aware service communication and migration in an unplanned area. Use of these two technologies has its pros and cons. By integrating the two, the advantages of one technology can address the drawbacks of the other. However, achieving the benefit by integration of the two requires an algorithm for cost-effective network selection for the migration of LDCAMS from one node to another.

This chapter is divided into three major sections. Section 1 presents a brief overview of existing experimental (simulation) tools and amendments made in simulation software to support the solution design presented in this research. Section 2 presents results validating the amended software used for simulations. Finally, Section 3 presents and discusses the performance evaluation of a cooperative and cost-effective network selection algorithms (CACENSA) in different scenarios to support LDCAMS communication and migration in unplanned areas.

6.1 Selection of Simulator

Three major areas need to be considered and modelled to perform VANETs-related simulations. These areas are described as follows.

- Communication Model
- Vehicular mobility model.
- Traffic Model

6.1.1 Communication Model

The communication model addresses the communication-related issues such as inter-vehicular communication. It defines the behaviour of the network protocols. There are several simulators such as NS-2 and OMNET++ to support a variety of networking protocols. Some of these simulators are briefly described below:

6.1.1.1 OMNet++

OMNet++ is a public-source, free for academic and non-profit use simulation software package that offers simulation of communication networks with sophisticated GUI support.

It offers simulation using Ethernet, IPV4, IPV6 and MPLS. OMNet++ has quite an open design to support other applications, as well. OMNet++ modules uses the network definition language NED for scenario definition while the behaviour and functionality of protocols is coded in C++ [130].

6.1.1.2 NS-2

Network simulator 2 (NS-2) is an open source, discrete event simulator frequently used by the computer network research community. NS-2 uses OTcl for the implementation of communication models. The functionality of protocols is usually coded in C++. The NS-2 library contains modules for the most commonly used network technologies and applications. The NS-2 is widely accepted in networking research community as it offers easy and fast network design specification and simulation[131].

6.1.1.3 QualNet

QualNet is a network simulator offering simulations for wireless network scenarios besides its support for wired networks. It is based on GloMoSim developed at the University of California, Los Angeles (UCLA). GloMoSim uses the Parallel Simulation Environment for Complex Systems (PARSEC) for basic operations. QualNet offers a GUI to create communication models. The QualNet GUI provides far easier way to specify small and medium scale networks as compared to specifying all network parameters in a model file manually. QualNet is a commercial simulator available for many platforms i.e. Linux as well as for Windows[132].

6.1.1.4 SimPy

SimPy is an extension of the Python language that is commonly used for scripting purposes, released under the GNU Library license. It offers discrete event simulation with the advantage of easy modifiability. However, it exhibits lower simulation performance[133].

6.1.1.5 Enterprise Dynamics

Enterprise Dynamics is another simulator that mainly targets industrial processes with a sophisticated GUI for developing the model and simulating it afterwards. Since its main area of specialization is not network simulation, it does not give optimized performance [134].

6.1.1.6 AnyLogic

AnyLogic is another commercial simulator that supports discrete, continuous and hybrid simulation methods. However, the simulator is only available for Windows[135].

6.1.1.7 NS-Miracle

Considering the cost, performance and acceptability to the research community, NS-2 can be a good choice. However, NS-2 does not offer use of multiple network modules in a single layer. NS-2 Miracle is an adapted form of NS-2 that offers use of multiple radio modules at same layer. Moreover, NS-Miracle supports back end functionality for cross layer communication. This research uses NS-Miracle with some amendments presented in chapter 5 to simulate several scenarios to evaluate the performance of LDCAMS migration using CACENSA.

6.1.2 **Vehicular Mobility Model**

Vehicular mobility related issues are addressed by a different set of tools that generates mobility patterns, also called mobility traces. Literature presenting the integration of vehicular mobility model and wireless communication models shows significant results. Although, in [136], the authors ensure the influence of one vehicle's mobility on a following vehicle; however, multi-lane assumption is not considered. Moreover, if the employed mobility model is not accurate, the results become unreliable. Hence, to achieve reliable simulation results, an accurate mobility model is required showing realistic vehicular mobility.[3, 26-28] Mobility models in MANETs in general are divided into two groups.

1. Stochastic Models
2. Random Mobility Models

Stochastic Mobility models constrain the random movement of vehicles and force them to move in pre-defined routes given on the graph. The graph represents road topologies over which vehicles move following a causal path taken by individual or group dynamics at randomly chosen speeds. Stochastic models are the simplest vehicular mobility models, as they do not consider many realistic mobility parameters like the effect of one car's mobility on another car's mobility and intersections are ignored. One exemplar mobility model that belongs to this category is the City Section Mobility Model[137]. The city section mobility model defines a grid with bi-directional edges and single-lane roads. Furthermore, this model is characterised by cars moving at constant speeds, nodes move on the defined topology in the form of a grid, random selection of intersections as destination of cars, no car-to-car interactions, and no pauses at intersections. All these characteristics are unrealistic to assume.

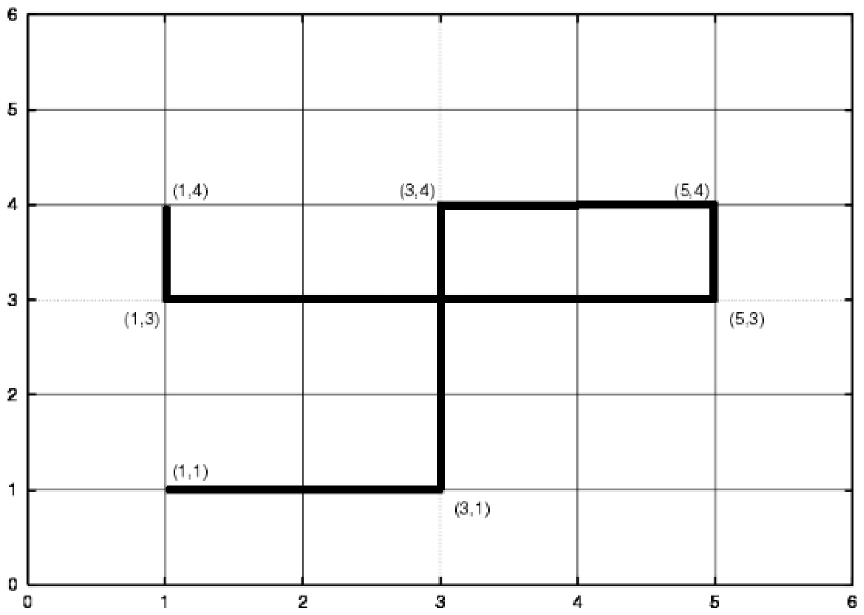

Figure 6-1 Mobility Model using Grid [137]

Random Mobility Models do not constraint the random movements of vehicles on the road, such as random walk and random way point mobility models[137]. In the next section of this chapter an overview of several VANET mobility models in context of performing simulations are presented along with their shortcomings.

6.1.2.1 Vehicular Mobility Models for VANET Simulations

Vehicular mobility has its own features that characterize it separate from other types of mobility. Vehicular mobility can further be classified as macro mobility and micro mobility.

6.1.2.1.1 Macro Mobility in VANET:

Macro mobility deals with macroscopic aspects of vehicular traffic, such as road topology, maximum and minimum speed limits assigned to the roads, number of road lanes, allowance of overtaking, and traffic signs and safety rules.

6.1.2.1.2 Micro Mobility in VANET:

Micro mobility refers to an individual vehicle's behaviour. It also includes driver's attitude and his/her interaction parameters such as travelling speed in different traffic conditions, average acceleration, deceleration and driver's attitude, generally related to sex, age and/or mood.

It is obviously desirable to consider maximum factors that are related to either macro mobility aspects or micro mobility aspects in modelling vehicular mobility for VANET simulations. The few well-known mobility related factors that can influence network performance are presented in the next section of this chapter.

6.1.2.2 VANET Mobility Factors

Several factors may be considered in vehicular mobility modelling. These factors are presented as follows:

- Road layouts: vehicular mobility is characterized by the fact that it is constrained by road layouts. Road layout significantly affects vehicular mobility patterns. For instance, the number of lanes in the road affects vehicular movements on the road, such as overtaking process.
- Average speed: average speed of a vehicle can directly affect vehicular network topology. Vehicle's speed determines how quickly the VANET topology is changing.
- Interdependent vehicular motion: vehicles on the road have to accommodate the other vehicles moving on the road. This research considers the vehicular traffic system as one of the best examples of cooperative and trust models. A vehicle's speed and location (like lane) may need to be changed while accommodating the motion of other vehicles on the road. The vehicular mobility models needs to reflect this effect of motion.
- Traffic control system: traffic signals influence vehicular mobility and needs to be considered as an important parameter of a vehicular mobility model [61].

6.1.2.3 Selection of Mobility Model

There are several mobility models to show node mobility in simulations. To make a choice for showing vehicular movements in unplanned areas, a brief overview is presented in this section.

6.1.2.3.1 Random Way Point model

The random waypoint model[138] shows random movements of nodes in the simulation area. This model is one of the most popular models to evaluate mobile networks with random movements because of its simplicity and wide availability; however, it does not incorporate node movement constrained by specific rectangular shapes such as roads for vehicular movements. Thus, the nodes in this model moves randomly and without any geographical restriction. This drawback makes this mobility model a poor choice for modelling vehicular mobility.

6.1.2.3.2 Free-way model

In the freeway mobility model, each node in the scenario follows a particular path in a certain direction. Maps are used in freeway modelling of node mobility. In the freeway model, the vehicles in the scenario are restricted to their own lanes on freeways so no random movement of the nodes (vehicles) is present, because the nodes follow a particular direction. Velocities of vehicles are dependent temporally on the previous velocities. There is a safety distance kept between two nodes, which must be maintained while propagating the same lanes and in that case, the velocity of the node behind cannot exceed the velocity of the node in front of it. The freeway mobility model has high spatial and temporal dependencies and applies strict geographic restrictions on nodes because the nodes are restricted to their lanes only.

6.1.2.3.3 Manhattan Mobility Model

This research employs the Manhattan mobility model for vehicular movements in unplanned areas. The Manhattan mobility model employs a probabilistic approach for a node’s movements.

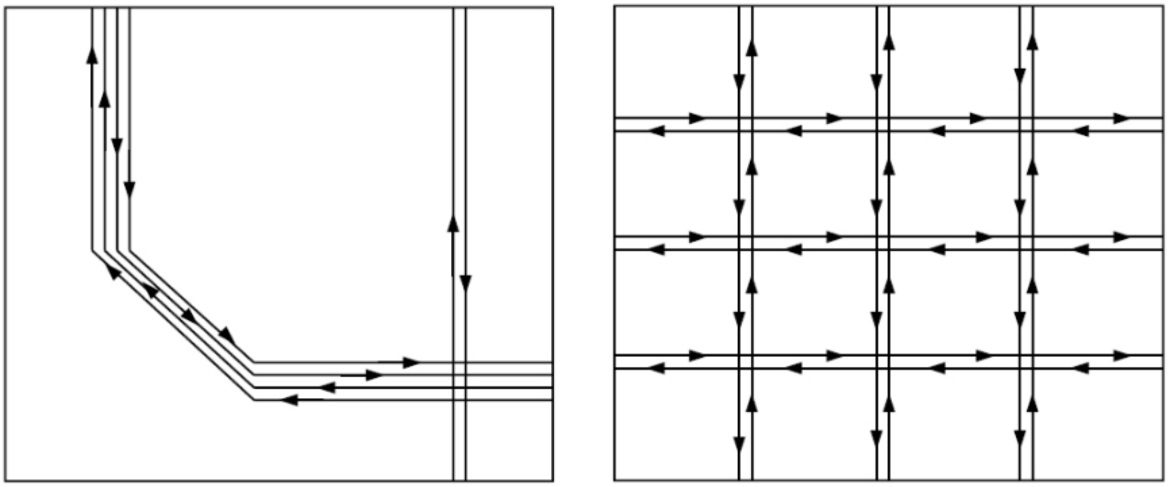

Figure 6-2 Mobility Models adapted from [137]

Like the freeway model, this is a generated-map-based model to simulate an urban environment. The simulation area is represented by a map (generated before the simulation start) containing vertical and horizontal roads made up of two lanes, allowing motion in both directions (north-south for the vertical roads and east-west for the horizontal ones). Before starting the simulation, vehicles are randomly placed in the simulation area i.e. roads and start moving continuously according to history-based. When reaching a crossroads, the vehicle randomly chooses a direction to follow that is continuing straightforward, turning left, or turning right according to a triplet of probabilities. This model provides flexibility for the vehicles so that they can change directions following geographical restrictions on node mobility.

The Manhattan mobility model has the following characteristics:

- Mobile node or vehicle is permitted to move horizontally or vertically in any direction on the map.
- At an intersection, the vehicle can movie left or right or straight with certain probabilities

There are several amendments made to the Manhattan mobility model while generating node mobility patterns to reflect unplanned areas. These amendments include dispersion of nodes on the map tobe extremely irregular and uneven. Another amendment is varying node velocity. In addition, quick road turns and roadside obstacles are also contributed for better reflection of unplanned geographical areas.

6.1.3 Traffic Model

Another requirement for selection of a simulator is the support for several types of network traffic. As there are diverse types of applications that run over VANETs, hence the support for the types of traffic generated by these applications is essential for successful VANETs deployment. In this research scenario, where the area under consideration is unplanned i.e. lacking roadside infrastructure and due to unplanned road topology, the amount of network traffic and the mobility patterns are unpredictable. Under such conditions, migration of LDCAMS is a challenge. To cope with these challenges, this research provides a cooperative & cost-effective integrated network selection algorithm to support LDCAMS migration and communication. Rather than migrating the actual LDCAM service in a real test bed, this research models the migration of LDCAMS as a specific amount of traffic introduced in the network as high priority data from a source node. It can be envisioned that there will be different sizes of applications, thus to accommodate this diversity of application sizes, several simulations have been performed by varying the size of data item from 10KB to 150MB.

6.1.4 Radio Wave Propagation Model:

It defines the estimated signal strength. An antenna can only receive a signal if the signal to noise ratio (SNR) is greater than a specific threshold called signal to noise ratio threshold (SNRT). The radio signal can be degraded by interference at receiving antennas caused by propagation over multiple paths with different delays, attenuation, and phase shift values. Several propagation models presented in literature and available in the NS-Miracle simulator are as follows.

- ***Free Space Model*** considers ideal conditions.
- ***Two Ray Ground Model gives*** better results than free space model. It considers direct line and ground reflection as two potentially interfering rays between the source and destination.
- ***Rayleigh Fading Model*** uses multiple indirect paths between source and destination.

- ***Ricean Fading Model*** makes use of direct line of sight
- ***Nakagami Fading Model*** *realizes* fast fading to characterise wireless channel. Research literature shows vehicular communication can take place using Nakagami fading model[128]. This research has used Nakagami fading model as propagation model.

6.1.5 Selection of Routing Protocol

The routing protocol used in this research is the Adhoc On demand Distance Vector routing protocol(AODV). The performance of routing protocol is out of the scope of this research; hence, AODV, a well-known and widely accepted routing protocol for MANETs is used for all the experiments in this research where it is required.

After having reviewed the experimental setup for system design, the next section of this research presents the results for validation of simulator.

6.2 Validation of Simulator

This section presents the results of two sets of simulations performed considering a simple vehicular communication scenario for the purpose of validation of the adapted version of simulator NS-Miracle-V that is used for further simulations in this thesis. The first set of simulations shows the results gained by using NS-Miracle-V are acceptably close to that produced using NS2, a widely used and accepted network simulator. The second set of simulations shows how many iterations for each simulation is required to obtain stable and acceptable results.

6.2.1 Validation of Simulator

In this section, a simple scenario of VANET communication is taken for validating the simulator. The scenario is presented as follows:

6.2.1.1 Scenario

This section considers the scenario of congestion detection in VANETs and presents the results of a set of simulations to validate the adapted version of NS-Miracle for vehicular environment, NS-Miracle-V.

Network congestion in Vehicular ad hoc Networks varies with the number of vehicles acting as data sources on the road and with the number of active nodes forwarding communication. Overall, in this research scenario, channel status is detected by using a simple approach of sending Request to Send (RTS) packets and Receiving Clear to Send (CTS) packets. The time between sending RTS and receiving CTS is calculated and an average of this time shows the status of the communication channel. It is a relatively simpler approach for congestion detection that is discussed in detail in the forthcoming sections of this chapter. In addition, the results obtained are compared against the same simulations performed in NS-2 to validate the results. For this set of simulations, three mobility scenarios based on speed of the vehicles are assumed. Based on speed of the vehicle these scenarios are classified as low mobility scenario, medium mobility scenario and high-speed mobility scenario. The other simulation parameters are shown in the table below:-

Low Mobility	Medium Mobility	High Mobility
Speed 5-10 km/h	Speed 40-60 km/h	Speed 90-120 km/h
Traffic Type : CBR		
Data rate: 2 Mbps		
Mobility Model: Manhattan Mobility Model		
Area: 1000x1000 m		
Routing Protocol: AODV		
Number of Nodes: Variable		

Table 6-1 Scenario Assumptions for Congestion Detection

6.2.1.2 Performance Metric

As the objectives of this set of simulations are limited to compare and validate the simulator so only two parameters i.e. 'average delay of RTS-CTS trip' and 'end to end delay' are taken as performance metric.

6.2.1.3 Results and Discussion

In low mobility scenario, the simulation results are shown in the graph as follows:

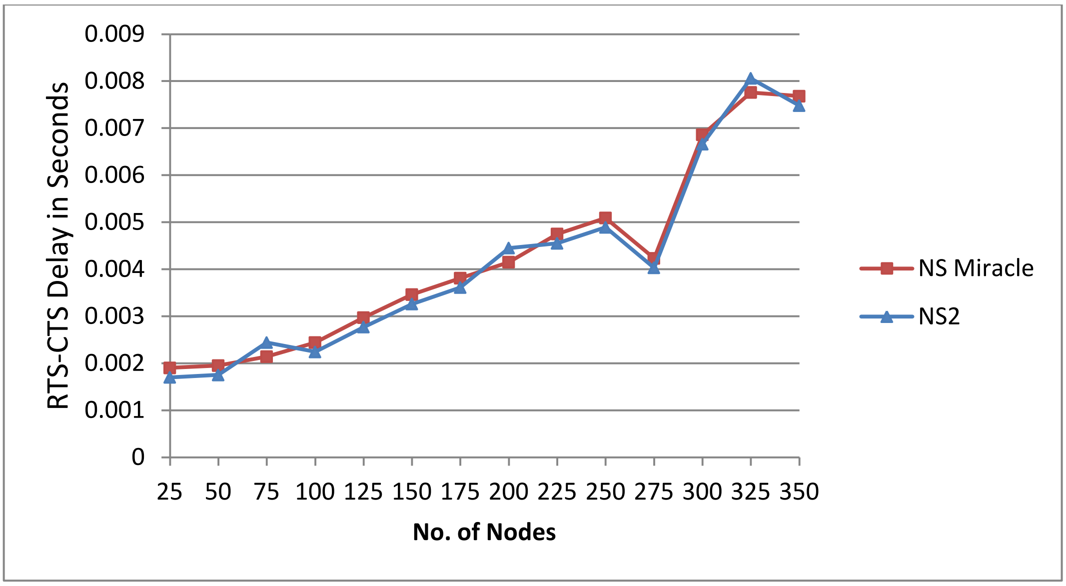

Figure 6-3 RTS-CTS Delay against Number of Nodes in Low Mobility Scenario

The results show quite similar results for RTS-CTS delay in a low mobility scenario that are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle has not affected the performance of already existing protocols in NS-Miracle. In the medium mobility scenario, the simulation results are shown in the graph that follows:

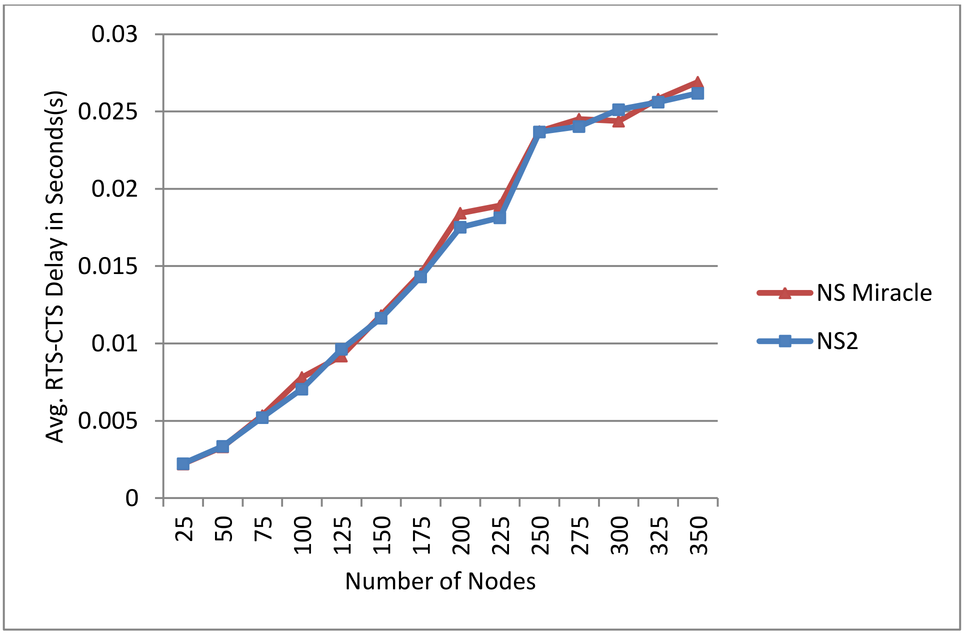

Figure 6-4 RTS-CTS Delay against Number of Nodes in Medium Mobility Scenario

The results show that quite similar results for RTS-CTS delay in the medium mobility scenario are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle-V has not affected the performance of already existing protocols in NS-Miracle. The simulation results for high mobility scenario are in figure: [6-5].

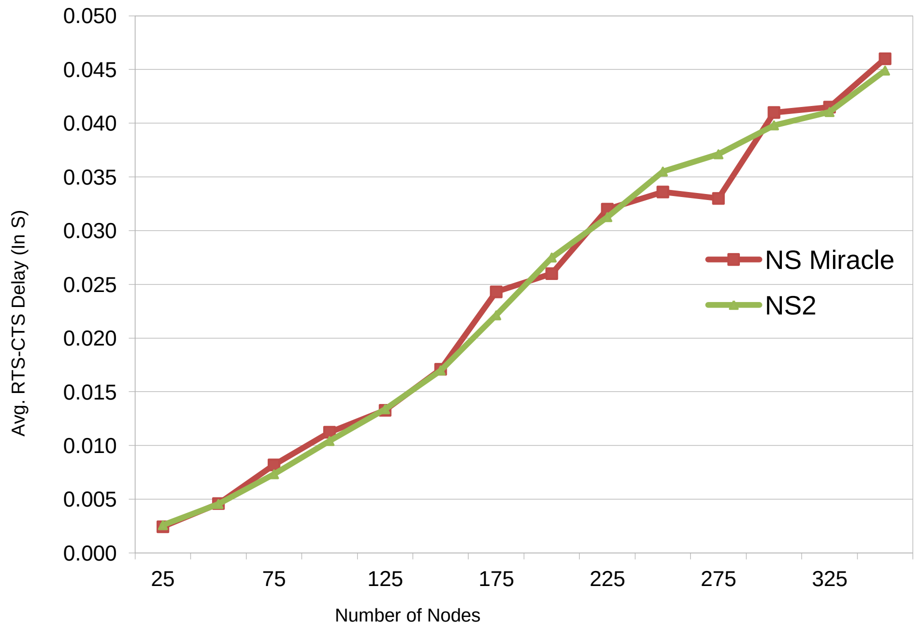

Figure 6-5 RTS-CTS Delay against Number of Nodes in High Mobility Scenario

The results show quite similar results for RTS-CTS delay in a high mobility scenario that are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle has not affected the performance of already existing protocols in NS-Miracle.

In the section below the results obtained for average End-to-End delay, using NS2 and Ns-Miracle-V are presented for all the three mobility scenarios. In a low mobility scenario, the simulation results are shown in the graph that follows.

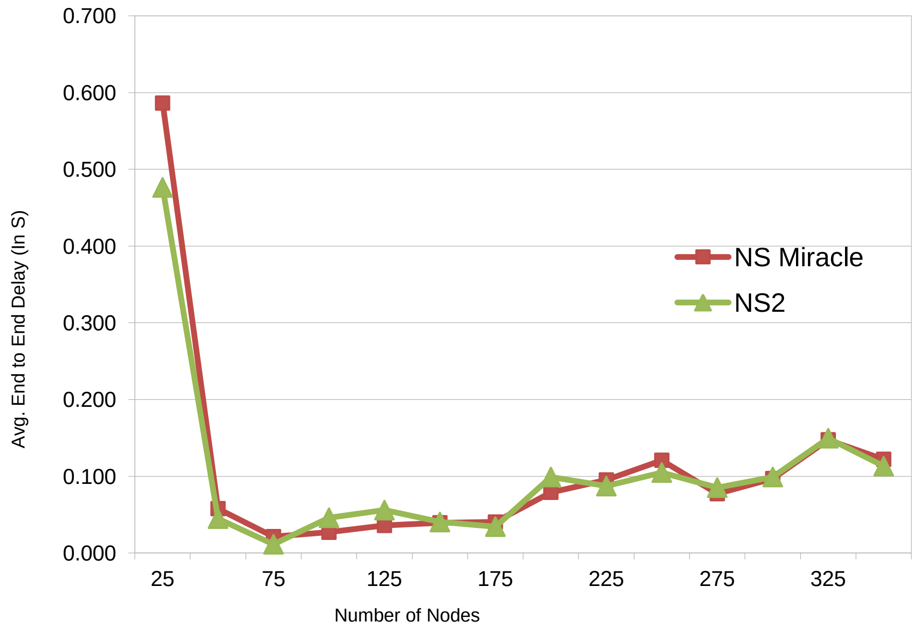

Figure 6-6 End to End Delay against Number of Nodes in Low Mobility Scenario

The results show similar results for average end to end delay in a low mobility scenario that are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle has not affected the performance of already existing protocols in NS-Miracle.

In the medium mobility scenario, the simulation results are shown in the graph that follows.

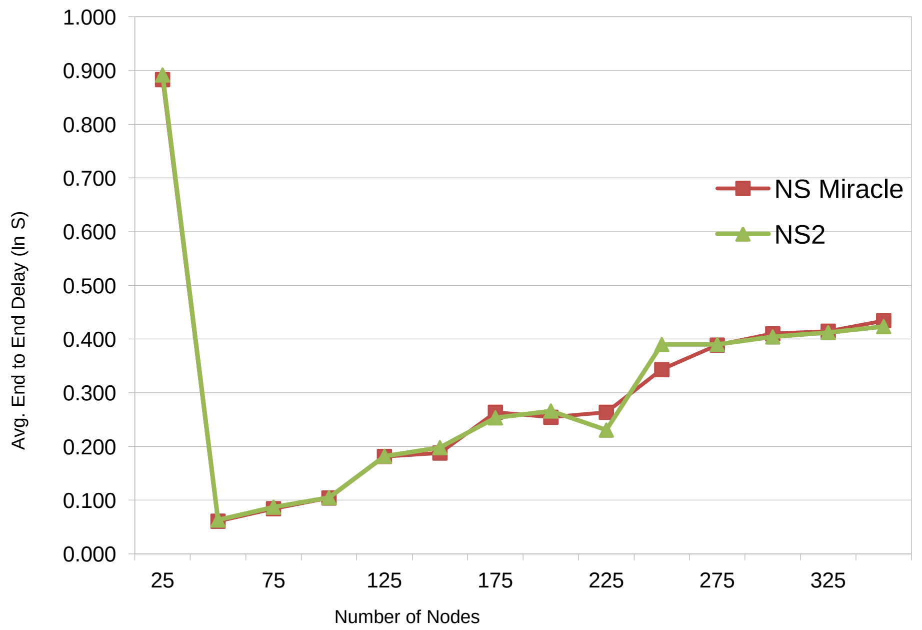

Figure 6-7 End to End Delay against Number of Nodes in Medium Mobility Scenario

The results show similar results for average end to end delay in the medium mobility scenario that are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle has not affected the performance of already existing protocols in NS-Miracle. In the high mobility scenario, the simulation results are shown in the graph that follows.

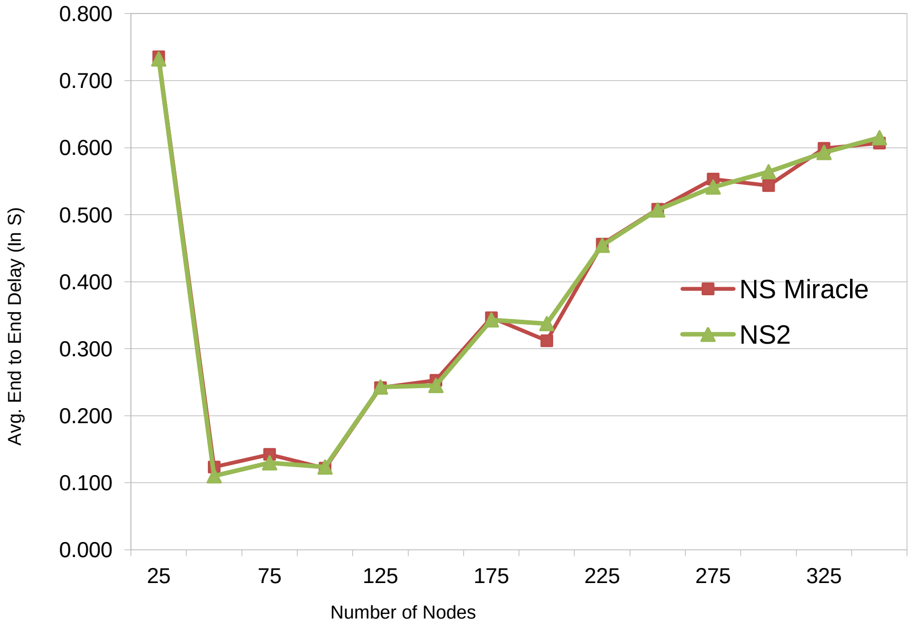

Figure 6-8 Average End to End Delay against Number of Nodes in High Mobility Scenario

The results show quite similar results for average end to end delay in the high mobility scenario that are obtained by using NS-2 and NS-Miracle-V. It shows that incorporating 802.11p in NS-Miracle has not affected the performance of already existing protocols in NS-Miracle-V.

6.2.1.4 Conclusion

For all the considered mobility scenarios, the results of simulations performed in NS-2 are closely similar to the results of simulations performed in NS-Miracle-V; hence, it is justified to perform the rest of simulations in this research using NS-Miracle-V.

6.2.2 Validation of Number of Simulation Runs

It is important to estimate the number of runs for each simulation to reach a required level of confidence in the quality of the simulation results. For this purpose, a set of simulations are performed. This section presents the results of the simulations that are performed to estimate required number of runs.

6.2.2.1 Scenario

A simple scenario of multihop communication is considered. In high-speed case, number of nodes is assumed 50. The other parameters defining the scenario are presented as follows:

High Mobility Scenario
Speed: 90-120 km/h
Traffic Type : CBR
Data rate: 2Mbps
Mobility Model: Manhattan Mobility Model
Area: 1000x1000 m
Routing Protocol: AODV
Number of Nodes: Variable

Table 6-2 Scenario Parameters to validate the correct number of runs of simulations

6.2.2.2 Performance Metric

Throughput, defined as number of packets per second, is taken as the performance metric. It is measured as number of packets per second received at the destination node.

6.2.2.3 Results & Discussion

The results of simulations performed under the above-mentioned scenario are presented as follows.

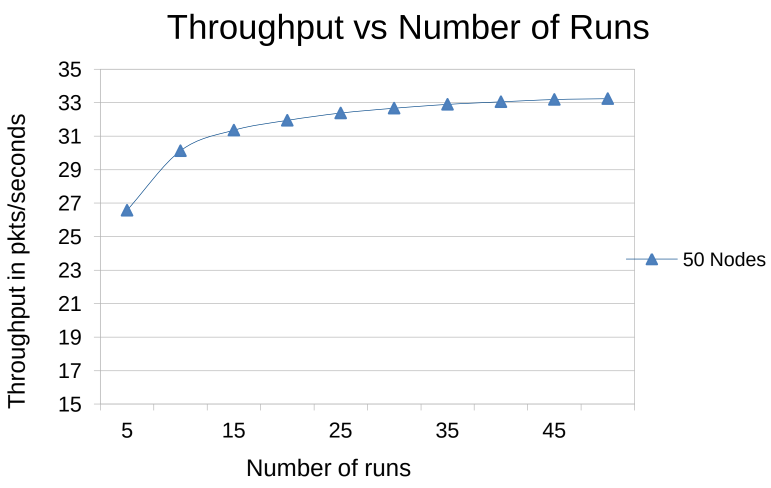

Figure 6-9 Average Throughput against Number of Runs

The graph clearly shows that if number of runs is less than 25, the value of the throughput is varying significantly; however, when the number of runs exceeds 25, the variation in the value of the average throughput becomes acceptably negligible.

6.2.2.4 Conclusion

Based on these simulations, the number of runs for all the remaining scenarios is taken as 25. Which means each simulation is performed 25 times in NS-Miracle-V, and the average value for each measurement is calculated and presented in this research.

6.3 Network Traffic Modelling

LDCAMS successful deployment on VANETs using the presented system design depends upon two factors:

1. LDCAMS communication
2. LDCAMS migration

However, as this research is focussed to present the LDCAMS migration using the cooperative & cost-effective network selection algorithm, LDCAMS communication is not considered further. To present and prove the efficacy of the algorithm presented in this research, this research models the migration of LDCAMS as a specific amount of traffic introduced into the network as high priority data from the source node. It is envisioned that there will be different sizes of applications, thus to accommodate this diversity of application sizes, several simulations has been performed by varying the size of data item from 10KB to 150MB.

The different sizes of data units used for simulations are shown in the following table:-

10KB	50KB	250KB	1250KB	6250KB	31250KB	156250KB

Table 6-3 Size of Files

To achieve the objectives of this research, a number of simulations have been performed with assumptions defined in the forthcoming section. Following are the scenarios simulated to achieve the research goals.

6.3.1 System's Context Monitoring Traffic

For the deployment of location based context aware migratory services, it is important for a node hosting the service to decide the next host of LDCAMS. As has already been discussed in chapter 5, several factors influence this decision. Such as:

- Vehicle Location: every vehicle needs to know its current location. In this research, it is assumed that every vehicle has a GPS module through which every vehicle knows its current location. The candidate vehicles who can host LDCAMS share their locations by broadcasting, so the host node can use this information as a parameter contributing to the decision making process for next host selection.
- Vehicle's communication resources: includes communication capabilities, like WAVE, UMTS etc
- Vehicle's speed: every vehicle has the knowledge of its average speed and it shares this information with its neighbours.
- Vehicle's direction: every vehicle knows its direction of motion. This research has considered single direction of motion on a road.
- Vehicle's destination: vehicle may share its destination
- Vehicle's route to destination every vehicle may decide the route to its destination before the start of its journey. It is also important information that may be shared with neighbours, if required; however, privacy limitations may restrict the sharing of this information.

- Vehicle's network status: in unplanned areas, network traffic may vary significantly in very short amounts of time; moreover, due to high-speed mobility in VANETs, the number of disconnections is higher than for infrastructure networks. So periodic monitoring of network traffic is important. To check the network channel status for congestion or performance, a simpler approach in this research has been proposed. The effectiveness of this approach compared to existing approaches is proved through simulations performed. The results of these simulations are presented in the next section.

6.3.1.1 Network Congestion Detection

Congestion detection can be achieved by measuring utilization level with in node (like queue over flow or average packet wait time in queue) or by measuring channel characteristics like end to end delay or packet arrival patterns. This dissertation uses the second approach, in which the average time between sending RTS and receiving CTS is measured. For Unicast applications, it is a much simpler way to measure channel congestion. Moreover, our results show that it is more robust and reliable for congestion measurements. This research defines congestion threshold as the maximum value of average time delay between sending RTS and receiving CTS acceptable to an application.

There are two categories of factors affecting channel congestion. They are Network or System based attributes and Application based attributes. Network or System based attributes include participating number of nodes, transmission power, queue size, efficiency of broadcasting algorithms in terms of number of transmission and retransmissions, efficiency of routing protocol and types of applications & services in operation concurrently. The application based attributes include message size, message generation rate, proximity validity of message and message age. Following is description of some these attributes:

Participating Number of Nodes

A larger number of participating nodes in a communication network generates more traffic on the channel. This participation could be in the form of a message (Traffic) generator i.e. (Data source or producer) as well as a forwarder i.e. sink or consumer as in case of multihop communication.

Message Size

A larger message size needs more time for transmission, so in a contention-based channel it leads to less transmission time for traffic generated by other applications.

Message Generation Rate

It may be represented as number of messages generated by the application for transmission per unit time. This parameter actually depends upon the type of application. Usually these applications generate messages periodically.

Proximity validity of Message

Proximity of message shows the same relationship i.e. it is directly proportional to the channel congestion as the above mentioned parameters. I.e. greater is the area a message needs to be flooded or transmitted, the more it contributes to congestion.

Message Age

Time during which a message remains valid and usable is another factor that affects congestion in a directly proportional way.

Transmission Power

Transmission power is also an important factor that has direct impact on channel congestion.

Congestion detection in vehicular ad-hoc network scenarios can improve control over channel congestion through initiating adaptations, either following strict layered structure or cross layer adaptations. Different congestion detection methods are presented below:

On Demand Congestion Detection

Congestion detection is initiated on demand by application and services. An example of use of this detection method is a service, in order to achieve its QoS, may initiate the process so that it may adapt its components to act accordingly. Several adaptations on different parameters like transmission power, message generation rate, and proximity are possible.

Periodic Congestion Detection

This congestion detection category includes congestion detection method, which detects channel congestion at regular intervals of time and manages channel information. These methods are usually defined in management services. The information collected through these methods related to channel status is persistent and may be used for different active applications.

Event Oriented Congestion Detection

Occurrence of an event (like accident, fire or other emergency) may also cause detection of congestion to support relevant applications to perform efficiently and achieve acceptable results.

A channel congestion detector and manager is responsible to initiate adaptations for congestion control at application, network, or MAC level. In order to perform these adaptations, the actual problem is to decide the metric that this detector will use.

There are two different approaches to detect or assess congestion. One is at System level, measuring buffer occupancy, average packet wait time, and packet drop at queue due to over flow. The other approach takes a closer look into the channel by measuring end-to-end delay, measuring MAC retries and Packet arrival patterns. Yunpeng Zang et al in [139] calculated channel usage by approximating channel busy time. This approach measures the time a channel remains busy or idle. This approach is quite complex and difficult to implement in real network scenarios with multiple traffic flows, services concurrently running and asking for different QoS requirements. Moreover, real scenarios are more complex with various kinds of traffic flows having different priorities. Yoshihisa Kondo et al. in [140] exploited measurement of fluctuations in packet arrival intervals, with the jitter of this distribution as a channel congestion parameter. Yoshihisa Kondo et al used Hello packets for congestion detection in 802.11 wireless networks. Some of the routing protocols sometimes do not use Hello packets. Moreover, in high-speed networks, it needs to be explored. Changhee Joo et al in [141]used ECN with time of packet staying in MAC waiting for transmission. This approach does not gives actual channel congestion status as packet could also stay in MAC due to presence of high priority traffic in other queues. Z. Fu et al[142] detects congestion using the number of MAC retries. Lars Wischhof et al[143] monitored channel busy time considering the time during which the MAC was transmitting, receiving or sensing a busy medium.

Chieh-Yih Wan etc in [144] presented a way to detect congestion at the receiver side using channel loading condition, buffer occupancy and report rate/fidelity measurements. Buffer occupancy does not provide an accurate indication of congestion except in extreme cases, when the queue is empty or about to overflow. In other words, it is hard to quantify congestion level using buffer occupancy as an indicator. Moreover, in the case of multiple priority traffic flows, it would be an insufficient indicator. One method is that a sensor listens to the channel, trace busy time, and calculates local channel loading conditions. Usually this technique gives accurate information about how busy the communication medium is. However, due to the complexity of this process, it is not considered.

6.3.1.2 Congestion Detection Simulations

6.3.1.2.1 Scenario

To prove the effectiveness of channel congestion detection approach presented in this research, several simulations have been performed. The parameters defining the three scenarios are given in table [6-4]

Low Mobility	**Medium Mobility**	**High Mobility**
Speed 5-10 km/h	Speed 40-60 km/h	Speed 90-120 km/h
Traffic : CBR		
Data rate: 2 Mbps		
Mobility Model: Manhattan Mobility Model		
Area: 1000x1000 m		
Routing Protocol: AODV		
Nodes and Data Sources: Variable		

Table 6-4 Scenario Parameters for Congestion Detection in NS-Miracle

6.3.1.2.2 Performance Metric for Congestion Detection

In these simulations following are some of the parameters that are compared for their use as congestion indicators.

- Packet /drops due to Queue Overflow
- End to End Delay
- Average Number of Tries / Retries.
- Round Trip Time using RTS/CTS

6.3.1.2.3 Results & Discussion

a. Low Mobility Scenario

In the low mobility scenario, it is evident that with an increasing number of nodes, the average time delay between RTS and CTS increases. A similar pattern is shown by the average number of tries to send a packet. However, end to end delay shows a sharp drop with is fewer nodes, which this research believes is due to scarceness of connectivity among fewer nodes in the network.

Figure [6-10] shows the average RTS-CTS delay increasing with an increase in the number of nodes participating in the communication. The number of nodes is increased from 25 nodes to 325 nodes. The average time delay between RTS and receiving CTS shows a continuous increase in the line of graph. This means it is a reliable parameter to measure busyness of the communication channel.

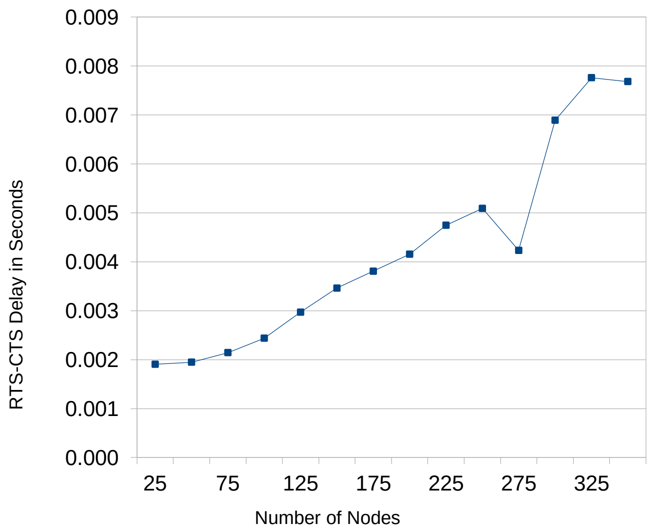

Figure 6-10: RTS-CTS Delay Vs Number of Nodes

The graph in figure [6-11] shows end-to-end delay against increasing number of nodes in the communication. The graph shows a sharp drop if the number of nodes participating in communication is low. It is because number of nodes is low so there are more chances of distant placement of these nodes. Due to this distant placement the end-to-end delay is higher. Initially the end-to-end delay decreases as the number of nodes increases due to the improved connectivity. However, it starts increasing again as the number of communicating nodes are increased. It is evident that although end-to-end delay is a good parameter to show end-to-end communication success, it does not show if the channel is actually congested.

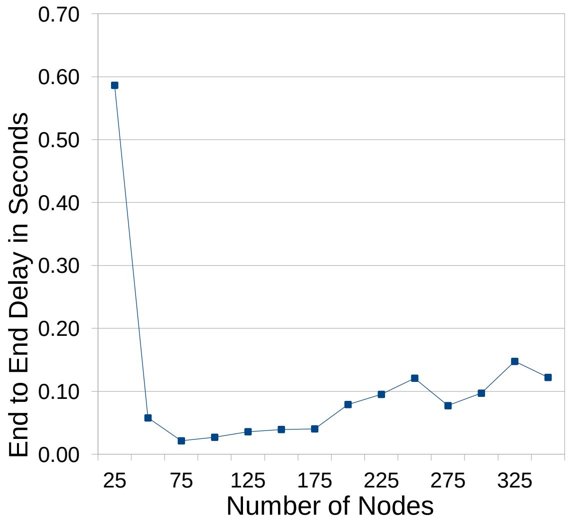

Figure 6-11: End to End, Delay Vs Number of Nodes

The graph shown in figure [6-12] presents the average number of tries to deliver a packet against increasing number of nodes participating in the communication. The graph line indicates an increase in average number of tries to deliver a packet as the number of communicating nodes increases. It shows that average number of tries is also a reliable method that can be considered as an alternate approach to check the status of communication channel.

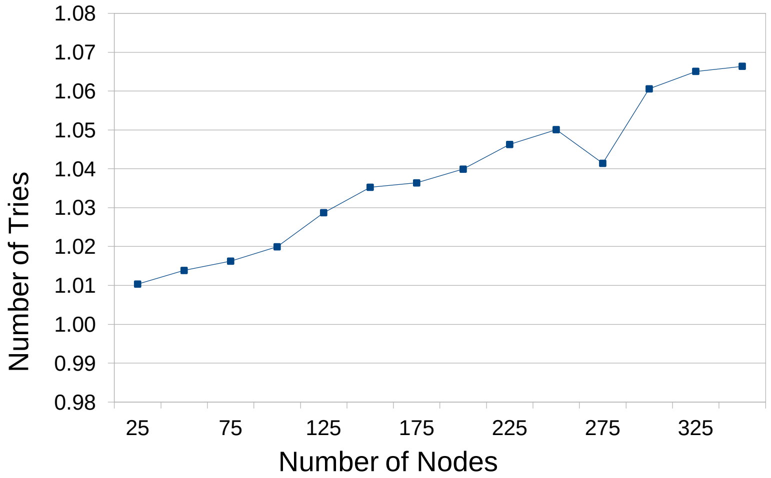

Figure 6-12: Avg. No. of Tries Vs Number of Nodes

In figure [6-13], the average RTS-CTS delay is shown against increasing number of data sources. It can be seen that that with an increase in the number of data sources, the average delay also increases. The increase in the average RTS-CTS is not very sharp when the number of data sources is low. However, when the number of data sources increases over 20, the increase in delay is relatively sharper.

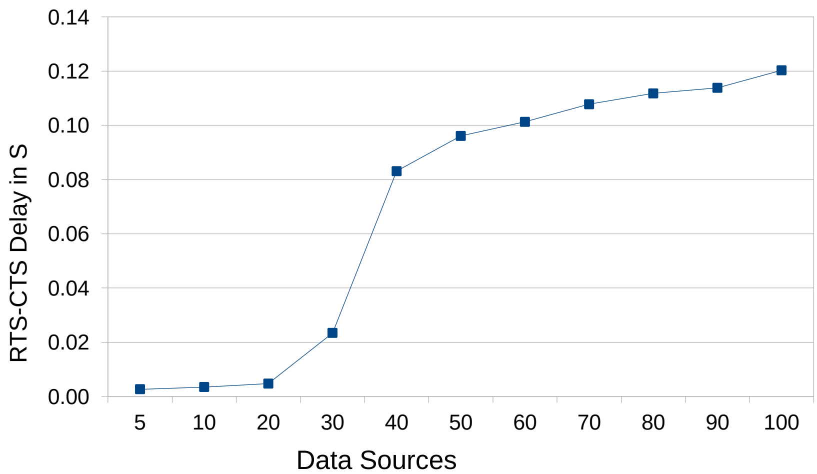

Figure 6-13: RTS-CTS Delay Vs Data Sources

In figure [6-14], the average end to end delay is shown against increasing number of data sources. It can be seen that with increase in number of data sources the average end-to-end delay increases. It can be observed that similar to the RTS-CTS pattern shown in figure [6-13] the increase in the average End-to-End delay is also not very sharp when the number of data sources is low. However, when the data sources increase over 20, relatively sharper increases in end-to-end delay can be seen.

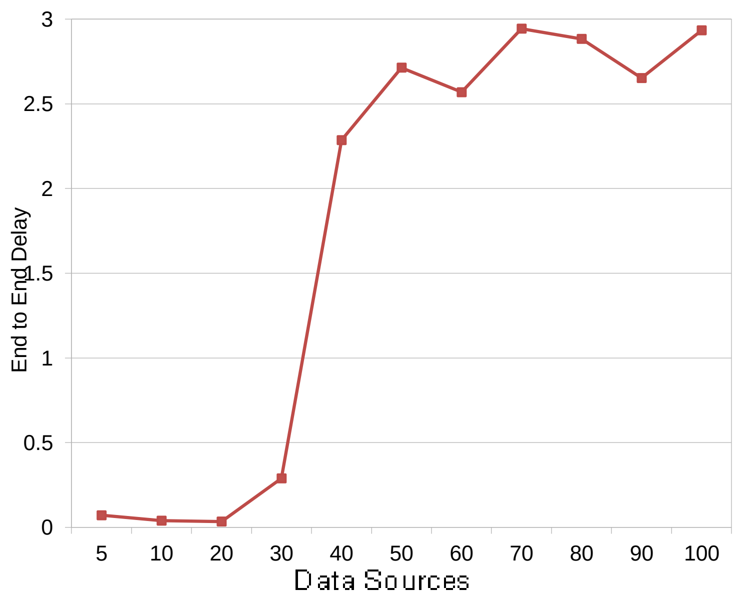

Figure 6-14: End to End Delay Vs Data Sources

Figure [6-15] presents the average number of tries against increasing number of data sources. It can be seen that that with an increase in the number of data sources, the average number of tries increases. Similar to the RTS-CTS delay pattern shown in figure[6-13], the increase in the number of tries with increasing number of data sources is also not very sharp, particularly when the number of data sources are low. However, as the data sources increase over 20, a relatively sharper increase in average number of tries can be seen.

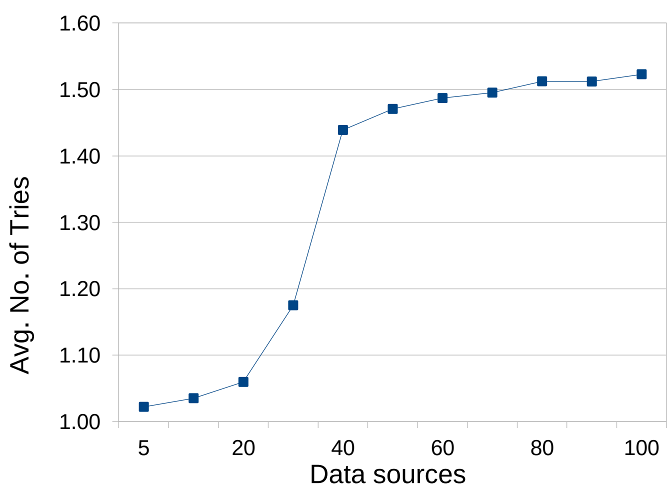

Figure 6-15: Avg. No. of Tries Vs Number of Data Sources

b. Medium Mobility Scenario

In the medium mobility scenario, relatively sharper increase in RTS-CTS delay and average number of retries is observed as compared to the low mobility scenario. End-to-end delay shows similar behaviour i.e. if the number of nodes is low it shows greater delay due to inconsistent connectivity. However, in case of fixed number of nodes with increasing number of data sources it shows a remarkably rapid increase. The results for medium mobility are presented and discussed below-

In the graph shown in figure [6-16] average RTS-CTS delay is measured and shown as increasing with an increase in the number of nodes participating in the communication. The number of nodes is increased from 25 nodes to 275 nodes. The average time delay between RTS and receiving CTS shows a continuous increase in the line of graph. It evident that average RTS-CTS delays is an effective parameter to measure busyness of communication channels. The graph also shows the average RTS-CTS delay in the medium mobility scenario is higher than that of the low mobility scenario.

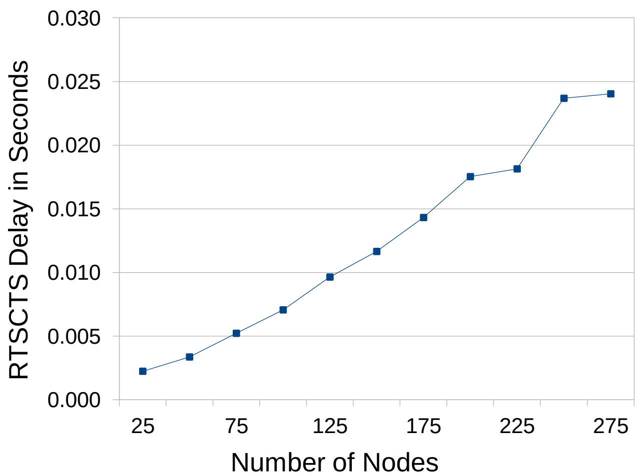

Figure 6-16: RTS-CTS Delay Vs No. of Nodes

In the graph shown in figure [6-17], average end to end delay is measured and presented. The number of nodes is increased from 25 nodes to 275 nodes. The graph shows high values of delay fewer nodes participating in the communication. It is believed that these higher values of end-to-end delay are due to inconsistent connectivity with fewer nodes on the road. When the number of nodes increases, connectivity becomes better and average end-to-end delay decreases. When the number of nodes increases beyond a certain value, the average end-to-end delay starts increasing again. This increase is due to busyness of communication channel. It is also observed in this graph that the average end-to-end delay in the medium mobility scenarios is higher than that of the low mobility scenario.

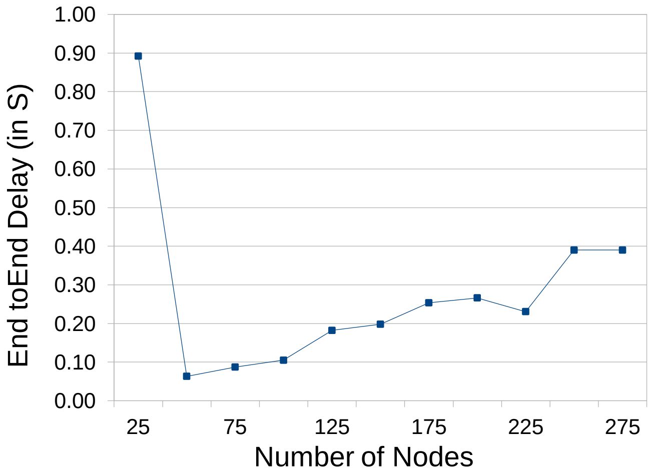

Figure 6-17: End to End, Delay Vs Number of Nodes

In the graph shown in figure [6-18], average number of retries is measured and presented. The number of nodes is increased from 25 nodes to 275 nodes. The number of retries plotted in the graph shows a continuous increase. It is evident that the average number retries is an alternate to average RTS-CTS delay as a parameter to measure busyness of the communication channel. The graph also shows the average number retries in the medium mobility scenarios is higher than that of the low mobility scenario.

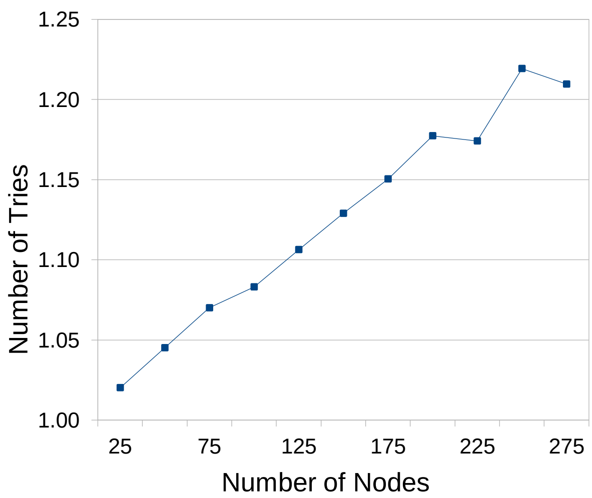

Figure 6-18: Avg. No. of Tries Vs Number of Nodes

In the figure [6-19], average RTS-CTS delay is shown against increasing number of data sources. It can be seen that in the medium mobility scenario, with an increase in number of data sources the average delay also increases. The increase in the average RTS-CTS is not very sharp when the number of data sources is low. However, when the number of data sources increase over 20, the increase in delay is relatively sharper. The results observed in this graph provide evidence of the reliability of average RTS-CTS delay as a parameter to measure network congestion in medium mobility scenarios.

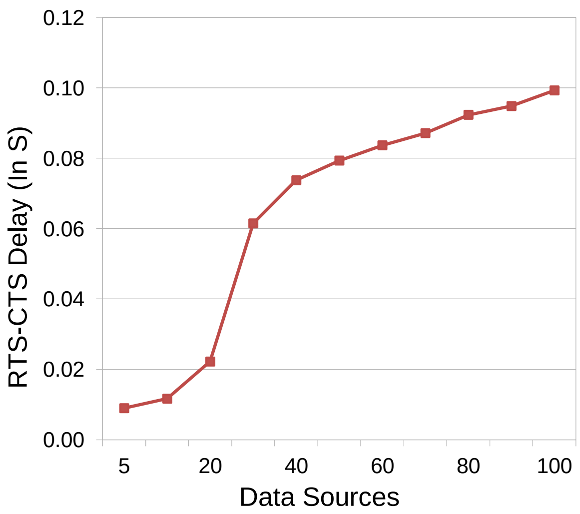

Figure 6-19: RTS-CTS Delay Vs Data Sources

In figure [6-20], average end to end delay is shown against increasing number of data sources. It can be seen that in the medium mobility scenario with an increase in the number of data sources, the average end-to-end delay also increases. It may be seen that with fewer data sources the increase in the average end to end delay is not very sharp. However, when the number of data sources increases over 20, the end to end delay increases relatively sharply.

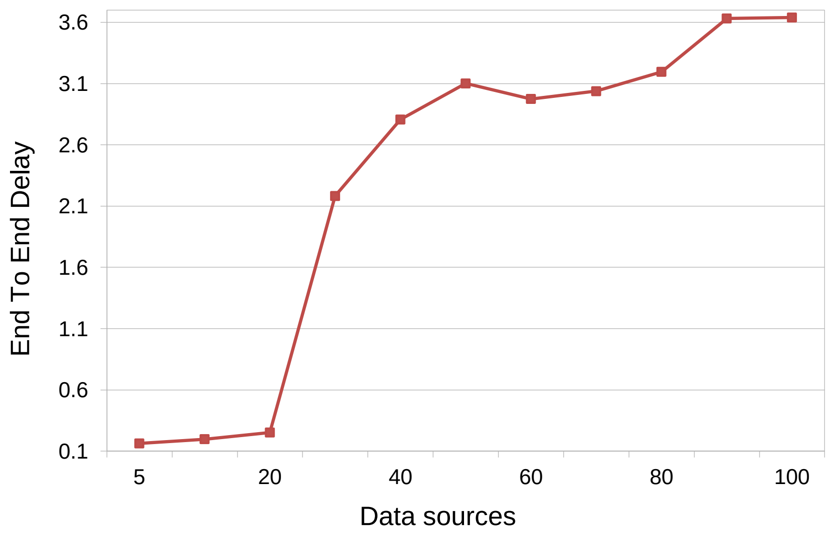

Figure 6-20: End to End Delay Vs Data Sources

In figure [6-21], average number of tries is shown against increasing number of data sources. It can be seen that in the medium mobility scenario, with an increase in the number of data sources, the average number of tries also increases. The results show the efficacy in terms of reliability of average number of tries to deliver a packet as an alternative parameter to measure network channel congestion.

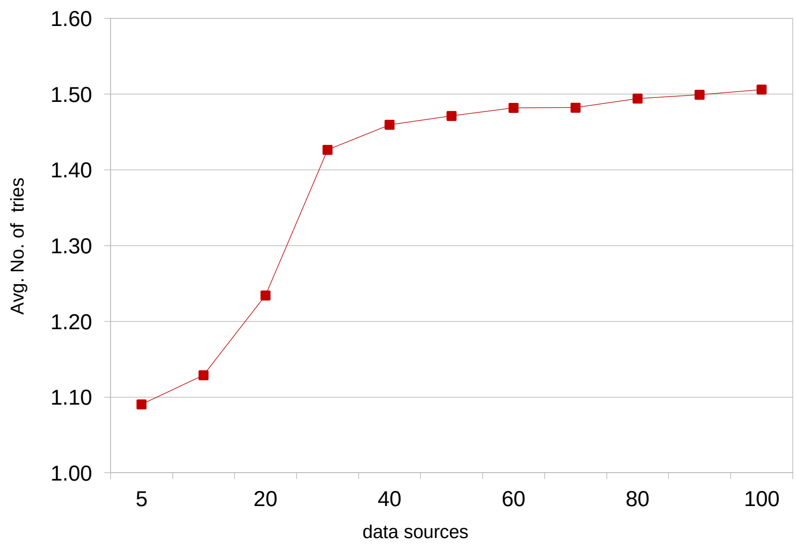

Figure 6-21: Avg. No. of Tries Vs Data Sources

c. High Mobility Scenario

In the high mobility scenario, a relatively sharper increase in RTS-CTS delay and average number of tries is observed as compared to low and medium mobility scenarios. Average end-to-end delay shows similar behaviour i.e. if the number of nodes is low, it shows greater delay due to inconsistent connectivity. However, in case of fixed number of nodes i.e. 150 with increasing number of data sources, it shows remarkably quick increase. The results for the high mobility scenario are presented and discussed below.

In the figure [6-22] average RTS-CTS delay is measured and shown as increasing with an increase in the number of nodes participating in the communication. The number of nodes is increased from 25 nodes to 250 nodes. The average time delay between RTS and receiving CTS shows a continuous increase in the line of graph. It shows evidence of the reliability of average RTS-CTS delays as a parameter to measure busyness of communication channels. The graph also shows the average RTS-CTS delay in the high mobility scenarios is higher than that of the low and medium mobility scenarios.

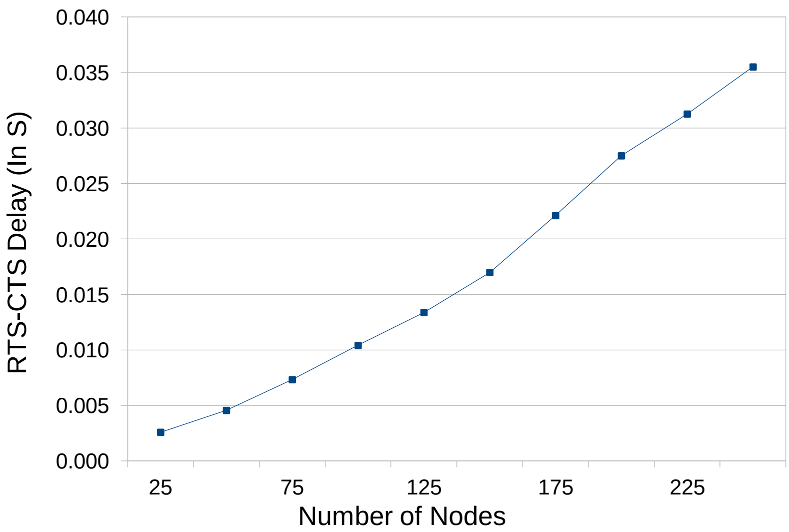

Figure 6-22: RTS-CTS Delay Vs Number of Nodes

In figure [6-23], average end to end delay is measured and presented. The number of nodes is increased from 25 nodes to 250 nodes. The graph shows high values of delay with a small number of nodes participating in the communication. It is believed that these higher values of end-to-end delays are due to inconsistent connectivity with fewer nodes on the road. When the number of nodes increases, connectivity becomes better and average end-to-end delay decreases. When the number of nodes increases from a certain value x e.g. (x=50), the average end-to-end delay starts increasing again. It is believed that the increase in average end-to-end delay is due to busyness of communication channel. It is also observed in this graph that the average end-to-end delay in high mobility scenario is the higher than that of low and medium mobility scenarios.

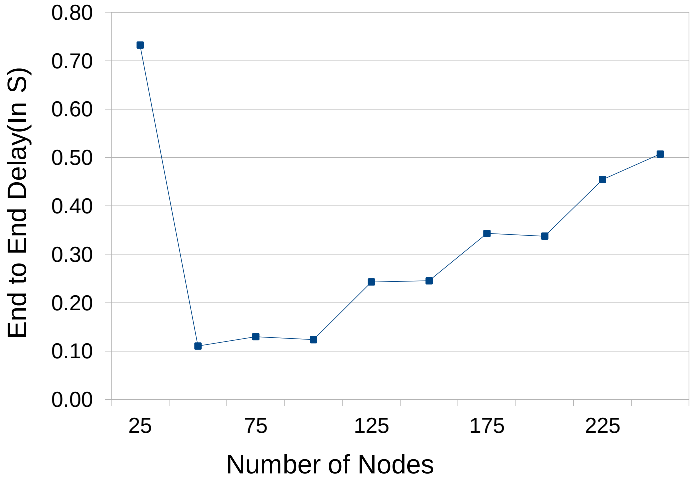

Figure 6-23: End to End, Delay Vs Number of Nodes

In figure [6-24], average number of tries is measured and presented. The number of nodes is increased from 25 nodes to 250 nodes. The average number of tries plotted in graph shows a continuous increase. It provides evidence that the reliability of the average number tries as an alternate to the average RTS-CTS delay as a parameter to measure busyness of the communication channel. The graph also shows the average number of tries in the high mobility scenarios is higher than that of the low and medium mobility scenarios.

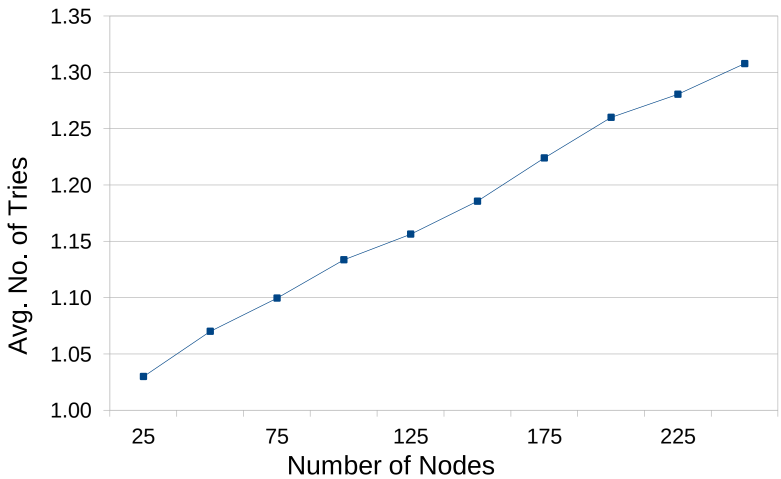

Figure 6-24:Avg. No. of Tries Vs Number of Nodes

In figure [6-25], average RTS-CTS delay is shown against increasing number of data sources. It can be seen that in the high mobility scenario, with an increase in the number of data sources, the average RTS-CTS delay also increases. The results observed in this graph provide evidence of the reliability of average RTS-CTS delay as a parameter to measure the network congestion in the high mobility scenarios.

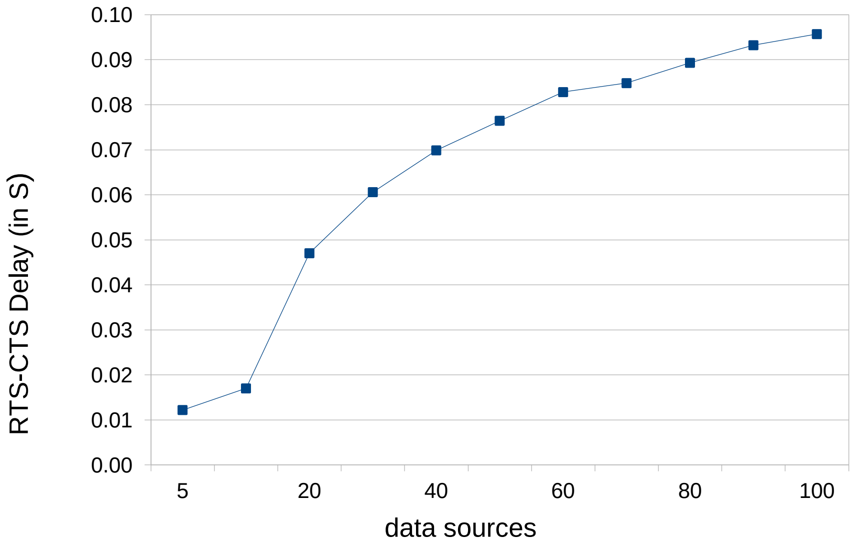

Figure 6-25: RTS-CTS Delay Vs Data Sources

In figure [6-26], average end to end delay is plotted against increasing number of data sources. It is observed that in the high mobility scenario, with an increase in the number of data sources, the average end to end delay also increases. It is also observed that average end-to-end delay in the high mobility scenario is greater than that of the low and medium mobility scenarios.

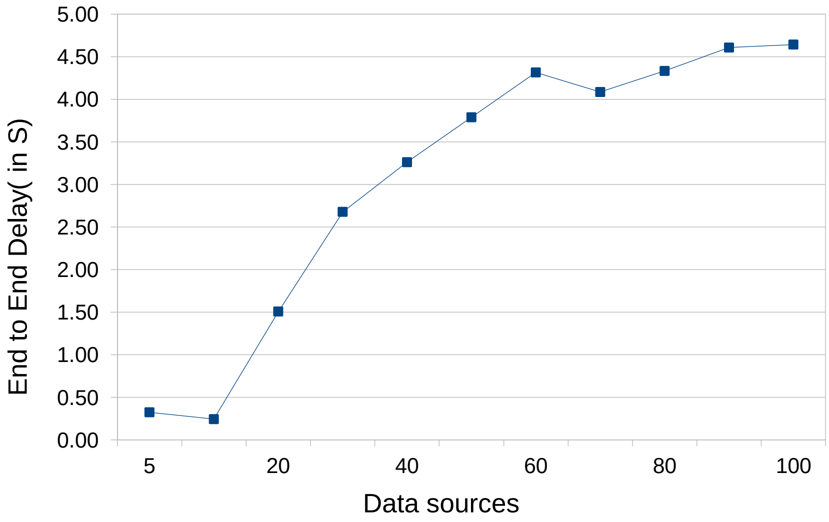

Figure 6-26: End to End Delay Vs Data Sources

In figure [6-27], the average number of tries is plotted against increasing number of data sources. It can be seen that in the high mobility scenario, with an increase in the number of data sources, the average number of tries increases. The results show the efficacy in terms of reliability of average number of tries to deliver a packet as an alternative parameter to measure the network channel congestion in the high mobility scenarios.

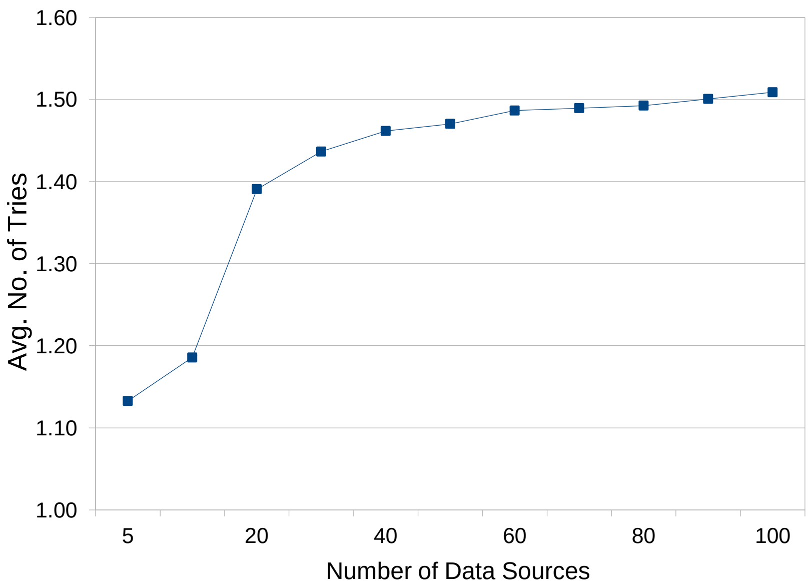

Figure 6-27: Avg No. of Tries Vs Data Sources

6.3.1.2.4 Conclusion:

The results presented in section 6.3.1.2 shows the efficacy (in terms of reliability) of average RTS-CTS delay as a parameter to measure network congestion. Hence, average RTS-CTS delay is considered as a contributing parameter to the decision-making process for LDCAMS migration and network handoff.

This research provides a cost-effective, cooperative, algorithm for network selection to achieve service migration from one vehicle to another in an unplanned area. The next section of this dissertation presents the experimental results and relevant discussion to support evidence that a cooperative & cost-effective network selection algorithm for LDCAMS migration and communication provides better performance in terms of network availability.

6.3.2 Cooperative & Cost-effective Network Selection Algorithm

The algorithm shown in figure [5-3] shows an integrated approach to the solution for LDCAMS migration and selection of network for LDCAMS migration. For the migration of LDCAMS, it is an important issue to select the next host. Several approaches may be considered for the selection of the next host, if LDCAMS needs to be migrated. Considering the selection algorithm of next host as out of scope for this research, this research focuses on several parameters that may contribute to the decision-making process for network selection for the migration of LDCAMS.

This research assumes the information collected as average RTS-CTS delay is forwarded to the communication manager. The algorithm running in communication manager based on this information finds if there is a need to perform network switching. The rest of the parameters are discussed as below:

- Cooperation level: this is an important parameter to contribute to next host selection as well as the network switching algorithm. It is assumed that all the nodes agree and cooperate in communication.
- Cost: it presents the cost associated with network usage. WAVE is set free to use whereas, UMTS has its cost model for usage. This research assumes cost of UMTS as x such that $x>0$.

6.3.3 LDCAMS Migration Traffic

To prove the improvements of LDCAMS migration as claimed in this research, the LDCAMS migration is modelled as the amount of network traffic that is going to be delivered from source to destination. This network traffic can be transferred from source to destination using either WAVE or UMTS. However, selection of network is done through the algorithm that has already been discussed in chapter 5. There are two set of simulations performed for showing the results of cooperative and cost-effective network selection. The first section presents the migration of LDCAMS using WAVE. It is assumed that WAVE, as a single network, does not provide an effective way for LDCAMS migration. This assumption is supported by the simulations results shown in the next section. The same amount of traffic is presented communicated using CACENSA. The simulation results show the reliability of the CACENSA algorithm in supporting LDCAMS communication and migration. The network traffic introduced by LDCAMS to the networks is presented as different file sizes. Table [6-3] shows the traffic assumptions in the form of file sizes.

6.3.3.1 LDCAMS Communication & Migration Simulations

6.3.3.1.1 Simulations Set 1

6.3.3.1.1.1 Scenario

The purpose of this scenario is to simulate and discuss the migration of LDCAMS using WAVE. The assumptions for this scenario are presented in the table [6-5] as below:-

Parameters	IEEE 802.11p	Notations
Tslot	13μs	A slot time
τ	2μs	Propagation delay
TP	32μs	Transmission time of the physical preamble
TDIFS	58μs	DIFS time
TSIFS	32μs	SIFS time
CWmin	15	Minimum backoff window size
TPHY	64μs	Transmission time of the PHY header
TSYM	8μs	Transmission time for a symbol
LH_DATA	28bytes	MAC overhead in bytes
LACK	14bytes	ACK size in bytes

Table 6-5 Scenario Parameters for IEEE802.11P

These simulations are performed considering two types of road traffic distribution situations.

1. Sparse Scenarios
2. Dense Scenarios

Separate simulations are performed for both scenarios; moreover, the rest of the parameters taken are presented as follows in table [6-6].

Low Mobility	***Medium Mobility***
Speed 5-10 km/h	Speed 40-60 km/h
Traffic : CBR	
Data rate: 2Mbps	
Mobility Model: Manhattan Mobility Model	
Area: 1000x1000 m	
Routing Protocol: AODV	
Nodes and Data Sources: Variable	

Table 6-6 Scenario Parameters for measuring Packet Loss in communication using IEEE802.11P

6.3.3.1.1.2 Objective

The objective of these simulations is to see what happens to the network in unplanned areas when the number of vehicles increases quickly.

6.3.3.1.1.3 Performance Metric

- Packet Loss: It is measured as percentage of lost packets against the packets sent.
- Cost: it is assumed to be zero for WAVE based networks.
- Migration Time: It is calculated and presented as time that is required to completely transfer different sizes of files.

- Failed Attempts: Number of failures is recorded as migration attempts failed due to unavailability of network.

6.3.3.1.1.4 Results and Discussion

To present the migration of LDCAMS over WAVE, several file sizes are assumed. These file size are assumed to be comprised of size of application, application data and session management or control data for LDCAMS migration. This data is transmitted over WAVE as CBR traffic and packet loss is measured. The packet loss shows the performance of the network for LDCAMS communication and migration.

In figure [6-28], packet loss is shown against increasing number of vehicles. The scenario is characterized by low speed mobility and sparse distribution of vehicles on the road. It can be seen that when the number of vehicles on road is very low e.g. less than 20, the packet loss is nearly 0.4 packet per second, which is decreased to 0.15 packet per second when the number of vehicles on the road increases over 20, however, It is evident that with increasing number of vehicles on the road packet loss increases.

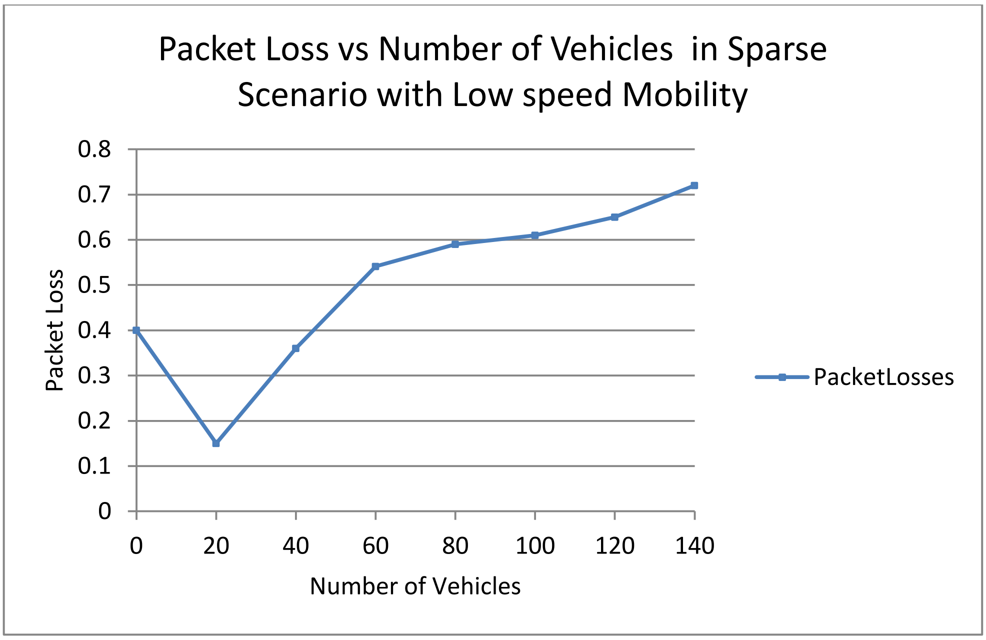

Figure 6-28 Packet Loss vs. Number of Vehicles in Sparse Scenario with Low speed Mobility

In figure [6-29] packet loss is shown against increasing number of vehicles. The scenario is characterized by medium speed mobility and sparse distribution of vehicles on the road. It can be seen that when the number of vehicles on road is very low, e.g. less than 20, the packet loss is nearly 0.53 packet per second, which is decreased to 0.19 packet per second when the number of vehicles on the road increases over 20, however, It provides the evidence that with increasing number of vehicles on the road the packet loss is increasing.

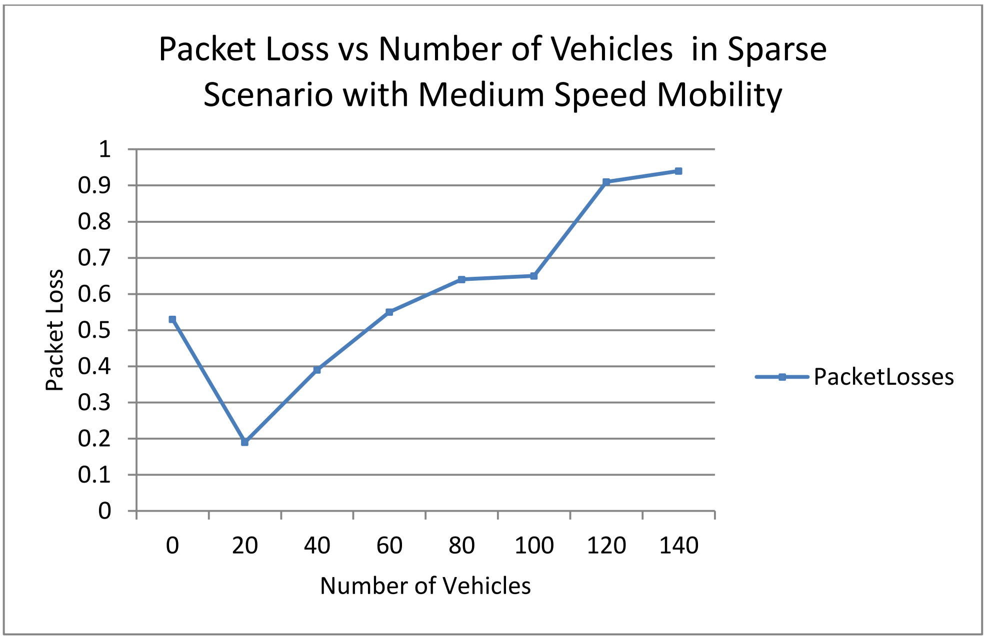

Figure 6-29 Packet Loss vs. Number of Vehicles in Sparse Scenario with Medium Speed Mobility

In figure [6-30], packet loss is shown against increasing number of vehicles. The scenario is characterized by high density of vehicles with low speed mobility on the road. It can be seen that with an increasing number of vehicles on the road, the packet loss increases.

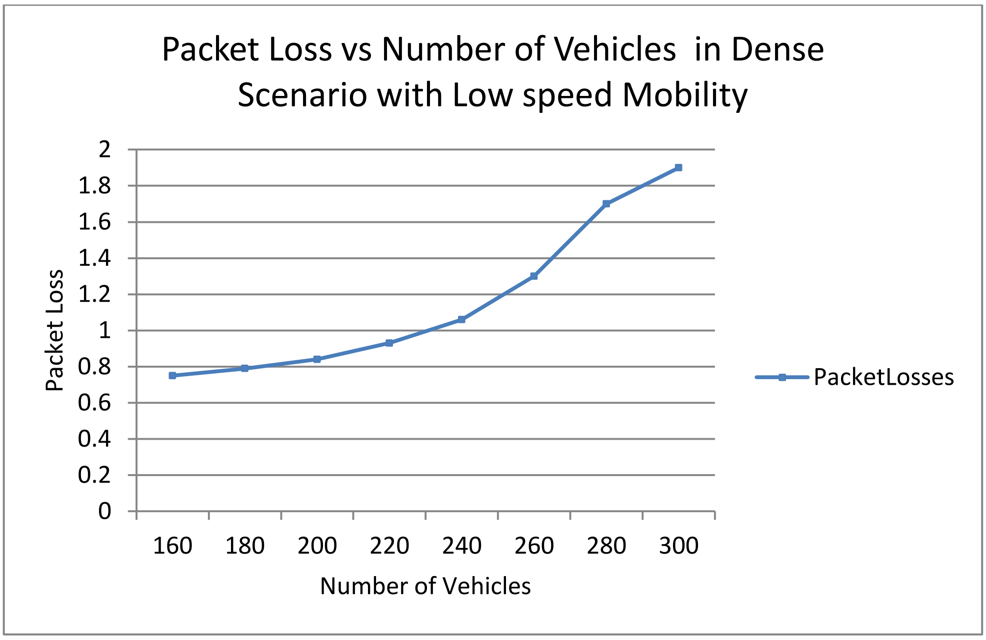

Figure 6-30 Packet Loss vs. Number of Vehicles in Dense Scenario with Low speed Mobility

In figure [6-31], packet loss is shown against increasing number of vehicles. The scenario is characterized by high density of vehicles with medium speed mobility on the road. It can be seen that with an increase in number of vehicles on the road, the packet loss is increasing.

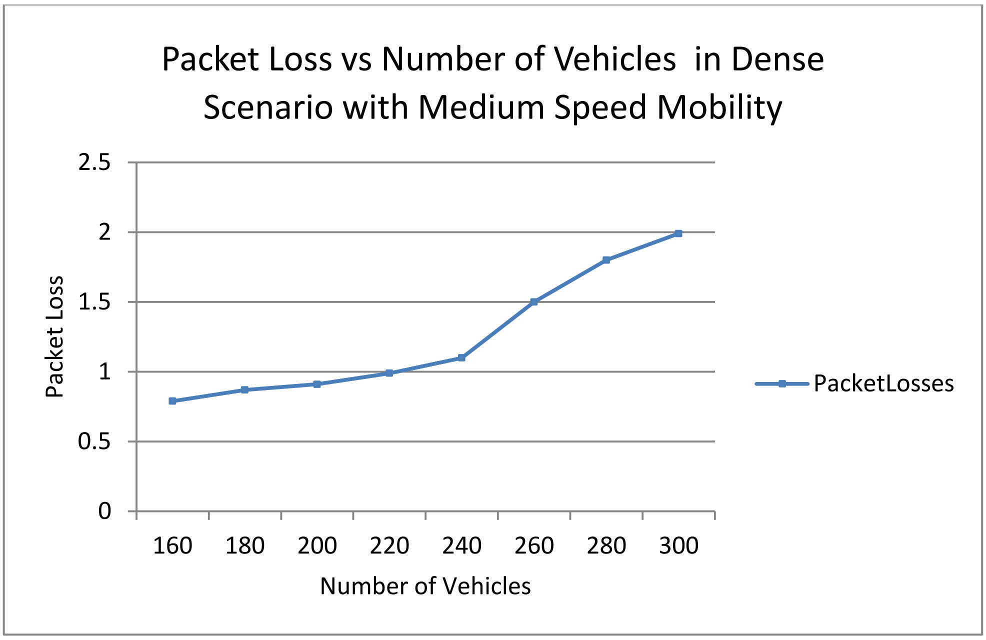

Figure 6-31 Packet Loss vs. Number of Vehicles in Dense Scenario with Medium Speed Mobility

6.3.3.1.1.5 Conclusion

The simulations shown in figure 6-28 to 6-31 provides sufficient evidence to establish the fact that in unplanned areas, with increase in number of vehicles, the packet loss increases. Thus, it can be said that WAVE network performance degrades with increasing number of vehicles.

6.3.3.1.2 Simulation Set-2

This set of simulations is executed to investigate the efficacy of having an alternate supporting network for LDCAMS communication and migration.

6.3.3.1.2.1 Scenarios

The first section of these simulations are performed to compare the ideal time for transfer of certain amount of data using a WAVE network offering a data rate of 2Mbps with the actual time taken for the transfer of the same over that network. The same set of simulations is performed to check the ideal time for the transfer of a certain amount of data using UMTS offering a data rate of 384Kbps with the actual time taken for the transfer of the same over UMTS offering the data rate of 384Kbps. The number of vehicles is assumed to be 150 and medium mobility is considered to perform the simulations. The second section of these simulations is performed to show more reliable LDCAMS communication and migration over the integrated network.

6.3.3.1.2.2 Results & Discussion

The results are shown in figure [6-32] and figure [6-33]. It can be seen that with increasing file size, the time taken to transfer the file increases. In addition, it can be seen that the actual time taken for transferring a file is higher than the ideal time that the file should have taken. This is due to packet loss that occurs due to channel contentions as well as several other reasons. This packet loss has already been shown in the previous set of simulations.

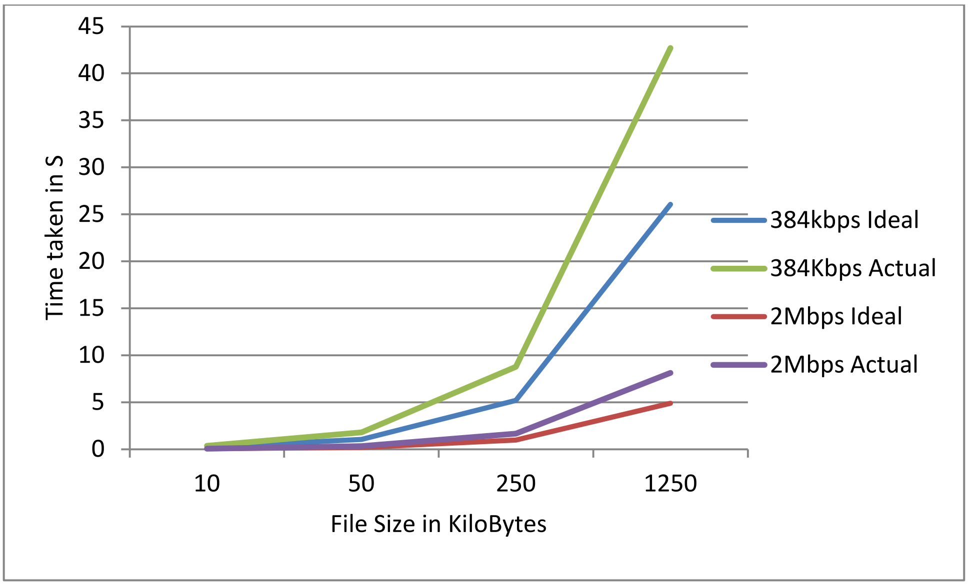

Figure 6-32 Migration time vs. small to medium Size of File

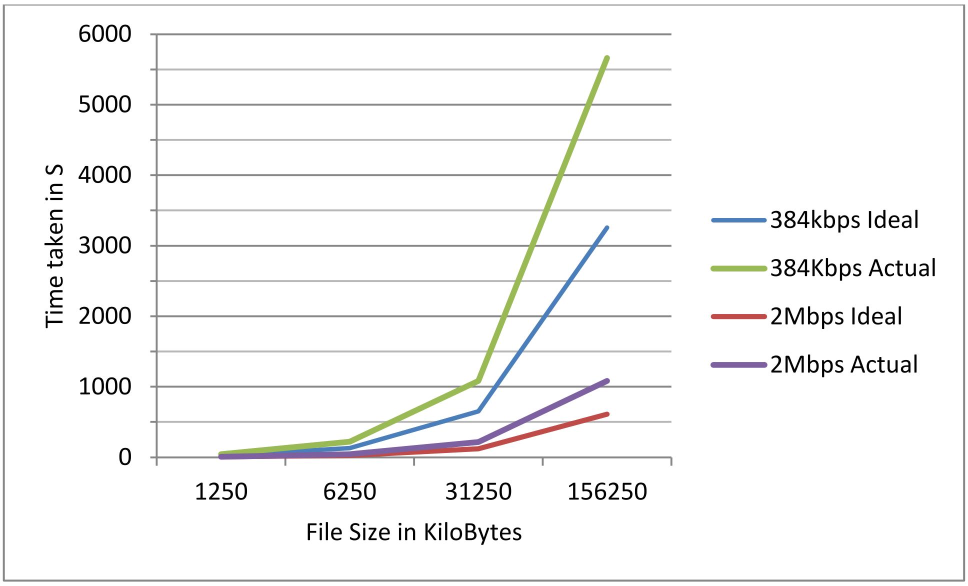

Figure 6-33 Migration time vs. medium to large Size of File

6.3.3.1.2.3 Conclusion:

It has been established that with increasing number of vehicles in communication, packet loss increases. Hence, the total time for the migration of LDCAMS takes more time than the ideal time. Furthermore, due to the number of disconnections and packet losses, the network performance degrades. In such a situation, the absence of a supporting network will brings the system to a failed state.

6.3.3.1.3 Scenario

The use of the UMTS network as a supporting network is presented in this research. For this purpose, a cost-effective algorithm has also been employed. The performance comparison and discussion on the efficacy of the cooperative and cost-effective algorithm is presented in the next section. This simulation is performed using the following parameters.

Mobility	Medium at 40-60Km/h
Traffic : CBR	
Data rate: WAVE at 2 Mbps, UMTS at 384Kbps	
Mobility Model: Manhattan Mobility Model[adapted to show unplanned areas]	

Area:	1000x1000 m
Routing Protocol:	AODV
Nodes and Data Sources:	150 Nodes
Networks:	Single Home and Multihomes
Application Size:	10KB to 156250KB

Table 6-7 Scenario Parameters for measuring Service Migration Time

6.3.3.1.4 Assumptions for Scenario

This research addresses the network volatility leading to network failure of WAVE by providing a supporting network i.e. UMTS. A WAVE-based network may fail due to several reasons:

1- A WAVE device is not available on the target/destination node.

2- The WAVE network becomes unavailable due to communicating nodes becoming distant from each other(out of communication range), thus causing network failure.

3- WAVE network underperforms significantly due to network congestion and is considered as network failure

To overcome these issues, network failure is assumed to occur at several points during LDCAMS migration. These network failure points (NFP) are define as the percentage of application traffic transferred from source to destination. For example, network failure may occur while 20% of application traffic was transferred from source to the destination node. Thus, it makes the network failure point as 20% of the total application file size. This research assumes a NFP will trigger Network switch (N/S) to supporting network i.e. UMTS. The simulations also create such network failures by introducing raw traffic to create network congestion. These types of network failures are also created at ranging from 20% to 80% of size of file. These network failures lead to N/S to the supporting network.

6.3.3.1.5 Results & Discussion

The graph shown in figure [6-34 to 6-40] shows the transfer of 10KB to 156250KB file as LDCAMS communication or LDCAMS migration. It can be seen that if the network becomes congested at a point where 20% of the file or LDCAMS has been migrated, it will take more time for completion of migration than if the network switching had taken place later on during communication. The reason for this result is that the data rate offered by UMTS is less than that of WAVE. Hence, the earlier the network switches from WAVE to UMTS, the higher will be the cost in time.

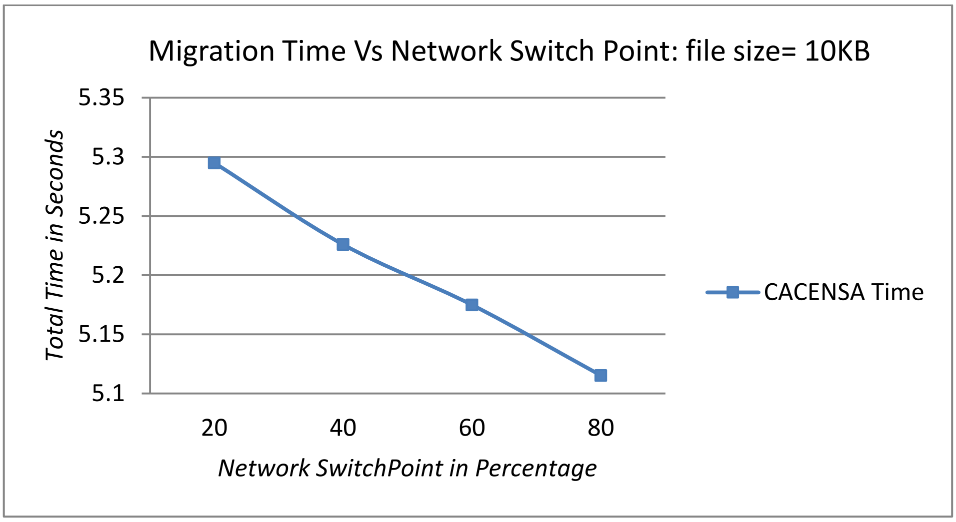

Figure 6-34 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 10KB

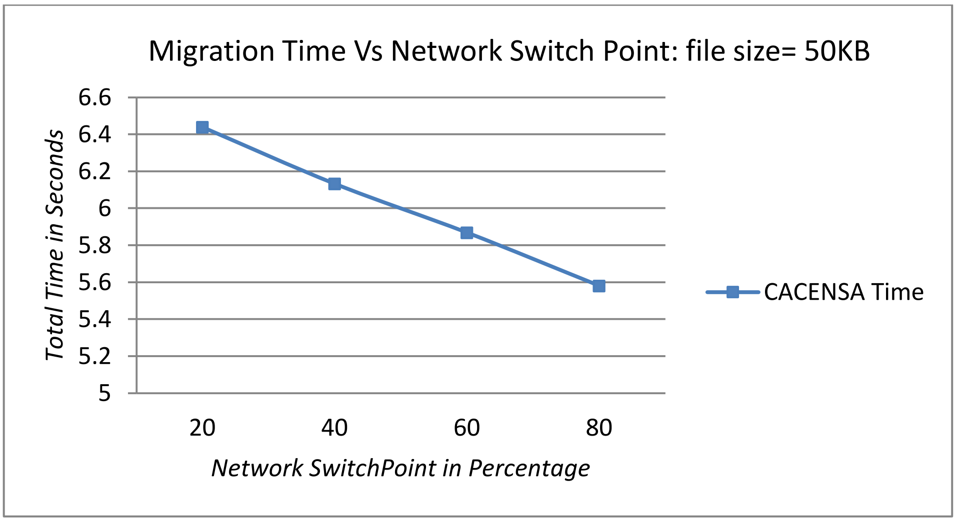

Figure 6-35 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 50KB

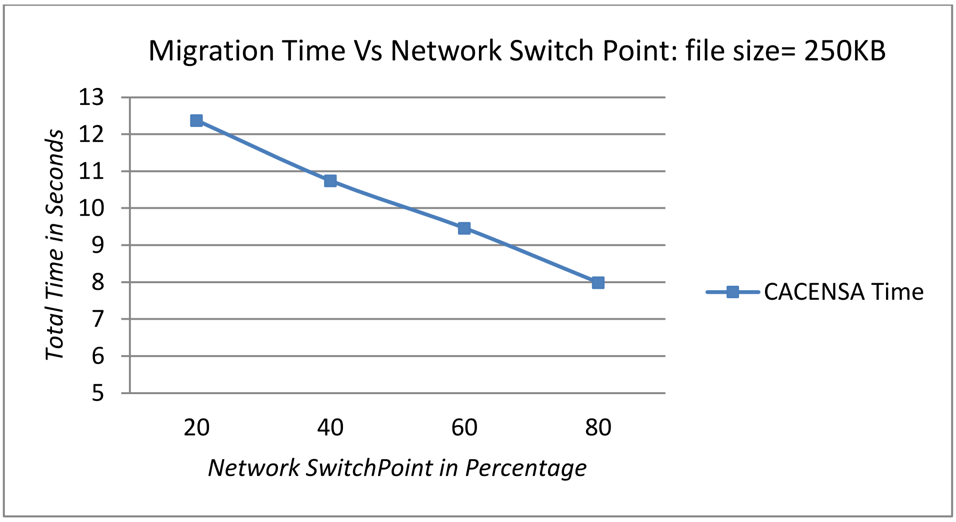

Figure 6-36 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 250KB

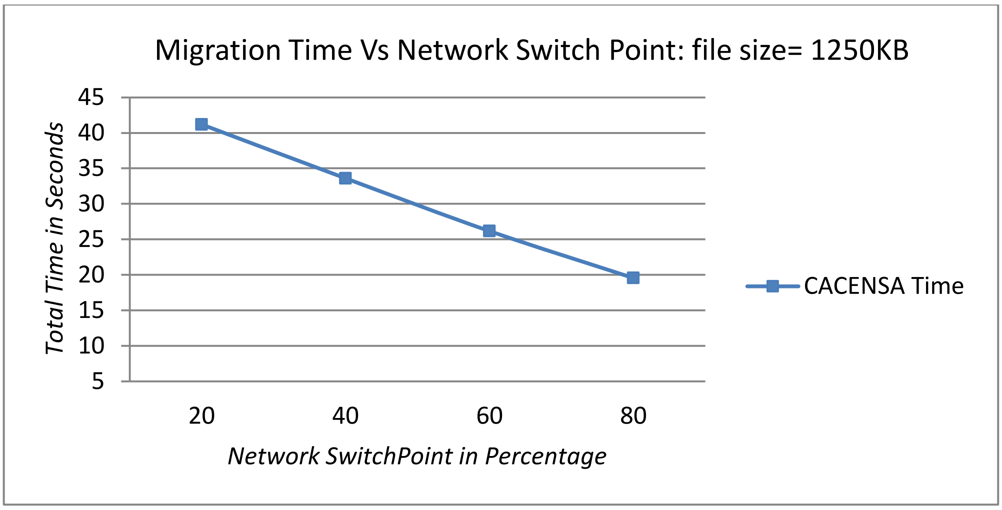

Figure 6-37 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 1250KB

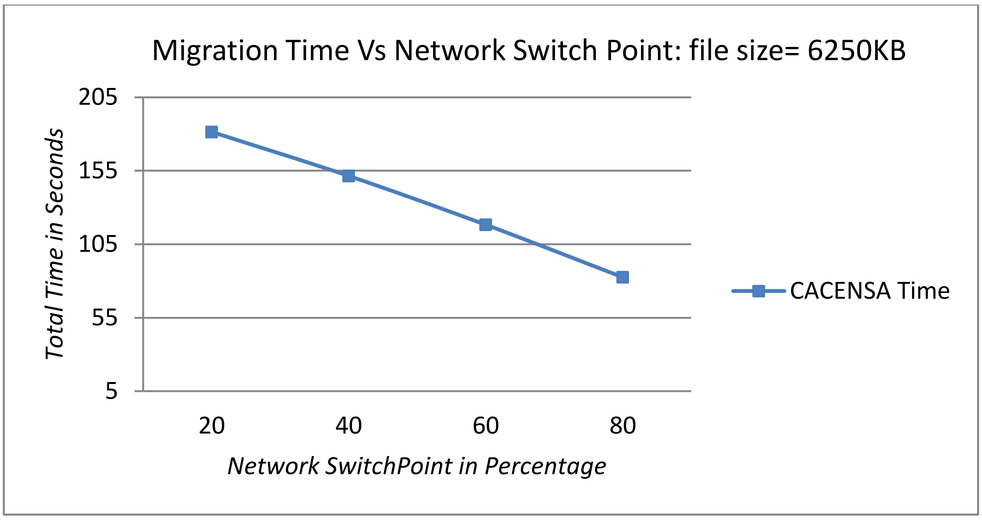

Figure 6-38 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 6250KB

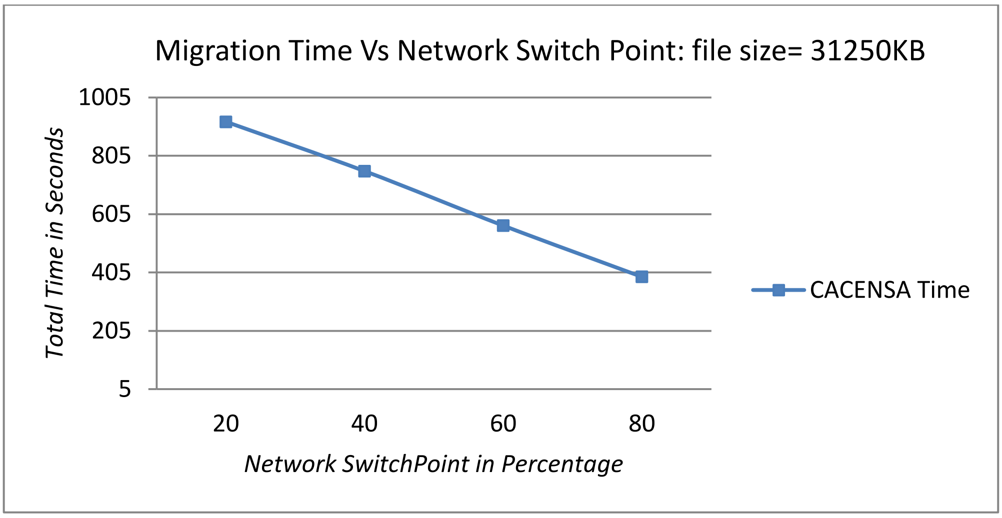

Figure 6-39 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 31250KB

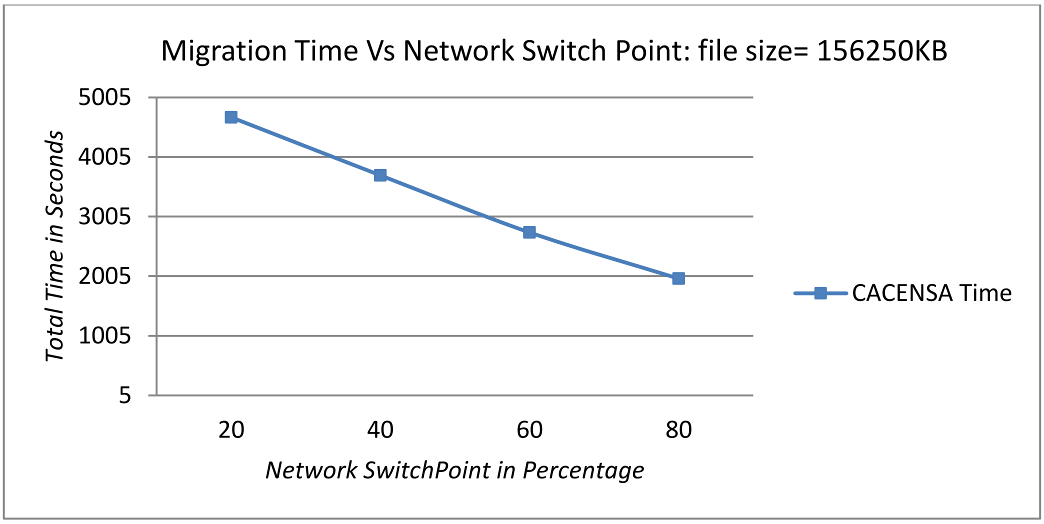

Figure 6-40 Total Migration time vs. Network Switch Percentage from WAVE to UMTS: File size 156250KB

6.3.3.1.6 Conclusions

It is evident that although, the network selection from WAVE to UMTS increases the cost of communication and LDCAMS migration, it adds reliability. It is important to have such reliability in unplanned geographic areas such as areas with security issues that requires continuous monitoring.

6.3.3.2 LDCAMS Communication and Migration Comparison using WAVE, UMTS and CACENSA

6.3.3.2.1 Scenario

Performance of WAVE, UMTS, and CACENSA is presented in this section. These simulations are shown in two parts. Part-1 shows small to medium size file i.e. 10KB to 1250KB whereas the part 2 of these simulations shows the results of medium to large file sizes i.e. 1250KB to 156250KB. The performance is measured in terms of time required to migrate LDCAMS. Moreover, for CACENSA, exactly one switch i.e. from WAVE to UMTS is assumed.

6.3.3.2.2 Results & Discussions

The graphs shown in figures [6-41 to 6-44] show the LDCAMS communication or LDCAMS migration as transfer of 10KB to 1250KB size files with single network switching point at 20%, 40%, 60%, and 80% respectively. It can be seen that WAVE takes a minimum amount of time if it is used for complete LDCAMS migration. However, in unplanned areas, there are many chances that WAVE becomes unavailable or degrades in performance to support the LDCAMS migration. It is noted that UMTS takes a greater amount of time than WAVE. This is due to higher data rate offered by WAVE. When the performance of UMTS is compared with CACENSA, it can be seen that UMTS performs better for smaller file sizes such as 10 KB to 1250KB. This is because additional time of network selection and switching is added to the CACENSA-based LDCAMS migration time. When the file size increases over approx. 300KB, it is evident that CACENSA outclasses UMTS. For larger files, CACENSA performs better than UMTS in terms of cost as well as time. However, it is also seen that whenever WAVE is available, it performs better than UMTS and CACENSA. It is also evident that CACENSA time decreases if the network switching takes place at later stage.

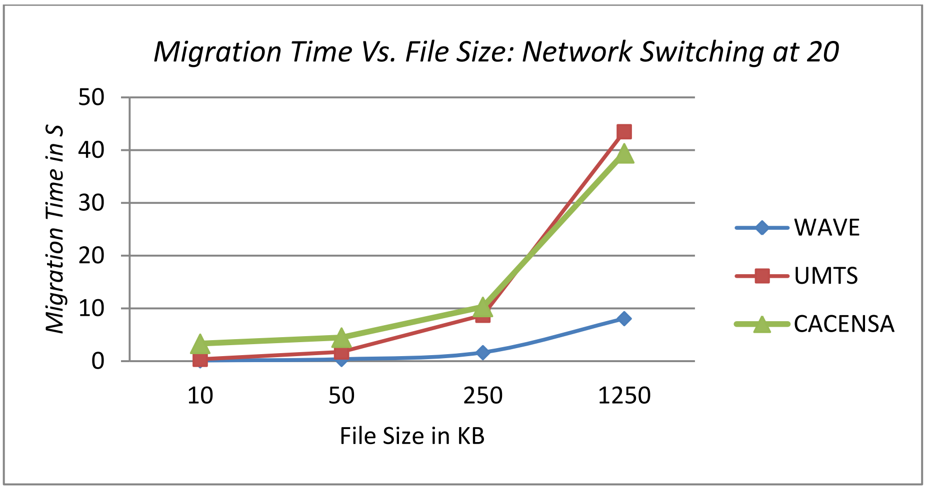

Figure 6-41 Comparison of WAVE, UMTS and CACENSA in Small to Medium Size File with N/S at 20%

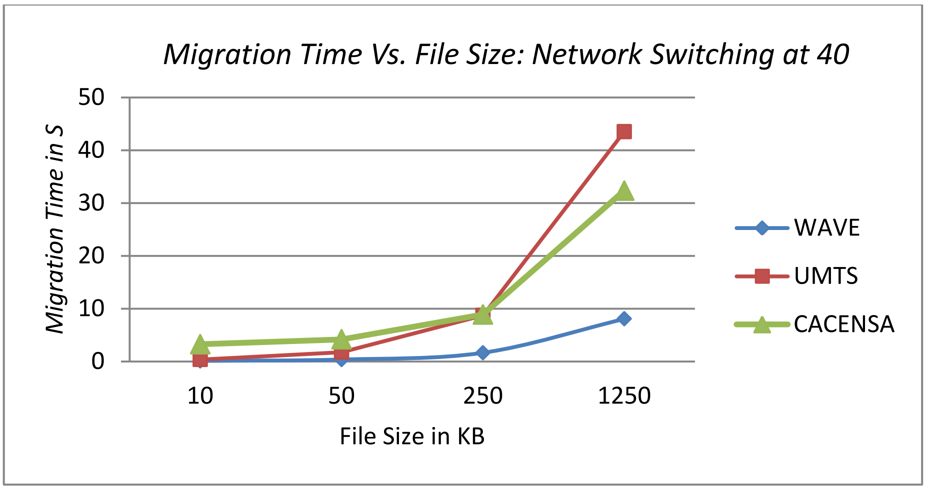

Figure 6-42 Comparison of WAVE, UMTS and CACENSA in Small to Medium Size File with N/S at 40%

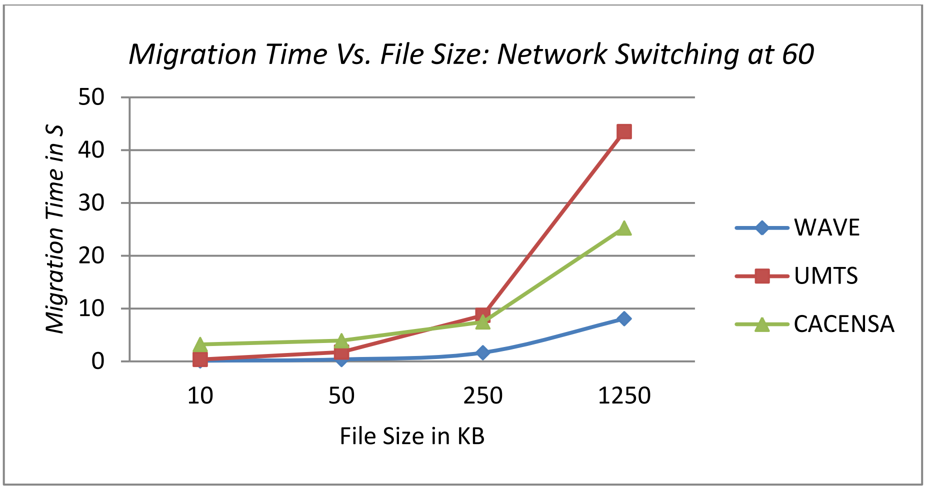

Figure 6-43 Comparison of WAVE, UMTS and CACENSA in Small to Medium Size File with N/S at 60%

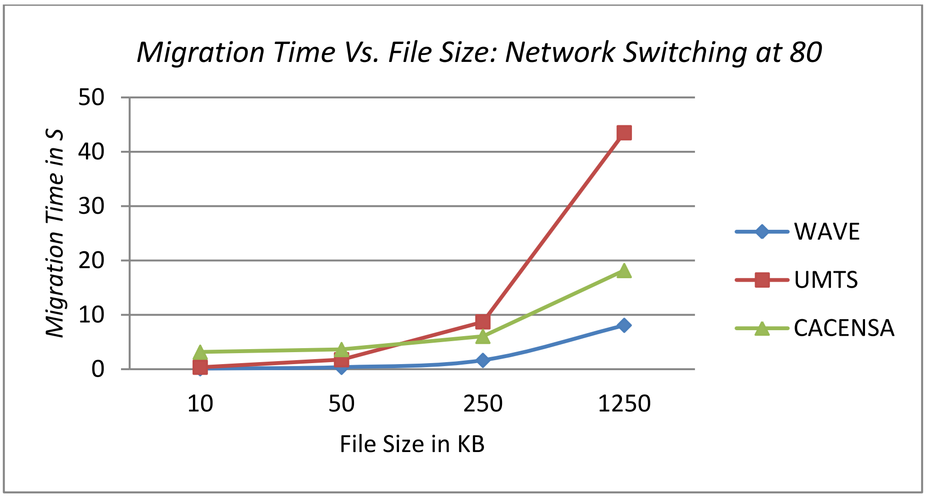

Figure 6-44 Comparison of WAVE, UMTS and CACENSA in Small to Medium Size File with N/S at 80%

The graphs shown in figures [6-45 to 6-48] show the LDCAMS communication or LDCAMS migration as transfer of 1250KB to 156250KB size files with single network switching point at 20%, 40%, 60%, and 80% respectively. It can be seen that WAVE shows a similar pattern and takes the minimum amount of time to complete LDCAMS migration. However, in unplanned areas there are many chances that WAVE becomes unavailable or degrades in performance to support LDCAMS migration. Moreover, it is evident that UMTS takes a greater amount of time than WAVE. This is due to the higher data rate offered by WAVE. For medium to large file size communication and migration, when the performance of UMTS is compared with CACENSA, it can be seen that CACENSA performs better than UMTS. For larger files, CACENSA performs better than UMTS in terms of cost as well as time. However, it is also seen that whenever WAVE is available, it performs better than UMTS and CACENSA. It is also evident that CACENSA time decreases if the network switching takes place at later stage.

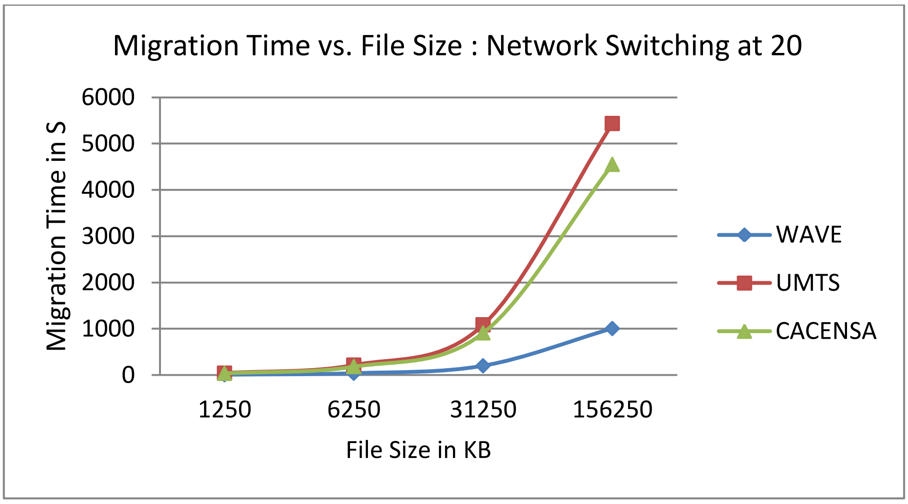

Figure 6-45 Comparison of WAVE, UMTS and CACENSA in Medium to large Size File with N/S at 20%

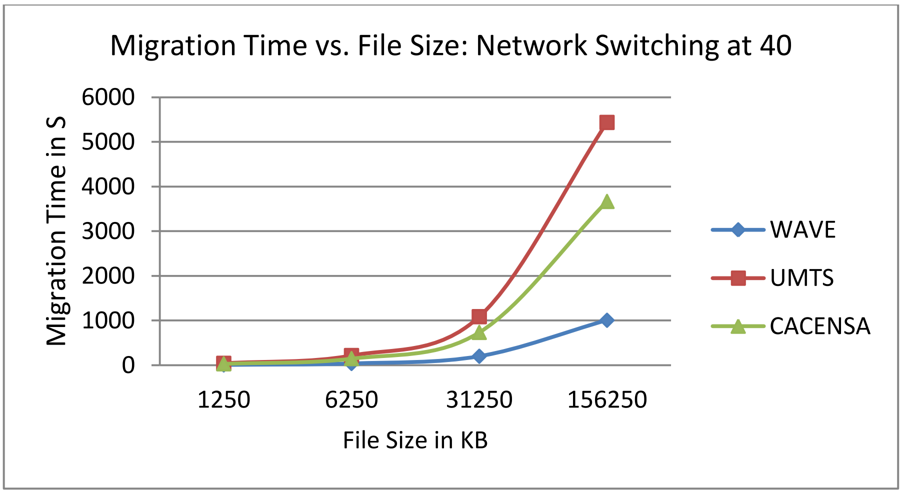

Figure 6-46 Comparison of WAVE, UMTS and CACENSA in Medium to large Size File with N/S at 40%

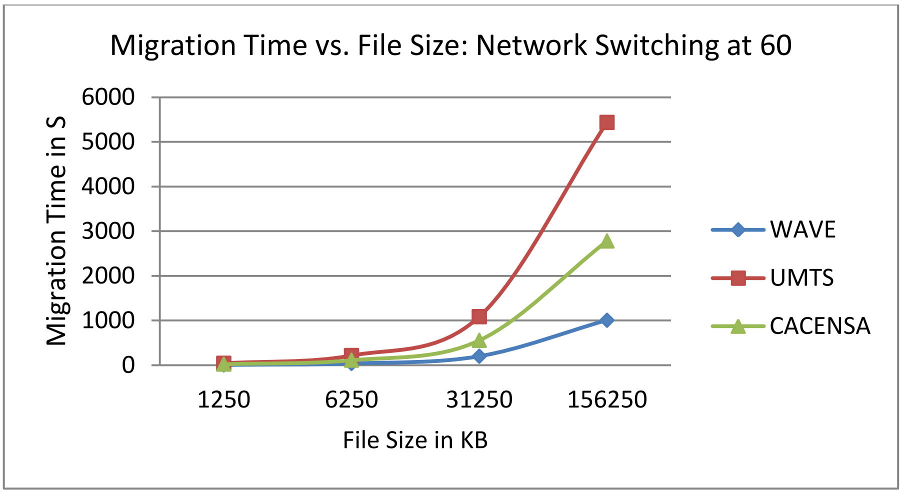

Figure 6-47 Comparison of WAVE, UMTS and CACENSA in Medium to large Size File with N/S at 60%

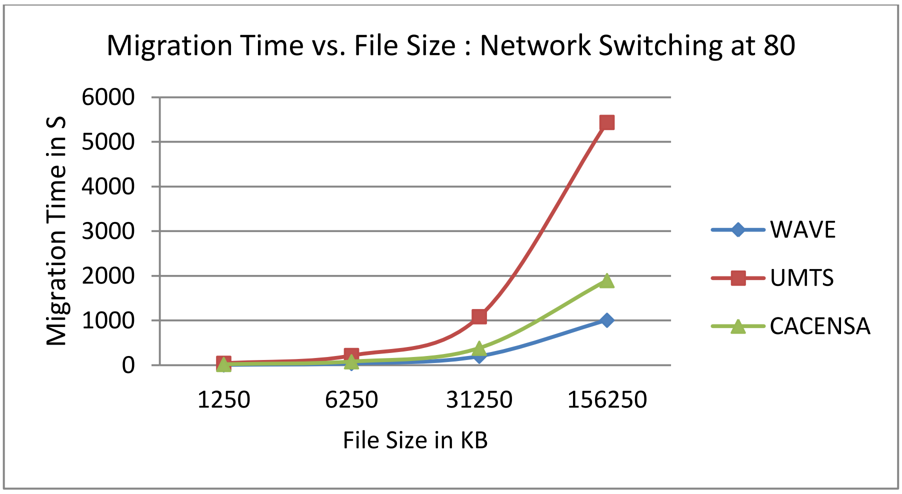

Figure 6-48 Comparison of WAVE, UMTS and CACENSA in Medium to large Size File with N/S at 80%

6.3.3.2.3 Conclusions

Figures [6-41] to [6-48] clearly show that availability of a supporting network assists to provide reliability and continued service availability in unplanned areas.

6.3.3.3 LDCAMS Communication and Migration Comparison using WAVE (with additional applications traffic), UMTS and CACENSA

6.3.3.3.1 Scenario

This section presents the results of simulations performed to compare performance of WAVE and UMTS networks offering data rate of 2Mbps and 384Kbps, respectively, with

CACENSA-based integrated network to support LDCAMS migration. The major difference of these scenarios from those previously presented is to consider multiple network traffic flows generated by other VANET applications over WAVE. In realistic scenarios, there are several non-safety applications assumed to run over the WAVE network. Thus, the extra network traffic generated by these applications limits the available bandwidth for LDCAMS. These simulations are performed considering the following parameters:

Mobility	Medium at 40-60Km/h
Traffic : CBR	
Data rate: WAVE at 2 Mbps, UMTS at 384Kbps	
Mobility Model: Manhattan Mobility Model[adapted to show unplanned areas]	
Area: 1000x1000 m	
Routing Protocol: AODV	
Nodes and Data Sources: 150 Nodes	
Networks: Single Homed and Multihomed	
Application Size: 250KB to 156250KB	

Table 6-8 Scenario Parameters for measuring Service Migration Time

6.3.3.3.2 Results & Discussions

The graph shown in figure [6-49 to 6-52] shows the LDCAMS migration as transfer of 250KB to 156250KB size files with single network switching point at 20%, 40%, 60%, and 80%, respectively. This scenario particularly considers extra traffic generated by several other non-safety applications. The additional traffic limits the available bandwidth for LDCAMS migration, thus the performance of the WAVE network degrades. The performance of such a network is compared with a CACENSA-based network. A CACENSA-based network considers switching the network to UMTS at different points during the migration and shows a better performance than WAVE to support LDCAMS migration. However, it may be noted that UMTS may perform even better in terms of time under certain circumstances; however, due to cost involved for using UMTS, it is important to perform cost-effective network selection for LDCAMS migration, thus, only when WAVE underperforms or is unavailable, should UMTS be considered to support LDCAMS migration.

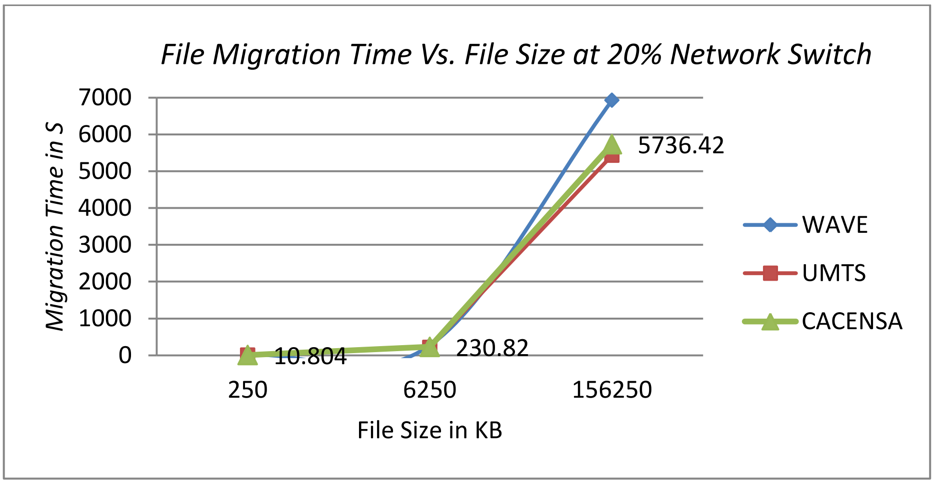

Figure 6-49 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at 20%

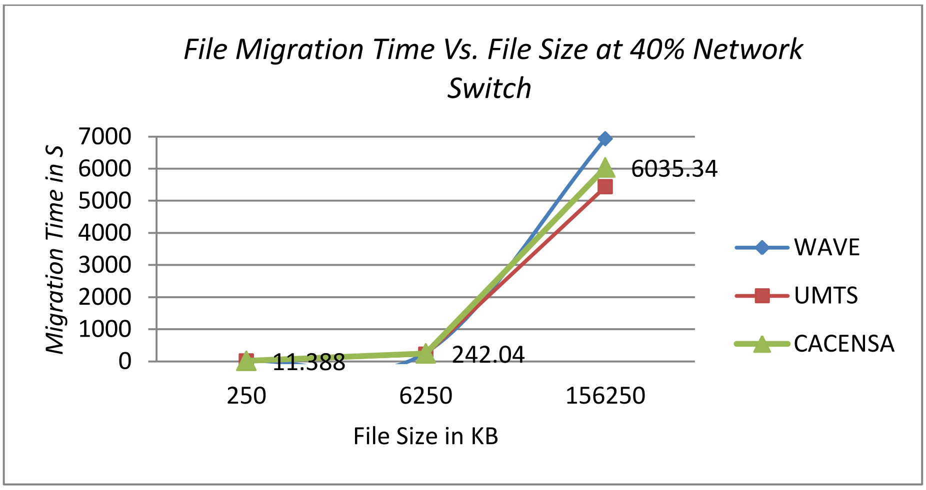

Figure 6-50 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at 40%

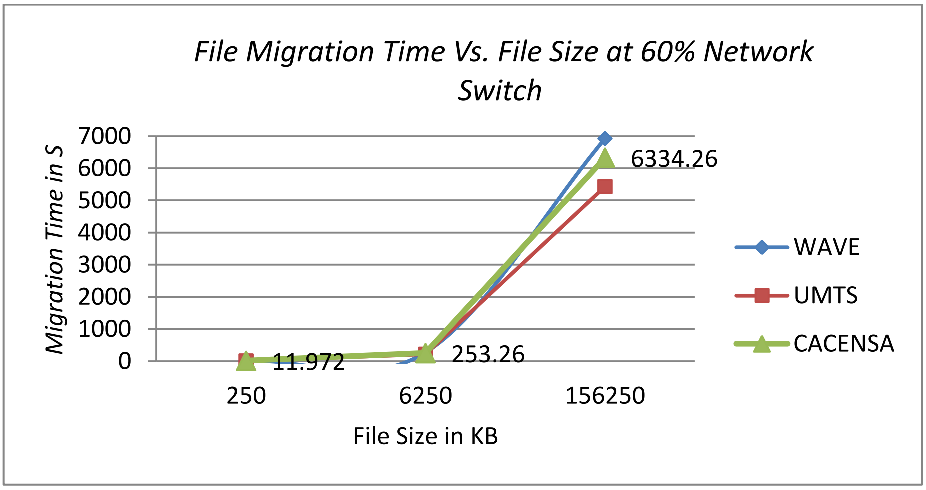

Figure 6-51 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at 60%

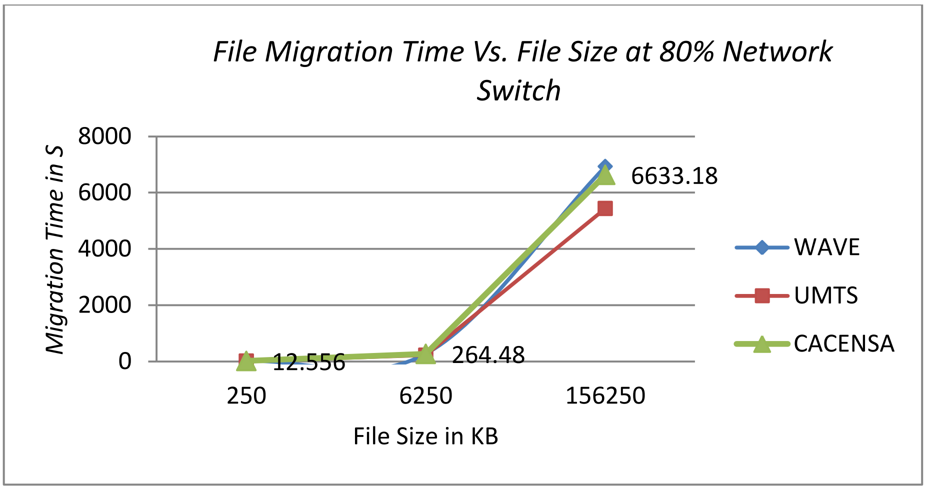

Figure 6-52 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at 80%

It can be seen from the graphs presented in figure 6-49 to figure 6-52 that in case of network failure at any point during LDCAMS migration, supporting network assists to provide continuity for completion of service migration. Furthermore, while WAVE's performance degrades significantly during congestion, network switch to UMTS improves the performance by minimizing the migration time by 13% to 17%. Choice of UMTS may be considered as an option for complete migration of LDCAMS; however, it is not cost-effective approach.

The graph in figure 6-53 shows that switching network while WAVE network underperform significantly, reduces the time taken for LDCAMS migration. It also shows that UMTS performs even better in terms of time; however, to select UMTS for complete service migration, the cost incurred to use UMTS services needs to be considered. Thus, CACENSA provides cost-effective network selection for LDCAMS migration.

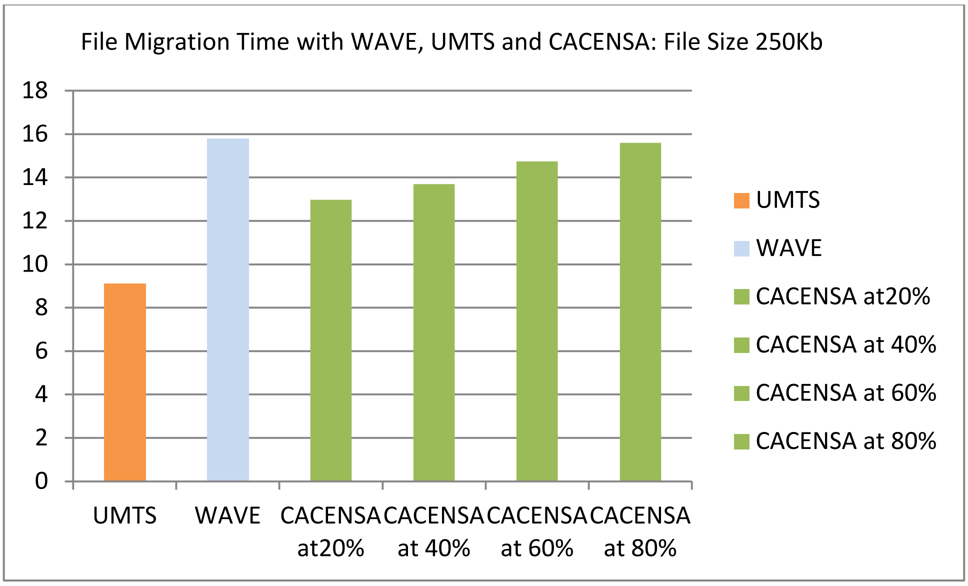

Figure 6-53 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at Several points (file size 250kb)

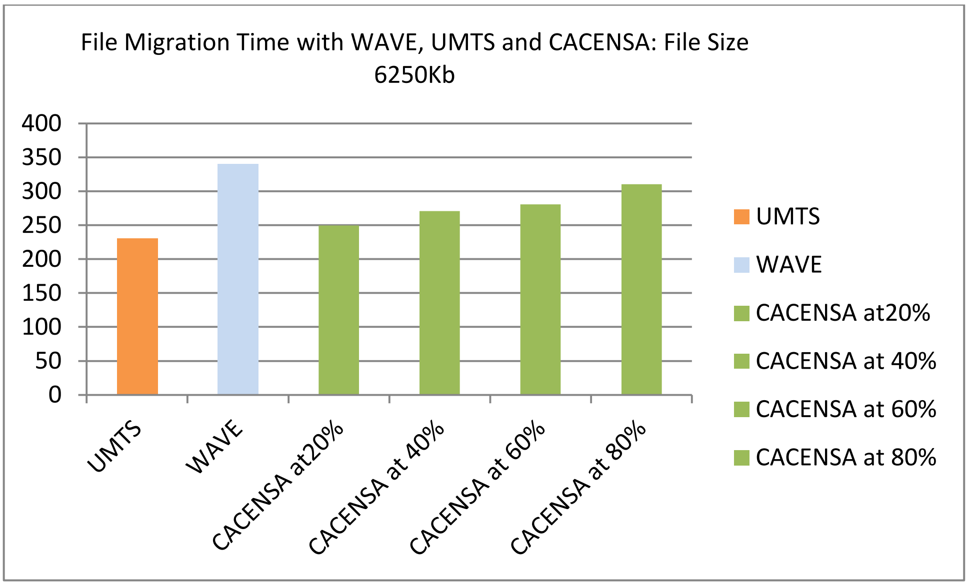

Figure 6-54 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at Several points (file size 6250kb)

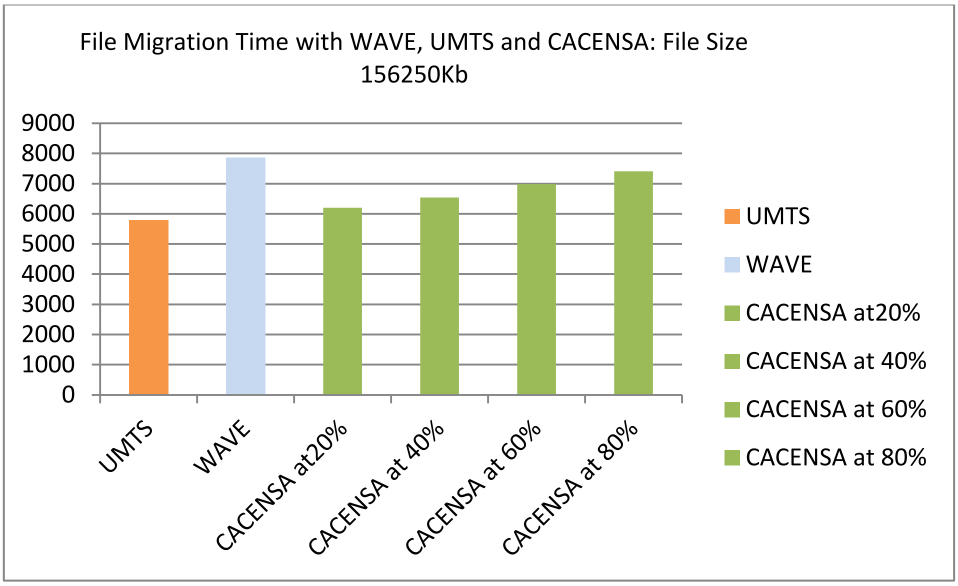

Figure 6-55 Comparison of WAVE (with additional network traffic), UMTS and CACENSA with N/S at Several points (file size 156250kb)

Similar to the graph shown in figure 6-53, the results presented in figure 6-54 and 6-55 show that switching the network while the WAVE network underperform significantly reduces the time taken for LDCAMS migration. It can be seen that the time required for complete migration increases if the network switch is taken later during the migration. The behaviour is due to continuous underperformance of the WAVE network. Thus, an earlier switch to UMTS shows minimal time taken for LDCAMS migration. However, it is obvious that the cost of UMTS usage will be greater if an earlier network switch is triggered.

6.3.3.3.3 Conclusions

The results presented in this section demonstrates the effectiveness of CACENSA for LDCAMS migration. The graphs contribute to establish the facts as follows:

- WAVE network is volatile and may underperform significantly or become unavailable during LDCAMS migration.
- The supporting network, UMTS, helps to support continuous service migration in minimal time.
- CACENSA contributes cost-effective network selection for LDCAMS migration.

6.3.3.4 APPLICATION SIZE VS COST

Another direction to improve performance is that if WAVE is showing degraded performance or is unavailable in vehicles and UMTS has been selected for the complete LDCAMS migration, then LDCAMS migration should be completed using UMTS. This would increase the cost; however, the network traffic may be reduced by not starting the migration repeatedly. Here the cost function is simply shown as follows:

$$C(I) = \mu_t f_t(I) + \mu_m f_m(I) \quad \text{for } I \in \{\text{WAVE, UMTS}\}$$

In the given function, f_t (I) and f_m (I) denotes the variables for data rate and monetary cost in network I, respectively. In (I), $\mu_{t,}$ and μ_m denotes the weight of each factor, which are set according to user preferences.

The constraint pertaining to $\mu_{t,}$ and μ_m is given by $\mu_t + \mu_m = 1$

Network I improves with lower values of C (I)

6.3.3.5 *Number of Failed Attempts*

Finally, the next section of simulations presents the number of failed attempts to complete LDCAMS migration due to network unavailability.

6.3.3.5.1 Scenario

This section presents the results of simulations performed to compare performance of WAVE and CACENSA in terms of number of failed attempts to migrate LDCAMS. The simulations are performed considering the following parameters:

Mobility	Medium at 40-60Km/h
Traffic : CBR	
Data rate: WAVE at 2 Mbps	
Mobility Model: Manhattan Mobility Model[adapted to show unplanned areas]	
Area: 1000x1000 m	
Routing Protocol: AODV	
Nodes and Data Sources: 150 Nodes	
Networks: Single Homed and Multihomed	
Application Size: 250KB to 156250KB	

Table 6-9 Scenario Parameters for measuring Service Migration Time

6.3.3.5.2 Performance Metric

These simulations are run to record the number of failed attempts of LDCAMS. These failed attempts can be due to any of the following reasons

- The WAVE network not available at destination node
- The destination node crashes/becomes out of reach for unlimited time
- Failure due to network congestion of WAVE-based network

6.3.3.5.3 Results and Discussion

Figure [6-56], presents the results of simulations to evaluate WAVE-based network and CACENSA. The results show that migrating LDCAMS over the WAVE-based network, particularly in unplanned areas, where the distribution of vehicular traffic can be uneven to a large extent. The uneven vehicular traffic produces not only uneven network traffic but also a network node distributions that is characterized by network disconnections. In addition, such node distributions may cause nodes unavailable to each other for any communication.

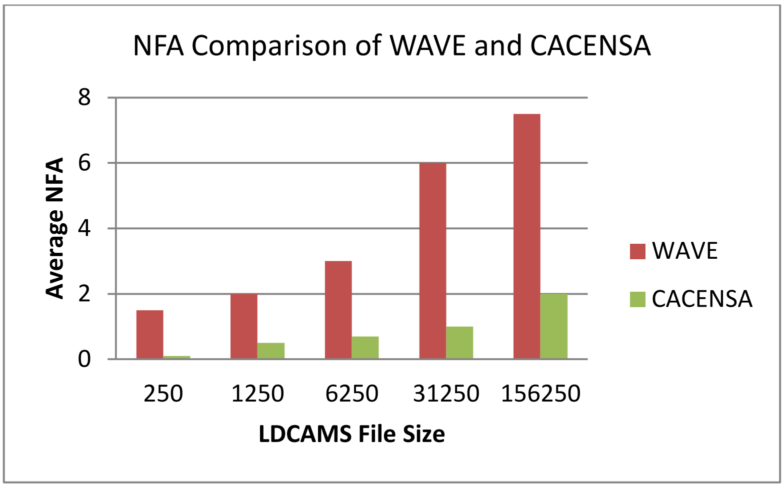

Figure 6-56 NFA Comparison of WAVE and CACENSA with different File Sizes

The results presented in this figure demonstrates the higher number of failed attempts for WAVE-based network.

6.3.3.5.4 Conclusion

These simulations validate the significant reliability offered by additional network support. The reliability is achieved at the cost of UMTS usage cost, however, CACENSA contributes to use UMTS only in a cost-effective way.

6.4 Concluding Remarks

This chapter presented results and discussion considering several scenarios that are simulated to investigate the effectiveness of the claim made in this research. The first set of simulations shows the amendments made to NS-Miracle to support IEEE 802.11P does not affect the reliability of the simulator. The amended version of NS-Miracle is named NS-Miracle-V, i.e. for vehicles. After validation of simulator, a novel approach to congestion detection is presented. Then, to determine how many simulation runs should be made, results of simulations have been shown and discussed. After showing the validation of simulator used, it is shown that in unplanned areas, when the number of vehicles are increased, it affects the performance of WAVE and it may leave WAVE unable to host a service. Finally, series of simulations are presented to support the evidence that in the presence of backup supporting network, LDCAMS communication, and migration is more reliable. For this purpose, a simple algorithm CACENSA is implemented and its performance is compared with the performance of WAVE and UMTS alone. The performance comparison shows that depending upon the size of LDCAMS and Network switching time, 10% to 20% improvement in terms of time required transferring LDCAMS from source to destination along with management data is achieved. The analysis of results shown in further complex scenarios where WAVE's performance degrades considerably, UMTS network support can improve the system reliability as well as it minimizes the time required for LDCAMS migration. In addition, the CACENSA contributes to determining the network switch point, thus making the network selection for LDCAMS not only reliable but also cost-effective.

CHAPTER 7. CONCLUSIONS & FUTURE WORK

The research community is expected to launch several innovative applications over Vehicular Ad hoc Networks (VANETs). The vehicular industry is supporting the notion of pervasive connectivity by agreeing to equip vehicles with devices required for vehicular *ad hoc* networking. Equipped with these devices, mobile nodes in VANETs are capable of hosting several types of applications. Provision of such applications to address problems in developing countries in a cost-effective manner is challenging. For security reasons, unplanned areas (i.e. areas that lack communication infrastructure and planning) in developing countries may need to be monitored. Furthermore, in case of emergency events on roads, several applications and services can be helpful in such unplanned areas. VANET applications or services are classified as safety- (failure or unavailability of which may lead to a life threat) and non-safety-critical (failure of which do not lead to a life threat) applications. Concurrent provision of safety- and non-safety-critical applications in VANETs is important; however, despite several advantages of this approach (such as less incurred cost), there are drawbacks that cannot be compromised. In particular, failure of safety-critical applications may have severe outcome such as loss of life.

This research proposes two separate systems for safety- and non-safety-critical systems. This research covers non-safety-critical applications since the research community has overlooked this class of applications. More specifically, this research focuses on provision of VANET location-dependent services in unplanned areas. Location-dependent, context-aware migratory services (LDCAMS) are services that are designed to operate in unplanned area by resolving location-dependence. LDCAMS migrate from a node leaving a location to another node available at that location. However, unplanned areas are prone to intermittent or poor network connectivity. Thus, it is a challenge to host location dependent non-safety applications over VANETs. Unplanned areas show irregular vehicular traffic on the road. Network traffic flows produced by irregular vehicular traffic lead to VANET communication channel congestion, or they leave the communication channel under-utilized. In both cases, this leads to a communicational bottleneck within a VANET. The simulation results in chapter 6 conclude there is a high number of network failures in unplanned areas. These network failures are due to uneven distribution of vehicular traffic on the roads.

Successful deployment of services, particularly location-dependent, context-aware migratory services (LDCAMS) over VANETs largely rely on the performance of the underlying network. The major contribution of this thesis falls in this area. It discussed the use of WAVE as the only available network, and concluded that it is not able to meet the challenges for communication and service migration due to the intermittent nature of network connectivity. Secondly, the choice of using UMTS as an underlying network cannot be fully entertained due to its capacity limitations and the cost to use the UMTS network. Finally, this thesis discussed provision of UMTS as additional network support for LDCAMS migration. However, this integrated approach to support LDCAMS deployment requires an efficient algorithm for triggering hand-offs between the WAVE network and the UMTS network to provide efficient and cost-effective, context-aware service migration performance in an unplanned geographical area. For such integration, chapter 5 of the thesis presented how the two networks, i.e. WAVE and UMTS, can be integrated into a single operational unit. Furthermore, a comprehensive system design is presented to show how LDCAMS can be hosted and migrated from one node to another.

To evaluate the performance of the underlying integrated network, several amendments were made to NS-Miracle, resulting in NS-Miracle-V. However, due to the amendment made to the original version of NS-Miracle, NS-Miracle-V requires validation. Chapter 6 presents satisfactory results for validation test of NS-Miracle-V.

After validation of the simulator, the first objective of this research is met through detecting network congestion through a simpler approach i.e. measuring RTS-CTS delay. The results are presented in chapter 6. Chapter 6 presents simulation results to show that, in unplanned areas, using average RTS-CTS delay network performance can be measured. These simulations are performed for several mobility scenarios and varying data source scenarios. The simulation results presented in chapter 6 also concluded that the WAVE network is significantly prone to disconnection. Thus, the availability of the underlying network can be improved. A series of simulations are presented to provide evidence that in the presence of a backup supporting network, LDCAMS communication and migration is more reliable. For this purpose, a simple algorithm CACENSA is implemented, and its performance is compared with the performance of WAVE and UMTS alone. The performance comparison shows that depending upon the size of LDCAMS and Network switching time, 10% to 20% improvement in terms of time required to transfer LDCAMS from source to destination along with management data in the presence of additional network traffic on the WAVE network. It is important to consider that additional network (UMTS) charges for use. The analysis of results shows in further complex scenarios where WAVE's performance degrades considerably, the UMTS network support can improve the system reliability as well as minimize the time required for LDCAMS migration. The performance gain of the CACENSA algorithm can be improved if UMTS provides 2Mbps; however, as in developing countries, the usual data rate offered is 384 kbps, and thus up to 20% performance gain can be achieved.

7.1 Contributions

The contributions in this research are listed as follows

1- Proposed separate systems for safety-critical and non-safety-critical applications.
2- Comprehensive system design is presented to deploy LDCAMS in unplanned areas.
3- A simple approach to detect network congestion is presented.
4- To deploy LDCAMS in unplanned areas, additional network support (i.e. UMTS) is proposed.
5- A cooperative and cost-effective network selection algorithm is presented.
6- Several amendments are made to the Manhattan Mobility Model to reflect unplanned areas
7- NS-Miracle is adapted to NS-Miracle-V (with IEEE802.11p WAVE support) for simulating VANET scenarios with more than single network connectivity.

7.2 Open Issues

Several open challenges and issues need to be addressed in order to provide reliable LDCAMS deployment. All the results presented in this research are based on the simulations performed. A Real Test Bed (RTB) is missing in this research so that real experiments may be performed and results can be compared with the simulation results to validate the effectiveness of this research.

Currently Network Simulations are performed and Network failures are created by design. One important direction is to explore how dynamic network events affect the performance of CACENSA.

A priority mechanism for LDCAMS needs to be employed if there are more than one types of LDCAMS priority, affecting how CACENSA will compute and select the underlying network.

A real time prototype is required to see how code migration and execution migration performs under a volatile network and under a CACENSA-based network.

7.3 Future Work

A very practical future direction is to investigate the possibility of educating the public with respect to their driving behaviour by monitoring road traffic using public vehicles. Such a system could also be used to identify misbehaving vehicles, and those that cause unpleasant events on the road.

To evaluate the performance of LDCAMS in unplanned areas supported by CACENSA, a prototype needs to be engineered. Results gathered through this prototype shall be compared with simulation results presented in this thesis.

References:

1. Amirtahmasebi, K. and S.R. Jalalinia, *Vehicular Networks – Security, Vulnerabilities and Countermeasures Master of Science*, in *Department of Computer Science and Engineering* 2010, Chalmers University of Technology University of Gothenburg: Göteborg.
2. Bhattacharjee, P.K. and R.K. Pal, *Vehicular Ad Hoc Network in Mobile Communications with Different Routing Protocols.* Assam University Journal of Science & Technology, 2011. **7**(Physical Sciences and Technology): p. 29-35.
3. Jakubiak, J. and Y. Koucheryavy. *State of the art and research challenges for VANETs*. in *IEEE CCNC*. 2008.
4. Domingo, M.C. and A. Reyes, *A Clean Slate Architecture Design for VANETs.* Springer Science+Business Media, LLC, 2011.
5. Qian, Y. and N. Moayeri. *Design Secure and Application-Oriented VANET*. in *IEEE VTC*. 2008.
6. Jin, X., W. Suy, and Y. Wei, *A Study of the VANET Connectivity by Percolation Theory*, in *Consumer Communications and Networking Conference (CCNC), 2011 IEEE* 2011: Las Vegas, USA. p. 85-89.
7. Park, J.-S., et al., *Delay Analysis of Car-to-Car Reliable Data Delivery Strategies based on Data Mulling with Network Coding.* IEICE - Transactions on Information and Systems archive, 2008. **E91-D**(10): p. 2524-2527
8. Vegni, A.M., et al., *Modeling of Intermittent Connectivity in Opportunistic Networks: The Case of Vehicular Ad hoc Networks*, in *Routing in Opportunistic Networks*. 2013, Springer New York. p. 179-207.
9. ARNIC, *Spectrum Requirements for Dedicated Short Range Communications(DSRC) Public Safety and Commercial A pplications*. 1996, Georgia Tech Research Institute, Georgia Institute of Technology.
10. Morgan, Y.L., *Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics* Communications Surveys & Tutorials, IEEE, 2010. **12**(4): p. 504 - 518
11. webpage. *http://www.3gpp.org/Technologies/Keywords-Acronyms/article/umts*. [cited.
12. Riva, O., et al., *Context-aware Migratory Services in Ad Hoc Networks (2007)* IEEE Transactions on Mobile Computing, 2007. **6**: p. 1313-1328.
13. Webpage. *Gunmen shoot Sri Lanka cricketers*. 2009 [cited; Available from: http://news.bbc.co.uk/2/hi/south_asia/7920260.stm.
14. Webpage. *Seven killed in gun attack on Sri Lankan cricket team*. 2009 [cited; Available from: http://en.wikinews.org/wiki/Seven_killed_in_gun_attack_on_Sri_Lankan_cricket_team.
15. Webpage. *Sri Lankan cricketers injured in terror attack*. 2009 [cited; Available from: http://www.espncricinfo.com/pakvsl/content/story/393212.html.
16. Dahiya, A. and R.K.Chauhan, *A Comparative study of MANET andVANET Environment* Journal of Computing, 2010. **2**(7).
17. Yang, Y. and R. Bagrodia, *Evaluation of VANET-based Advanced Intelligent Transportation Systems* in *VANET'09*. 2009: Beijing, China.

18. Shekar, S., et al., *GPS Based Shortest Path for Ambulances using VANETs*, in *International Conference on Wireless Networks(ICWN2012)*. 2012: Singapur.
19. Lee, U., et al., *Dissemination and Harvesting of Urban Data using Vehicular Sensing Platforms.* IEEE Transactions on Vehicular Technology, 2009. **58**(2): p. 882 - 901.
20. Halonen, T. and T. Ojala, *Cross-layer design for providing service oriented architecture in a mobile Ad Hoc network*, in *5th International Conference on Mobile And Ubiquitous Multimedia*. 2006.
21. Neema, H., et al. *SOAMANET: A Tool for Evaluating Service Oriented Architectures on Mobile Ad hoc Networks* in *14th IEEE/ACM Symposium on Distributed Simulation and Real-Time Applications*. 2010.
22. Natchetoi, Y., H. Wu, and Y. Zheng, *Service-Oriented Mobile Applications for Ad-Hoc networks*, in *IEEE International Conference on Services Computing* 2008. p. 405-412.
23. Choudhury, P., A. sarkar, and N.C. Debnath. *Deployment of Service Oriented architecture in MANET: A research roadmap*. in *IEEE International Conference on Industrial Informatics (INDIN)*. 2011.
24. Fiore, M. and P.d. Torino, *Mobility Models in Inter-Vehicle Communications Literature*. 2009.
25. Fiore, M., P.d. Torino, and C.D.d. Abruzzi, *Vehicular Mobility Simulation for VANETs*, in *40th Annual Simulation Symposium, 2007. ANSS '07.* 2007: Norfolk, VA
26. H¨arri, J.e.o., F. Filali, and C. Bonnet, *Mobility Models for Vehicular Ad Hoc Networks: A Survey and Taxonomy*. 2006, Institut Eur´ecom Department of Mobile Communications: Sophia-Antipolis.
27. H¨arri, J.e.o., et al., *A Realistic Mobility Simulator for Vehicular Ad Hoc Networks*, in *Networks*. 2007.
28. Härri, J., et al., *Vehicular Mobility Simulation with VanetMobiSim.* Simulation, 2011. **87**(4): p. 275-300
29. Pigne, Y., et al. *A Vehicular Mobility Model based on Real Traffic Counting Data*. in *Third International Workshop, Nets4Cars/Nets4Trains 2011*. 2011. Oberpfaffenhofen, Germany.
30. Saha, A.K. and D.B. Johnson, *Modeling mobility for vehicular ad-hoc networks*, in *VANET'04*. 2004.
31. Yan, G., et al., *Cooperative Collision Warning through mobility and probability prediction* in *Intelligent Vehicles Symposium (IV), 2010 IEEE*. 2010: San Diego. p. 1172 - 1177.
32. Gerlach, M., *Assessing and Improving Privacy in VANETs*
33. Ranjan, P. and K.K. Ahirwar, *Comparative Study of VANET and MANET Routing Protocols* in *International Conference on Advanced Computing and Communication Technologies (ACCT 2011)*. 2011.
34. Hsiao, H.-C., et al., *Efficient and Secure Threshold-based Event Validation for VANETs*, in *WiSec '11 Proceedings of the fourth ACM conference on Wireless network security* 2011.
35. Moreno, M., A. Festag, and H. Hartenstein, *System Design for Information Dissemination in VANETs*, in *Proceedings of 3rd International Workshop on Intelligent Transportation(WIT),*. 2006: Hamburg, Germany. p. 27-33
36. Huang, J. and H.-S. Tan, *Design and implementation of a cooperative collision warning system*, in *Intelligent Transportation Systems Conference, 2006. ITSC '06. IEEE* 2006: Toronto, Ont. .

37. Misener, J.A., R. Sengupta, and H. Krishnan, *Cooperative Collision Warning: Enabling Crash Avoidance with Wireless Technology*, in *12th World Congress on ITS*. 2005: San Francisco. p. 6 – 10
38. Sengupta, R., et al., *COOPERATIVE COLLISION WARNING SYSTEMS: Concept Definition and Experimental Implementation*, in *California PATH Research Report*. 2006, INSTITUTE OF TRANSPORTATION STUDIES UNIVERSITY OF CALIFORNIA, BERKELEY: BERKELEY.
39. Knorr, F., et al., *Reducing Traffic Jams via VANETs.* TRANSACTIONS ON VEHICULAR TECHNOLOGY, 2012. **61**(8).
40. WebPage. *http://cs.njit.edu/~borcea/invent/*. [cited.
41. Patel, V.J. and A.P. Gharge, *A Review on Routing Overhead in Broadcast Based Protocol on VANET* International Journal of Engineering and Innovative Technology(IJEIT), 2012. **2**(5).
42. *FleetNet project – Internet on the road*. 2000 [cited; Available from: http://www.et2.tu-harburg.de/fleetnet2000.
43. Hartenstein, H., B. Bochow, and A. Ebner, *Position-Aware Ad Hoc Wireless Networks for Inter-Vehicle Communications: the Fleetnet Project*, in *MobiHOC*, ACM, Editor. 2001: Long Beach, CA, USA.
44. Meincke, M., et al., *Wireless Adhoc Networks for Inter-Vehicle Communication.* Zukunft der Netze - Die Verlezbarkeit meistern, 16. DFN-Arbeitstagung über Kommunikationsnetze, 2002 p. 233-245.
45. *Car2Car Communication Consortium*. 2000 [cited Feb, 2014]; Available from: www.car-to-car.org.
46. *www.vehicle-infrastructure.org*. 2011 [cited.
47. Zeadally, S., et al., *Vehicular ad hoc networks (VANETS): status, results, and challenges.* Telecommunication Systems, 2012. **50**(4): p. 217-241.
48. CAMP, T., et al., *Vehicle Safety Communications Project : Identify Intelligent Vehicle Safety Applications Enabled by DSRC*. 2005, CAMP 39255 Country Club Drive, Suite B-30 Farmington Hills, MI 48331.
49. Hartman, K. and J. Strasser. *Saving Lives Through Advanced Vehicle Safety Technology: Intelligent Vehicle Initiative Final Report* 2005 [cited February, 2014]; Available from: http://ntl.bts.gov/lib/jpodocs/repts_pr/14153_files/ivi.pdf.
50. Hartman, K. and J. Strasser, *Saving Lives through Advance Vehicle Safety Technology: Initial Vehicle Initiative Final Report*, in *Saving Lives*. 2005.
51. Festag, A., et al. *'NoW – Network on Wheels': Project Objectives, Technology and Achievements*. in *6th International Workshop on Intelligent Transportation(WIT)*. 2008. Hamburg, Germany.
52. Feiri, M., J. Petit, and F. Kargl, *The Impact of Security on Cooperative Awareness in VANET*, in *Vehicular Networking Conference (VNC)*. 2014, IEEE.
53. Fiore, M., et al., *Discovery and Verification of Neighbor Positions in Mobile Ad Hoc Networks.* IEEE Transactions on Mobile Computing, 2013. **12**(2): p. 289-303.
54. Laganà, M., et al., *Secure Communication in Vehicular Networks – PRESERVE Demo*, in *Proceedings of the 5th IEEE International Symposium on Wireless Vehicular Communications*. 2013, IEEE.
55. Weiß, C. *Integrating value-added services: connected mobile life.* Safe and Intelligent Mobility 2013 [cited; Available from: http://simtd.de/index.dhtml/enEN/Vision/Integration_Mehrwertdienste.html.

56. Civera, P., et al., *Wireless Sensors Network for Intelligent Transportation Systems*, in *IEEE 69th Vehicular Technology Conference: VTC2009-Spring*. 2009: Barcelona, Spain.
57. Brignolo, R., *The SAFESPOT Integrated Project - Co-operative systems for road safety*, in *TRA Conference* 2006: Goteborg.
58. Mäkinen, T., et al., *DRIVE C2X methodology framework*, in *DRIVE C2X*. 2011.
59. Papazoglou, M.P., et al., *Service-oriented computing (2003)* Communications of the ACM, 2003.
60. Petric, A., et al., *Agent-Based Support for Context-Aware Provisioning of IMS-Enabled Ubiquitous Services*, in *SOCASE '09 Proceedings of the AAMAS 2009 International Workshop on Service-Oriented Computing: Agents, Semantics, and Engineering*. 2009. p. 71-82.
61. Preuveneers, D. and Y. Berbers. *Pervasive Services on the Move: Smart Service Diffusion on the OSGi Framework*. in *Proceedings of the 5th international conference on Ubiquitous Intelligence and Computing*. 2008.
62. Vijayalakshmi, M. and A. Kannan, *Proactive location-based context aware services using agents.* International Journal of Mobile Communications 2009. **7**(2): p. 232-252
63. Podobnik, V., K. Trzec, and G. Jezic, *Context-Aware Service Provisioning in Next-Generation Networks: An Agent Approach* Agent Technologies and Web Engineering: Applications and Systems, 2009: p. 19-38.
64. Satoh, I., *Mobile Agent-based Context-aware Services.* Journal of Universal Computer Science, 2010. **16**(15).
65. DOM. *Der Orientierte Mensch.* . [cited; Available from: http://www.der-orientierte-mensch.de.
66. Ioannidis, N. *Location Aware Visually Enhanced Ubiquitous Services*. 2001-2004 [cited; Available from: http://loveus.intranet.gr/.
67. Kang, P., et al., *Smart Messages: A Distributed Computing Platform for Networks of Embedded Systems.* The Computer Journal, 2004(Special Focus-Mobile and Pervasive Computing): p. 475–494.
68. PostNote, *ICT IN DEVELOPING COUNTRIES*. 2006.
69. Yavwa, Y. and P. Kritzinger, *Enabling Communication in Developing Regions.* EJISDC, 2001. **6**(1): p. 1-15.
70. Wu, J. and M. Zitterbart, *SERVICE AWARENESS AND ITS CHALLENGES IN MOBILE AD HOC NETWORKS* in *In Workshop der Informatik 2001: Mobile Communication over Wireless LAN: Research and Applications*. 2001.
71. Abrougui, K., *Design and Performance Evaluation of Service Discovery Protocols for Vehicular Networks*, in *Ottawa-Carleton Institution for Computer Science Faculty of Graduate and postdoctoral Studies*. 2011, University of Ottawa: Ottawa. p. 207.
72. Lee, Y.-H., et al., *An Efficient Geo-aware Peer-to-Peer Resource Discovery and Sharing Scheme in Vehicular Ad-hoc Networks*, in *Ninth International Conference on Information Technology - New Generations*. 2012.
73. Pauty, J., et al. *Research Challenges in Mobile and Context-Aware Service Development*. in *Future Research Challenges in Software and Services (FRCSS 06)*. 2006. Vienna, Austria.
74. Boban, M., O.K. Tonguz, and J. Barros, *Unicast Communication in Vehicular Ad Hoc Networks: A Reality Check.* IEEE COMMUNICATIONS LETTERS, 2009. **13**(12).
75. Singh, R., R. Babu, and I. Chatterjee, *A Reliable multicast routing approach for VANET.* IJCSI International Journal of Computer Science Issues, 2012. **9**(2).

76. Zhang, G., et al., *Multicast Capacity for VANETs with Directional Antenna and Delay Constraint.* IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, 2012. **30**(4).
77. Liu, Y., J. Bi, and J. Yang, *Research on Vehicular Ad Hoc Networks*, in *Control and Decision Conference, 2009. CCDC '09*. 2009.
78. Harsch, C., A. Festag, and P. Papadimitratos, *Secure Position-Based Routing for VANETs*, in *IEEE 66th Vehicular Technology Conference (VTC Fall)*. 2008: Baltimore, MD, USA.
79. Khan, L., N. Ayub, and A. Saeed, *Anycast Based Routing in Vehicular Adhoc Networks (VANETS) using Vanetmobisim.* World Applied Sciences Journal, 2009. **7**(11).
80. Bononi, L. and M.D. Felice, *A Cross Layered MAC and Clustering Scheme for Efficient Broadcast in VANETs*, in *The Fourth IEEE International Conference on Mobile Ad-hoc and Sensor Systems*. 2007: Pisa, Italy.
81. Tonguz, O., et al., *Broadcasting in VANET*, in *IEEE INFOCOM 2008*. 2008.
82. Yang, L., J. Guo, and Y. Wu, *Channel Adaptive One Hop Broadcasting for VANETs*, in *11th International IEEE Conference on Intelligent Transportation Systems. ITSC 2008.* . 2008, IEEE: Beijing.
83. Bovée, B., et al., *Evaluation of the Universal Geocast Scheme For VANETs* in *IEEE 74th Vehicular Technology Conference: VTC2011-Fall 5-8 September 2011*. 2011: San Francisco, United States.
84. Das, S. and D.K. lobiyal, *Analysis of Next Hop Selection for Geocasting in VANET.* Trends in Computer Science, Engineering and Information Technology Communications in Computer and Information Science, 2011. **204**: p. 326-335.
85. Tse, Q. and B. Landfeldt, *Interference-Aware Geocasting for VANET*, in *IEEE International Symposium on World of Wireless, Mobile and Multimedia Networks (WoWMoM)*. 2012: San Francisco, CA
86. Ververidis, C.N. and G.C. Polyzos, *Service Discovery for Mobile Ad Hoc Networks: A Survey of Issues and Techniques.* IEEE Communications Surveys & Tutorials, 2008. **10**(3).
87. Taleb, T. and A. Benslimane, *Design Guidelines for a Network Architecture Integrating VANET with 3G & Beyond Networks*, in *IEEE Globecom 2010*. 2010: Miami, Florida, USA.
88. Kenney, J.B., *Dedicated Short-Range Communications (DSRC) Standards in the United States*, in *Invited Paper*. 2011.
89. Webpage. *Dedicated Short Range Communication Services and Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Service in the 5.850-5.925 GHz Band (5.9 GHz Band).* [cited; Available from: Dedicated Short Range Communication Services and Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Service in the 5.850-5.925 GHz Band (5.9 GHz Band).
90. Draft, *IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager*, in *IEEE Vehicular Technology Society (VTS)*. 2006, IEEE.
91. Draft, *IEEE Trial-Use Standard for Wireless Access in Vehicular Environments - Security Services for Applications and Management Messages*. 2006, IEEE.
92. Draft, *IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services*. 2010, IEEE.
93. Draft, *IEEE Standard for Wireless Access in Vehicular Environments (WAVE)--Multi-channel Operation*. 2010, IEEE.

94. webpage. *IEEE 802.11 Standards*. [cited; Available from: http://www.ieee802.org/11/.
95. Ergen, M. *IEEE 802.11*. Tutorials [cited; Available from: http://wow.eecs.berkeley.edu/ergen/docs/ieee.pdf.
96. Association, W.R., *World Road Association, Road Network Operations Handboook*. 2002.
97. Ghandour, A.J., et al., *802.11p/WAVE Vehicular Network: Analytical Study and Protocol Enhancements.* Pervasive and Mobile Computing, 2014. **11**: p. 3-18.
98. Kaur, M., *Performance Evaluation of MAC Protocols in VANETs.* International Journal of Engineering Research and Applications (IJERA), 2012. **2**(6).
99. Tariq, S., *MAC Algorithms in Wireless Networks Applications, Issues and Comparisons*. 2011, Umeå University, Sweden Department of Computing Science
100. Miao, L., et al., *A Survey of IEEE 802.11p MAC Protocol* Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), 2011. **2011**.
101. Stein, J. *Survey of IEEE802.21 Media Independent Handover Services*. 2007 [cited; Available from: http://www.cse.wustl.edu/~jain/cse574-06/ftp/handover/.
102. Kaaranen, H., et al., *UMTS Networks: Architecture, Mobility and Services, 2nd Edition*. 2nd ed. 2005: John Wiley & Sons. 422.
103. Xylomenos, G., V. Vogkas, and G. Thanos, *The multimedia broadcast/multicast service.* WIRELESS COMMUNICATIONS AND MOBILE COMPUTING, 2006.
104. Zang, Y., et al., *A HYBRID SOLUTION FOR VEHICULAR COMMUNICATIONS*, in *ITS World Congress 2009*. 2009: Stockholm, Sweden. p. 12.
105. Draft, *Cooperative Cars, CoCar Feasibility Study – Technology, Business and Dissemination, Public Report by the CoCar Consortium*. 2009.
106. Roy, S.D. and S. AU Anup, *Received signal strength based vertical handoff algorithm in 3G cellular network*, in *IEEE International Conference on Signal Processing, Communication and Computing (ICSPCC)*. 2012. p. 326-330.
107. Yevale, P.S. and S.S. Sambare, *A Survey of Vertical Handoff Algorithms to Minimize Probability of False Handoff.* International Journal of Engineering Research and Applications (IJERA), 2013. **3**(1): p. 96-105.
108. Cheelu, D., M.R. Babu, and P.V. Krishna, *A Study of Vertical Handoff Decision Strategies in Heterogeneous Wireless Networks* International Journal of Engineering and Technology (IJET), 2013. **5**(3).
109. Pahlavan, K., et al., *Handoff in hybrid mobile data networks.* Personal Communications, IEEE, 2000. **7**(2): p. 34-47.
110. Chen, W., J. Liu, and A. H. Huang, *An adaptive scheme for vertical handoff in wireless overlay networks*, in *Proceedings on the 10th International Conference on Parallel and Distributed Systems (ICPADS 2004)*. 2004. p. 541-548.

.
111. Wang, W., R. Katz, and J. Giese, *Policy-enabled handoffs across heterogeneous wireless networks*, in *Second IEEE Workshop on Mobile Computing Systems and Applications, 1999 (Proceedings WMCSA'99)*. 1999. p. 51-60.
112. Keeney, R. and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs.* . 1976, New York, NY, USA: Wiley.

113. Stevens-Navarro, E. and V. Wong. *Comparison between vertical handoff decision algorithms for heterogeneous wireless networks*. in *Proceedings of IEE Vehicular Technology Conference (VTC-Spring)*. 2006.
114. S. Quiqyang and A. Jamalipour, *A network selection mechanism for next generation networks*, in *International Conference of Communications (ICC 2005)*. 2005. p. 1418-1422.
115. Saaty, T.L., *How to make a decision: The Analytic Hierarchy Process.* European Journal of Operational Research, 1990. **48**.
116. T. Ahmed, K. Kyamakya, and M. Ludwig. *A context-aware vertical handover decision algorithm for multimode mobile terminals and its performance*. in *Proceedings of the IEEE / ACM Euro American Conference on Telematics and Information Systems (EATIS 2006),*. 2006.
117. S. Balasubramaniam and J. Indulska, *Vertical handover supporting pervasive computing in future wireless networks.* Computer Communications and Networks, 2009. **27** (8): p. 708–719.
118. Zang, Y., et al., *Wireless local danger warning using inter-vehicle communications in highway scenarios*, in *European Wireless Conference 2008.* 2008: Prague, Czech Republic.
119. Schoenhof, M., et al., *Coupled vehicle and information flows: Message transport on a dynamic vehicle network.* Physica A: Statistical Mechanics and its Applications, 2006. **363**.
120. Bianchi, G., *Performance analysis of the IEEE 802.11 distributed coordination function.* IEEE JSAC, 2000. **18**(3).
121. Zang, Y., et al., *Congestion control in wireless networks for vehicular safety applications.*, in *European Wireless 2007*. 2007: Paris.
122. Sories, S., J. Huschke, and M.-A. Phan, *Delay performance of vehicle safety applications in umts*, in *15th World Congress on ITS*. 2008: New York.
123. Riva, O., *Middleware for Mobile Sensing Applications in Urban Environments*, in *Department of Computer Science Series of Publications* 2007, University of Helsinki Finland: Helsinki.
124. Riva, O., J. Nzouont, and C. Borcea, *Context-Aware Fault Tolerance in Migratory Services*, in *MobiQuitous* 2008, ACM: Dublin, Ireland.
125. Kinder, R., *Cost effective updates of Automotive Software*, in *Automotive MegaTrends Q2*. 2015.
126. Jayaraman, K., *Connected Cars in Connected Era*, in *Automotive MegaTrends*. 2015.
127. Boagey, R. and S. Slusser, *New functionalities, new risks: it's time to secure the connected car*, in *Automotive Mega Trends Q2*. 2015.
128. Webpage. *NS-Miracle*. [cited; Available from: http://telecom.dei.unipd.it/pages/read/58/.
129. SK, a. *IEEE802.11P TCL*. 2013 [cited; Available from: https://github.com/hbatmit/ns2.35/blob/master/tcl/ex/802.11/IEEE802-11p.tcl.
130. Webpage. *OMNET++*. [cited; Available from: http://www.omnetpp.org/.
131. Webpage. *The Network Simulator*. [cited; Available from: http://www.isi.edu/nsnam/ns/.
132. Webpage. *QualNet*. [cited; Available from: http://web.scalable-networks.com/content/qualnet.
133. Webpage. *SimPy*. [cited; Available from: http://simpy.sourceforge.net/.

134. Webpage. *The Enterprise Dynamics*. [cited; Available from: http://www.incontrolsim.com/.
135. Webpage, *Anylogic.*
136. Choffnes, D.R., F.E. Bustamant, and E. Mustafa, *STRAW-An Integrated Mobility and Traffic Model for VANETs*, in *Student paper*. 2011.
137. Davies, V.A., *EVALUATING MOBILITY MODELS WITHIN AN AD HOC NETWORK*, in *Department of Mathematical And Computer Sciences*. 2000.
138. Bettstetter, C., G. Resta, and P. Santi, *The Node Distribution of the Random Waypoint Mobility Model for Wireless Ad Hoc Networks.* IEEE Transactions on Mobile Computing, 2003. **2**(3).
139. Yunpeng, Z., et al., *Congestion Control in Wireless networks for Vehicular Safety Applications*, in *8th European Wireless Conference*. 2007: Paris, France.
140. Kondo, Y., et al., *Wireless Channel Detection Based on Fluctuation of Packet Arrival Interval*, in *15th IEEE International Conference On Networks ICON, Nov,2007.* . 2007.
141. Joo, C., S. Bahk, and H. Kim. *Detecting Spatial Congestion in Multihop Wireless Network*. in *Proceedings of the international conference on Wireless communications and mobile computing, 2006.* 2006.
142. Fu, Z., et al., *The Impact of Multihop wireless channel on TCP throughput and loss.*, in *INFOCOM 2003, Twenty-Second Annual Joint Conference of the IEEE Computer and Communications Societies.* 2003.
143. Wiaschhof and H. Rohlin, *Congestion Control in Vehicular Adhoc Networks* in *IEEE International Conference on Vehicular Electronics and Safety, 2005.* 2005.
144. Wan, C.-Y., S.B. Eisenman, and A.T. Campbell, *CODA:Songestion Detection and Avoidance in Sensor Networks*, in *Proceedings of the 1st international conference on Embedded networked sensor systems, 2003.* 2003.