Adaptive data transfer for dedicated short range communications (DSRC)-based vehicle networks.

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Adaptive Data Transfer for Dedicated Short Range Communications (DSRC)-Based Vehicle Networks

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This thesis is dedicated to the Almighty God for His mercies, and wisdom given to me to undergo this research. I also dedicate it to my wife Mrs. Dorathy Nwizege, and to my two children Favour Nwizege and Lesor Nwizege.

Declaration

I herewith declare that this thesis has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

The thesis work was conducted from 2010 to 2014 under the supervision of Dr. Kyeong Soo (Joseph) Kim, and Dr. Petar Igic.

Signed...
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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

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Abstract

Vehicular communications occur when two or more vehicles come into range with one another, to share data over wireless media. Its applications are far-reaching, from toll collection to collision avoidance.

Rate Adaptation Algorithms (RAAs) in IEEE 802.11 wireless networks maximize throughput by selecting their transmission rates among the multiple available transmission rates based on the time-varying and location-dependent wireless channel conditions. In this thesis, a detailed study is made on Adaptive Context-Aware Rate Selection (ACARS) algorithm that is efficient for data transfers, improving energy utilization, and also suitable for road safety applications. The goal of ACARS is to implement a RAA that can reliably estimate Signal-to-Noise-Ratio (SNR) to the Physical (PHY) layer by the integration transmission power, and Access Point (AP) coordination into its design.

One of the major challenges of deploying mobile nodes in wireless networks is the power management. ACARS is able to minimize the total transmission power in the presence of propagation phenomena and mobility of vehicles, by rapid estimation of SNR to the PHY layer.

Regarding safety applications in vehicular communications, RAAs need to minimize delay. ACARS minimizes the delay by using optimum data rates which reduces the network load in order to meet the application requirements. Simulation results confirm that the air-time (delay) as one of the key factors for safety applications is within the range of 100 ms recommended by the Institute of Electrical and Electronic Engineers (IEEE) standard for vehicle safety applications.

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List of abbreviations

AC	Access Category
AK	Acknowledgement
AP	Access Point
AR	Access Router
AMPS	Advanced Mobile Phone System
ADAS	Advanced Driver Assistance System
AES	Advanced Encryption Standard
AWN	Affected Wireless Network
ACARS	Adaptive Context-Aware Rate Selection
ARF	Automatic-Rate Fallback
ASN	Abstract Syntax Notation
AARF	Adaptive Automatic-Rate Fallback
AIFS	Arbitrary Inter-Frame Space
ATT	Average Transmission Time
ATIM	Ad-Hoc Traffic Indication Message

AU	Application Unit
BE	Best Effort
BK	Background
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CW	Contention Window
CARS	Context-Aware Rate Selection
CTS	Clear-to-Send
CSMA/CA	Carrier-Sense Multiple Access with Collision Avoidance
CQI	Channel Quality Indicator
CCA	Clear Channel Assessment
CARA	Collision-Aware Rate Adaptation
CFB	Contention Free Burst
CW	Contention Window
CW	Collision Warning

CSR	Connection Set-up Request
CCH	Control Channel
CN	Correspondent Node
CCW	Cooperative Collision Warning
CRC	Cyclic Redundancy Check
CCA	Clear Channel Assessment
CSW	Curve Speed Warning
DSRC	Dedicated Short Range Communication
DIFS	Distributed Inter-Frame Space
DCF	Distributed Coordination Function
DSL	Digital Subscriber Line
DMT	Discrete Multi-Tone
DSSS	Direct Sequence Spread Spectrum
EDCA	Enhanced Distributed Coordination Function
ECS	European Committee for Standardisation

EBL	Emergency Brake Light
EU	European Union
ES	Expanded Spectrum
ETF	Education Trust Fund
EWMA	Exponentially Weighted Moving Average
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FH	Frequency-Hopping
FHSS	Frequency-Hopping Spread Spectrum
FM	Frequency Modulation
FDMA	Frequency Division Multiple Access
GPS	Global Positioning System
HRDS	High-Rate Direct Sequence
HCF	Hybrid Coordination Function

ICT	Information and Communication Technology
ID	Identification
ISM	Industry Scientific and Medical
IR	Infra-red
ICWA	Intersection Collision Warning/Avoidance
ITS	Intelligent Transport System
IP	Internet Protocol
IEEE	Institute of Electrical and Electronic Engineers
IFS	Inter-Frame Space
LAN	Local Area Network
LOS	Line-Of-Sight
LTA	Left Turn Assist
LCW	Lane Change Warning
MATLAB	Matrix Laboratory
MAC	Medium Access Control

Msg	Message
MIB	Management Information Base
MPS	Mega Bits Per Second
MPS	Metre Per Second
MR	Mobile Router
MNN	Mobile Network Node
MANET	Mobile Ad-Hoc Network
MDRS	Model-Driven Rate Selection
MD	Movie Download
MVMAX	Multi-Vehicular Maximum
MSDU	MAC Service Data Unit
NIC	Network Interface Card
NS-2	Network Simulator 2
NAV	Network Allocation Vector
OBU	On-Board-Unit

OSI	Open Systems Interconnection
OFDM	Orthogonal Frequency-Division Multiplexing
OAR	Opportunistic Auto-Rate
PDA	Personal Digital Assistant
PKT	Packet
PER	Packet Error Rate
PRMA	Packet Reservation Multiple Access
PDR	Packet Delivery Ratio
PHY	Physical
PC	Personal Computer
PMD	Physical Medium Dependent
PLCP	Physical Layer Convergence Procedure
PCF	Point Coordination Function
PIFS	PCF Inter-Frame Space
PC	Power Control

PCF	Point Coordination Function
PCS	Pre-Crash Sensing
QoS	Quality of Service
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QAP	QoS enabled Access Point
RF	Radio Frequency
RA	Rate Adaptation
RAA	Rate Adaptation Algorithm
RWP	Random Waypoint Model
RECV	Received
RBAR	Receiver-Based Auto Rate
RA	Receiver Address
RSS	Received Signal Strength

RSSI	Received Signal Strength Indicator
RTS	Request-to-Send
RSU	Road Side Unit
RRAA	Robust Rate Adaptation Algorithm
SCH	Service Channels
SA	Service Announcement
SNR	Signals-to-Noise Ratio
SINR	Signal-to-Noise Interference Ratio
SIRs	Signal-to-Interference Ratios
SIFS	Short Inter-Frame Space
SDL	Specification and Description Language
STRAW	STreet RAndomWaypoint
SSM	Stop Sign Model
SSA	Stop Sign Assist

SGRA	SNR-Guided Rate
TCP	Transmission Control Protocol
TXOP	Transmission Opportunity
TKIP	Temporal Key Integrity Protocol
TG	Task Group
TSM	Traffic Sign Model
TSV	Traffic Signal Violation
TVSP	Transit Vehicle Signal Priority
T-R	Transmitter-Receiver
TA	Transmitter Address
TDMA	Time Division Multiple Access
TC	Toll Collection
UHF	Ultra High Frequency
US	United States

UPS	User Priorities
VoIP	Voice over Internet Protocol
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
VSC	Vehicle Safety Communication
VC	Vehicle Collision
VCA	Vehicle Collision Avoidance
VANET	Vehicular Ad-Hoc Network
VO	Voice
VI	Video
WFQ	Weighted Fair Queuing
WAVE	Wireless Access to Vehicular Environment
WLAN	Wireless Local Area Network
WZW	Work Zone Warning

Notations

θ	Angle
$\overline{V}$	Average speed
$\overline{N}$	Average retries
ξ	Average energy efficiency
η	Back-off
$\ddot{B}$	Bit error rate
$\vec{C}_R$	Communication range
ctx	Context-information
d_c	Cross distance
V_{const}	Constant speed
$\hat{G}_R$	Data rate
K	Density estimate
ℓ	Empirical path loss
$g_s(t)$	Fast fading, coefficient t-time
E_c	Function that uses context-information
T_{xo}	Lower limit of transmit power
$\vec{V}_{Mob}$	Mobility function
$g_m(t)$	Multipath fading

CW_{min}	Minimum contention window size
CW_{max}	Maximum contention window size
SNR_{min}	Minimum SNR
CW_o	Minimum total contention window size
$\wp_{min}$	Minimum received power
V_{max}	Maximum number of vehicles
ρ_{max}	Maximum density
M_R	Maximum transmission range
Thr_{max}	Maximum throughput
P_{TX}	Normalised transmit power
$\tilde{P_{TX}}$	Noise power
κ	Optimal transmit power
γ	Path loss exponent
P_L	Packet length
$g_p(t)$	Path loss model
ϵ	Power tolerance
E_H	Past transmission statistics
ρ	Penalty of unsuccessful transmission

$g_(t)$	Power gain
Pos_{new}	Position of vehicles
Pos_{AP}	Position of AP
$\Re$	Received signal strength
P_{rx}	Received power
δ	Rate
$g_s(t)$	Shadow fading
σ	Shadow deviation
t_{slot}	Time slot
$\vec{TV}$	Transmitting vehicle
CW_t	Total contention window range
$\tilde{B_{TX}}$	Transmitted bit
$TX_{attempt}$	Transmission attempt
$\tilde{P_{TX}}$	Transmit power
Thr	Throughput
$\vec{TR}$	Transmission range
λ	Wavelength
α	Threshold of context-information for EWMA

1

Introduction

1.1 Overview

The frequent occurrence of accidents on our roads is a major concern for every nation, since accidents contribute a significant percentage to the daily death rate. This concern is one of the challenges facing research in vehicular communications and road safety. For several years now, vehicular networks have been a topic of unique research interest in the area of wireless and mobile communications. The number of road accidents can be reduced with greater communication and co-operation between vehicles and Road Side Unit (RSU) offered by the Intelligent Transport Systems (ITS) [7].

Dedicated Short Range Communication (DSRC) is regarded as one of the most promising technologies to provide a robust communication medium and is affordable enough to be built into every vehicle. It is designed to support both road safety and commercial applications. Road safety applications will require reliable and timely wireless communications, while commercial applications will expect a high data rate. In order to provide a high rate of reliable data rate, an important technique for wireless communications is adaptive modulation and coding, which adapts to the communication channel conditions and attempts in order to provide the best possible communication performance. However, due to the high speed of vehicles, the time during which two vehicles or a vehicle and a roadside AP are in a communication range can be very short, which pose a big challenge for the rate adaptation of vehicle communication networks. In this project, adaptive and context-aware Rate Adaptation Algorithms (RAAs) are investigated for DSRC-based vehicle networks, with transmit power control and AP coordination to improve data transfer performance [8].

In order to adaptively transfer data in vehicular networks, it is needful to develop a context-aware rate selection algorithm so that vehicles can change bit rate in the midst of fast movement of vehicles to the bit rate that will give an optimum throughput performance. With this rate selection scheme, vehicles can communicate with each other efficiently with minimal delay and good throughput performance for optimum system utilization. By integrating power control scheme into our proposed rate selection algorithm, it will minimize energy consumption of communication system, enhance Quality of Service (QoS), improve collision avoidance due to AP coordination, and reduce congestion due to range checking. In order to evaluate the performance of the power control scheme integrated in this proposed algorithm, simulation will be done for different environments using path loss exponent and shadowing. By these simulations, analyses on the impact of propagation phenomena on the rate selection schemes will be considered.

Since packet collisions are mitigated by reducing the network congestion, it is necessary to have a RSU that will coordinate the communicating vehicles (clients) and reduce the number of vehicles contending for the network resources at a given time using the range checking technique.

This chapter starts with a general overview of DSRC and then assume RAAs. Evolution of wireless communication technology will also be considered, and explain motivations in this research. The aims and objectives of this research will be provided, including statements of originality in this thesis. Finally, the outline of this thesis will conclude the chapter.

1.2 Rate Adaptation Algorithms (RAAs)

Rate adaptation is a link layer mechanism critical to the system performance in IEEE 802.11 Wireless Local Area Networks (WLANs) [9]. It is the process to choose the optimum rate for the current channel conditions. It is also one of the fundamental resource management issues for 802.11 devices which are used to deal with channel dynamics. The reason for rate adaptation is to maximize the throughput via exploiting the multiple transmission rates available for 802.11 devices and adjusting their transmission rates dynamically to the time-varying and location dependent wireless channel conditions.

1.3 Evolution of Wireless Communication Technology

Since the early 1990s, there have been remarkable changes and challenges in the area of wireless and mobile communication. The development of semi-conductors and integrated circuits is the basis of the working principle of mobile communication [10]. In the late 1990s, this area experienced a rapid growth and interest with the existence of 2G, 3G, and 4G cellular networks. Due to the flexibility and portability of this technology, it motivated many researchers in the field of Information and Communication Technology (ICT) with telecommunication engineers interested in how to employ the capabilities of this technology. In the last few years, we have witnessed a dramatic growth in the wireless industry which has created a lot of employment as well as financial revolution in the wireless industry. Since the introduction of this technology, there has been a tremendous shift away from landlines telephones which were very effective since their introduction in 1979 to mobile cellular telephony in 1980.

The Advanced Mobile Phone System (AMPS) was launched in 1982 in the United States due to the growth of mobile communications in order to deploy mobile services to people. The system was allocated a 40 MHz bandwidth within the 800-900 MHz frequency range by the Federal Communications Commission

(FCC) for AMPS. An additional 10 MHz bandwidth called Expanded Spectrum (ES), was allocated to AMPS in 1988 [3].

The importance of wireless technology is ubiquitous in that everyone can feel the impact of this technology, since it is deployed both at home, schools, coffee shops, hospitals, offices and many other places. It makes life easier than before when it comes to wireless and mobile technology and devices such as Personal Digital Assistant (PDA), laptops, IPADs and mobile phones are used to deploy these services [11]. The existence of this technology is what makes DSRC technology a reliable mechanism to be built into every vehicle in the near future.

Every part of the world have been identified with the revolution of wireless technology, and you can hardly mention any country now that has not experienced the benefits of wireless technology in areas such as Internet surfing, mobile phones and video conferencing. Furthermore, the spread and development of wireless technology continues to gain more recognition due to the promotion and motivation received from researchers in the field of wireless and mobile networks [12]. Nowadays, wireless technology has absorbed our lives by numerous applications such as video conferencing, watching videos on YouTube [13], social networking and Internet surfing. Today, the IPAD has almost taken over as one of the important portable computer devices thanks to the support of wireless technology.

1.4 Statement of Originality

This thesis deals with the design and implementation of ACARS algorithm. This algorithm is based on the principles of the Context-Aware Rate Selection (CARS) algorithm [14] [15]. Implementing ACARS is based on mitigating the weaknesses of CARS such as, not robust to errors in context-information [14], cannot estimate SNR at the PHY layer, and then improved it while implementing ACARS. The results show that ACARS performs better than the existing RAAs in many scenarios, because it can estimate SNR to the PHY layer and also with the role of the power control scheme integrated into ACARS algorithm..

1.5 Thesis Motivation

In order to design an adaptive context-aware rate selection algorithm, it was important to study and investigate the problems faced by vehicular networks. The communication range between vehicles or between a vehicle and RSU is very short due to the high mobility of communicating vehicles. With this challenge, the primary focus of this proposed rate selection scheme is how to implement a RAA that will combat of these problems, expressed by the following questions: when should vehicles change rates depending on network conditions and how fast should these changes occur?.

1.6 Aims and Objectives

- Investigate the performance measures for adaptive context-aware rate selection algorithms;
- Evaluate the adaptive and context-aware data transfer protocol with power control and access point coordination;
- Mitigate the network congestion through power management schemes;
- Improve QoS through power control;
- Reduce packet collisions for efficient and reliable data transfer for vehicular communication, by using Request-to-Send/Clear-to-Send (RTS/CTS) mechanisms.

1.7 Key Contributions

1. **IEEE 802.11 MAC/PHY Layer Modelling**
   The Medium Access Control (MAC) layer is responsible for managing transmission activities to provide fairness and QoS within the wireless network. Tthe back-off counter scheme was used to determine which station can

transmit, depending on whether the station is busy or idle so as to reduce collisions between communicating vehicles which strongly affects the performance of the wireless network. The PHY layer has also been modelled using estimated SNR. In this model, SNR was calculated for different bit-rates in order to estimate Packet Error Rate (PER)to the PHY layer. This was done using an interpolation of Bit Error Rate (BER) table generated during simulations which is one of the parameters needed in the proposed rate selection algorithm. These parameters were used to implement the proposed algorithm and present a meaningful performance increase in the network functionality compared to existing RAAs.

1. **IEEE Rate Selection Schemes**
   Existing RAAs such as AARF, CARS, ONOE, and SAMPLERATE, used in the IEEE 802.11 standard were investigated. Their heuristic approaches and performance in wireless networks were also considered. In this research, a robust rate selection algorithm known as Adaptive Context-Aware Rate Selection (ACARS) is proposed. This algorithm has better performance than existing RAAs as it can control transmit power in vehicular networks. This proposed algorithm takes care one of the problems of rate selection in the short communication range between communicating vehicles.

1. **Managing Received Signal Strength (RSS) with adaptive rate algorithm**
   Several factors encountered in normal driving conditions compromise the received signal strength. Tall buildings, trees and vehicle mobility pose big challenges for vehicular communications. The presence of propagation phenomena (free space path loss, log-normal fading and Rayleigh fading) affect the performance of transmitting vehicles. A robust rate algorithm is implemented that performs better than existing schemes in the presence of these propagation phenomena. This algorithm reveals that power management control aids QoS in wireless networks and presents a major problem for vehicular communications that can be adopted using a robust algorithm like ACARS and satisfying the transmission requirements by contending

work stations. Another potential problem is due to the high speed of vehicles. The time during which two vehicles or a vehicle and a roadside AP are in communication range can be very short, which pose big challenges on rate adaptation for vehicular networks. The core contribution of this work intends to solve the problem mentioned above by proposing a novel scheme that uses context-information from the environment to perform fast rate adaptation in dynamic environments: this Robust Rate Adaptation Algorithm (RRAA) helps to improve data transfer performance in vehicular communications.

1. Other Contributions

- ACARS can adapt to fast link changing conditions as vehicles move at varying speeds;
- ACARS has the ability to minimize power consumption in vehicular communications;
- ACARS can adapt to varying channel environments in the midst of propagation phenomena and give a throughput improvement in the presence of wide range of different propagation parameters such as path loss exponent and shadowing deviation.

1.8 Thesis Layout

This thesis is organised into seven chapters. Below is a summary of the remaining chapters:

- **Chapter 2:** The second chapter presents the theoretical background and survey of available literature for existing rate algorithms and transmit power control techniques that have been implemented and their performances. This illustrates how existing rate algorithms are implemented and their performances in wireless networks. It also explains the mobility models and network scenarios used in their implementation. It also covers wireless networking technology and radio propagation models which deal with varying propagation effects on signal reception. In addition, different environmental effects on the proposed RAA and assume different mobility models used in vehicular networks. The MAC and PHY layers are also considered here. In this chapter, DSRC is also examined here which is the IEEE 802.11p wireless standard and vehicular technology for the safety and non-safety applications in vehicular communications.

- Chapter 3: This chapters reviews and compares the performance of existing RAAs. It also analyse their MAC/PHY layer which is very important for ACARS. In this chapter, contention window size, traffic prioritization, QoS issues, and full implementation of existing and proposed RAAs is considered. This chapter details a number of rate adaptation algorithms and their performance. With knowledge established in this chapter, designing and implementing the proposed RAA is considered in Chapter 4.

- Chapter 4: This chapter covers the design and implementation of adaptive rate algorithms. It explains how the proposed RAA performs using mathematical analysis and simulation models, using flow charts, figures and algorithmic representations of the proposed algorithm. This chapter also explain concepts related to the design and implementation of the proposed algorithm. Some of these concepts are propagation phenomena, which involve free-space path loss model, and slow and fast fading. It also examine transmitting vehicle communications in different environments; by varying path loss exponent and shadowing deviation parameters to evaluate the performance of vehicles in a particular environment. This chapter also investigates the transmissions using Request-to-Send/Clear-to-Send (RTS/CTS) messages to alleviate the hidden node problem common to all wireless and mobile networks.

- **Chapter 5:** Chapter 5 discusses the results obtained and analyses performance metrics without fading, and path loss exponent and the impact of context-information on adaptive rate algorithms. Several performance metrics such as Packet Error Rate (PER), average energy efficiency, success probability, throughput, collision probability, airtime and others were used to analyse the performance of existing RAAs, and compare them with the performance of the proposed algorithm. This chapter also considers the network scenario where vehicles are not restricted to some communication range to evaluate the impact of communication range on vehicular communications and to evaluate the impact of increased SNR in these networks.

- **Chapter 6:** Chapter 6 discusses the results obtained for different performance metrics and the analysis with fading, path loss exponent, AP coordination and transmit power control. It also analyse the performance of existing RAAs in the presence of propagation effects such as shadowing and fading, and also compare their performances with proposed algorithm in different environments. This is to study the effect of interference encountered by vehicles as they move from one environment to the other while experiencing the varying channel condition. This chapter also analyse the impact of AP coordination since it improves QoS performance and energy utilization.

- **Chapter 7:** This final chapter concludes the thesis and offers recommendations for future work. It also offers critical analysis and the limitations of this thesis.

2

Theoretical Background and Literature Survey

It is very essential to demonstrate a good understanding of existing RAAs with the attendant architectural designs that follow its application in this research. These topics have been carefully chosen to form the core part of this design, so that they are fully understood before the actual design chapter. In this chapter, the followings will be considered:

- Wireless networking technology;
- MAC and PHY layer implementation;
- Mobility modelling;
- Radio propagation model.

2.1 Wireless Networking Technology

One of the remarkable differences between wired and wireless networks is MOBILITY. The users can connect to existing networks and can then move about freely without having to worry about getting disconnected. The other fact is

FLEXIBILITY. This means that modern day wireless networks can be deployed in very short span of time and it does so without creating much clutter. To set up a wireless network, base station (s)is needed and antennas. Once this is configured the users can connect to the network easily through their wireless Network Interface Card (NIC) present in their Personal Computers (PCs) or laptops or other wireless capable hand held devices. Other advantages of wireless networks over wired are; it is cheaper to deploy, it is scalable.

The central feature of all wireless networks is their ability to transmit data over the air in the form of electromagnetic signals. Ideally the wireless technology should free the user of any physical boundaries so that the user can roam freely without worrying about losing connectivity and performance degradation. For IEEE 802.11 networks, two sorts of media were conceived in the electromagnetic spectrum. The infra-red light and radio frequency. Devices like printers, and mobile phones use infra-red technology to exchange data, while most IEEE 802.11 devices use radio frequency as their transmission media.

Wireless networks have emerged so well and become popular as they are deployed in almost every sector of life such as schools, hospitals, coffee shops, airports, restaurants etc. Modern mobile devices such as laptops, PDAs are some of the tools used in deploying wireless services in these sectors. The interesting thing is that, multimedia services such as Voice over Internet Protocol (VoIP), video can be deployed using wireless technology known as WLAN. IEEE 802.11e using MAC is an emerging supplement to the IEEE 802.11. Wireless devices are required to use only a specific frequency band of the entire radio frequency spectrum. This frequency band plays a major role in determining the bandwidth as each band has unique propagation characteristics. This propagation characteristic determines the amount of data that can be transmitted through the air without any loss of information, called the bandwidth of the spectrum. The bandwidth mainly measures the amount of data that could be exchanged or transmitted over the link in bits per second. Frequency band and the bandwidth hold the key to the capacity of the wireless network. The wider the frequency band is the higher the bandwidth becomes thereby increasing the capacity of the wireless link. It has been proved using mathematical techniques, information theory and signal processing techniques that higher bandwidth slices have the capability of transmitting higher amount of data [2]. The use of radio frequency spectrum is controlled by the government regulatory authorities through the licensing process. For example, mobile phones operate over 900, 1800 or 1900 MHz frequency band. The carrier companies like Cingular, T-Mobile acquire permission from these regulatory authorities to use this band for their operations and services. In turn, they pay a license fee to the regulatory authority for this permission. In the United States (US), Federal Communications Commission (FCC) is the regulatory authority that controls and provides this permission. Table 2.1 shows the different frequency bands used in the United States and the type of service available in each band. The frequency band used by DSRC falls in the C-Band satellite uplink looking at Table 2.1 [2].

Table 2.1: List of Common Frequency Bands used in USA.

Band	Frequency Range
UHF ISM	902-928 MHz
S- Band	2-4 GHz
S-Band ISM	2.4-2.5 GHz
C-Band	4-8 GHz
C-Band Satellite Downlink	3.7-4.2 GHz
C-Band Radar (Weather)	5.25-5.925 GHz
C-Band ISM	5.725-5.875 GHz
C-Band Satellite Uplink	5.925-6.425 GHz
X-Band	8-12 GHz
X-Band Radar (Police/Weather)	8.5-10.55 GHz
Ku-Band	12-18 GHz
Ku-Band Radar(Police)	13.4-14 GHz

The rate at which WLAN and multimedia applications are so popular and challenging, makes it a great interest to work in this area, because almost every sector now makes use of WLAN, and wants to communicate via it using any of the multimedia applications. It is applicable in road safety via DSRC technology [2]. The IEEE 802.11 standard, 1999 edition is a revision of IEEE Standard 802.11-

1997 [5]. This standard defines the protocol and compatible interconnection of data communication equipment via the air, radio or infra-red, in a Local Area Network (LAN) using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol medium sharing mechanism. The MAC supports operation under control of an AP as well as between independent stations. The protocol includes authentication, association, and re-association services, an optional encryption or decryption procedure, power management to reduce power consumption in mobile stations, and a point coordination function for time bounded transfer of data. The standard includes the definition of the Management Information Base (MIB) using Abstract Syntax Notation 1 (ASN.1) and specifies the MAC protocol in a formal way, using the Specification and Description Language (SDL). The infra-red implementation of the PHY supports 1 Mbps data rate with an optional 2 Mbps extension. The radio implementation of the PHY layer specifies either a Frequency-Hopping Spread Spectrum (FHSS) supporting 1 Mbps and an optional 2 Mbps data rate or a Direct Sequence Spread Spectrum (DSSS) supporting both 1 and 2 Mbps data rates. The scope of this standard is to develop MAC and PHY layer specifications for wireless connectivity for fixed, portable, and moving stations within a local area. The purpose of this standard is to provide wireless connectivity to automatic machinery, equipment, or stations that require rapid deployment, which may be portable or hand-held, or which may be mounted on moving vehicles within a local area. This standard also offers regulatory bodies - a means of standardizing access to one or more frequency bands for the purpose of local area communication. Specifically, this standard;

- Describes the functions and services required by an IEEE 802.11 compliant device to operate within Ad-Hoc and infrastructure networks as well as the aspects of station mobility (transition) within those networks;
- Defines the MAC procedures to support the asynchronous MAC Service Data Unit (MSDU) delivery services;
- Defines several PHY signalling techniques and interface functions that are controlled by the IEEE 802.11 MAC;

- Permits the operation of an IEEE 802.11 conformance device within a WLAN that may coexist with multiple overlapping IEEE 802.11 wireless LANs;

- Describes the requirements and procedures to provide privacy of user information being transferred over the Wireless Medium (WM) and authentication of IEEE 802.11 conformance devices [3][16].

The advent of wireless data communications goes back to who first encoded data onto a wireless medium between 1870 – 1874 using 5-bit encoding known as Baudot code. Since that time wireless communication of encoded data has advanced in leaps and bounds, but the technology we predominantly use today is actually based on wired data communication protocols and functions [17]. The IEEE 802.11 specifications, which are in use on the majority of personal computer equipment, inherit much from the wired counterpart, IEEE 802.3 [3] more commonly referred to as Ethernet. The IEEE 802.11 standards have been at the core of wireless communication since the mid-1990's, and advances are now driven by the proliferation of wireless equipment into many electronic devices [3][18] [19]. Wireless networks have emerged so well and become popular as they are deployed in almost every sector of life such as schools, hospitals, coffee shops, airports, restaurants etc. Modern mobile devices such as laptops, PDAs are capable of deploying these services. The interesting concept is that, multimedia services such as VoIP, video can be deployed using wireless technology known as WLAN. IEEE 802.11e wireless standard has better performance for QoS which is an emerging supplement to the IEEE 802.11. Figure 2.1 shows the modern trend of wireless systems with mobility features which makes applications and deployment of mobile and wireless services flexible and easier than before. Table 2.2 is a comparison of different wireless technologies. This table summarizes the basic parameters for three wireless technologies. It can be seen from the table that DSRC requires the lowest latency compared to the others. This is because of the stringent requirements owed to its applications such as video, voice, collision avoidance etc.

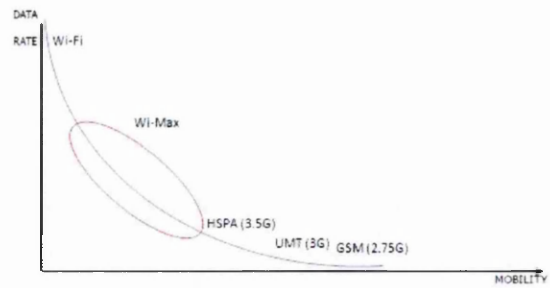

Figure 2.1: Data Speed Vs Mobility for Wireless Systems [1].

Table 2.2: A Comparison of Wireless Technologies.

Parameters	DSRC	Cellular	Satellite
Range	100 to 1000 meters	Kilometres	Thousands of Kilometres
Latency	200μs)	1.5 to 3.5 s	10 to 60 s
Cost	None	Expensive	Very Expensive

2.2 IEEE 802.11 Wireless Communications

The IEEE 802.11 wireless networks consist of two basic architecture, the Ad-Hoc and Infrastructure networks. An Ad-Hoc network is the collection of mobile nodes connected in arbitrary positions. In this set up, two or more stations communicate with each other without an access point. These stations normally communicate with each other and not the outside internet. If they want to connect to the outside Internet then one of the stations is made to act like a router, or the users will have to use the second type of configuration called the infrastructure network. Both of these architectures can also operate in a single network; then both of them can be combined. These basic wireless network architectures can implement any type of network demand depending on what type of outcome that is expected by the user. Due to the demand of high data rate and high speed of vehicles, the vehicles need to be equipped with an OBU that will be responsible for communicating among V2V or the RSU. In this research, a V2I network is implemented without implementing the V2V because, it is by far the most complex communication network scenario to implement because of the required specific routing solutions [20]. Apart from this reason, the aim of this set up is to achieve low latency communications among vehicles which can be extended in terms of their connectivity and satisfy our goal of safety applications in vehicular networks. Another reason for adopting this approach is that, it is useful for distribution of time critical data. Figures 2.2 and 2.3 show the two types of network configurations discussed in this section.

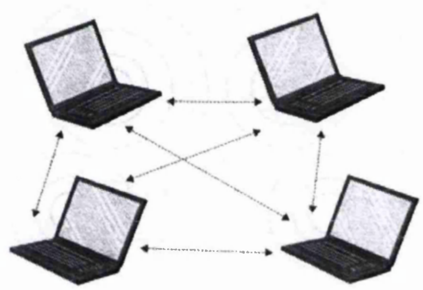

Figure 2.2: IEEE 802.11 Ad-Hoc Network Set up [2].

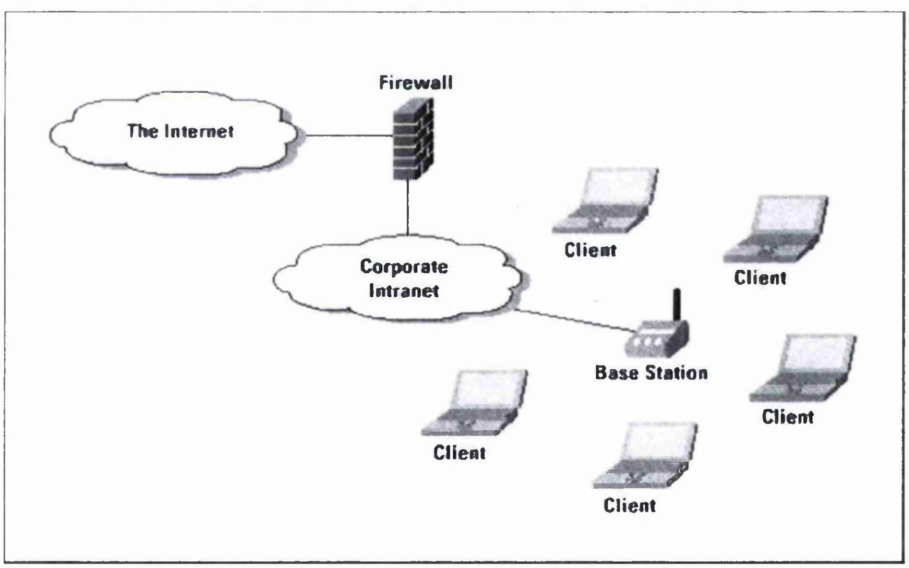

Figure 2.3: IEEE 802.11 Infrastructure Network Set up [2].

From Figure 2.4, a combination of both V2V and V2I form a single network. From this Figure, the beginning of the network is a V2V and then it is extended and merged with a V2I network.

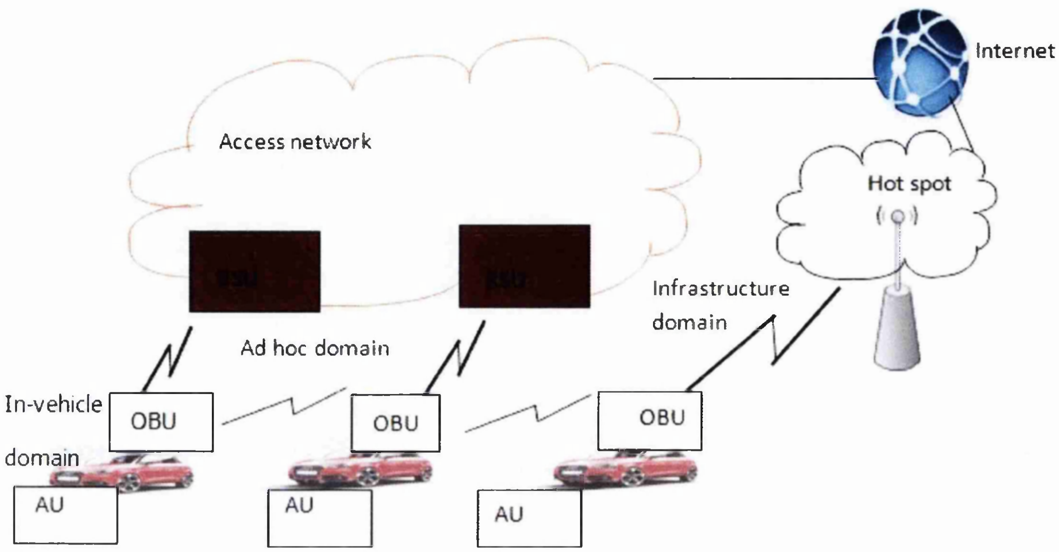

Figure 2.4: V2V and V2I Network Configuration.

2.2.1 IEEE 802.11 Family

The IEEE 802.11 family consists of wireless LANs with different characteristics. One of the unique features of each of them is their data rate and effectiveness [21]. The most basic security features of 802.11 are: authentication, confidentiality, and integrity. The IEEE 802.11 family currently includes six over-theair modulation techniques that all use same protocol. 802.11a, b, g are the most popular techniques. IEEE 802.11b was the first widely accepted wireless networking standard, followed by 802.11a and 802.11g. IEEE 802.11b and 802.11g standards use the 2.40 GHz band while 802.11a standard uses the 5 GHz band.

2.2.2 Description of 802.11 Wireless Standards

There are various classes of IEEE wireless standards. The peculiar feature of each standard is the date rate or bit rate. Some of them are represented in Table 2.3.

Table 2.3: WLAN standards [2].

Standard	Release	Data Rate	Range (Maximum)
802.11	1997	2 Mbps	20 metres
802.11a	1999	54 Mbps	35 metres
802.11b	1999	11 Mbps	38 metres
802.11g	2003	54 Mbps	38 metres
802.11n	2009	$>$ 200 Mbps	70 metres

2.2.3 IEEE 802.11a

This was released after 802.11b [2]. It is more expensive than 802.11b and not so much adopted. Manufactures of equipment for this standard responded to lack of market success by improving the implementations and by making technology that can use more than one 802.11 standard. It has advantage of less interference because of its 5 GHz band occupancy. The disadvantage of this standard is that there is restriction in its line of site, because of high frequency band requirements, this makes this standard to employ more APs. 802.11a cannot penetrate as far as 802.11b, since it is absorbed more easily.

2.2.4 IEEE 802.11b

IEEE 802.11b usually written as IEEE 802.11b-1999 [2] is an amendment to the IEEE 802.11 wireless networking specification that extends throughput up to 11 Mega Bits Per Second (Mbps)and uses the same 2.4 GHz band. This wireless standard has been implemented all over the world as with the specification marketed as Wireless-Fidelity (Wi-Fi). The related amendment of this wireless standard was incorporated into the IEEE 802.11-2007 standard.

The IEEE 802.11b standard operates at 11 Mbps, but will scale back to 5.5 Mbps, then 2.0 Mbps and then 1 Mbps. This standard is less susceptible to corruption due to interference and signal attenuation. Some of the advantages of this standard are: price reductions, good signal coverage in the range of 30 m at 11 Mbps and 90 m at 1 Mbps.

2.2.5 IEEE 802.11e

This is an enhanced version of the IEEE 802.11 standard; it offers more QoS features because of the access mechanisms use. Details about how the MAC layer enhance performance of this standard is discussed in later chapter. This explains how the nodes communicate and transmit with the help of the minimum contention window for different traffic classes for efficient channel utilization. Resource control is efficient in this type of wireless network when properly planned and implemented [2].

2.2.6 IEEE 802.11g

This wireless standard has net throughput like that of IEEE 802.11a [2], and works in the 2.4 GHz band like 802.11b but operates at a maximum raw data rate of 54 Mbps. It suffers from same interference problem as 802.11b which is already crowded in the 2.4 GHz range. The devices that operate in this range include: Bluetooth, cordless telephones, and microwave ovens. The presence of 802.11b reduces the rate of 802.11g network in co-located deployments.

2.2.7 IEEE 802.11i

This is a supplementary draft standard with its intention to improve WLAN Security. This standard describes the encrypted transmission of data between systems of 802.11a and 802.11b WLANs. This standard also defines a new encryption key protocols including the Temporal Key Integrity Protocol (TKIP) and the Advanced Encryption Standard (AES). AES requires hardware upgrades. This is the ratified security standard [2].

2.2.8 IEEE 802.11n

This wireless standard is about 50 times faster than IEEE 802.11b [2], and up to 10 times faster than 802.11a or 802.11g. The real data throughput is estimated to reach a theoretical 540 Mbps; this requires a higher raw data rate at the physical layer. The development of this standard started in 2002 and was implemented in 2009.

2.2.9 IEEE 802.11r

This is a standard in development for fast roaming between APs. Due to re-authentication of each AP resulting due to mobility of the users, it leads to delays which disruptive low latency applications such as voice and video. This new standard will allow pre-authentication with other APs before the handover takes place [2].

2.2.10 IEEE 802.11s

As of march 2006, the IEEE mesh networking Task Group (TG) was developing a standard for wireless mesh networks (IEEE 802.11s) [2]. Although there are existing Wi-Fi mesh network that play the same role, this standard was ratified in 2007. Mesh networks have some peculiar characteristics such as expandability, resilience, large coverage, flexibility and other such features.

2.2.11 IEEE 802.11p

IEEE 802.11p is an extension of 802.11 Wireless LAN MAC and PHY layers [2]. It can be used by the Advanced Drivers Assistance (ADAS) and Intelligent Transport Systems (ITS). IEEE 802.11p is orthogonal OFDMbased to compensate for both time and frequency-selective fading. It is very similar to 802.11a in that it uses 5.2 GHz while 802.11p use 5.85 – 5.925 GHz. IEEE 802.11p emphases on reduced channel spacing (10 MHz instead of 20 MHz in 802.11a).

2.2.12 IEEE 802.11p Multi-Channel Operation

The IEEE 802.11p protocol is designated to the WAVE [5][22], containing approval of modifications to the IEEE 802.11 standard with enhanced wireless access functionality which will permit applications in ITS. These enhancements allow exchange of data in both V2V and V2I networks among high-speed vehicles.

The IEEE 802.11p standard consists of a multi-channel operation, with seven 10 MHz channels as shown in Figure 2.5 on page 22 (there are no guard channels specified currently, so the frequency band is contiguous) at the 5850-5925 MHz range (usually abbreviated to the 5.9 GHz range) of the spectrum. The allocation of this spectrum has been implemented both in EU and the US and currently being implemented in other countries as each country reviews the allocated spectrum available to their region of operation. IEEE 802.11p is part of the family of IEEE 1609 standards which also defines higher layer protocols [22]. IEEE 802.11p operates at 5.9 GHz band US and 5.8 GHz band (Japan and Europe) with 75 MHz bandwidth that has been set aside especially for vehicular communication as part of the DSRC. This channel allocation is free but it uses a licensed frequency band. IEEE 802.11p physical layer is identical to IEEE 802.11a. IEEE 802.11a PHY layer employs 64-sub-carrier OFDM, out of which only 52 is used for actual transmission consisting of 48 data sub-carriers, and 4 pilot sub-carriers. Moreover, the transmission power may be higher (up to 44 dBm) in 802.11p compared to that in 802.11a. IEEE 802.11p MAC layer is derived from the basic IEEE-802.11 Distributed Coordination Function (DCF). The channels are made up of a Control Channel (CCH), 4 Service Channels (SCH), a high power and long range channel and an accident avoidance/safety of life channel. These channels are normally scanned by the equipment at predefined cycles in the order: CCH>SCH>CCH>SCH>CCH
>SCH>CCH>SCH. This covers all the SCH without losing time in the CCH [23]. All WAVE devices need to monitor the CCH during the CCH interval. At the beginning of each scheduled channel interval, a guard interval is used to account for variations in channel interval time and timing inaccuracies. Upon start up, a device monitors the CCH until an announcement of service that utilizes a SCH,

or the device chooses to utilize the SCH based on WAVE announcement frames it transmits.

A node listens to the CCH at least a certain amount of time. On the CCH announcements, services can be transmitted. These services can then be provided on the SCH. The WAVE standard does not define if one radio should listen to channels in time slots or if multiple radios can be used to observe several channels simultaneously. The channel access is defined in IEEE 1609.4 [24]. So far, most ITS-related VANET research focuses on applications operating on a single channel as if in isolation (i.e.the only application using the channel).

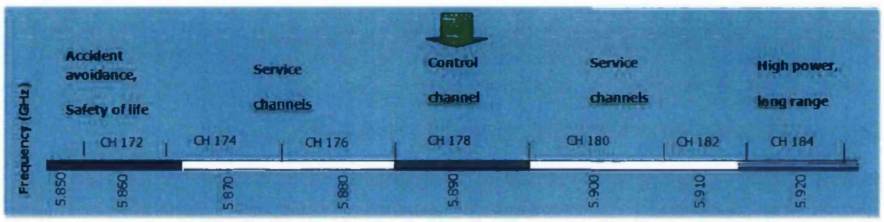

Figure 2.5: Proposed DSRC Channels.

Figure 2.5 shows the seven proposed DSRC channels and their frequency bands. Each band is 10 MHz wide and by using OFDM several channels can operate simultaneously. Hence it is called multi-channel operation.

2.2.13 Other IEEE Wireless Standards

Other standards in the family (c-f, h, j) are service enhancements and extensions or corrections to previous specifications.

2.2.14 MAC and PHY Layer Implementation

The purpose of the MAC layer is to coordinate the use of communication medium. This protocol helps to decide which node will access the shared medium at any instant of time [25]. Prior to transmission of frames, a station have to gain access to the medium first, i.e. to a radio channel that is shared stations. The

802.11 standard defines two forms of medium access: DCF and Point Coordination Function (PCF). With DCF, the 802.11 stations contend for access and attempt to send frames when there is no other station transmitting. If another station is sending, other stations will wait until the channel is free. While PCF uses the centralized or polling based to provide free channel access in the 802.11 MAC layer, more explanation on this MAC layer types are given in later sections. The MAC Layer checks the value of its Network Allocation Vector (NAV) which is a counter resident at each station that represents the amount of time that the previous frame needs to be sent. NAV must be zero before a station can attempt to send a frame. Before transmitting a frame, a station calculates the amount of time required to send a frame based on the frame's length and data rate. When stations receive frames, they will examine this duration field value and use it as a guide for setting their corresponding NAVs. This process then reserves the medium for the sending station. There are two basic limitations of the MAC layer protocol; they are asymmetric interactions and sub-optional default allocation. The former is the interference between two flows either at the sender or at the receiver which results to one flow to be shut-off, while the sub-optional default allocation shows that the default allocation of the transmission medium by the MAC layer fails to meet the requirements of some applications. More sophisticated back-off protocols or slot algorithms can be used to implement more flexible allocation policies like Weighted Fair Queuing (WFQ). Other solutions to this can also be achieved by using a combination of both back-off and slot allocation algorithm. Furthermore, since the MAC layer of 802.11 lacks QoS support, 802.11e which has EDCF features which was lacking in DCF used by 802.11 to improve the performance metrics of wireless networks. The IEEE 802.11p MAC protocol is a derivative of the DCF of the IEEE 802.11, and it uses the IEEE 802.11e EDCF with QoS support.

2.2.15 The MAC Layer

The MAC layer of WAVE protocol is defined in IEEE 1609.4 as well as in IEEE 802.11p [2]. The fundamental MAC protocol is identical to the IEEE 802.11 DCF whereas EDCA of IEEE 802.11e provides the basis for the MAC extensions.

These include introducing the AC and Arbitrary Inter-Frame Space (AIFS) used for differentiation and prioritization. Different applications are assigned different ACs and corresponding values are chosen for AIFS and Contention Window (CW) sizes. Four different data traffic categories are available with their corresponding priorities: Video (VI), Voice (VO), Best effort (BE), and Background (BK) traffics. The CSMA/CA, a window-based back-off algorithm is generally employed in wireless medium MAC protocols. In this mechanism, the node senses the medium first. In case the medium is in use, the node chooses a uniformly distributed random back-off time value from the interval $[0, CW + 1]$, where CW_{min} is the initial value of the CW. If the subsequent transmission attempt is unsuccessful, the interval size is doubled until CW value reaches CW_{max}. The main emphasis of IEEE 802.11p MAC protocol is to ensure the reliable transmission of time critical information while optimizing the available radio resources.

In the highly mobile environment, especially the contention-based phase in 802.11p as show in Figure 2.6, uses the EDCA originally provided by IEEE 802.11e. Four priority classes ensure four different QoS levels. Fixed waiting times $AIFS$ of different lengths are used to make sure that high priority packets get access to the medium first. Within the respective priority classes, however, packet collisions are still possible. After a packet collision has occurred, a back-off time is randomly chosen from an interval (CW). The window size is also coupled to the priority level, giving high priority packets the higher probability of channel access after a collision. The initial size of the CW is given by the factor CW_{min}. Each time a transmission attempt fails, the CW size is doubled until reaching the size given by the parameter CW_{max}. Table 2.4 on page 30 summarizes the parameter defined for EDCA in 802.11p, where 1 denotes the highest priority level, and 4 the lowest. The parameters are given in time slots where one slot is defined as 8μ s. Although these priorities can be used to increase the probability of certain packets to get access to the wireless channel, there are no guarantees that this will happen before a predefined deadline [26][27].

In the MAC layer, the physical CSMA/CA does not rely on the ability of stations to detect a collision by hearing their own transmission; an Acknowledgement (ACK) is transmitted by the station to signal the success of the transmitted packets. And then transmission of ACK is immediately done following the received packets after a Short Inter-Frame Space (SIFS). The packet is re-scheduled if either the transmission of a different packet or if the transmitting station does not receive the ACK within a specified ACK-Timeout period [28][29]. When a node wants to transmit a packet, it will wait until the medium is idle for at least a Distributed Inter-Frame Space (DIFS) and then it will pick a random time within its back-off window and waits until this time expires. In case the medium has been idle during the entire back-off period, it will send packet and resets the back-off window to the minimum value. Otherwise, it doubles the back-off window and waits until the medium is idle for at least a DIFS period of time, and then begins the back-off period again.

2.2.16 Distributed Coordination Function (DCF)

This is one of the basic access mechanisms used by IEEE 802.11 MAC to provide contention based channel access and MAC layer protocol in 802.11 standards. It is based on CSMA/CA scheme with binary exponential back-off. DCF is also regarded as a mandatory based access mechanism [28][30]. The problem of 802.11 legacy is that is does not support the concept of differentiating frames with different priorities. Also due to the random nature of channel based, the MAC is not able to provide guaranteed QoS.

DCF provides channel access with equal probabilities to all stations contending for the channel access in a distributed manner. On the other hand, equal access probabilities are not desirable among stations with different priority frames. DCF does not guarantee QoS; it can only support best effort services. In DCF, all the stations compete for the available resources and the channel having the same priority.

DCF has many limitations: It does not provide a QoS guarantee, neither does it support real time applications. It was primarily designed for equal priorities, so it does not support the concept of differentiation of frames with different user priorities. Increasing time during contention at the channel leads to throughout degradation and high delay. However, it is simple and robust and can provide a priority service with little modifications. To start a DCF transmission, a station must sense the medium idle for a minimum duration called the DIFS. If the channel is busy at the time the station tries to access the medium, then the station needs to sense the channel idle for additional random time period. This is called the back-off procedure. This operation is shown in Figures 2.6, and 2.7 on page 26 respectively.

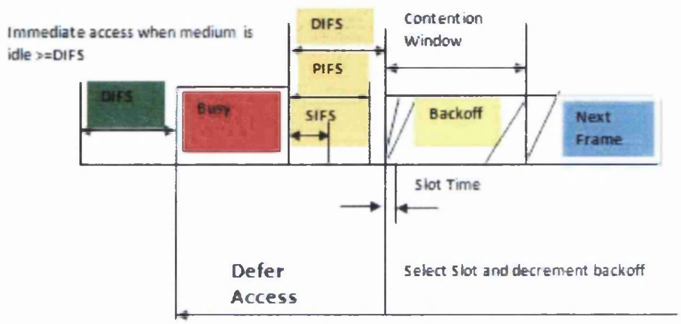

Figure 2.6: IEEE 802.11 DCF Channel Access.

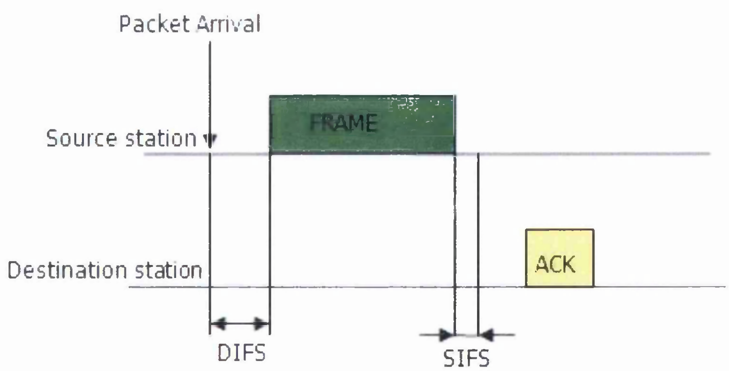

Figure 2.7: DIFS and SIFS Mechanism.

Furthermore, where a medium is observed to be busy, a random back-off interval is selected. In this case, the back-off time counter with a random back-off interval is selected. The back-off time counter is decremented as long as the channel is sensed idle; it is stopped when the transmission is detected on the channel, and re-activated when the channel is sensed idle again for more than a

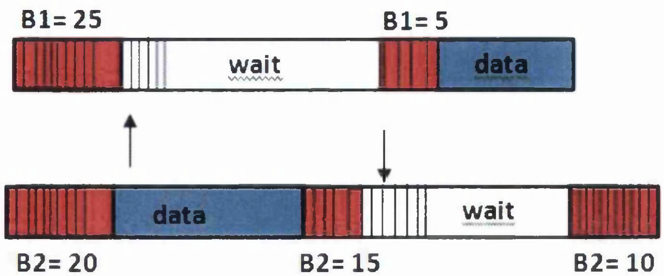

Figure 2.8: B1 and B2 are Back-off Intervals at Node 1 and 2.

DIFS. The station transmits when the back-off time reaches 0. In addition, to avoid channel capture, a station must wait a random back-off time between two consecutive packet transmissions, even if the medium is sensed idle in the DIFS time.

2.2.17 Point Coordination Function (PCF)

This uses the centralized protocol or polling to provide free channel access in 802.11 MAC layer and it is an optional access mechanism. This mechanism can provide a level of service that guarantees a central scheduling scheme unlike DCF which introduces extra complexity and protocol overhead. However, it provides good real time operation and also enhances data transmission rate. PCF defines a coordinator station that is known as point coordinator, which might start transmission after if it senses the channels is idle for a PCF Inter-Frame Space (PIFS). To avoid collision with current transmissions, PIFS must be higher than the Short Inter-Frame Space (SIFS) which is used for fragmentation and control frames [30]. PCF mechanism has some problems that may lead to poor QoS performance, and hence is not widely used among existing WLAN, and in all, it is not ideal for handling QoS requirements; it can only be used in infrastructure networks.

2.2.18 Role of Enhanced Distributed Coordination Function (EDCF) in Wireless Networks

This mechanism clearly differentiates between 802.11 and 802.1e wireless standards. It is able to provide a differentiated channel access to frames with different priorities. This exhibits an optional feature called the Contention-Free Burst (CFB) that enables multiple MAC frame transmissions during a single TXOP. With this new scheme, multiple queues can work independently with a single MAC which is not available in DCF mechanism. The functionality of this MAC layer in wireless networks is shown in Figure 2.11. This figure shows how different functions interact with each other in the MAC layer. It also shows the back-off count operation in the MAC layer.

This mechanism of the MAC layer is responsible for QoS. It functions so that transmitted packet is given priority, depending on the traffic type to be transmitted. They are classified as AC.

Access Category

IEEE 802.11p defines four ACs for eight different User Priorities (UPs), and employs EDCA mechanism. In packet transmission, usually video traffic is given highest priority because of its stringent delay requirement. They are as follows:

- AC_{BK}: background;
- AC_{BE} : best effort;
- AC_{VI}: video;
- AC_{VO}: voice.

Each AC is assigned a TXOP for conducting frame exchanges and utilizes EDCA parameters set to contend TXOPs. The value of each AC is listed in Table 2.4 on page 30 which represents the type of traffic, and the corresponding value that is allocated to each traffic type. In this simulation, only values of

AIFSN were considered because, simulation was not done for specific traffic type but values of CW_{min}, and CW_{max} respectively were used only. Figure 2.9 also show the different traffic types and the values assigned to each traffic type. It also relates the SIFS scheme and how transmission opportunity is allocated to each traffic type in order to avoid collision and adopting fairness. Table 2.4 on page 30 shows the different traffic types.

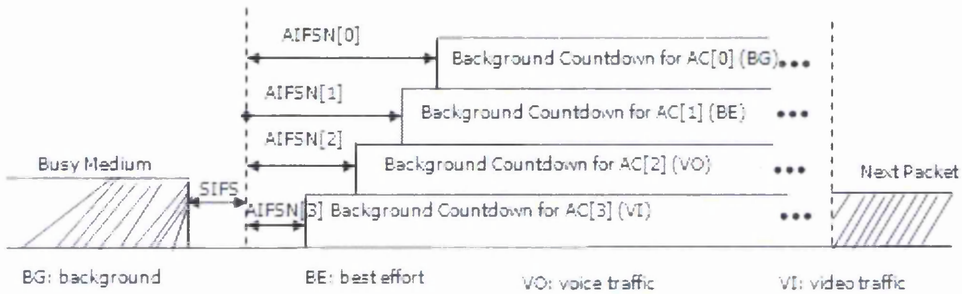

Figure 2.9: Example of Packet Transmission using EDCA.

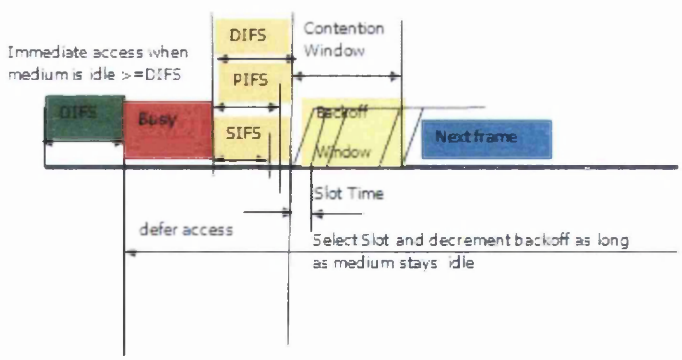

Figure 2.10: EDCA Prioritized Channel Access.

In this scheme, a station cannot transmit a frame that goes beyond a time interval called EDCF TXOP limit [23]. EDCF is not a separate coordination function but part of a single coordination function known as Hybrid Coordination Function (HCF) which combines both attributes of DCF and PCF [18]. In EDCA, each traffic flow has one of the four ACs, with each one having a different medium access priority; this works well when the network is moderately loaded as shown in Table 2.4 on page 30. This mechanism provides service differentiation and also classifies the traffic in to 8 different classes, and is also able to provide contention-based channel access.

Table 2.4: EDCA Parameters.

AC	CW_{min}	CW_{max}	$AIFSN$
AAC_{BE}	7	152	6
AC_{BE}	7	152	6
AC_{VO}	3	7	3
AC_{VI}	3	7	2

2.3 Contention Window Size

In the MAC layer, the Contention Window (CW) plays an important role in adjusting the network. The CW of a vehicle is adapted according to the neighbourhood density of a Road Side Unit (RSU). In the MAC protocols, the Binary Exponential Back-off (BEB),is widely used because of its simplicity. In this algorithm each node doubles its CW value up to contention window maximum value (CW_{max}) after a collision and resets CW to contention window minimum value (CW_{min}) after a successful transmission. For instance, if a node has a very high back-off counter and another has small back-off counter, it will reach the zero first and transmit its packets and reset the CW to minimum value and may be can choose small back-off value again and transmit when another node does not reach zero because its back-off value is too high [31].

2.3.1 Managing The Contention Window

A station with a packet to transmit monitors the channel activity until an idle period equal to a DIFS has been observed. In case the medium is sensed busy, a random back-off interval is selected. The back-off time counter is decremented as long as the channel is sensed idle, stopped when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than AIFS. The station transmits when the back-off time reaches 0. In addition, to avoid channel capture, a station must wait a random back-off time between two consecutive packet transmissions, even if the medium is sensed idle in the DIFS time [28][32][33]. Back-off time is calculated using:

$$\eta = CW_{size} \times slot\ time \tag{2.1}$$

In the design of ACARS, the role of the back-off counter is to coordinate the transmission of packets. It also functions in range checking of vehicles, so as to determine the number of vehicles that enters into range, and the ones out of range. From Figure 2.17, the contention window size is also used to regulate the priority of traffic type. High priority traffic like video and voice are always given high priority, because of their stringent delay requirements, while background and best effort traffic are given low priority, since delay will not have much adverse effect on their transmissions.

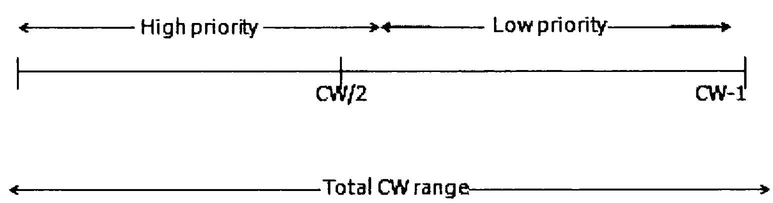

Figure 2.11: Different CW Ranges for Different Priorities.

2.3.2 The Hidden Node Problem

The hidden node effect is the problem faced by all wireless networks. This problem affects some Rate Adaptation Algorithms (RAAs) such as ARF, AARF, and ONOE. This effect makes it difficult for them to distinguish between losses due to collision from losses due to the channel. As shown in Figure 2.12 on page

32, station B and C can communicate with each other via A. Node B, and C are hidden from each other. The distance between them and their inability to communicate prevents one of the nodes from courteously backing-off if they were to send data at the same time. Instead, the two nodes are forced to compete for access to node A. Any of them closer to node A, will have stronger signal than the other. In summary, A and B can hear each other, A and C can also hear other, but B and C cannot hear each other.

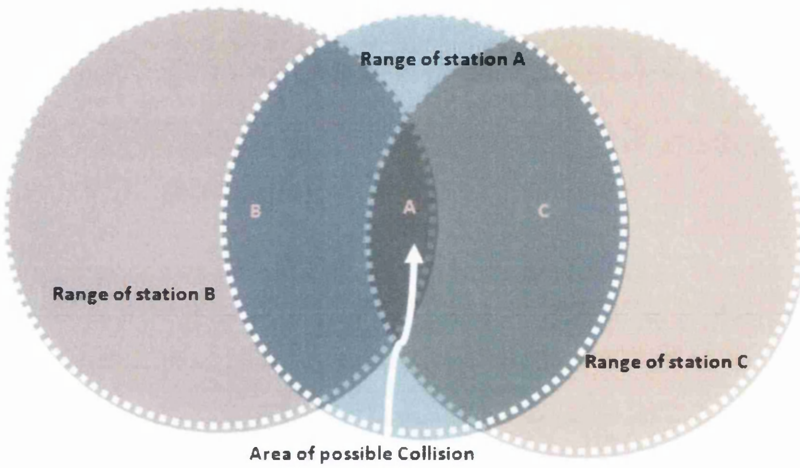

Figure 2.12: Hidden Node Effect In Wireless Networks [3].

2.3.3 RTS/CTS Exchange in IEEE 802.11

Performance of CSMA/CA can be seriously affected in wireless networks when hidden nodes exist in the network. On the other hand, the means to alleviate this challenge is to use the RTS/CTS frame exchange technique. But doing this leads to increase in overheads. However, it is very useful in heavily-contending WLAN environments, where lots of transmission may fail as a result of collisions. RTS/CTS scheme also helps to differentiate between channel error and error due to collision.

RTS/CTS exchange is useful in heavily-contending WLAN environments, where many transmissions might fail due to collisions, and the advantage could be amplified with relatively large data frames. The transmission of an RTS frame should be triggered based on the RTS threshold, using the RTS/CTS frames for other possible purposes, not restricted to the original definition, can be found in supplementary standards. According to the emerging IEEE 802.11e standard [34], the RTS/CTS exchange can be used independently of the RTS threshold.

For example, the RTS frame can be transmitted to reserve a time interval, called Transmission Opportunity (TXOP), for the consecutive transmissions of multiple data frames. Meanwhile, an 802.11g transmitter can initiate an RTS/CTS exchange or simply transmit a CTS frame with the receiver address equal to itself in order to reserve the channel for the transmission of non-basic rate, i.e., OFDM-modulated, frames to address the co-existence problem between the 802.11g and legacy 802.11b devices.

To evaluate the behaviour of ACARS in the presence of hidden node induced stations, the RTS/CTS scheme was implemented to handle this issue. When hidden stations exist in the network, the performance of the basic CSMA/CA can be severely degraded. The unprotected time interval, can be shortened to the RTS transmission time, by preceding the data frame transmission, with the exchange of two short control frames, i.e., RTS and CTS frames, and hence the hidden station problem can be ameliorated. This is known as the original objective of the RTS/CTS exchange. The RTS/CTS exchange is illustrated in Figure 2.13 on page 33 in which the wireless channel is reserved for the transmitter station after a successful exchange of RTS/CTS frames. According to the 802.11 standard, the decision to use the RTS frame transmission is made solely at the transmitter side. That is, the RTS frame is used when the size of the pending data frame is equal to or larger than the RTS threshold value. However, in most of the typical 802.11 devices operating in infrastructure-based WLANs with Access Points (APs), the RTS threshold is set to the largest value, i.e., 2347 octets, which basically disables the usage of RTS/CTS exchange. Accordingly, the RTS and CTS frames are rarely observed in the real WLANs [34].

ACARS is implemented by considering the RTS/CTS frame exchange that handles the hidden node problem common to all wireless networks. In order to get both RTS/CTS length in this design, the PHY header was added to the value of RTS/CTS respectively. This enables us to determine the successful transmission time from our simulation. The RTS/CTS handshake has similar functionality as the CSMA protocol in the MAC layer as shown in Figure 2.13. It demonstrates when a packet is to be sent, and when a successful packet is received with a feedback by acknowledgement. From Figure 2.13 on page 33, there are two transmitting stations $S1$ and $S2$ with a single receiver $R1$, illustrating how data packet is transmitted between stations, and how transmitted data is handled by the receiver.

Figures 2.14-2.16 show some of the most common frames formats. The frame control defines the type of frame (e.g. data frames, control frames and management frames) and depending on the frame type the duration is different. RA and TA are the receiver address and transmitter address, and Cyclic Redundancy Check (CRC).

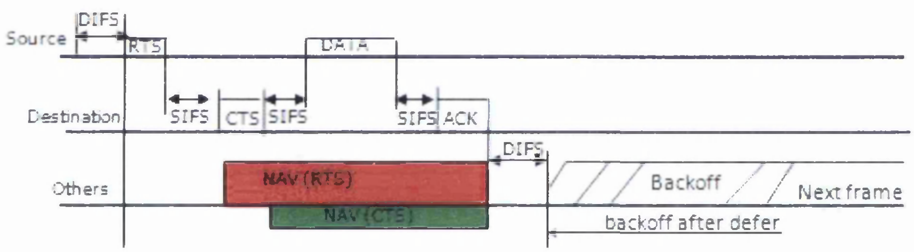

Figure 2.13: RTS/CTS Exchange Mechanism for IEEE 802.11.

Collision can be caused by a high delay, and hidden node. To mitigate the effect of vehicle collision so as to enhance effectiveness in ACARS, the RTS/CTS mechanism was considered. Since the goal of ACARS is to have a delay not greater than 100 ms. The RTS/CTS mechanism assist in reducing the occurrence of Collision effect. Although the benefit of improving rate selection is largely negated by the overhead introduced by the RTS/CTS frames.

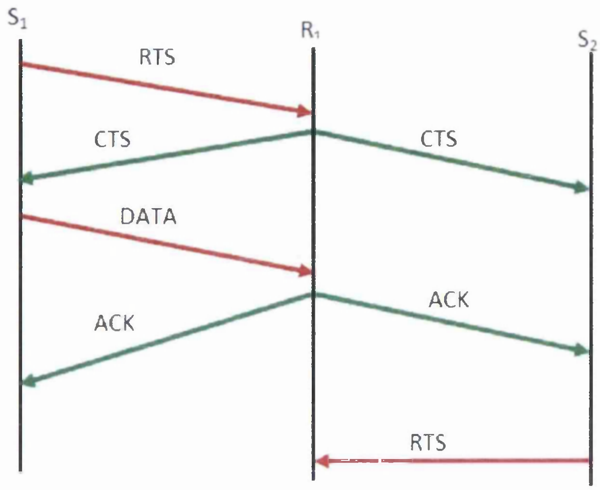

Figure 2.14: RTS/CTS Handshake [4].

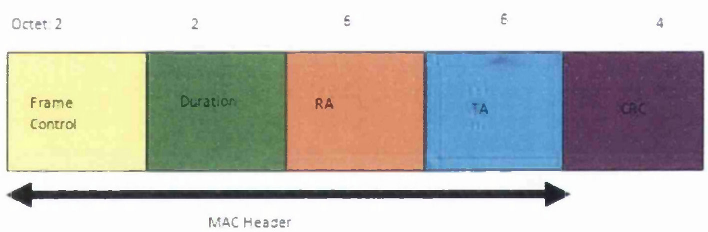

Figure 2.15: RTS Frame Format [4].

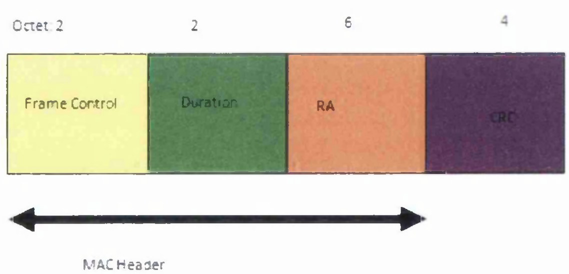

Figure 2.16: ACK Frame Format [4].

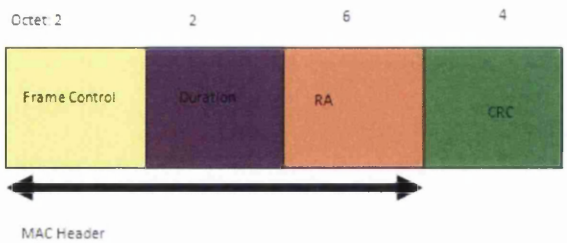

Figure 2.17: CTS Frame Format [4].

2.3.4 Impact of RTS/CTS Mechanism in ACARS Performance

Figures 2.17-2.19 are used to explain the polling processes [35]. They show the best and worst case waiting time that occurs with polling messages. This process helps to explain the collision-free phase of the super-frame. The effectiveness of this scheme is what determines the rate of collision that occurs in the MAC layer. This works in conjunction with the RTS/CTS mechanism that makes a request on when a packet is to be sent in order to avoid collision.

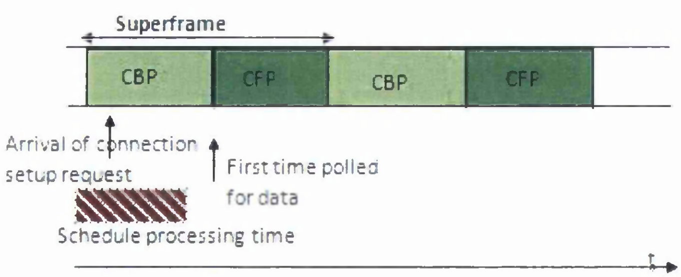

Figure 2.18: Best Case Waiting Time Between Successful CSR and First Polling Message.

2.3.5 The PHY layer

The difference in the physical layer of the Ethernet and IEEE 802.11 networks pose many challenges for the MAC layer. The main component of the 802.11 networks is the radio link. The radio link quality therefore determines the "quality"

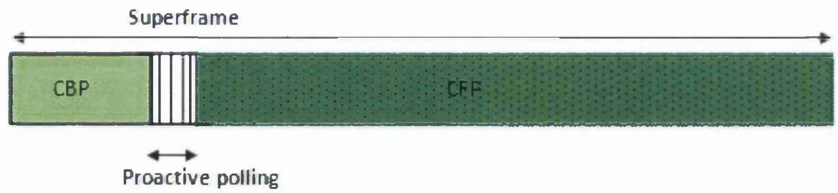

Figure 2.19: Proactive Polling Phase (PPP) as part of the Collision-Free Phase of the Super-frame.

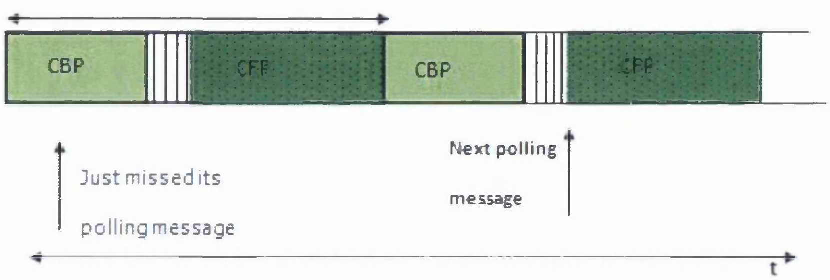

Figure 2.20: Worst Case Waiting Time until Connection Setup for Proactive Polling.

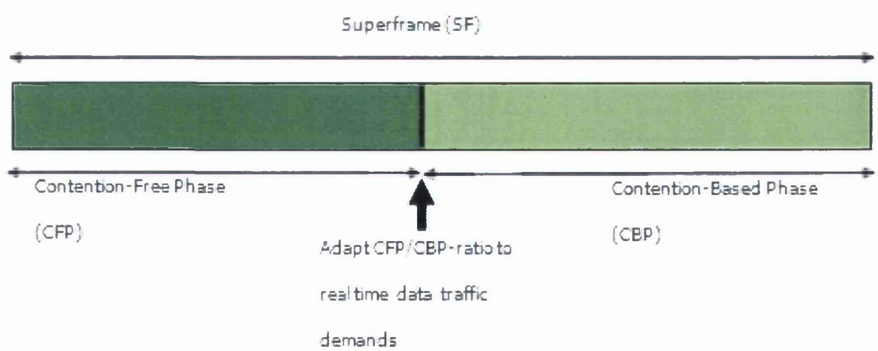

Figure 2.21: Adaptable Radio Between CFP and CBP.

of air that the station will see. In comparison to the Ethernet where irrespective of physical presence of the station on the network the "quality" of the physical media does not change with distance or presence of objects like wall, partitions etc. the radio link quality changes drastically from one place to another according the distance and also with the presence of walls and other obstructions. Radio link quality also matters with the kind of frequency that is employed. Since the 802.11 networks use the unlicensed Industrial Scientific and Medical (ISM) band along with other devices like microwave oven and cordless telephones as mentioned before, therefore presence of noise and interference in the medium is expected. The presence of walls and other obstructions give rise to multi-path fading which could potentially degrade the signal quality received at the station.

Below the MAC layer is the physical layer which deals with the actual transmission of the bits received from the MAC layer above into electromagnetic signals. The PHY layer is important to this thesis discussion because certain parameters like SNR-estimation, power control and propagation model, depend on the working of the PHY layer. The physical layer in the 802.11 standards has been divided into two sub-layers: the Physical Layer Convergence Procedure (PLCP) sub-layer, and the Physical Medium Dependent (PMD) sub-layer. The PLCP layer acts as the gate between the MAC and the PHY layers. It adds its own header information to the frames passing from the MAC to the PHY layer. A preamble is added to the frames to help synchronize the timing for the incoming transmissions. Different modulations techniques might place different kinds of preamble sequences. The PMD has the responsibility of converting the frames received from the PLCP into bits for transmission over the physical media.

The physical layer also has an additional function called the Clear Channel Assessment (CCA) function. Its role is to inform the MAC layer about signal detected on the channel. The 802.11 specifications standardized the physical layers in two stages. First stage had Frequency Hopping (FH) using spread spectrum, Direct Sequence (DS) using spread spectrum and Infra-red Signals (IR). The second stage has two new physical layers being added. They are Orthogonal Frequency Division Multiple Access (OFDMA), High-Rate Direct Sequence or High-Rate Direct Sequence Spread Spectrum (HR/DS or HR/DSSS) respectively. Explain on multiplexing technique is considered in Chapter 4 on pages 88, and 89.

The 802.11 devices also have to deal with the limited range of each radio and therefore the famous hidden node problem; this is shown in Figure 4.9. The hidden node effect is apparent in all wireless networks where two stations try to transmit to a neighbour when out of range of each other. The problem of hidden nodes can be mitigated by the RTS/CTS mechanism and by advanced channel assessment strategies, this is one of the challenges of all wireless and mobile networks. The hidden node effect is shown in Figure 2.12 on page 32 to illustrate how this effect occur in wireless networks.

2.4 Dedicated Short Range Communications (DSRC)

The DSRC specification, was originally developed in the Unites States (US), but it is now in place in the European Union (EU) as well. It is a set of protocol and standard for operating one-way or two-way communications between vehicles in close range. Vehicles move at high-speed in unison using the inter-vehicle communications to allow very close quarters and coordinated velocity/direction changes. One of the applications of this is in electronic toll collection, where drivers entering or leaving certain road sections are automatically charged for their usage. Both the FCC in the US and the European Telecommunications Standards Institute (ETSI) in the EU have allocated spectrum in the 5.9 GHZ range for DSRC. The European Committee for Standardisation (CES) specifies the DSRC physical layer, the data link layer, and the application layer. Some remarkable research has been done on DSRC ranging from computer simulations of a complex road-system to measure throughput, delay and packet success [3] to experimental measurements for outdoor set up and analysis of context-information for safety and non-safety applications on DSRC [14]. This is a continuation of the research in RAA using context-information, but with some improvements in weaknesses of existing RAAs. This research considers our an adaptive data transfer for DSRC-based vehicle networks, where it is focused on designing an adaptive rate algorithm that will use contextual-information for data transfer and apply its results in safety measures as provided in the service channels that deals with road safety application in the nominal frequency allocation band as shown in Figure 2.5 on page 23.

2.4.1 Standardization and Protocol for Dedicated Short Range Communications

Dedicated Short Range Communications (DSRC) is the communication standard for V2V and V2I radio frequency communication links. Rapid advances in wireless technologies provide opportunities to utilize these technologies in support of advanced vehicle safety applications. Particularly, the new DSRC offers the potential to effectively support V2V and vehicle-to-roadside safety communications, which has become known as Vehicle Safety Communication (VSC) technologies [36]. It is designed to offer complete solutions for mobile data broadcast and also to active Wireless Access to Vehicular Environment (WAVE) protocol. DSRC is a short to medium range communication service that supports applications such as electronic toll collection and public safety, which needs high data rate and low latency [37] DSRC enables a new class of communication applications that will increase the overall safety and efficiency of the transportation system. Figure 2.6 shows two safety channels available in DSRC; the control and service channels to deal with safety and non-safety applications respectively. Figure 2.5 shows the frequency allocations for DSRC. Some of the characteristics of DSRC include:

- 5.85 – 5.925 GHz, divided into seven channels (each of 10 MHz);
- Short range audio (300 m);
- High data rate (6 – 27 Mbps);
- Half duplex (stations cannot both send at the same time, but one after the other).

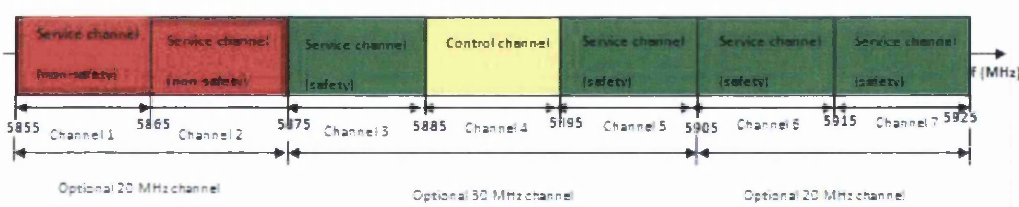

Figure 2.22: Nominal Carrier Frequency Allocation for WAVE [5].

Some of the safety applications of DSRC are shown in Table 2.4 while Table 2.5 lists non-safety applications.

Table 2.5: Public Safety Applications.

Safety Application	Deployment Time Frame
Traffic Signal Violation Warning	Short-Term
Curve Speed Warning	Short-Term
Emergency Electronic Brake Light	Short-Term
Pre-Crash Warning	Mid-Term
Cooperation Forward Collision Warning	Mid-Term
Left Turn Assistance	Mid-Term
Stop Sign Movement Assistance	Mid-Term
Lane Change Warning	Long-Term
Cooperative Collision Warning	Long-Term
Intersection Collision Warning	Long-Term

Table 2.6: Non-Public Safety Applications.

Access Control	Gas Payment	Point-of-Interest Notification
Drive-Through Payment	Data Transfer	Instant Messaging
Car Rental	Fleet Management	Entrance Ride Guidance
Truck Stop Data Transfer	Parking lot Payment	Toll Collection

The channel allocation in DSRC is classified as follows: Small and medium zone service channels, which are kept for extended data transfer, and service channels; designated for special safety application. Public safety application and messaging have priority in all these channels as shown in Figure 2.6.

2.5 Mobility Modelling

Mobility models are used to generate movements of mobile nodes in Ad-Hoc networks. They play a significant role in determining the protocol performance, hence it is desirable hat these models emulate the movement pattern of targeted

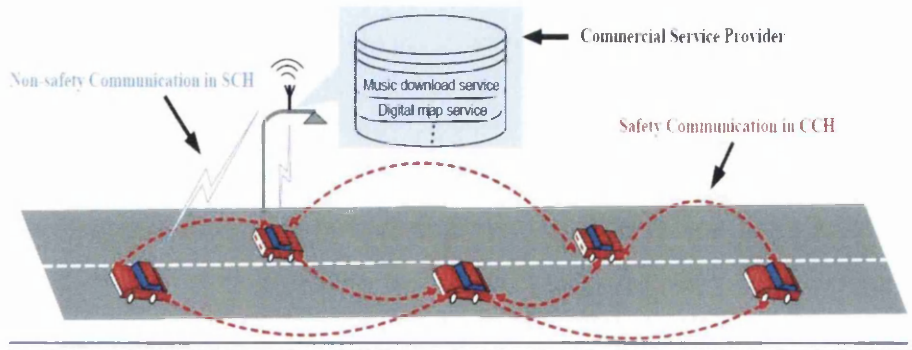

Figure 2.23: Applications of DSRC in Control and Safety Channels [6].

real life applications in a reasonable way [38]. Position, speed and moving direction of nodes are defined by the mobility model during the whole simulation and changes over time. Since mobility causes constant changes in the topology of the Ad-Hoc network, it has a large impact on the performance of the network protocols. In this section, different metrics to evaluate mobility, network topology and routing protocol performance is presented. [8][39].

One of the most difficult and crucial aspects of application and system design of mobile wireless networks is to define what their realistic mobility model depicts [40]. Traces and synthetic mobility models are two essential types of mobility patterns that can be used to evaluate mobile network protocols and algorithms by means of simulations. Synthetic models are mathematical models, such as equations, which try to capture the movement of nodes whereas traces are obtained by means of measurements in deployed networks with logs of connectivity or location information. It is worthy to note that mobility patterns do affect multi-casting routing and other protocol performance. This was verified in [41] by implementing some mobility metrics, including direct mobility metrics, like host and relative speed, and also by derived mobility link changes, link duration, and multicast density. As a matter of fact, networking environment is made challenging because of these peculiar features of node mobility, such as high speed of cars, strict constraints on nodes movement patterns, traffic jams, clusters of nodes etc. These phenomena can only be captured with a limited level of realism in the simulated car movements [42].

As seen in Figure 2.7, the network mobility enables mobile networks to maintain internet-connectivity as it moves as a whole entity [43]. From this figure, a mobile network is composed of one or more Mobile Network Nodes (MNNs) and Mobile Routers (MRs) connected to the MR. From this architecture, it follows that the mobility network is transparent to the MNNs embedded in the mobile network. The MR is responsible for managing the mobility of the MNNs. From this network, any Correspondent Node (CN) that wants to send message to the mobile node only has to send message to the home address of the mobile node.

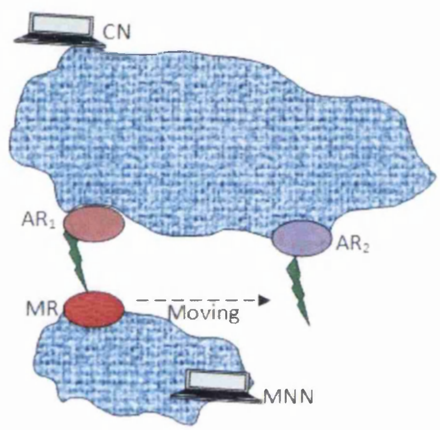

Figure 2.24: Basic Network Mobility Concept.

The choice of mobility model plays a crucial role in performance of vehicular Ad-Hoc networks. Although every mobility model has its own advantages and limitations, the proper choice must be made to achieve the desired realistic model. High predictability is be expected from simulation studies if the mobility model is closely related to real scenarios [44]. Also, overheads of mobile systems depend largely on their node mobility. Figure 2.7 shows the basic concept of the mobility of nodes in a wireless network as discussed in this section. Figure 2.7 shows the relationship between mobile nodes and routers which acts as servers in many wireless network topologies.

2.5.1 Factors Affecting Mobility in Vehicular Ad-Hoc Networks (VANETs)

This section discusses some factors that influence the movements of mobile nodes in wireless networks. **Layout of Streets** forces nodes to confine their movements to well defined paths irrespective of their final destination [45].
Traffic Control Mechanism such as stop signs and traffic lights are the most common traffic control mechanisms at intersection points on the road. These mechanisms contribute to queues and cluster formation of vehicles at intersection points, which reduces average speed of movements.
Speed Limit decides how quickly or slowly a vehicle position changes at any instant of time. The limit of speed encountered on the road depicts how existing routes are broken. (**Block Size** is the smallest area surrounded by streets. The size of a block is a determinate factor for the number of intersections in any location of that area, and this determines the frequency of vehicle stops.
Interdependent Vehicular Motion is the movement of every vehicle dependent on the movement of other surrounding vehicles. For instance, a vehicle may maintain a minimum distance from the one in front of it, and then increase or decrease its speed, or it can also change to another lane to avoid congestion.

2.6 Synthetic Models

Synthetic models are used to mimic the behaviour of mobile nodes in different application scenarios. In entity-based mobility models, each node acts independently of other nodes. Group-based models organize nodes in different groups which move together towards a common destination (e.g. a group of soldiers assigned to a common task). Another category are vehicular mobility models which take into account interactions with other vehicles in their proximity. In the simplest case, a vehicle maintains a constant distance to the front vehicle [8]. Synthetic models are further classified into:

- mobility models with temporal dependency, that is, when the movement of a mobile node is likely to be affected by its movement history. In some mobility scenarios, the mobile nodes tend to travel in a correlated manner [8];

- mobility models with geographic restriction, where the movement of nodes is bounded by streets, free ways or other obstacles [8];
- mobility models with spatial dependency, where nodes tend to travel in a correlated manner [8].

2.7 Vehicular Mobility Models

Research in vehicular mobility started as early far back as in the 60s for the analysis of vehicular traffic in order to design coherent traffic management systems. Recently, the interest in vehicular networks assumes vehicular mobility models that are available in network simulators [46][47].

Mobility models are used for simulating and evaluating the performance of mobile wireless systems and their protocols. It is a great task to manage the movement of mobile nodes in different channel conditions, so it is a challenging research issue for vehicular networks to support a variety of ITS applications [48]. The mobility management schemes available for Internet and Mobile Ad-Hoc Networks (MANETs) are not able to meet the requirements of vehicular networks, so they lead to degrading of the performance of vehicular networks especially in high mobility scenarios.

There are several mobility models often used in vehicular networks. Most of them are implemented in simulators like OMNeT++ [49][50]. On the other hand, depending on the tool used for simulations, some of the tools may not have implemented mobility models; then mathematical modelling is used in describing the type of mobility to be used. In this design, mathematical evaluation is used in describing and implementing the mobility to evaluate the proposed algorithm. This is because Matrix Laboratory (MATLAB) has no implementation of mobility models unlike other simulators as Network Simulator -2 (NS-2), OMNeT++ etc. In this design, several specific mobility models are considered to gain knowledge on how mobility models affect vehicular networks and how they influence the overall performance that may be obtained for a given mobility scheme adopted.

2.7.1 Type of Mobility Models

There are numerous mobility models implemented in different simulation platforms; but discussion is made on few of them, because they are too many to be discussed. Figure 2.8 shows different categories of mobility models. All types of mobility models can be classified under each category shown in this Figure 2.8. This means that each existing mobility model from each category must belong to at least one of the categories shown in Figure 2.8.

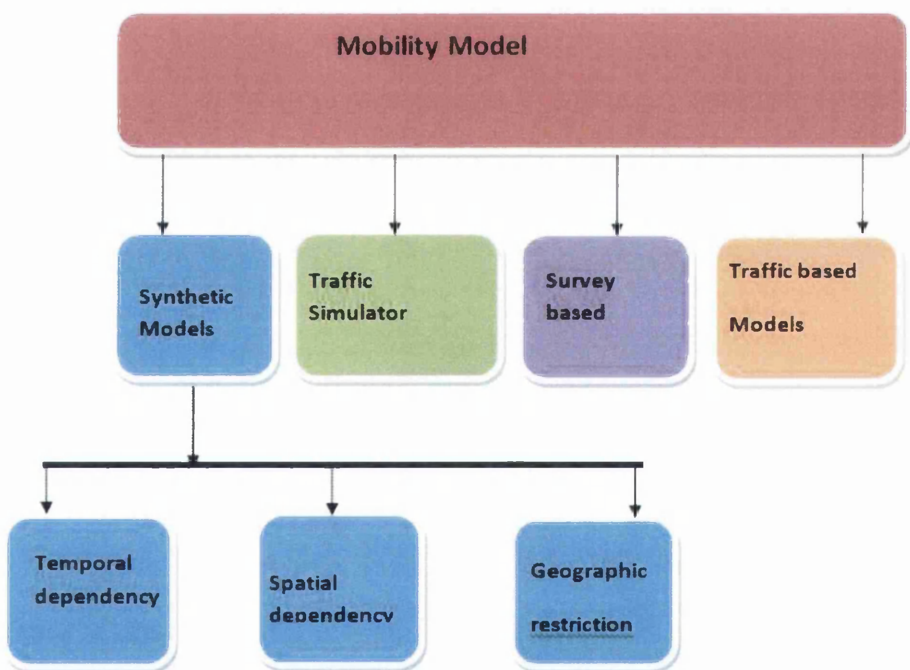

Figure 2.25: Categories of Mobility Models.

2.7.2 Random Walk Model

The Random Walk Model was originally proposed to emulate unpredictable movements of particles in Physics. It is also referred to as the Brownian motion because some mobile nodes are believed to move in an unexpected way. Random walk mobility model is proposed to mimic such movement behaviour [51]. The random walk model has similarities with the Random WayPoint Model because the node movements have strong randomness in both of these models. We can examine random walk model as the specific Random Waypoint model assuming zero pause time. It is the simplest synthetic type mobility model which is widely used to represent purely random movements of the entities in a system in various disciplines from Physics to Meteorology. However, it is not a suitable mobility model for simulating wireless networks, because node movements do not present continuous random changes of direction which is the main characteristic of this model [40].

2.7.3 Random WayPoint Mobility

The Random WayPoint (RWP) model is a random model for the movements of mobile users, and how their location, velocity and acceleration change over time [44][52]. It is one of the mobility models that is widely used in the simulation studies of mobile Ad-Hoc networks to compare the performance of various mobile Ad-Hoc networks. Result obtained from this model, shows that it fails to provide a steady state in that the average nodal speed consistently decreases over time. In [52], recommendation was that this model should be capable to predict the average speed of nodes in simulations. This model assumes that nodes can move around in an open space without obstructions in any direction [45].

2.7.4 Freeway Model

The Freeway mobility model proposed in [8][53] models the behaviour of vehicles travelling on a free-way. The movements of a node are restricted to a lane on a free-way and it is temporally dependent on the previous speeds and other vehicles travelling in front in the same lane. Relationship between the speeds at subsequent time slots is :

2.7.5 Constant Speed

In the ConstSpeed Mobility model, vehicles can move along a lane with constant speed to a randomly chosen target, and when the target is reached, it randomly selects a new one. It was used to model the random positions and also to help to calculate a new target position that the vehicle will move to, and get the distance and when the next vehicle changes speed [15][54]. This mobility model was adopted in the proposed algorithm because; vehicles are required to select speed uniformly over a given range, and also for the purpose of range checking, since communication range between transmitting vehicles and AP is set.

2.7.6 STreet RAndomWaypoint (STRAW)

STRAW uses roads defined by real street maps to model vehicular mobility. A car following model is implemented to model inter-segment mobility. Vehicles adapt their speeds to the vehicle in front in the same lane. Simplified traffic control mechanism models are employed to describe the behaviour of vehicles at intersections [8][53].

2.7.7 Manhattan

This mobility model was mainly proposed for the movement in urban areas, where the streets are laid in an organized manner. It uses a grid road topology. In this mobility model, the mobile nodes move in vertical or horizontal direction on an urban map. The Manhattan model employs a probabilistic approach in the selection of nodes movements, since, at each intersection, a vehicle chooses to keep moving in some direction; the probability of going straight is 0.5, and taking a left or right is 0.25 each [53]. Important characteristics of Manhattan mobility model are:

- The mobile node is allowed to move along the grid of horizontal and vertical streets on the map;
- At intersections of horizontal and vertical streets, the mobile node can turn left, right or go straight with certain probability;
- Moreover, the inter-node and intra-node relationships involved in the Manhattan model are the same as in the Freeway model.

2.7.8 Stop Sign/Traffic Sign Model

An important characteristic of vehicular mobility is the behaviour of mobile nodes at traffic intersections (e.g.stop signs, traffic lights, roundabouts). [53] proposed two mobility models which simulate the influence of stop signs and traffic lights on the mobility of nodes. In the Stop Sign Model (SSM), each vehicle stops at every intersection and waits for a fixed time period [8]. In the Traffic Sign Model (TSM) vehicles stop with the probability of 0.5 for a random time in front of a traffic light. It is possible in both models that vehicles queue at an intersection before proceeding with their journey [45]. This leads to a clustering of nodes which have strong influence on the routing protocol performance.

2.8 Mobility Metrics

Mobility models are used to generate movements of mobile nodes in Ad-Hoc networks. Position, speed and moving direction of nodes are defined by the mobility model during the whole simulation. Since mobility causes constant changes in topology of the Ad-Hoc network, it has a large impact on the performance [8]. For mobile nodes, it is quite challenging to maintain multi-hop communication routes, since the topology is time-varying and once a route has been established, the local route maintenance is necessary in order for that route to continue to exist [55].

This sub-section defines parameters associated with mobility.

Node Density The node density is defined as the number of nodes within a certain area, i.e.

$$\textbf{NodeDensity} = Node/Area \tag{2.2}$$

Node Distance The distance between two nodes a and b is defined as the Euclidian distance between the two nodes, i.e.

$$\textbf{Distance(a, b)} = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2 + ...(x_n - y_n)^2} \tag{2.3}$$

where a, b are points on both x and y coordinates, and n is the number of points on each coordinate.

Node Speed The speed of a node is the distance it travels at a given time.

$$\textbf{Speed} = Distance/Time \tag{2.4}$$

The neighbour distance is defined in the same way as the node distance, but this is calculated only for nodes which are neighbours.

2.9 Radio Propagation Model

In this section, discussion on different propagation phenomena used in this simulation including path loss exponent will be considered. The path loss exponent reflects the different environmental factors that affect received signals as the vehicle's move from one environment to another, while experiencing changing channel conditions. In the simulation, different values of γ is used to represent path loss exponent for different environment or the location where communication among vehicles and APs take place. The path loss exponent depends on the specific propagation environment. It is very expedient to select a free space reference distance that is appropriate to the propagation environment [37].

The propagation phenomena to be discussed in this section are: free-space path loss, shadowing and both slow and fast fading). Signal distortion caused by multipath fading channels, is one of the challenging and most serious problems that every mobile wireless communication systems have to cope with. However, the effect of severe signal fluctuation is still a challenge that has to be overcome even if multi-carrier techniques mitigate the frequency selectivity of wireless channels [56][57]. Hence, to keep the SNR approximately constant at some desired level, power control schemes or techniques must also be adopted.

Multi-path propagation is the most important characteristic of the vehicular communication channels. The radio waves reach the receiver via two or more paths. The effect is either constructive or destructive interference and phase shifting of the transmitted signal. Channel fading cannot be described by large scale fading alone as rather significant small scale fading occurs within meter distances [58].

The multipath propagation in mobile environment causes the transmitted wave to get reflected from distant objects and as well as to be scattered around the receiver resulting in a time-varying impulse response of the channel and amplitude fluctuations of the received envelope, random Frequency Modulation (FM), phase distortion, and frequency selective fading [59]. In a mobile network, provided that the power management scheme is properly implemented, each node will transmit at a minimum power level such that only a fixed number of neighbouring nodes can over hear the transmission. An architecture of power control scheme is shown in Figure 2.12 on page 41.

Power management is a new concept in wireless Ad-Hoc networks which attempts to improve the end-to-end network throughput, and the average power consumption and also to prolong the battery life of mobile nodes [60]. It is a crucial part of the design of this proposed algorithm that controls the power and energy consumption in the network. It is also one of the key aspects of this design that improves existing RAAs. Figure 2.12 shows the concept and operation of power control scheme in wireless and mobile networks. Power control employed in this proposed scheme is effective in the followings areas:

- Collision avoidance (important for road safety applications);
- Maintaining link QoS by adapting to node movements and channel variations;

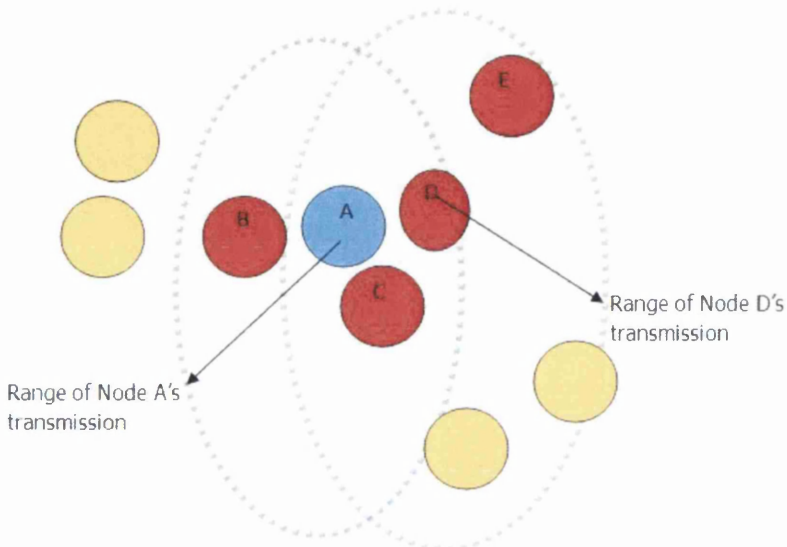

Figure 2.26: A PowerControlled Ad-Hoc Network.

- Reducing network congestion;
- Minimizing power consumption and prolong battery life of mobile nodes;
- Improving spatial reuse;
- Mitigating interference and increasing network capacity in mobile wireless communications [54].

2.9.1 Free-Space Model

In order to analyse the decay and loss of signal strength over a distance, research on the propagation phenomena in wireless and mobile communications has been crucial since the outbreak of vehicular communications. This model was put forward by T. Harald. Friis in 1946 [3][61]. Friis equation extends the ideal of free space loss to incorporate both receive and transmit antenna gains. Since multipath signals is one of the causes of interference at the receiver, in free-space transmissions, the received signal is exclusively a result of direct path propagation, so there will be no interference at the receiver [62].

Free-space path loss model is a power loss with the distance. Due to high mobility of vehicles, the distance between the transmitter and receiver changes, which makes it necessary to model the effect of distance on packet delivery probability. Such path loss accounts for the loss due to spreading of Radio Frequency (RF) energy as transmission of signals propagates through a free space. It is worth noting that the free-space model is unrealistic because it cannot account for numerous terrestrial multipath effects. Free-space analysis is modelled among propagation processes to evaluate the effect of integrated in Power Control (PC) schemes. PC is vital because it is a means of controlling energy consumption in mobile wireless networks, and a means of balancing received power levels or guaranteeing SIRs [62][63]. It aims to minimize energy consumption subject to maintaining a constant transmission rate.

2.9.2 Shadowing and Slow Fading

Fading is a terminology employed in describing fluctuations of a received signal as a result of multipath propagation. Fading can slow and fast and also can be defined in terms of flat or frequency selectivity. Path loss is a function of antenna heights, and the environment, and distance. Hence, the predicted path loss for a system operated in a particular environment will therefore be constant for a given base-to-mobile distance [64]. From Figure 2.13, the particular clutter (buildings, trees) along a path at a given distance varies for every path, causing variations of path attenuations. Some path will suffer from increased loss when being obstructed.

Fast fading is a propagation effect that is characterized by rapid fluctuations over very short distances. This fading occurs as a result of scattering from objects of close proximity; hence it is also called small-scale fading. It can be observed up to half wavelength distances. It is sometimes referred to as Rayleigh fading because Rayleigh distribution is often the best fit for many scenarios when there is no direct path (line-of-sight) [62].

Figure 2.13 shows channel modelling in wireless mobile communications. It shows how multipath fading and obstruction from tall buildings and trees affect

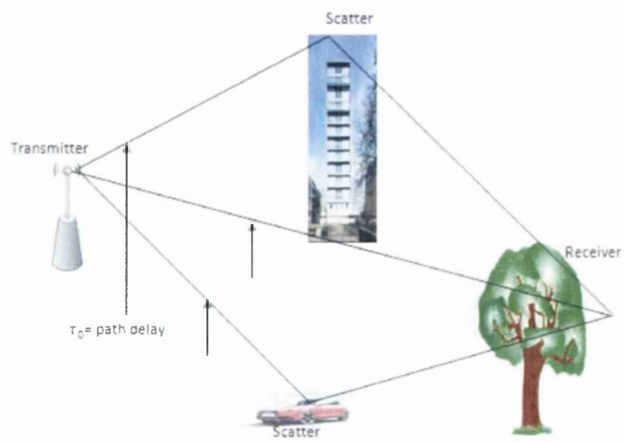

Figure 2.27: Multipath Fading in Wireless Networks.

the quality of signal reception and can impact the packet success rate.

2.9.3 Fast (Multipath) Fading

This type of propagation is sometimes called log-normal fading because a log-normal distribution tends to be the best to describe the fading process. Fading occurs as a result of scattering from distant large objects (shadowing) unlike in the case of fast fading and hence it also termed as large-scale fading [62]. Power control is an efficient technique to combat the effect of multipath fading that affects the received signals in wireless networks.

In vehicular communications, these effects are common due to tall buildings,and trees that spread along the roads as vehicles move from one destination to another. In order to combat this effect, a proper power control needs to be adopted to mitigate fading. PC can also be used to implement various dynamic network operations, such as channel selection and switching, hand off and admission control [65]. Power control schemes often focus on capacity and quality issues, but they should be a means of balancing received power levels of balancing or guaranteeing SIRs [66]. In cellular networks, the aim has been to minimize co-channel interference under Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Packet Reservation Multiple Access (PRMA), and or related protocols.

There are two common methods for controlling power in very fast fading channels. The first attempts to predict the channels behaviour based on past transmission statistics and use this information to update the transmitter power [57]. In order to implement this method, the following parameters are necessary: channel gain, received SNR at each time instant in addition to some statistical information about the communication system. In the second method, knowledge of the channel's mean gain which do not need to be updated until the channel's mean changes [67] is important. The purpose of this method is either to minimize the probability of fading-induced outage or by assigning the powers which bounded the outage probabilities of the user to the system [57]. There are basically two types of algorithms used in power control: open and close-loop algorithms. The former is designed to solve the near-far problem, while the latter helps in reducing the effect of Rayleigh fading [54][56][68]. The essence of open-loop power control is to ensure that the power received by all users is equal in average at the base station.

Usually, the links of wireless mobile networks occupy the same frequency spectrum; this makes them interfere with each other. For this reason, proper resource management is very important in order to combat this problem. Hence, the power of each transmitter is related to the resource usage of the link. Therefore, the users of a link will determine the best power distribution to be carefully managed. The denser the network, the more difficult it becomes to manage the power usage for each mobile node. For more efficiency, adequate resource management is needed to utilize the radio resources used among mobile nodes. Controlling the transmit power of mobile communication is a very efficient means to control the QoS and the capacity of wireless networks [69]. In environments where the channel vary slowly, existing power control schemes are designed to operate in such networks. But in case of vehicular networks, it does not perform well because user channels change very quickly and these methods fail in such scenarios. Power adjustment is needed in this case to tune the instantaneous SINR. Constant power coding is a technique that help nodes to transmit when the channel condition is favourable.

The importance of power control in wireless mobile communications are:

1. Due to channel variations of mobile nodes, constant power is necessary so that data rates can adapt to channel conditions. Scheduling can also be considered so that nodes transmit only when channel conditions are favourable;

2. Maintain constant SIR and therefore constant data rate [70].

2.10 Chapter Summary

In this chapter, the theories related to the design and implementation of the proposed algorithm has been discussed. This chapter has also considered wireless technology which is the basis of IEEE 802.11p standard implementation in this research. It has also expatiated on existing RAAs, their operation and challenges or limitations. Furthermore, the chapter has also explained different mobility models and also gave reasons for the chosen mobility model among the existing ones. This topic is very crucial because this proposed implementation focuses on mobility of vehicles. It is necessary to have the review of literature, so that proper knowledge of mobility models can be fully exploited. One of the key principles of transmission in the MAC layer that helps in collision avoidance, QoS was also considered. The MAC layer protocol was fully discussed so as to gain knowledge of the MAC layer operation and traffic type coordination.

Furthermore, discussion was made on the radio model and underlying propagation processes in vehicular communications on how channel conditions changes so fast due to high mobility of vehicles. This is one of the aspects we assumed in this design to handle power control in vehicular networks. With the knowledge established in this chapter, it will be used to design and implement RAAs in the next Chapters.

3

Review of Existing Rate Adaptation Algorithms

This chapter will deal with existing Rate Adaptation Algorithms (RAAs) and their implementations. It will also explain details of some existing RAAs and also express their implementations using algorithms. It will also show in summary how each of them behaves. This chapter will also highlight some of the challenges faced by these RAAs and also use it as a bench mark for designing and implementing the proposed RAA.

The aim of every RAA is to estimate channel quality and status of other stations (e.g. how many active stations are in a coverage area), and adjust transmission rate accordingly. Rate Adaptation (RA) offers an effective means of facilitating system throughput improvement in IEEE 802.11-based wireless networks by improving the PHY layer multi-rate option upon dynamic channel conditions.

The focus and goal of this research is to design a robust rate adaptation algorithm that will effectively switch bit-rate and adapt to fast channel conditions in a high mobile environment. This proposed RAA should be able to provide better throughput performance than existing rate schemes with the integration of power control scheme and SNR-based designed scheme. In addition, knowing that safety application is one of the reasons for vehicular communications, the proposed RAA should be able to provide latency and collision avoidance according to DSRC standard so as to meet the safety requirements which is provided by ITS for human safety. Power control will be integrated into this design to help minimize energy consumption by appropriate adjustment of vehicles transmitter power, reduce network congestion, improve quality of service and collision avoidance in vehicular networks. The key challenges in bit-rate selection are to determine which bit-rate will provide the best or highest throughputs and also knowing when to switch to another bit-rate that would provide better throughputs.

3.1 Rate Adaptation Algorithms

Rate adaptation is the process of dynamically switching data rates to match the channel conditions, with the goal of selecting the rate that will give a good throughput for the given channel condition. The two fundamental issues when designing a rate adaptation scheme are "when to increase and decrease the transmission rate". The effectiveness of a rate adaptation scheme depends greatly on how fast it may respond to the wireless channel variation [34].

One of the goals of RA is to maximize throughput via exploiting the multiple transmission rates available for 802.11 devices by adjusting their transmission rates dynamically based on to the time-varying and location dependent wireless channel conditions. Many rate adaptation schemes exist and some of them have been implemented either via simulation or experimental scenarios. RA schemes have been proposed in order to increase the throughput of WLAN by changing the transmission rate to the time varying wireless channels while satisfying a given Bit Error Rate (BER) or Packet Error Rate (PER). It is very important to be aware that transmission failure in rate adaptation occurs for two reasons, collisions and poor channels. These two factors will be analysed in later chapters where discussion of results obtained with existing RAAs and proposed algorithm will be considered.

Although several RAAs have been proposed in the literature [6][9][14][34][61][71] [72][73][74][75][76]. The working principle in rate adaptation is all based on indoor wireless networks. The characteristic of indoor wireless networks varies significantly from that of vehicular networks as a result of the high mobility of nodes. Some recently proposed rate adaptation schemes [77][78] deal with the problem of packet loss due to contention. These algorithms face the contention issue with the (RTS/CTS) mechanisms of IEEE 802.11. The RTS/CTS handshake increases data overhead, but it can decrease the collision duration in the presence of long packets. Indeed, it is better to use this mechanism only when losses are due to collisions. Therefore, algorithms like Collision-Aware Rate Adaptation (CARA) [14][34] and Robust Rate Adaptation Algorithm (RRAA) [61] propose to switch on and off the mechanism based on some heuristics.

In [14], a series of outdoor experiments were performed in order to understand how the existing rate adaptation algorithm in wireless network performs in a highly mobile vehicular environment. In their experiments, they observed that existing schemes for rate adaptation (significantly underutilize)[14] the wireless link capacity in vehicular networks. These adaptation schemes can be classified as: transmitter-based or receiverbased, packet statistics-based or SNR-based and window-based or frame-based.

3.1.1 Packet Statistics-Based Schemes

These group of rate adaptation algorithms operate on basis of consecutive success/losses or error rate. Some examples of rate adaptation algorithms in this category are:

- Auto rate retry (ARF) [14][75];
- Adaptive auto rate retry (AARF)[15][79], also known as Adaptive Multi-Rate Retry (AMRR) [2][71];
- ONOE [14][78] ;
- SampleRate [9];
- Context-Aware Rate Selection Algorithm (CARS) [14][72].

Packet Statistics-based scheme uses consecutive frame transmission failure and success counts as an indicator of the channel quality. In this approach, the sender utilizes long-term or short-term statistics from the past (consecutive) transmission results to determine adaptation of the transmission rate to the radio-channel condition change. For example, if the consecutive error rate has increased significantly, the transmission bit-rate may be dropped to the next lower bit-rate. Or, if the consecutive error rate is sufficiently lowered for a while, the transmission bit-rate may be raised to the next higher bit-rate. However, there are some problems with this approach. One of the problems is the decision of inaccuracy of the transmission rate change. For example, if the error rate is increased, most of the bit-rate selection algorithms in this approach reduce the bit rate to a lower bit rate. However, the characteristic feature of 802.11 in hotspots shows that the rate reduction is wrong if the loss is made due to the increased contention (not due to the decrease of radio-signal quality) since the reduction of bit- rate increases contention by occupying the media for an increasingly longer period of time [16].

3.1.2 SNR-Based Rate Adaptation Algorithm

In RAA, it is expected that exploiting PHY layer information that directly characterizes the channel quality would gives a better guideline for rate adaptation. In literature, many schemes have proposed to SNR to assist the rate adaptation so as to be able to estimate SNR to the PHY layer which should improve the network throughput since SNR is a good indicator of channel quality. Examples of these RAAs are Receiver Based Auto-Rate (RBAR), Opportunistic Auto-Rate (OAR), SNR-Guided Rate (SGRA) etc. A summary of rate adaptation algorithms in their classes are shown in columns 2 and 3 of Table 3.1 on page 51. From this table we have transmitter-received-based, SNR-based and window/frame-based rate adaptation algorithms.

Table 3.1: Classification of Existing Rate Adaptation Algorithms.

Schemes	T-R	SNR	Window/Frame	Implemented	Hidden Issue
ARF/AARF	Tx	No	Window	Yes	No
CARA	Tx	No	Window	No	Yes
RRAA	Tx	No	Window	Yes	Yes
SampleRate	Tx	No	Window	Yes	No
CHARM	Tx	Yes	Frame	Yes	No
SGRA	Tx	Yes	Frame	Yes	No
ONOE	Tx	No	Window	Yes	No
RBAR	Rx	Yes	Frame	No	No
OAR	Rx	Yes	Frame	No	No
RARA	Rx	Yes	Frame	No	No
RAM	Rx	Yes	Frame	No	Yes
CARS	Tx	No	Window	Yes	Yes

3.2 Types of Rate Adaptation Algorithms

This section will review existing RAAs from literatures. At the end of this section, background knowledge of existing rate schemes should have been established. This knowledge will help to enhance understanding of their implementations which will be discussed in Chapter 4.

3.2.1 Auto Rate Fallback (ARF)

The first and simplest documented bit-rate selection algorithm is Auto-Rate Fallback (ARF) [71]. It was developed for WaveLAN-II 802.11 cards as far back as 1996. These cards were one of the earliest multi-rate 802.11 cards and are able to send at 1 and 2 megabits. ARF was developed at the Bell laboratories and published in a journal in the summer of 1997 [2]. The idea behind ARF is to adapt the variable conditions in the wireless link by monitoring the amount of packet loss that the link experiences. It is designed to work with many different rates for the future IEEE 802.11 standards of the WaveLAN cards. The decision whether to increase or decrease the transmission rate is based on the number of consecutive successfully or unsuccessfully transmission attempts, respectively. This algorithm is widely adopted because it is simple. In ARF, the sender tries to send a packet at higher rate after a fixed number of continuous successful transmissions at a given rate. This packet is called a probe packet. The sender decreases the rate after 1 or 2 consecutive failures. If the probe packet is successful, the next packet will be sent at higher rate and if not, the sender will immediately lower the rate. The sender also lowers the rate after 2 consecutive failures.

This algorithm works by monitoring the current rate that is being used along with the number of lost packets. It makes use of the property of 802.11 networks that the packets need to be positively acknowledged by the receiver. The card reports this information to the MAC layer. The station tries to re-transmit the packet repeatedly untill it is either acknowledged or the number of retransmissions exceeds the maximum retry count set before hand. Afterwards it discards the packet and reports it to a higher layers called the transport layer. It starts by transmitting at the highest rate listed and builds the statistics for the number of retransmissions and successful transmissions. Furthermore, it adjusts the rate using the statistics it has built from precious transmissions. There is a time limit for this adjustment to be completed, hence this algorithm purely depends upon the packets to be transmitted during that time.

3.2.2 Adaptive Auto-Rate Fallback (AARF)

Adaptive Auto-Rate Fallback (AARF) is one of the statisticbased approach RAAs that uses packet transmission characteristics to make decisions. It waits for the ten successive successful transmissions before it moves to a higher rate and then moves to a lower rate when the first transmission fails. This algorithm assumes that higher rate cannot do better than the lower rate at any time [2].

The aim of ARF is to adapt to changing channel condition and take advantage of higher bit-rates. ARF was also designed to work on future WaveLAN cards with more than 2 bit-rates. For a particular link, ARF keeps track of the current bit-rate as well as the number of successive transmissions without any retransmissions.

ARF performance is poor in scenarios where links experience losses. It may increase the bit-rate past the highest throughput one to another which requires many retries for each packet. Its throughput may be very low, but ARF does not step down until a bit-rate experiences packet failure. As a result of this, it takes a longer time transmitting packets at a higher bit rate that does not work well. ARF may alternatively decrease the bit rate because of packet failures, but it may not step up again to a better performing bit-rate if lower bit-rates are lossy [16][61].

The main problem of this algorithm is that it cannot distinguish between losses due to collision from losses due to the channel, so it achieves poor performance in multi-user scenarios. In this paper, the authors analyse the problem of this algorithm, that this algorithm tries a higher rate every time it obtains a fixed number of successfully transmission attempts, even if the current rate is the most convenient. To alleviate this problem, the Adaptive ARF (AARF) algorithm [16] was proposed.

In AARF, each step-up parameter is doubled every time the algorithm tries to increase the bit-rate and the subsequent packet fails. It increases throughput dramatically, if the packet failures take up a large amount of transmission time. It exponentially waits longer before increasing the bit-rate if no other packet failures occur, which allows it to avoid throughput reduction resulting from trying higher bit-rates that do not work.

AARF is an adaptive variant of well known ARF that selects transmission rates based on the success and failures of recent packet transmission attempts. It behaves like ARF with the difference that the number of consecutive successfully transmission attempts before trying the higher rate is incremented exponentially every time the higher rate transmission fails. AARF performs better than ARF in case of single-user scenarios, but it has the same problems as ARF in a multi-user scenarios. AARF will instead wait exponentially longer before increasing the bit-rate if no other packet failures occur. The reasons for choosing AARF are as follows:

1. It is the simplest algorithm to implement;

2. It is the first proposed rate adaptation algorithm, and hence majority of publications on rate adaptation algorithms considers it;

3.2.2.1 Implementation

1. Move to the next lowest bit-rate if the packet was never acknowledged
2. Move to the next highest bit-rate if 10 successive transmissions have occurred without any retransmissions
3. Otherwise, continue at the current bit-rate

The challenge faced with this rate adaptation algorithm is that, it cannot distinguish between losses due to collision from losses due to the channel, so it achieves poor performance in multi-user scenarios. This problem is caused by hidden node. The solution is to use RTS/CTS handshake [74].

3.2.3 ONOE Rate Adaptation Algorithm

ONOE [61][75][77][78] was developed by MadWifi organization for Wi-Fi adapters with Atheros chips. ONOE is a credit-based algorithm which slowly adapts and tries to change the rate after a 1 second interval by maintaining the credit score of the current rate for every destination, and after the end of a second, it calculates the credit and makes the rate decision [77][78][79]. ONOE tries to overcome the loss-sensitivity of ARF, and it variants, by attempting to select the highest transmission rate with a packet loss rate of 50%.

For each individual destination, the ONOE algorithm keeps track of the current bit-rate for the link, and the number of credits that bit-rate has accumulated. It only keeps track of these credits for the current bit-rate and increments the credit if it is performing with very little packet loss. Once a bit-rate has accumulated a threshold value of credits, ONOE will increase the bit-rate. If a few error conditions occur, the credits will be reset and the bit-rate will be decreased [61][78]. It calculates the credit for the current transmission rate based on the packet loss ratio. The initial rate credit is set to be zero. ONOE observes received ACKs and increase the credit by 1 and then is increased to 1 when less than 10% of frames in a time window of 1 second need retransmission (and the total frame transmissions are at least 10), otherwise it decrements it by 1.

When the credit for the current rate reaches 10, it will increase the rate to the next higher level, else it decrements it to the next lower level if 10 or more frame transmission have been sent and more than 50% of the frame transmissions failed during the last period. Credit is reset to 0 when the rate changes. ONOE tries to find the highest bit-rate with less than a 50% loss rate, so it will step down from 11 megabits and will settle on 5.5 Mega bits. It decreases the bit-rate when the packets need at least 1 retry on average and increases the bit-rate when less than 10% of packets require a retry. ONOE is said to be a conservative algorithm because it does not increase the current transmission rate when it detects good channel quality, but waits until the credit values threshold is reached. Once it observes that a bit-rate will not work, it will not attempt to step up again until at least 10 seconds have gone by. The ONOE algorithm can also take time to stabilize [2][79].

The challenges faced by this RAAs are: ONOE is insensitive to burst losses because it cannot distinguish frames losses from transmission losses. It is not responsive to fast changes in wireless channels because it takes time to stabilize. And also, ONOE is very conservative because it does not increase the current transmission rate when it detects good channel quality, but waits until the credit value reaches the threshold.

ONOE was chosen as one of the existing rate algorithms to be implemented in this simulation because:

1. It is a very popular algorithm which the majority of publications in rate algorithms considers and talks about [79];
2. Its implementation is available in the MADWifi driver code which makes it resourceful [78].

3.2.3.1 Implementation

1. If no packets have succeeded, move to the next lowest bit-rate and return.
2. If 10 or more packets have been sent and the average number of retries per packet was greater than one, move to the next lowest bit-rate and return.
3. If more than 10% of the packets needed a retry, decrement the number of credits (but don't let it go below 0) and return.
4. If less than 10% of the packets needed a retry, increment the number of credits.
5. If the current bit-rate has 10 or more credits, increase the bit-rate and return.
6. Continue at the current bit-rate .

3.2.4 SampleRate Adaptation Algorithm

SampleRate uses a probing mechanism by transmitting every tenth packet at a different rate, randomly chosen from a set of sampled rates. It selects the rate that has the lowest average transmission time including the retransmission attempts [2]. SampleRate chooses the bit-rate it predicts and will provide better throughputs based on estimation of expected per-packet transmission time for each bit-rate. It periodically sends packets at bit-rates, different from the current one, to check whether they can provide better performance. When the estimated per-packet transmission time becomes smaller than the current one, it switches to another bit-rate. SampleRate reduces the number of bit rates it must sample by eliminating those that could not perform better than the one currently being used. SampleRate also stops probing at a bit-rate if it experiences several successive packet losses [2][61][79][80].

SampleRate algorithm takes the highest rate when it starts and stops using a particular rate as it experiences four successive failures. It periodically sends a number of data packets as sample packets, at a certain rate other than the current rate to gather its statistics so that it can make decision on appropriate rate selection [75][79]. For each transmission rate, SampleRate will calculate the Average Transmission Time (ATT) every 10 seconds based on the transmission results obtained. Any rate with the smallest result of ATT will be selected for normal packets in the next control period of 10 seconds. The transmission rate with the smaller ATT is normally selected from available rates compared to the current transmission rate for normal packets as it transmits sample packets in every tenth packets.

SampleRate does not try to send packets at 1 or 2 Mbits because the lossless transmission time for those bit-rates is higher than the ATT for both 11 and 5.5 Mbits. This is because, it sends most data packet at the rate it believes it will yield the highest throughput, it switches to a different rate when it observes that the throughput based on the other rates ATT is higher than the current rate.

The averaging scheme adopted in SampleRate makes it robust to rapid small-scale fading in the presence of constant large-scale path loss, but it is often slow to adapting to new channel conditions.

This algorithm is chosen to be implemented in our simulation for the following reasons:

- Our proposed algorithm is based on this. One of its function uses an Exponentially Weighted Moving Average (EWMA) of past frame transmission statistics for each bit-rate which is similar to the scheme in SampleRate;
- It is also considered because it is one of the most popular existing rate algorithms [14][79].

SampleRate is implemented in three functions : $apply_{rate}()$, which assigns a bit-rate to a packet, $process_{feedback}()$, which updates the link statistics based on the number of retries a packet used and whether the packet was successfully acknowledged, and $remove_{staleresults}()$, which removes results from the transmission results queue that were obtained longer than 10 seconds ago. SampleRate must address the following challenges when trying to pick the optimal bit-rate [79]. Details of this implementation are considered in Chapter 4.

- A bit-rate selection algorithm cannot conclude that higher bit-rates will perform poorly just because lower bit-rates perform poorly;

- The bit-rate that achieves the most throughput may suffer from a significant amount of loss. Algorithms that only use bit-rates with high delivery probability may not find the bit-rate that achieves the highest throughput ;

- Link conditions may change. Failing to react to changes in link conditions could result in needlessly low throughput;

- A bit-rate selection algorithm that constantly measured the throughput of every bit-rate would likely achieve low throughput. If a link sends every $10th$ packet at a bit-rate that requires 4 retries; it might get only half the throughput it is capable of. Bit rate selection algorithms must limit the bit-rates they choose to measure. When process feedback function runs, it updates information that tracks the number of samples and re-calculates the average transmission time for the bit-rate and destination and process feedback function performs the following operations;

- Calculate the transmission time for the packet based on the bit-rate and number of retries using the transmission time equation given below:

$$tx_{time(b;r;n)} = DIFS + back{-}off(r) + (r+1) \times (SIFS + ACK + Header + (n \times 8/b) \qquad (3.1)$$

  where tx_{time} is transmission time, b is bit-rate, n is number of packets, r is number of retries, $Header$ is 392 bits, ACK is 304, $SIFS$ is $30\mu s$, $DIFS$ is $50\mu s$ from Table 4.2 on page 79, and $back - off = CW_{size} \times slot\ time$ from Algorithm 3 on page 104.

- Look up the destination and add the transmission time to the total transmission times for the bit-rate.

- If the packet succeeded, increment the number of successful packets sent at that bit-rate.

- If the packet failed, increment the number of successive failures for the bit-rate. Otherwise reset it.
- Re-calculate the average transmission time for the bit-rate based on the sum of transmission times and the number of successful packets sent at that bit-rate.
- Set the current-bit rate for the destination to the one with the minimum average transmission time [61].

Append the current time, packet status, transmission time, and bit-rate to the list of transmission results. SampleRate is based on transmission statistics over cycles. It maximizes throughput by sending packets at the bit-rate that has the smallest average packet transmission time as measured by recent samples. It is implemented using three functions:

The $apply_{rate}()$ assigns a bit-rate to a packet. In SampleRate adaptation algorithm, it is implemented using the following steps:

1. If no packets have been successfully acknowledged, return the highest bit-rate that has not had 4 successive failures.
2. Increment the number of packets sent over the link.
3. If the number of packets sent over the link is a multiple of ten, select a random bit-rate from the bit-rates that have not failed four successive times and that have a minimum packet transmission time lower than the current bit-rate's average transmission time.
4. Otherwise, send the packet at the bit-rate that has the lowest average transmission time.

The $process_{feedback}()$ is implemented with the following steps:

1. Calculate the transmission time for the packet based on the bit-rate and number of retries using equation (3.1);

2. Look up the destination and add the transmission time to the total transmission times for the bit-rate.

3. If the packet succeeded, increment the number of successful packets sent at that bit-rate.

4. If the packet failed, increment the number of successive failures for the bit-rate. Otherwise reset it.

5. Re-calculate the average transmission time for the bit-rate based on the sum of transmission times and the number of successful packets sent at that bit-rate.

6. Set the current bit-rate for the destination to the one with the minimum average transmission time.

7. Append the current time, packet status, transmission time, and bit-rate to the list of transmission results.

The $remove_{staleresults}()$ is implemented using the following steps:

1. Remove the transmission time from the total transmission times at that bit-rate to that destination.

2. If the packet succeeded, decrement the number of successful packets at that bit-rate to that destination.

3.2.4.1 Implementation

The SampleRate algorithm is implemented using the following steps:

1. If no packets have been successfully acknowledged, return the highest bit-rate that has not had 4 successive failures.

2. Increment the number of packets sent over the link.

3. If the number of packets sent over the link is a multiple of ten, select a random bit-rate from the bit-rates that have not failed four successive times and that have a minimum packet transmission time lower than the current bit-rate's average transmission time.

4. Otherwise, send the packet at the bit-rate that has the lowest average transmission time. When process feedback() runs, it updates information that tracks the number of samples and recalculates the average transmission time for the bit-rate and destination and process feedback() performs the following operations:

5. Calculate the transmission time for the packet based on the bit-rate and number of retries using the equation (3.1) on page 56.

6. Look up the destination and add the transmission time to the total transmission times for the bit-rate.

7. If the packet succeeded, increment the number of successful packets sent at that bit-rate.

8. If the packet failed, increment the number of successive failures for the bit-rate. Otherwise reset it.

9. Re-calculate the average transmission time for the bit-rate based on the sum of transmission times and the number of successful packets sent at that bit-rate.

10. Set the current-bit rate for the destination to the one with the minimum average transmission time .

11. Append the current time, packet status, transmission time, and bit-rate to the list of transmission results.

The application challenge for this rate adaptation algorithm is that it may pick a random rate which yields even worse throughput compared to the current transmission rate.

3.2.5 Context-Aware Rate Selection (CARS) Algorithm

Context-Aware Rate Selection Algorithm (CARS), is a novel rate adaptation mechanism for VANETs that uses context-information (e.g. vehicle speed and distance from neighbour etc.) to learn the real-time link quality and systematically address the challenges faced by existing rate algorithms, while maximizing the link throughput. This algorithm achieves significant higher throughput compared to existing rate adaptation algorithms in the presence of high mobility of vehicles and varying channel conditions. Some extensive outdoor experiments were carried out when implementing this algorithm to show that existing rate adaptation schemes for 802.11 wireless networks underutilize the link capacity in vehicular environments [14].

This algorithm also show that CARS mechanism uses context-information to adapt to fast changing link conditions specific to vehicular networks. Another good implementation of this algorithm was mobility of vehicles. Many existing rate adaptation algorithms did not concentrate on implementing RAA with mobility. From the literature review, most implementation of rate adaptation algorithms are not with mobility. From the different scenarios carried out during their experiments, results show that CARS adapts to changing link conditions at high vehicular speeds faster than existing RAAs.

The basic concept of CARS algorithm is to make use of context-information from the application layer. In addition to the frame transmission statistics received from the lower layers, this algorithm helps to determine when to give preference to either the context-information or EWMA that deals with past transmission statistics. The CARS scheme makes use of an empirical model to learn the effect of context information on the packet delivery probability which goal is to predict Packet Error Rate (PER) as a function of the distance between the vehicles, the relative speed between the vehicles, and the transmission rate.

CARS algorithm was implemented on the open-source MadWifi wireless driver for Atheros chipset wireless cards. This implementation consists of 520 lines of C code. Context-information required for CARS was obtained using GPS-Daemon, a VANET application that interfaced with the wireless driver using a generic/protocol interface [14]. In their implementation, they were able to deal with some of these challenges faced with existing rate algorithms which are under-utilization of link capacity, effect of environment, effect of hidden-node collisions.

The limitation of this algorithm is that it is affected by the propagation phenomena and cannot estimate SNR to the PHY layer. The two basic challenges of CARS among others, are some of its limitations that this proposed algorithm has been able to solve. They are : Hidden station problem which is caused as a result of packet error statistics becoming polluted with collision-induced losses, and CARS not able to estimate SNR to the PHY layer.

3.2.5.1 Implementation

In this section, we will illustrate the approach and steps adopted in implementing the CARS algorithm. Algorithm 1 describes the CARS algorithm. This algorithm is used to estimate the link quality using both context-information and past transmission statistics. Context-information is represented as ctx, E_C is a function that uses context-information, transmission rate, and packet length as input parameters, and outputs estimates PER. The function E_H uses past transmission statistics similar to SampleRate for each bit-rate, this is also an input parameter to estimate PER for line 4. α is assigned based on vehicles speed, it is given as $\alpha = max(0, min(1, v/S)$. Here α is computed based on values of v which is speed of vehicles, S is speed normalizer, selected as 30 metres per second [14]. This algorithm calculates estimated throughput for each bit-rate and selects the bit-rate that will provide the most throughput. N is the number of retransmission, and $avg_{retries}$ is average retries. The weight that signifies the penalty given to unsuccessful packet transmission is given as ρ. From [14], this value is 8.

3.2.5.2 Application Challenges

This algorithm has the following challenges:

- Delay in estimation as a result of the estimation window, this is caused by idle station;

Algorithm 1 Context-Aware Rate Selection Algorithm

Input: ctx, α, len
Output: $rate$

$Max_{Thr} \leftarrow 0$
$Best_{Rate} \leftarrow MIN_{RATE}$
for *all rate* **do**
  $PER = \alpha.E_C(ctx, rate, len) + (1 - \alpha).E_H(rate, len)$
  $avg_{retries} = \frac{Rate}{avg_retries.(1-PER^N)^\rho}$
  if $Thr > Max_{Thr}$ **then**
    $Best_{Rate} \leftarrow bitrate$
    $Max_{Thr} \leftarrow Thr$
  end if
end for
$ReturnBest_{Rate}$

- Cannot estimate SNR to the PHY layer;
- Not adaptive to propagation conditions;
- It lacks the ability to tune the estimation window size dynamically, using the context-information;
- Depends on packets being continuously transmitted in order to calculate the packet loss estimate;
- Hidden station problem which is caused as a result of packet error statistics becoming polluted with collision-induced losses.

3.2.6 Signalto-Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI)-Based Scheme

The design most existing rate adaptation schemes rely only on frame losses to infer channel quality, but perform poorly if frame losses are mainly caused by interference [74]. Since SNR is a good prediction tool for channel quality, the

SNR-based rate scheme is necessary especially in vehicular networks where channel condition changes very fast due to high mobility of vehicles.

In cellular system, all algorithms are SNR-based, and transmission rate depends on SNR estimations. The nodes estimate the SNR of the downlink and reports it to the network as the so called Channel Quality Indicator (CQI). The network bases the transmission format (packet length, modulation scheme, coding rate) upon the CQIs. The network transmits data immediately to the nodes with the highest CQI, i.e. highest SNR. This is part of so-called "opportunistic scheduling", i.e. the ability to exploit the variations of channel conditions. Some examples of the RAAs in this category are:

- Receiver Based Auto-Rate (RBAR);
- CHARM;
- LeZiRate bit-selection;
- SNR-Guided Rate Adaptation (SGRA);
- Robust Rate Adaptation Algorithm (RRAA);
- Model-Driven Rate Selection (MDRS);
- Multi-Vehicular Maximum (MV-MAX);
- Opportunistic Auto-Rate (OAR).

3.2.7 Receiver Based Auto-Rate (RBAR)

Receiver Based Auto-Rate (RBAR) [61][69][71] is a SNR-based scheme that uses feedback from the receiver to select the sender optimal rate. In this scheme, the sender sends an RTS frame before every packet, and receiver measures the SNR and compares it with SNR thresholds from a priori calculated wireless channel model, calculates the optimal rate, and sends it back to the sender as part of the CTS frame [14].

In the RBAR scheme [12][14][74], the RTS/CTS handshake is mandatory. The receiver selects the best transmission rate on the basis of the receive signal strength indicator (RSSI) measured during the reception of the RTS frame. The selected PHY mode is sent at the minimum rate (i.e. 6 Mbps); hence they are robust against channel-related losses. On the other hand, it is observed that, when the RTS/CTS mechanism is used in an infrastructure scenario, collisions can occur only during the transmission of the RTS frame. Therefore, the RTS/CTS mechanism is a good way to distinguish between collision errors and channel errors.

3.2.8 CHARM

CHARM [74][71] is a SNR-based scheme which uses channel reciprocity to obtain channel information while incurring RTS/CTS overhead. The problem with using SNR as an estimate of channel quality is that in a rapidly changing channel, SNR can periodically fluctuate which leads to misleading predictions. Averaging the SNR values over a window will lead to the same estimation delay problem as in the frame-error-based schemes. This scheme uses the RSSI values of the ACK frames received by the transmitter to infer the channel condition at the receiver side based on the assumption of a symmetric channel [71].

3.2.9 LeZiRate Bit-Selection

LeZiRate algorithm uses the measurements of the quality of the signal received at the device to learn and predict the quality of signal in near future. LeZiRate does not monitor the network packets and therefore does not use any of the network resources rather, it monitors the signal quality received at the station and makes its decision based on that. It also makes the corrections to the prediction values by inducting the actual measurement of the signal quality on a real time basis so as to enable itself to make better predictions in the future. The LeZiRate algorithm monitors the signal quality and maps that to the received signal strength values, these values are quantized to map into a set of symbols. The frequency of occurrences of the string of these symbols is used to build a tree based on first order Markov model. It then selects the best bit-rate it believes would fetch the highest throughput. LeZiRate has a short setup and learning time to predict the first symbol [2].

3.2.10 SNR-Guided Rate Algorithm (SGRA)

This Algorithm is developed for novel automatic on-line calibration technique that rapidly reliably builds the SNRFrame Delivery Ratio (FDR) relationship on per node-pair basis through real time measurements [74]. In implementing this scheme, the authors carried out the followings: first conducted a systematic measurement-based study to confirm that in general SNR is a good prediction tool for channel quality, and identify two key challenges for this to be used in practice:

- The SNR measures in hardware are often un-calibrated, and thus the SNR thresholds are hardware dependent.
- The direct prediction from SNR-to-FDR is often over optimistic under interference conditions. SGRA is fully compliant with IEEE 802.11 wireless standards and a good scheme for SNR estimation.

3.2.11 Robust Rate Adaptation Algorithm (RRAA)

The Robust Rate Adaptation Algorithm [61] includes two mechanisms: the rate selector, called RRAA-BASIC, and the Adaptive Rts (ARts). The rate selector counts the number of transmission failures that occur during an observation window, at the end of this observation window, it takes statistics of the packet loss ratio and finally makes its decision. Furthermore, the authors propose a mechanism to decrease the rate even if the observing window is not ended: at any time when a transmission failure is detected, the packet loss is computed with the assumption that the remaining transmission attempts in the observation window will succeed.

With the use of the RTS/CTS mechanism, it is possible to estimate the number of transmission attempts made. The RTS/CTS mechanism is used when the counter is greater than 0 and then the counter is decreased by one for each attempt. Initially the RTS window is equal to 0, which is incremented by one when the RTS is not used and the last transmission attempt, fails. It is halved when the RTS is used and the last transmission succeeds, or when the RTS is not used and the last transmission fails. Every time the RTS window value is modified, the counter is set to the window value. RRAA has been implemented in a testbed and it performs better than ARF and AARF when a multi-user scenario is considered, with or without hidden nodes [14][61].

Since different causes of frame loss require different reactions, there is need to adopt a strategy that will appropriately adjust data rates based on channel conditions. Rate adaptation is a strategy that determines the optimal rate most appropriate for the current wireless channel conditions. Rate adaptation generally consists of two functions: channel assessment and rate adjustment. Channel assessment estimates the channel condition or variation trends whereas rate adjustment determines the most appropriate rate based on the assessment [61].

3.2.12 Model-Driven Rate Selection (MDRS)

Model-Driven Rate Selection (MDRS) [81] is based on the loss-rate versus RSSI curves for the fact that in a mobile network error rate versus RSSI plots, there are consistency for each link rate across different scenarios. It is also based on the fact that the loss-rate and RSSI are predictable to model expected behaviour [81]. The loss-rate versus RSSI is used in two ways: to make the sender estimate RSSI for the receiver and to make the sender decide the best transmission rate, given the estimated RSSI at the receiver and the model of loss rates.

MDRS mainly addresses vehicular Wi-Fi networks. The approach adopted by this algorithm is similar to RBAR [81], but it does not need a receiver-to-sender control channel to inform the signal strength to the sender. Instead, it forces the sender to predict the signal strength so that the algorithm can be easily deployed without significantly changing the involved Wi-Fi stations. The algorithm requires change only in the Wi-Fi driver at the sender. It does not require changes of any other things, such as protocols, standards, receivers and applications. Therefore, the algorithm should be well suited in AP at the roadside to transmit data to the passing vehicles.

MDRS permits the sender to infer the degree of signal asymmetry between the sender and the receiver, and then to dynamically determine the most appropriate data rate to adapt to the degree of asymmetry. The sender begins by assuming that the signal strength between the sender and the receiver is symmetric. However, over time MDRS adjusts the degree of symmetry for the signal strength between the sender and the receiver. The sender utilizes the signal strength of ACK frames arriving from the receiver for estimating the RSSI at the receiver [81].

3.2.13 Multi-Vehicular Maximum (MV-MAX)

Multi-Vehicular Maximum (MV-MAX) is the highest SNR-based medium-access method that opportunistically grants wireless access to the vehicular Wi-Fi clients being capable with the best transmission rate and focuses on roadside multi-vehicular Wi-Fi networks to improve not only the individual throughput for each vehicular Wi-Fi client but also the overall throughput in the Wi-Fi network [82]. It is based on the fact that every vehicle eventually has good throughput performance when it is near the AP. However, according to the critical performance anomaly in Wi-Fi networks due to DCF [83], when multiple vehicles are in the range of an AP, the vehicles on the fringe Wi-Fi coverage area degrade the performance of all other vehicles. For this reason, MV-MAX does not allow a vehicle to transfer data with the AP when it has a poor signal quality. It permits data transfer only when the vehicle has a good signal quality (i.e., the highest SNR which roughly corresponds to the best transmission rate). In this way it is expected that not only every vehicle eventually gets individual throughput equally over the long term, but also the overall Wi-Fi network throughput is dramatically increased [81]. MV-MAX does not determine the transmission rate. The rate is determined by the underlying bit rate selection algorithm at the MAC layer in the vehicle. However, MV-MAX modifies the scheduling of data transmission for all the attached vehicular Wi-Fi clients.

3.2.14 Opportunistic Auto-Rate (OAR)

Opportunistic Auto-Rate (OAR) [79] takes advantage of higher bit-rates when rapid changes in channel quality takes place. OAR nodes opportunistically send multiple back-to-back data packets whenever the channel quality is good; this allows OAR to increase channel through-put by allocating equal amounts of transmission time to senders. The intuition behind OAR is that channel coherence times typically exceed multiple packet transmission times, and by taking advantage of high link qualities when they appear, channel throughput can be increased. OAR uses the RTS/CTS exchange for rate control purposes (like RBAR), but grants each sender the same amount of time in the CTS as the transmission time of a packet at the base rate. Other nodes that hear the CTS will not send during this time, and if the link is performing well, the sender can send multiple packets at a high bit-rate in the same time that one transmission would take at a lower bit-rate.

3.3 Chapter Summary

This chapter has reviewed existing RAAs and how they are implemented. It has also established background knowledge for the design and implementation of the proposed RAA. The following (AARF, CARS (MODIFIEDCARS, ONOE, and SampleRate) RAAs have also chosen to be implemented with the proposed RAA with reasons that has been given under each type.

4

Adaptive Context-Aware Rate Selection (ACARS) Algorithm for Vehicular Networks

This chapter will explain the main ideas used in the design and implementation of the Adaptive Context-Aware Rate Selection (ACARS). It will also explain all mathematical analyses used in designing and implementing ACARS algorithm. Prior to the design of ACARS, problems and challenges of existing RAAs were first identified. The next approach is to solve problem(s)of existing RAAs. ACARS is designed by modifying the existing CARS algorithm, and tackling the problem(s) of existing RAAs, especially CARS as highlighted in [14].

The key motivation of the ACARS algorithm is to implement a robust SNR-based adaptive rate scheme for data transfer in DSRC for vehicular communications. This algorithm uses AP coordination with power control technique to minimize energy consumption, maintain delay limit for safety communication for vehicles, control congestion of vehicles, minimizes collision, and maintains QoS in vehicular networks.

This research concentrates on the safety channel which is more important than the service channel. This is because, it relates to safety of life; since road accident is a major problem and concern on our roads. Non-safety application of the DSRC channel band will be considered in the future, such as car parking, infotainment, toll fare. Road safety is very important in vehicular communications which is one of the reasons ACARS algorithm is implemented in the safety channel.

There are different stages of implementing the ACARS algorithm; these stages have been summarised in their different algorithms in this chapter. All RAAs are faced with these key challenges. In this research, a new RAA is proposed to solve these problems:

1. Due to rapid variations of the link quality caused by fading and mobility at different vehicular speeds, the transmission rate must adapt fast in order to be effective;

2. During frequent and bursty transmission, the rate adaptation scheme must be able to estimate the link quality with few or no packets transmitted in the estimation window ;

3. The rate adaptation scheme must distinguish losses due to environment from those due to hidden-station induced collision (discussed in Chapter 2 on page 31)

In the design of ACARS algorithm, some of these key issues are considered:

- **Minimal network resource wastage** - Most of the existing RAAs use the network resources to transmit packets; to assume their transmission status, and make the decisions;

- **Sensitivity to changes** - RAAs should be sensitive to short term as well as long term changes in the radio link quality. Short term changes should not trigger changes in the transmission rate under normal circumstances;

- **Past transmission statistics** - RAAs should have some amount of state information or past record so as to remove the chances of non-useful rates from being considered;

- **Proper selection** - RAAs should not assume poor performance of a higher bit-rate based on the poor performance of the lower bit-rates [2].

ACARS is implemented using parameters in Tables 4.1-4.4

Table 4.1: Network Configuration.

Parameters (Units)	Values
Length of Road (m)	1000
Number of Vehicles	150
Number of Iterations	4
Propagation Delay	0
Position of AP (m)	500
Frequency (GHz)	5.89
Speed of Light (m/s)	299792458
Minimum SNR (dB)	8.628
Normalized Transmit Power (mW)	40,50
Noise Power (dBm)	-90
Speed Normaliser (mps)	30
Communication Range (m)	300
Average Packet Size (Bytes)	1500
Penalty of Unsuccessful Transmission (ρ)	8
Number of Retransmission	3
a(EWMA and Bper compared values)	0.003

In this design, the PHY layer handles estimation of SNR to the PHY layer, and power control. From the PER table provided in the simulation, at each transmission time, the suitable SNR value is chosen as a result of the corresponding value of PER from the look-up-table. As a result of this, different values of SNR for each bit-rate used for transmission are generated. In the PHY layer, the estimated SNR is used in ACARS algorithm as shown in Algorithm 4 so as to implement rate selection handled in the MAC layer. For ACARS implementation, the estimated SNR aids selection of the transmission rate to be used. When the transmission rate is selected, it sends packet to be monitored in order to get a successful transmission. These stages are controlled by the power control scheme shown in Figure 4.6 on page 98. The PHY layer is responsible for the stages involved in Figure 4.6 that implements power control model used in

Table 4.2: 802.11p PHY/MAC Parameters.

Parameters (Units)	**Values**
PHY and MAC Protocol	802.11p
Slot time (μs)	9
DIFS (μs)	50
SIFS (μs)	10
HPHY (bits)	192
HMAC (bits)	200
HEADER	HMAC+ HPHY
ACK	112 + HPHY
RTS	160 + HPHY
CTS	112 + HPHY
Maximum retransmission (Mac.m)	3
Contention window dimension (CW_{min})	32
Number of back-off stages(CW_{max})	$2^{Mac.m}$. CW_{min}
Data rate (Mbps)	3,4.5,6,9,12,24,18,27

ACARS implementation. The multiplexing techniques among others discussed in this chapter used in the implementation of ACARS is the OFDM technique. Each multiplexing technique is based on one of the modulation technique listed in Table 4.5 on page 90.

IEEE 802.11p is based on OFDM technique which compensates for both time and frequency-selective fading, and is very similar to 802.11a in that it uses 5.2 GHz while the later uses 5.850 – 5.925 GHz. IEEE 802.11p has more emphasis on reduced channel spacing using 10 MHz instead of 20 MHz as in 802.11a. IEEE 802.11p allows the use of frequencies at 5.8 GHz using only the OFDM bit-rates [77] which are a variation of the IEEE 802.1a standard. The 10 MHz used by IEEE 802.11p is to accommodate tolerance for multi-path propagation effects caused by both constructive and destructive interference and phase shifting of the signal and is optionally implemented. The IEEE802.11p PHY employs 64-sub-carrier OFDM, out of which, only 52 is used for actual transmission consisting of 48 data sub-carriers and 4 pilot sub-carriers [84].

Table 4.3: Typical Values for Path Loss Exponent.

Environment	Path Loss Exponent (γ)
Free space	2
Urban Area Cellular Radio	2.7-3.5
Shadowed Urban Cellular Radio	3-5
In Building Line-of-Sight	1.6-1.8
Obstructed in Buildings	4-6
Obstructed in Factories	2-3

Table 4.4: Typical Values for Shadowing Deviation.

Environment	Shadowing Deviation (σ)
Outdoor	4-12
Office, Hard Partition	7
Office, Soft Partition	9.6
Factory, LOS	6-8
Factory, no LOS in Factories	6.8

4.0.1 Spread Spectrum Techniques

Frequency Hopping over Spread Spectrum (FH or FHSS)- In this technique the devices hop from one frequency to another in the available spectrum at a definite interval. The sequence of jumps is also predefined and agreed upon by the participating stations. The stations remain on the frequency for a short period of time called the Dwell Time and transmit a burst of information. Precise timing coordination is required for the Frequency Hopping (FH) techniques to control the hopping pattern etc. It is one of the standard techniques used in the modern bluetooth networks.

Direct Sequence over Spread Spectrum (DS or DSSS) - The stations using DSSS spread the signal power over the whole available frequency spectrum with the help of mathematical coding techniques. It multiplies the data to be transmitted by a "noise" signal. This noise signal is pseudorandom sequence of 1 and -1 values. Direct Sequence systems require more sophisticated digital signal processing techniques; therefore they need more complex hardware than the frequency hopping systems.

Orthogonal Frequency Division Multiplexing (OFDM) - Uses a technique of dividing the available channel into multiple sub-channels and encodes a part of the signal and transmits each part into each of those sub-channels simultaneously. This is similar to the Discrete Multi-Tone (DMT) technique used by some Digital Subscriber Line (DSL) modems.

Direct Sequence systems require more sophisticated digital signal processing techniques; therefore they need more complex hardware than the frequency hopping systems. Precise timing coordination is required for the Frequency Hopping (FH) techniques to control the hopping pattern etc.

Wireless networks allow different modulation techniques for different link qualities. This allows the links to choose the modulation technique that best suites the condition and optimizes the throughput as the link quality could vary by large amount. Each rate uses a modulation technique to transform the incoming data into a stream of symbols which are then encoded by varying the amplitude, frequency or the phase of the electromagnetic signal being used. The amount of information that a particular modulation technique can transmit depends upon the number of distinct symbols the technique can use to represent the data assuming all the techniques transmit symbols at a constant rate. This set of unique symbol values is called a Constellation. The minimum distance between any of the two unique values in a constellation determines the amount of noise it takes to confuse or cause a bit-error. The lesser the distance between these values the higher the chances of bit-error. Sparse constellations tend to experience less bit-error rates than the denser ones. Sparse constellations are resilient to noise interference and experience bit-error at a much lesser Signal-to-Noise (S/N) ratio than the dense constellations. Table 4.5 on page 90 shows some of the modulation techniques used in the 802.11 networks [2].

Table 4.5: Different Modulation Techniques.

bit rate (Mbps)	Modulation	Coding rate	Bits per symbol	Duration (μs)
6	BPSK	1/2	24	2012
9	BPSK	3/4	36	1344
12	QPSK	1/2	48	1008
18	QPSK	3/4	72	672
24	16-QAM	1/2	96	504
36	16-QAM	3/4	144	336
48	64-QAM	2/3	192	252
54	64-QAM	3/4	216	224

4.1 Design

In vehicular communications, context-informations include speed, acceleration of the vehicle, position, distance from the neighbouring vehicle, and environment factors such as location, time of day, weather, type of road and traffic density etc. In ACARS, only two significant parameters were used; speed of vehicles, and the distance of the vehicles from the AP. This algorithm is based on CARS algorithm with some assumptions, modifications to original CARS algorithm. The full implementation of the CARS algorithm is not known from [14] because some information such as context-information where not discussed and therefore making it difficult to implement line 4 of the CARS algorithm [14].

In this design, mathematical illustrations are used in evaluating context-information, and used for implementing the CARS algorithm. For this reason, the original CARS algorithm as seen in [14] is re-named as modified CARS, because it is not identical to the original CARS algorithm. The two basic layers out of the seven layers of the Open System Interconnection (OSI) reference model that implement ACARS are the MAC and the PHY layer. The vehicles also known as Mobile Nodes (MN) which use information from the application layer available in each MN, while the MAC layer handles the rate selection algorithm, while the PHY layer handles RTS/CTS frame exchange, SNR estimation and power control.

ACARS was developed to improve its performance over MODIFIEDCARS, a modified version of the CARS algorithm since its original implementation was not disclosed. This researched is focused on designing and implementing an adaptive rate algorithm which estimates SNR to the PHY layer. It handles the hidden node problem by using RTS/CTS frame exchange. Integrating power control scheme into ACARS also improve its performance over other RAAs.

ACARS is designed with robust adaptation to transfer data for DSRC in vehicular networks; so as to mitigate the problem of Vehicle Collision (VC) for road safety. With this goal, ACARS algorithm can adapt to fast channel changes due to propagation phenomena, and yields better performance due to AP coordination and transmission of power control scheme. This algorithm is adaptive to wireless and mobile environments, since it is able to mitigate the challenges of short duration, fast change in link condition and underutilization of link capacity which affect other schemes from selecting the optimum data range, since the time to communicate between two nodes is very short. The proposed RAA is designed to quickly track the rate decrease/increase associated with the channel change, when the channel quality deteriorates/improves as a mobile user walks away/towards the AP. This algorithm is also able to adapt fast in the presence of severe channel degradation induced by the interfering sources e.g. hidden stations. Figure 4.1 on page 92 summarizes the different functions that make up the ACARS algorithm. It also show how each parameters and function relates to each other, hence the structure how the ACARS is designed is shown in Figure 4.1. The full explanation and implementation of the ACARS algorithm is done in the later sections. Tables 4.1-4.4 on pages 86 – 88 show the parameters used in simulation.

In the design of ACARS, several parameters are used in performing simulations. Some of the configuration parameters used in the design of this algorithm are listed in Tables 4.1-4.4. These parameters are significant in the implementation of this algorithm. Since the parameters are so many, just few of them have been mentioned in these tables.

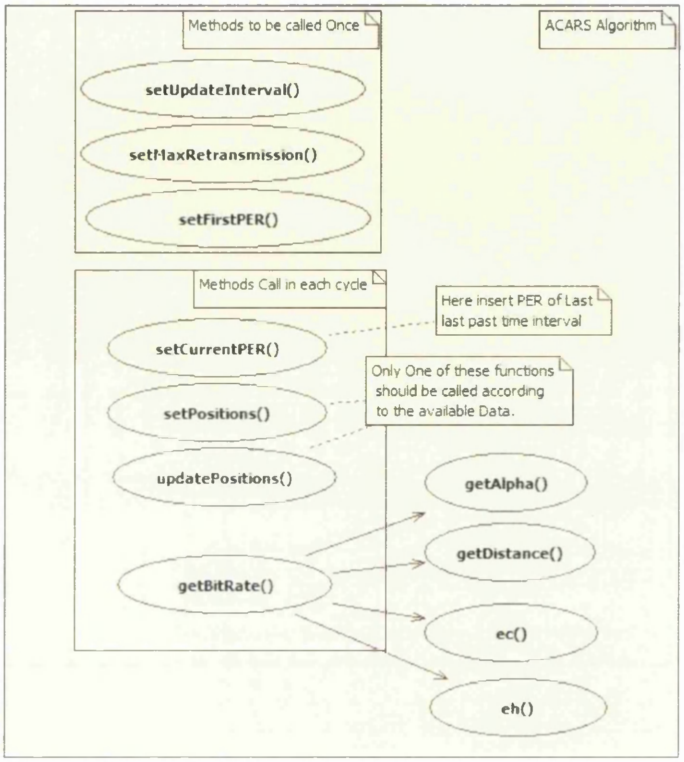

Figure 4.1: Structure of Adaptive Context-Aware Rate Selection (ACARS) Algorithm.

4.2 Role of MAC protocol in ACARS Design and Implementation

In this design, the MAC layer handles rate changes and makes the decision to decrease on increase rate depending on the value of the SNR. SNR-based rate selection scheme like ACARS relies on the RTS/CTS to provide instantaneous receiver-side SINR information to the transmitter. With the knowledge of the SINR at the receiver, the transmitter directly sets the transmission rate without wasting time to probe. But the trade-off in a SNR-based rate selection scheme is that, when trying to solve the hidden node problem using RTS/CTS mechanism, it introduces significant overhead because of the time it takes in communicating with the receiver. Some of the MAC parameters used in the simulation are shown in Table 4.1 on page 87.

Prior to sending packet to any destination, the sender first implore the path loss prediction algorithm to estimate the current path loss to the destination and uses the transmit power, and the noise level received to obtain an estimated SNR at the receiver. If there is any transmission failure, there will be retransmission attempt up to 3 times as shown in Table 4.2 on page 87. Upon successful transmission, there will be an ACK, which provides more up to date information on the SNR, and it continues updating until he gets the bit rate to be chosen for transmission. Rate selection is mainly handled in the MAC layer. The value of the transmit and noise power used in this simulation is shown in Table 4.1.

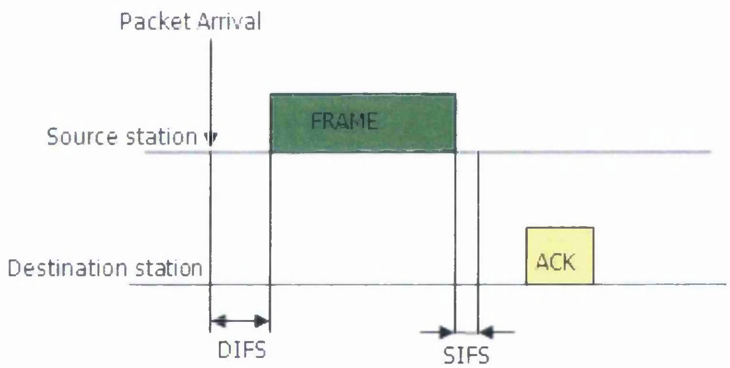

Figure 4.2: Interaction between the source and destination stations.

From Figure 4.2 on page 93, the SIFS (10 μs) is shorter than the DIFS (50 μs) as shown in Table 4.1 on page 87. This shows that the time interval between the data frame and ACK is very small, compared to the duration it takes the station to sense the medium, either busy or idle before transmitting.

4.3 Implementation

In this design, context-information is obtained using mathematical analysis as summarized in Figure 4.3, and 4.4 on pages 95, and 96. This information was not disclosed in the original CARS algorithm. Since this algorithm is a modification with some improvements on the weaknesses in the original CARS algorithm, ACARS is designed on improvements based on the weaknesses of CARS such as inefficiencies in SNR estimation, inefficiency in adapting to propagation phenomena.

4.3.1 Basic Assumptions

The following assumptions were made to simplify the mathematical model. These basic assumptions are chosen to give clarity to readers and answer the question "why" were these assumptions not part of this implementation. For example, Doppler shift is common in propagation model, and which would be expected to be implemented as FSPL is considered, but is complicated to be handled in this case using MATLAB. It is also expected that in multipath channel as shown Figure 4.7 on page 10, has path delay, but we have assumed it to be negligible. These assumptions are just made, to neglect some of the parameters that are unable to be obtained for implementing this simulation.

- Vehicles are assumed to have a single radio and all vehicular radios use the same channel: Having multiple radios is feasible;
- Vehicles are assumed to move in the same direction: This assumption will be met as long as the APs on opposite sides of a roadway either are physically staggered or allocated different channels so that there is no interference between them. This is consistent with current channel allocation best practices;
- It was assumed that all vehicles experience the same signal profile as they pass the access point. This implies that they travel at the same speed, and use identical equipment and software;
- It was also assumes that the Radio Frequency (RF) links are symmetric: Measurements indicate that although radio links are not completely symmetric, this assumption is valid to first order [82]. Investigating the effect of asymmetric links is future work; From the theory of electromagnetic wave propagation, two antennas show the same gain if used to transmit from A

to B or vice-versa, provided that they use the same transmission gain (reciprocity principle). And this holds regardless of reflections, directionality of the antenna and obstacles. But in practice, it is not exactly true, but we have assumed it to be true for purpose of this simulation.

- Slight variation in the signal strength values does not alter the channel quality considerably;
- Neglected the effect of Doppler shift by assuming that frequency demodulation is perfect [84];
- A negligible path delay was assumed, by assuming that channel timing is also perfect [84].

4.3.2 Overview of Simulation Implementation

This sub-section deals with some mathematical expressions and supporting illustrations used in generating vehicle positions and also calculating the distances. Mathematical expressions were also used in estimating vehicles in communication range and those out of communication range. For simulation purpose, Figures 4.3, and 4.4 on page 95, and 95 are used to generate the position of the vehicles and also to calculate the distance between the vehicles and AP.

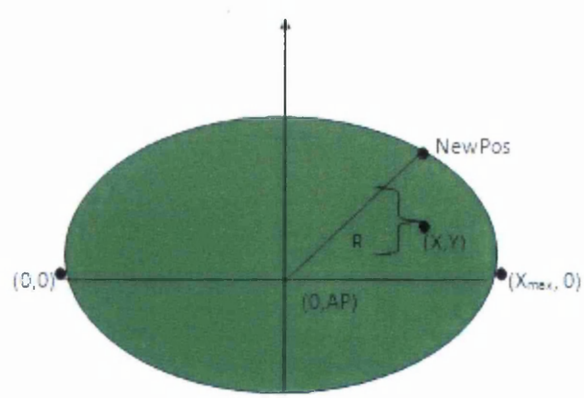

Figure 4.3: Generating Positions of Vehicles.

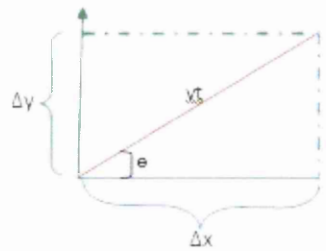

Figure 4.4: Distance Between Vehicles and AP is Calculated Using this Figure.

From Figure 4.4 the distance of the vehicles in both x and y axis are calculated using equations (4.1) and (4.2) respectively.

$$\Delta x = vt \cos\theta \tag{4.1}$$

$$\Delta y = vt \sin\theta \tag{4.2}$$

The position for each coordinate is determined using Figures 4.3, and 4.4 on page 95, and 95, and also equation (4.3).
where v is the speed of the vehicles at a given time t, x and y are the positions generated for each coordinate, d is the position of the node, and n is the total number of nodes from equations (4.1-4.3).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 ... + x_n - y_n^2} \tag{4.3}$$

Therefore, the distance between vehicle to vehicle or vehicle to AP can be determined by using equation (4.5). Furthermore, vehicles in communication range and those out of range can also be determined with the following equations.

$$Pos_{new} = Pos_{old} + v \times t \tag{4.4}$$

$$d = |Pos_{new} - Pos_{AP} ... + Pos_{new_n} - Pos_{AP_n}| \tag{4.5}$$

$$I(v_i) \triangleq \begin{cases} 1 & \text{if } v_(i) \text{ is within } \vec{C_R} \\ 0 & \text{otherwise} \end{cases} \tag{4.6}$$

$$N_{totalin\vec{C_R}} = \sum_{i=1}^{N_{total}} I(v_i) \tag{4.7}$$

$$N_{notin\vec{C_R}} = N_{total} - \sum_{i=1}^{N_{total}} I(v_i) \tag{4.8}$$

If C is a class of vehicles in $\vec{C_R}$ (communication range), then from equation (4.6) that $v_1 \cdots v_n$ will be elements of C. $(v_1, v_2, \cdots v_n) \in C$. equations (4.6-4.8) are used to determine the number of vehicles in communication range and the ones outside communication range using an indicator i as seen in equation (4.4).

4.3.2.1 Geometry of the Simulation Model

As shown in Figures 4.3 and 4.4, the positions of nodes are generated, and using equation (4.5), so as to calculate their distances. From Figure 4.6 on page 96, the distance L affects the received signal power level within the affected wireless network. While the distances d and e affect the interference power level received at the Affected Wireless Network (AWN).

4.4 Power Control Through Propagation Phenomena

In a simplified radio link, the transmitter uses the transmission power, while the channel is characterized by the power gain. In this design, power control is integrated into this algorithm for effectiveness in rate changes, energy consumption, congestion control, collision control, QoS etc. This section highlights on SNR estimation, path loss exponent, and other propagation phenomena. The implementation of power control scheme is summarised in Figure 4.7. This figure shows how power control handles SNR-estimation and rate selection. The flow chart summarizes the operation of the power control mechanism used in ACARS implementation.

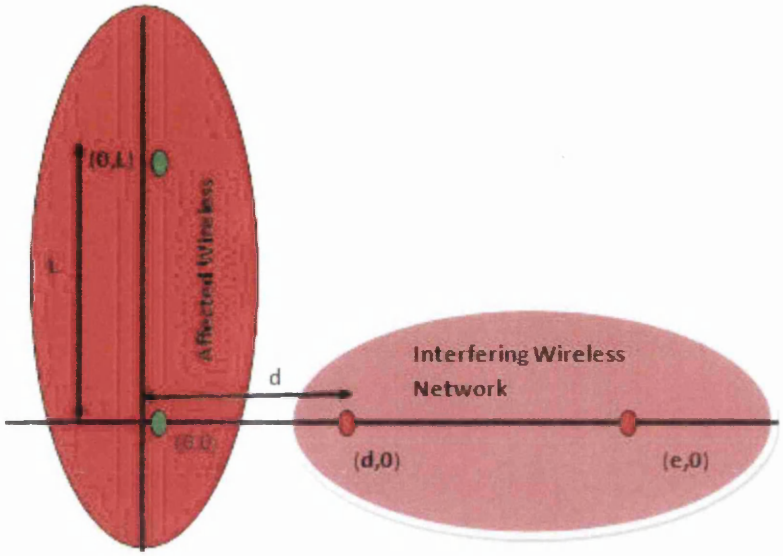

Figure 4.5: Geometry of the Network.

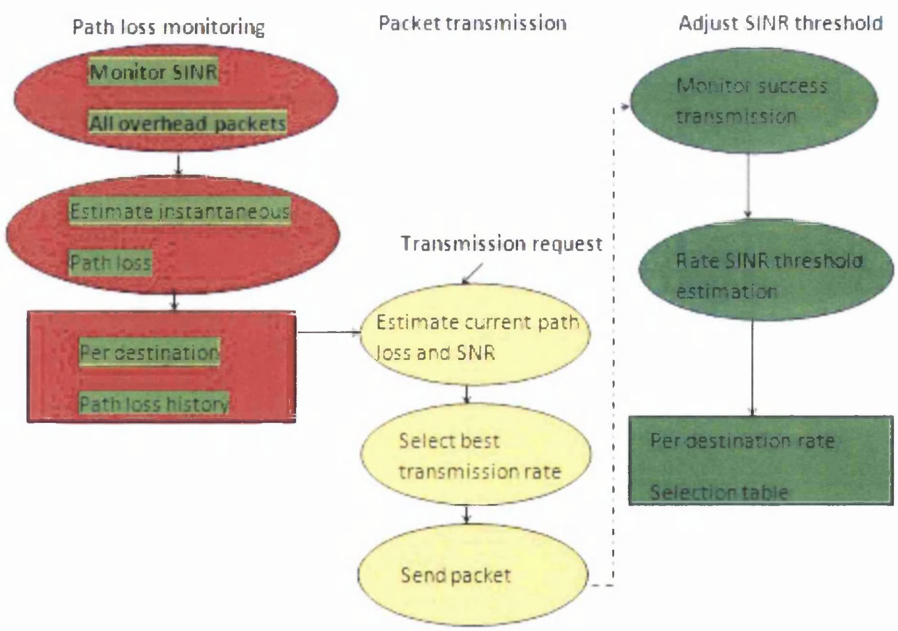

Figure 4.6: Overview of Power Control Scheme:Implemented with Path Loss and SINR-Estimation.

4.4.1 Overview of Power Control Scheme

The power control scheme shown in Figure 4.16 has four components:

- **Path loss monitoring** - Vehicles continuously monitor transmission rates from a potential destination. Based on the readings of $RSSI$, estimation of instantaneous path loss to that destination is carried out by influencing channel reciprocity;
- **Path loss prediction** - Before transmitting a packet, the sender uses past history of path loss information for the destination to estimate the current path loss to that destination;
- **Rate selection** - SINR estimation is done at the receiver as a result of predicted path loss of the sender; with this information, the best transmission rate is selected from the rate selection table with the minimum required SNR threshold for each destination and for each transmission rate;
- **Rate SINR threshold estimation** - Each transmission rate has a minimum SINR that is required for a successful packet reception to occur with a good probability, depending on the success or failure outcomes of the past transmissions, threshold is gradually updated by sender using the rate selection table.

The relationship between transmission power and transmission range is expressed in equation (4.9). From this equation, since transmission power is directly proportional to transmission distance, this means that, with greater transmission power, greater transmission distances can be achieved.

$$\frac{P_r}{P_t} = \frac{G_r G_t}{F_t} (\frac{\lambda}{4\pi R})^2 \tag{4.9}$$

where P_t is the transmission power of the device, P_t is the received power, G_t is the transmit antenna gain, G_r is the received antenna gain, λ is the wavelength of the wireless device, F_t is the loss factor that adjusts for signal loss in the communication system, and R is the transmission distance(or transmission range)

4.4.2 Propagation Model

Implementing test-beds for vehicular network experiments is very complex and difficult, hence simulation tools are widely used [20]. In vehicular Ad-Hoc networks, mobile terminals, other devices in the city are some of the causes of obstructions and interferences. Radio propagation has great effect on both higher level protocol and simulation results. This effect results in dropped packets which causes losses. Simpler propagation model such as two-ray ground or shadowing can be used to model these losses.

4.4.2.1 Free Space Path loss

The Free Space Path Loss (FSPL) is the loss in signal strength which occurs as a result of electromagnetic wave travelling over a line-of-sight path in free space. In these circumstances, there are no obstacles which might cause the signal to be reflected and refracted, or that might cause additional attenuation. Free space path loss model is a power off with the distance. Due to high mobility of vehicles, the distance between the transmitter and receiver changes, this makes empirical free space path loss necessary in order to model the effect of distance on packet delivery probability. This space loss accounts for the loss due to spreading of Radio Frequency (RF) energy as transmission of signals propagates through free space. From the equation of path loss, it is seen that the power density is reduced by $1/d^2$ as distance is increased as seen in Figure 4.7.

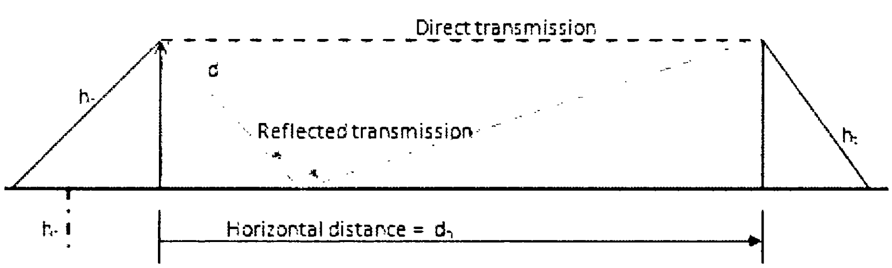

Figure 4.7: The Two-Ray Ground Model.

The two-ray ground model takes the path loss exponent from the path between transmitter and receiver where it has reflected of the ground (Earth's surface of other reflective material). The model calculates the reflection point as the distance where the path would reach the inverse height of the receiving tower.

During movement, signal spreads out from a transmitter). As a result, the signal will move away from the source, spreading out over a sphere. When this happens, the surface area of the sphere increases, which obeys the law of the conservation of energy that states that "as the surface area of the sphere increases, the intensity of the signal also decreases". As a result of this, the signal decreases in a way that is inversely proportional to the square of the distance from the source of the radio signal.

$$\aleph = 1/(d^2) \tag{4.10}$$

From Figure 4.9, d is distance, $\aleph$ represents the signal, h_t and h_r are transmit and receive antenna heights respectively.

$$\ell(dB) = 10log10(4\pi\frac{d}{\lambda})^2 \tag{4.11}$$

$$P_{tx} = 10log_{10}(P_{TX} \times 10^3) \tag{4.12}$$

$$P_{rx} = P_{tx} - \ell \tag{4.13}$$

$$P_{rx} = P_{tx} - \ell \tag{4.14}$$

$$P_{rx} = P_{tx} - \ell \tag{4.15}$$

$$P_{rx} = P_{tx}(\frac{\lambda_0}{4\pi d})^2 \tag{4.16}$$

where λ is wavelength in meters, d is distance in meters, ℓ is empirical path loss, P_{rx} is received power, P_{tx} is transmit power in milliwatts, P_{TX} is normalized transmit power in milliwatts, γ is path loss exponent, $\frac{P_{tx}}{4\pi d^2}$ is the power density, and power is the normalized transmit power. In free space, the power of electromagnetic radiation varies inversely with the square of distance, making distance an ideal indicator of signal level as well as loss rate. Due to imperfect propagation environment, in practice, it is not exactly the inverse square. Distance between sender and receiver gives a high correlation between signal level and error rate as this affects the number of transmitted packets that will be received [85].

$$\ell \propto (d/\lambda)^{\gamma} \tag{4.17}$$

$$\kappa = \ell + \epsilon \tag{4.18}$$

where λ is wavelength in meters, ϵ is power tolerance limit below which correct reception of a packet cannot be guaranteed, γ is path loss exponent, d is distance in meters, ℓ is path loss, and κ is optimal transmit power. In practice, since the lower limit of the transmit power is 0 dBm, κ is the minimum of $1mW$ as shown in equation (20) in [86].

4.4.2.2 Path Loss Exponent

Since vehicles move from one environment to the other, the radio wave attenuation effects encountered differ. In practice, different environment or channel condition is given different values known as the path loss exponent. The value of the path loss exponent is specific for the type of environment. These values are shown in Table 4.3 on page 74. In this simulation, different values of path loss exponent have been used to evaluate the impact of propagation effect on the RAAs for several environments.

$$P_{rx} = P_{tx} - g_t \tag{4.19}$$

$$\Re = P_{rx} - \tilde{P}_{TX} \tag{4.20}$$

4.4.3 Power Gain

Power gain is made up of three components; path loss, shadowing and multipath fading. The aim of power control scheme is to optimize link performance such as link throughput and energy efficiency. In this design, the metrics considered will be discussed in Chapters 5 and 6.

$$g(t) = g_p(t) + g_s(t) + g_m(t) \tag{4.21}$$

$$P_{rx} = P_{tx} - gt \tag{4.22}$$

$$\Re = P_{rx} - \tilde{P}_{TX} \tag{4.23}$$

where $g_(t)$ is power gain, $\tilde{P}_{TX}$ is noise power in dBm, $g_p(t)$ is path loss, $g_s(t)$ is shadowing, $g_m(t)$ is multipath fading, and $\Re$ is the received signal strength.

4.4.4 Rate SNR Threshold Estimation

This proposed algorithm is a SNR-based RAA. SNR is a good prediction tool for channel quality [87]. It helps to rate the network either to be good or bad depending on the value of SNR. For each transmission rate, there is a minimum SNR required for packet reception to occur with a good probability. From this implementation, ACARS can estimate SNR to the PHY Layer. The network uses estimated SNR to compute the PER the context-information function E_C. To do this, the network uses PER tables which are generated by MATLAB simulations. The PER table to be used depends on the nominal transmission rate, propagation conditions (such as urban or rural area) and relative speed between the AP and the node.

There are two reasons why rate selection and switching to lower rate is important. The first is that, since we want to deliver the packet, and since the first transmission may fail which must have been as a result of high rate. Secondly, there is up to date information on the estimated SNR when there is a successful delivery due to an ACK. By using transmit power and noise level of the transmitter, the SINR estimate at the receiver can be obtained. The node estimates the SNR of the downlink and reports it to the network CQI. The network transmission format is based on CQI. The network then transmits the data immediately to the nodes with higher CQI, i.e. higher SNR. This is part of the so called 'opportunistic scheduling' i.e. the ability to exploit the variation of channel conditions instead to combat them as in the past. Fairness is an objective of the scheduling opportunistic means by exploiting the channel at best when it is good, this improves overall system performance. The SINR estimate obtained is finally used to determine a set of transmission rates via a look-up-table with SINR thresholds for the intended receiver.

In this simulation, the look-up-table is generated using MATLAB. The simulation uses the value of SNR for each node in each transmission attempt. In the first transmission attempt, the highest rate is chosen from the estimated SINR value, for the purpose of maximizing the channel throughput. In the case of retransmissions, lower rates are chosen and the look up table helps to determine which rate is appropriate to be chosen for transmission depending on the value of SINR.

4.5 Algorithm

This section will demonstrate the implementation of ACARS by summarising the implementation of RAAs using algorithms. The design and implementation of ACARS is summarized in Algorithm 3, while Algorithms 1 and 2 are part of ACARS implementation in Algorithm 3 on page 110, and 111. The dynamic range transmission algorithm summarizes the steps in selecting transmission range used in ACARS implementation, while the *RSS* algorithm is for calculating Friis path loss and *RSS* and Algorithm 3, shows full implementation of ACARS.

All the above algorithms are summarized and embedded in the final ACARS design and implementation. The key contribution of this algorithm in adding new functionalities to the existing CARS algorithm are:

1. Designing a SNR-based algorithm which is not implemented in CARS;
2. Using mathematical modelling to determine context-information which was not disclosed in CARS implementation;
3. Integrating a power control scheme into the ACARS algorithm which is not available in the CARS algorithm;
4. Analysing various path loss exponents with propagation loss process to investigate the effects of signal reception for different channel conditions which was not implemented in CARS;
5. Using RTS/CTS scheme to solve hidden node problem, this was implemented in CARS.

4.5.1 Implementation of Algorithm 1

The density estimate is used to develop an algorithm that sets a vehicle transmission range dynamically according to local traffic conditions [7]. This research does not employ the density estimate, and a chosen communication range was used in this case. Hence, Algorithm 1, cannot dynamically choose transmission range. In the actual implementation of dynamic transmission range, where density is a required parameter, communication range for vehicular communications do not need to be set, rather the algorithm does that dynamically.

For simplicity, communication range of 300 metres was chosen in this research. Communication range for vehicular communications is between $200 - 1000$ metres [88]. Algorithm 3 uses this value for range checking as vehicles transmit. Algorithm 1 shows how transmission range is determined, but this value is assigned to be computed in place of output of Algorithm 1. The choice of the maximum transmission range in free-flow is due to two reasons: 1) estimation of density within the free flow traffic range is difficult, but it is easy to detect the free-flow phase; 2) it is expected that distance between vehicles in free-flow is long; therefore a longer than optimal transmission range will not have the same adverse affects as in dense network, and can help maintain the network stability [7].

Algorithm 1 Dynamic Transmission Range Algorithm.

Input: $\frac{T_s}{T}$
Output: T_R

1. *a is a constant*
2. $N = \frac{T_s}{T}$
3. M_R *is maximum transmission range*
4. T_R *is transmission range*
5. $\frac{T_s}{T}$ *is the time a vehicle is stopped*

$$K = estimate_K(NT_s/T),\ \textit{is the density estimate} \tag{4.24}$$

6. **if** $\frac{T_s}{T} == 0$ **then**
   $T_R = M_R$
7. **else**
   Calculate

$$T_R = \min(M_R \times (1 - K), \sqrt{\frac{(M_R \times ln(M_R)}{K + a \times M_R}}) \tag{4.25}$$

8. **end if**

4.5.2 Implementation of Algorithm 2

Algorithm 2 is used to determine, RSS used in Algorithm 3. From Figure 4.9, the cross distance dc is calculated by:

$$d_h = 4h_r h_t/\lambda \tag{4.26}$$

This algorithm calculates path loss and RSS depending on the values of d. d is the horizontal distance, P_{rx} is received power, P_t is transmit power, and ℓ is path

Algorithm 2 Received Signal Strength Algorithm.

loss.

Output: RSS

1. *Take transmitted signal strength* P_t
2. *Calculate distance between sender and receiverd*
3. *Calculate the horizontal distance* d_h
4. *Compute* d *from equation*(4.9)
5. **if** $d > d_h$ *then* **then**
   Calculate Friis path loss ℓ
6. **else**
   Calculate received signal strength $P_{rx} = P_{tx} - \ell$
7. **end if**

4.5.3 Implementation of Algorithm 3

Algorithm 3 is a summary of ACARS implementation. The goal of this algorithm is to return the best rate to be chosen at each transmission attempt. With the integration of power control into this algorithm, the bit-rate with the highest SNR is chosen for transmission in each transmission attempt. The transmission attempts for each bit-rate is done for 3 times, after which algorithm tries with another bit-rate.

The two key functions in this algorithm are E_C, and E_H. E_C uses context-information represented with ctx as input parameter, and helps to implement line 14 of Algorithm 3 which is PER, PER is represented with Ψ. It is determined from:

$$Ec(\vec{TV}, jj) = min(1, exp(polyval(P_{TX}(jj, :), SNR_{\vec{TV}})) \tag{4.27}$$

α is assigned based on vehicle speed, it is given as $\alpha = max(0, min(1, v/S))$, it determines when to give priority to the E_C function or the E_C function. $\vec{V}_{Mob}$ is the mobility function that uses input parameters for ctx is context-information such as speed, length of road, position of vehicle, communication range, position of AP. This function helps to determine the distance between the vehicles and the AP. When it is called in the simulation, it helps in range checking. The number of vehicles in communication range and those out of range is determined by this function. In order to implement range checking, equation (4.4) on page 82, determines which vehicles is in or out of communication range. This is done by comparing the values obtained from this equation with the value chosen in this research as 300 m for communication range. Any value from equation (4.4) greater than 300 m is out of communication range, therefore, that vehicle has no impact on the network performance, since it does not contend for the network resources.

From algorithm 3, E_H uses an Exponentially Weighted Moving Average (EWMA) of past transmission statistics of each bit-rate. It is determined as:

$$E_H(T\vec{V}, \delta(T\vec{V})) = E_H(T\vec{V}, \delta(T\vec{V})) \times (1 - a) + \ddot{B} \times a \tag{4.28}$$

$$E_H = E_H(T\vec{V}, :) \tag{4.29}$$

In order to determine what value of α to be used in Algorithm 3, It is computed as :

$$\alpha = max(0, min(1, v/S)) \tag{4.30}$$

When speed is zero, there is no opportunity for doing any prediction of link quality using context-information, hence EWMA is given preference, but when vehicle speed is high, context-information is given preference. More precisely, α is determined using equation (4.26). Speed normalizer, S is selected as 30 (metres per second) as the best value, which corresponds to a vehicle speed of about 65 miles per hour, as shown in Table 4.1 on page 72.

The values of E_C, and E_H help to compute PER in line 13 of Algorithm 3. It is determined as:

$$\Psi = E_C \times \alpha + (1 - \alpha) \times E_H \tag{4.31}$$

Other parameters used in Algorithm 3 are: $\overline{N}$ is average retries which computes the average number of retransmission attempts. It is determined as:

$$\overline{N} = (N \times \Psi^{(N+1)} - (N+1) \times \Psi^N + 1)/(1 - \Psi) + N \times \Psi^N) \tag{4.32}$$

ρ signifies the penalty of unsuccessful packet transmission, this value is chosen to be 8 from [14] as shown in Table 4.1 on page 72. S is the speed normalizer, v is the speed of the vehicles, a is chosen as 0.003 for averaging the number of errors blocks, as shown in Table 4.1 on page 72. δ is the transmission rate, $\vec{TV}$ is transmitting vehicles, $\vec{C_R}$ is communication range, and Thr is throughput determined as:

$$Thr = \delta/\Psi \times (1 - \Psi^N)^\rho \tag{4.33}$$

P_L is packet length, η is back-off time. This is calculated using equation (2.4), and X_{max} is length of the road. To estimate SNR to the PHY layer, this algorithm uses $\ddot{B}$ from the look-up-table, and chooses the BER generated for each node, and use for each transmission attempt.

From equation (4.18), the received power can be computer, and once the received power is known, Algorithm 3 computes RSS from equation (4.19) to execute line 2. Transmission rate changes based on the value of the estimated SNR. The algorithm calculates estimated throughput for each bit-rate and selects the bit-rate that it predicts will provide the most throughput. Since ACARS is a SNR-based scheme, its transmission rate is chosen based on which bit-rate has the highest estimated SNR, so that the bit-rate with the highest SNR is returned after the throughput is computed using line 14. When all the parameters defined and explained are determined, Algorithm 3 will execute all the 17 lines, and then return the best rate using line 18.

Algorithm 3 The Adaptive Context-Aware Rate Selection Algorithm.

Function : $ACARS\_GetRate$
Output: δ
Input: ctx, α, P_L

1. $update\ counter\ of\ packet\ transmissions\ at\ each\ rate(try[\ ])$
2. $update\ average\ RSSIs\ of\ recent\ ACKs(RSSI)$
3. $Best_{Rate} = find_{Best_{Rate}}(try[\ ])$
4. $Determine\ \alpha$
5. $Compute\ back-off$
6. $Decrement\ all\ back-off\ counters$
7. $Update\ the\ simulation\ time\ accordingly$
8. $Requires:\ \vec{V_{mob}}(t, v, Pos_{new}, Pos_{AP},$
   $\vec{C_R}, \vec{TV}, X_{max})$
9. $Update\ link\ condition\ by\ checking\ communication\ range$
10. $Compute\ Bper\ from\ the\ PER\ table$
11. $Compute\ E_C$
12. $Compute\ E_H$
13. $Compute\ PER$
14. $Compute\ throughput$
15. $Select\ \delta$
16. **if** $Thr > Thr_{max}$ **then**
    Update link condition

$Best_{Rate} \leftarrow Bit - rate$
$Thr_{max} \leftarrow Thr$

17. **end if**

18. *Return* $Best_{Rate}$

4.6 Chapter Summary

This chapter explains the techniques on how the adaptive context-aware rate selection algorithm is implemented. Chapters 5 and 6 will demonstrate the implementation of this algorithm by analysing the results obtained during simulations, discussing the results and then making comparisons between existing RAAs and ACARS algorithm; using different performance metrics. Chapters 5 and 6 will also demonstrate the performance of each rate selection algorithm in various environments and conclusion will be drawn based on the outcome of results obtained.

5

Comparative Analysis of ACARS Algorithm without Fading

This chapter will discuss the results obtained from simulations based on different metric analysis. This chapter will also evaluate the efficiency of the proposed algorithm. It will further evaluate the impact of communication range on RAAs from the results obtained. Furthermore, strengths and weaknesses of existing RAAs will be determined through results obtained from simulations. Based on these results, recommendations and future works will be drawn for further improvements where there are weaknesses.

For efficiency and productivity in vehicular networks, reliable communication is very essential. Reliable communication in networks means re-transmitting a message until it is acknowledged by the recipient(s). This is good for file transfer since even one missing byte may render the entire file un-usable. Thus reliable transmission protocols like Transmission Control Protocol (TCP) ensure each byte is received with certainty. The network design and configuration implemented in such as to achieve a reliable communication. In this simulation, a re-transmission attempt of 3 was adopted, so as to enhance retransmission of packets.

This chapter will only evaluate network configuration without a fading process. This is to analyse the performance of the proposed algorithm and existing

RAAs without fading effects. Chapter 6 will consider the impact of propagation phenomena on RAAs.

5.1 Simulation Methodology

This section will explain the network configuration that was adopted in the simulation. It will also analyse the methodology adopted, and finally evaluate the performance of the network configuration based on the results obtained from simulations.

5.1.1 Concept

The modelling and study of vehicular networks using computer simulation allow a great number of scenarios and situations to be studied. In this section, the system for simulation which can study the massive dimensional space of available parameters is presented. From the analysis of the results, universal behaviours in the network will be discovered.

5.1.2 Vehicle-to-Infrastructure (V2I) Communications

A V2I network is an architecture that allows communication between nodes with the help of the AP acting as a router. It coordinates the communication between nodes and also help when nodes are far away from each other, and may have difficulty in communicating with each other. In this thesis, both AP and RSU mean the same thing and have same role. A V2I architecture was implemented in this research for the followings reasons:

- Multiple vehicles transmit packets to a central base station. This scenario can be easily found in real world, where many vehicles send data to a base station which serves as a central storage/relay node;
- All vehicles in communication range can hear and communicate with the RSU.

In this network configuration, each time a vehicle enters into communication range, it will communicate with the RSU. It will add new vehicle information such as vehicle speed, position, distance etc. This information will help the RSU to broadcast the emergency information to the vehicle. Every minute, many vehicles leave and enter communication range at high speed. The RSU communicates to vehicles as soon as they enter the communication range, because for example if there are no vehicles within range and there is an accident or emergency message, at that time; as soon as any vehicle enters the range, the message will propagate through the first entered vehicle in that communication range. This roadside unit communication aids communication when there is no vehicle in the cluster range otherwise vehicle communication is possible very easily.

In this scenario, all vehicles act as clients. A fixed base station is used as a server which is similar to what is obtained in cities and highways having road-side units (e.g., kiosks and cafes) with wireless services. Our scenario consists of a road of length 1000 m with multiple lanes. The base station is located at the middle of the road. Vehicles select their speeds uniformly over the range $[\overline{V} \times 0.75, \overline{V} \times 1.25]$ km/h. All vehicles start at the same time at the beginning of the road and move towards the end of the road, crossing the server on the way. Once a vehicle is in the range of the server, it establishes a connection immediately. The average speed ($\overline{V}$) is selected to be 55 km/h, which results in average duration of 33 second for each connection.

Some of the network configuration parameters are listed in Table 4.1, and a communication range of 300 m is used since the standard is between $200 - 1000$ m [88].

In the design of safety application in vehicular communications, preference is given to large message ranges rather than smaller ones. On the other hand, large message ranges cause more difficulty in network design. The 300 m message range corresponds to the comfortable stopping distance of a high speed car. When the road is jammed, neighbouring vehicles will be much closer, therefore it should not be necessary to send safety messages over the same distance. IEEE 802.11a radios are designed to transmit over distances of $200 - 100$ m [89].

5.1.3 Vehicular Mobility Modelling

The modelling of vehicular mobility is primarily concerned with the movement of vehicles on a simulated road, and what velocity and heading changes they will make. This approach can be divided into various components; from driver type to vehicle age and condition. The environment in which VANET operates means that minor changes to operational parameters and settings can lead to large effects. Vehicles moving at high speeds will have a short opportunity to share data with each other via the AP, so the modelling of these movements is very important in this work [3].

Some mobility models have been reviewed in Chapter 2, and reason(s) for adopting the mobility model used in this implementation was also stated.

5.2 System Parameters and Performance Metrics

The study of network performance requires that a number of parameters are explored, and a number of metrics are used in measuring the effects in the network, and the performance of V2I communication primitives. This section will present the parameters that were varied, how they interact, and what effect they have in the network utilisation and operation. Also in this section, both system parameters and the metric parameters used in this simulation will also be considered. The system parameters explains some techniques that are useful in analysing the metric parameters, and also for implementation of the simulation results, while the metric parameters are those parameters used in analysing this simulation results.

5.2.1 System Parameters

Some parameters were varied in order to study how the network performance distinguishes from the parameters of the MAC and PHY layers. These parameters ar specified by the IEEE standard (i.e. 802.11p), and most devices (network interface cards, wireless adapters etc.) do not allow the tuning of these settings, other than switching between. Some of the parameters set by the DSRC standard are listed in Table 5.1. From this table, frequency (Hz), latency (msec) and range (m) for various communication types are listed.

Table 5.1: Safety Application Parameters.

Application	Communication Type	Frequency	Latency	Range
TSV	V2I, One-way, P2M	10	100	250
CSW	V2I, One-way, P2M	1	1000	200
EBL	V2V, two-way, P2P	10	100	200
PCS	V2V, One-way, P2M	50	20	50
CW	V2V, One-way, P2M	10	100	150
LTA	V2I and V2I, One-way, P2M	10	100	300
LCW	V2V, One-way, P2M	10	100	150
SSA	V2V, One-way, P2M	10	100	300

5.2.1.1 Vehicular Density

The density of vehicles affect the channel utilisation, and medium contention in a VANET. Given an average vehicle length of 4 m (this covers most vehicles and small vans, but not motorcycles or trucks) [7], the maximum number of vehicles per lane in a 1 km stretch of road would be approximately 250, but this would be static with vehicles bumper-to-bumper. The maximum number of vehicles in a given field V_{max} is:

$$V_{max} = L/l \tag{5.1}$$

where L is the length of the road (m), and l is the average length of a vehicle (m). Generally, for traffic in motion, the density will have to be much less than the maximum given in equation 5.1. However, for a VANET to arise, at least two vehicles must be within range of one another, so that there is a minimum number of vehicles in the field V_{min} to initiate communication:

$$V_{min} = L/TX_{range} \tag{5.2}$$

for a given transmission range TX_{range} (m), and a road of length L (m). The density of vehicles is given by V/L. The maximum density ρ_{max} is given by:

$$\rho_{max} = L/l/L = 1/l \tag{5.3}$$

The minimum density is strongly related to the transmission range, which is a function of the transmission power, this is discussed later in this section. Therefore, density can be considered as an important feature for VANETs. A protocol project should consider its influence on the quality of transmissions to allow continuous and reliable exchange of information between vehicles.

Simulation is used to examine the functional dependence of each metric (R) as a function (F) of the parameters varied.

$$R = F(\rho; s; f; p) \tag{5.4}$$

where ρ is the vehicular density (vehicles/m), s is the packet size sent in bytes, f is the transmission rate (Hz), and p is the transmission power (dBm). As the distance from a node to a given vehicle diminishes in relationship to the transmission range of that vehicle, the value of the density is increased.

Traffic flow theories explore relationships among three main quantities; vehicle density, flow, and speed. The flow q measures the number of vehicles that pass an observer per unit time. The density k represents the number of vehicles per unit distance. The speed u is the distance a vehicle travels per unit time. The units of these quantities are usually expressed in (veh/h/lane), (veh/km/lane), and (km/h), respectively. In general, traffic streams are not uniform, but vary over both space and time. Therefore, the quantities q, k, and u are meaningful only as averages or as samples of random variables. The three quantities are related by the so-called fundamental traffic flow relationship [7] as shown in Figure 5.1 on page 102.

$$q = u \times k \tag{5.5}$$

5.2.1.2 Density Estimate

Traffic flow theories suggest [7] that, the average vehicle speed can be expressed as a function of density;

$$u = f(k) \tag{5.6}$$

The fraction of vehicles stopped in traffic f_s, is related to the average speed of vehicles (including the stopped vehicles),

$$u = u_f(1 - f_s)^{n+1} \tag{5.7}$$

The value of f_s can be measured by an external observer counting the number of vehicles in the traffic. The two-fluid theory [7] relates the time a test vehicle circulating in a network is stopped, T_s, to the average fraction of vehicles stopped, f_s during the same period, T.

$$f_s = T_s/T \tag{5.8}$$

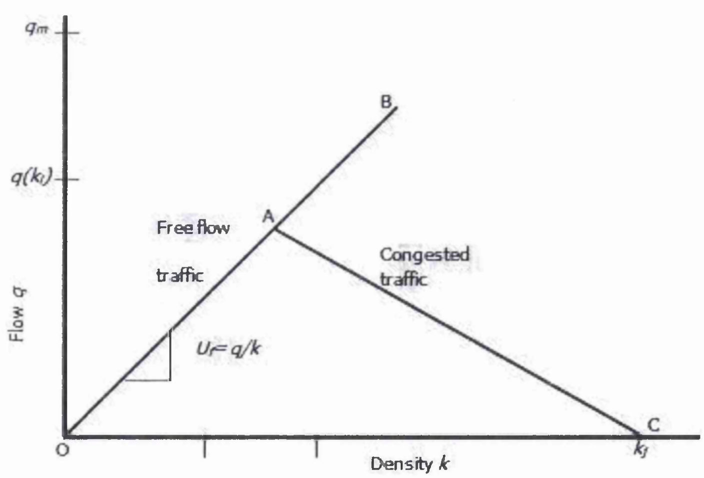

Figure 5.1: Flow-Density Relationship.

5.2.1.3 Back-off Time

The MAC protocol of the IEEE 802.11 is a stop-and-wait protocol which requires the sender to awaits an Acknowledgement(ACK). If there is no ACK received due to transmitted packet never reaching the recipient, the packet being incorrect at reception, or the ACK being lost or corrupted, a back-off procedure is invoked before transmission is allowed. For every attempt to send a specific packet, the size of the CW will be doubled from its initial value(CW_{start}) until a maximum value (CW_{end}) is reached.

Back-off time is a time value that determines the time of transmission. It is calculated by a random value, chosen based on the contention window, multiplied by a time slot. Higher priority is assigned to the least amount of back-off time [90][91].

$$\eta = CW_{size} \times t_{slot} \tag{5.9}$$

where η is back-off, CW_{size} is contention window size, and t_{slot} is time slot. The EDCA have four Access Categories (AC) and make use of the back-off procedure to determine which traffic is to be given priority to at a given time known as Transmission Opportunity (TXOP). Each AC obtains a differentiated channel access due to varying amount of time an AC would sense the channel to be idle and different length of the contention window size during back-off. EDCA supports eight different priorities, which are further mapped into four ACs. For the AC[i] (i=0; ...;3). The initial back-off window size is CW_{min}n [i], and CW_{max} [i] is the maximum back-off window size. Each AC has its own back-off counter (BO[i]), which is independent of others. If more than one AC finishes the back-off at the same time, the highest priority AC frame is chosen for transmission by the virtual collision handler. Other lower priority AC frames goes to the next round of back-off. Let CW_i denotes the total contention window size in a back-off round i. When i = 0, $CW_i = CW_0$ is the minimum total contention window size. In this study, it is taken as 32, which is the default for IEEE 802.11 DCF. Since total contention window is increased linearly, CW_i is given by:

$$CW_i = (i + 1) \times CW_o \tag{5.10}$$

where CW_i is the size of the total CW range.

The performance of CSMA/CA shows that to achieve an optimal operation, the system parameters must be properly selected according to traffic conditions. In particular, the fact that the optimal value of CW_{min} depends on the number of contending stations, suggests that the CSMA/CA can be improved by dynamically selecting the contention window size according to an estimate of the number of the contending stations based on measurements of the channel activity, performed by each station [92].

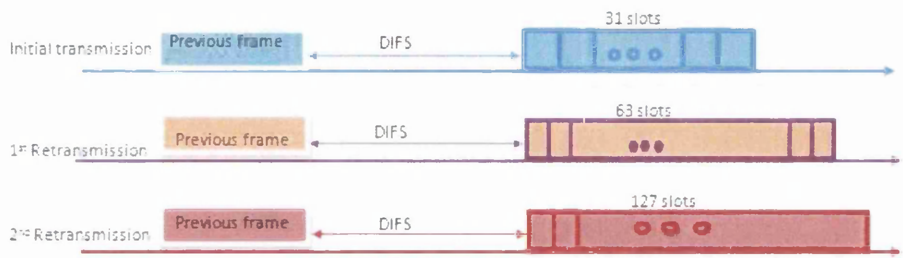

Figure 5.2: Back-off Procedure.

Packet Size - This is the size of the data packet being sent across through the network. The size of data being sent across the medium will affect the channel utilisation and back-off function of the MAC layer. The payload (the actual data being sent, without the encapsulated headers) is defined by the application running the transmissions.

The contention for the medium is based on the amount of time required to utilise the medium for data propagation. A larger packet requires longer time within the medium, and increases the contention (up to the maximum allowed size before it is necessary to fragment the packet) for access. Therefore, the performance of the application must be balanced between the data requirements and the required access to the medium. 1500 bytes is used in the simulation.

5.2.1.4 Emergency Warning Message (EWM)

EW is generated by Abnormal Vehicles (AVs). These are vehicles that have major mechanical fault, dramatic change of moving direction, deceleration exceeding a certain limit [93]. An EWM may encounter some waiting time in the system due to queueing and channel access delays, etc., and it may also suffer from retransmission delay due to poor channel conditions or packet collisions. Formally, the waiting time of an EWM ($Delay_{Wait}$) is defined as the duration from the time the EWM is issued by the vehicular collision warning communication module to the time it is transmitted on the wireless channel. EWM delivery ($Delay$) can be represented as,

$$Delay = (Delay_{Wait}) + (Delay_{Retransmission}) \tag{5.11}$$

From queueing theory, the system is known to be stable if $\lambda < \mu$

$$Delay_{Wait} = 1/\mu - \lambda + 1/\mu \tag{5.12}$$

where λ is the arrival time, and μ is the channel service rate. Queueing theory simple deals with waiting. This theory explains how delay in queue occurs. Queuing delay is the delay between the point of entry of a packet in the transmit queue to the actual point of transmission of the message. This delay depends on the load on the communication link, which is the channel service rate.

If EWM transmission rate is decreased too slowly, the total arrival rate of EWMs in the system may increase rapidly with the occurrence of new AVs. Assuming the i^{th} transmitted EWM message from an AV A is the first EWM correctly received by a receiver vehicle V, hence the EWM retransmission delay from A to V can be defined as the elapsed duration from the time when the first EWM is generated to the time when the i^{th} EWM is generated by the AV A as shown in Figure 5.3.

5.2.1.5 Transmission Rate

Transmission rate is directly related to the size of packet. It is the rate at which packet is transmitted. In order to avoid vehicular collisions in an emergency situation, much larger number of transmissions could be required, not only to send out more data, but also to tolerate the losses in a highly contended network. Most DSRC and WAVE technology applications suggest a maximum data rate

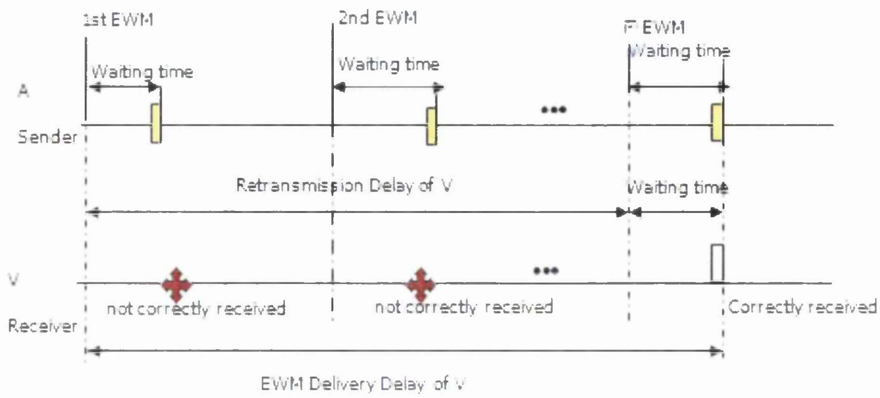

Figure 5.3: Waiting Time and Retransmission Delay.

of 6 Mbps using OFDM, so a channel is capable of carrying and holding a large amount of data, in VANET and ITS systems. This simulation intends to show how the network performs when under load condition, and how well data can be disseminated when the network load is less congested.

5.2.1.6 Transmit Power

There are two types of transmit power. They are :

- **Maximum transmit power** - The maximum overall nodes, of the transmit power used by a node (relevant only for static networks);
- **Average transmit power** - The average over all nodes, of the transmit power used by a node relevant only for static networks).

Transmission power is the power at which a packet is transmitted, expressed in Watts or decibels per metre (dBm). It influences the distance over which it is usefully received (useful referring to a reception power above a minimum to extract the signal). It would appear that increasing the transmission power to a large value would increase the probability of reception, but due to the contention for medium access in VANET, this may lead to a network blockage.

The power levels available for different devices are shown in Table 5.2.

Table 5.2: Power Levels for Different Devices.

Power for Devices	Power in dBm	Power in mW
802.11 Devices	13	19.95
Home Wi-Fi (802.11a/b/g/n)	17	50.11
Maximum EIRP allowed by ETSI	20	100
WiMAX	24	251.9

5.2.2 Performance Metrics

This section will define the performance metrics used in this simulation. These metrics help to analyse and give further evaluation on each type of RAA used in this simulation. It also help to study the behaviour of RAAs in various environmental conditions.

5.2.2.1 Packet Success Rate

The packet success rate is measured by vehicle and by simulated field. It also denotes the number of packets sent, and those which are received successfully and unsuccessfully. This metric provides the QoS that can be attained in a given scenario. ITS and safety applications rely on an appropriate level of packet success that ensure it is reached through these simulations.

$$SUC = BRX/(BRX + DROP) \tag{5.13}$$

where SUC is percentage success, $DROP$, is the amount of packets loss, and BRX is packets received per second. Also, successful packet is determined from simulation as:

$$Static_{pk_{suc}} = \sum(Pk_{suc})/(\sum(Pk_{tx})) \tag{5.14}$$

where Pk_{suc} is successful packet, and Pk_{tx} is transmitted packet.

5.2.2.2 End-to-End Latency (Airtime)

The time it takes a packet to leave the destination application, pass down the protocol stack, cross the medium and then be received, is important in calculating how many packets must be sent to disseminate data in a timely manner. When the network is lightly loaded, the end-to-end latency is expected to be the propagation time plus a small amount for processing the device circuitry. However, once the network becomes well-utilised, a number of delays can occur to the data packet. These delays could lead to loss of data and lack of timeliness in data reception. In applications such as collision avoidance, V2V communication is adopted in order to alert vehicles of a sudden breaking by vehicles ahead instead of relying on sight and ACK of the brake lights. The end-to-end latency of alarm dissemination is therefore a crucial parameter in assessing whether the V2I technology is capable of meeting the stringent performance requirements of safety-of-life applications.

$$Airtime = Mean(Pk_{airtime}/Pk_{suc}) \tag{5.15}$$

where $Pk_{airtime}$ is packet airtime, and Pk_{suc} is successful packet.

Overhead - This is the average non-useful transmission airtime needed to deliver a single packet. It is measured as the difference between the reception airtime and the transmission airtime per delivered packet. The cause of high overhead is due to retransmission over bad links.

5.2.2.3 Packet Loss

Packet loss is the failure of one or more transmitted packets to reach its destination. It is known as one of the three key error types in digital communications. Packet losses in congestion control are unavoidable owing to uncertainties and highly time-varying traffic patterns in the best effort service model, or in conservative end-to-end rate control scheme which uses additive-increase multiplicative decrease.

Reception Error - As data is taken off the medium, there is the tendency that some bits will be received in error. The entire packet is dropped when the Bit

Error Rate (BER) becomes too high. Sometimes, the packet may be corrupted or damaged in transit through the protocol stack.

Packet Delivery Ratio (PDR) - Packet delivery ratio is the ratio of the number of sent to received data packet at the destination. This shows the level of delivered data to the destination. Better value of packet delivery ratio means the better performance of the protocol.

Throughput - Throughput can be defined as the fraction of packets sent by any source that was successfully received at the intended destination.

$$Thr = \sum(Pk_{suc}) \times P_L \times 8/Sim_{time} \tag{5.16}$$

where Thr is throughput, Pk_{suc} is successful packet, P_L is packet length, and Sim_{time} is simulation time.

5.2.2.4 Energy Efficiency

Energy efficiency and capacity maximization are two of the most challenging issues to be addressed by current and future cellular networks since they rely on their battery life. It is also important because QoS in wireless mobile networks depend on energy utilization. In this simulation, energy efficiency is expressed as:

$$\xi = \sum(\tilde{P_{TX}})/\sum(\tilde{B_{TX}}) \tag{5.17}$$

where ξ is average energy efficiency, $\tilde{P_{TX}}$ is transmit power, and $\tilde{B_{TX}}$ is transmitted bits. In Figure 5.4, this model shows how the reception process takes place from propagation phenomena, and through BER before packet is finally received.

5.3 Simulation Scenarios

This section will discuss the network configuration used in this simulation for various rate selection algorithms. It will also discuss some of the concepts and

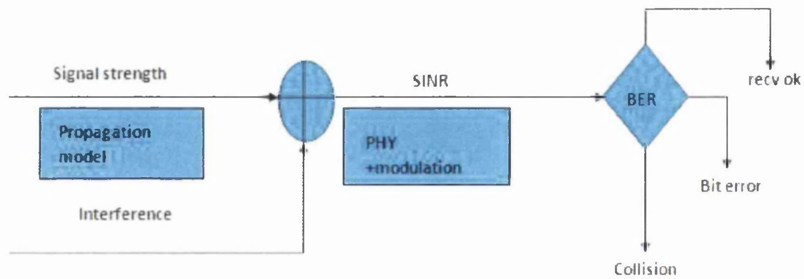

Figure 5.4: Generic Model to Evaluate Reception.

mechanisms used in evaluating the results in the simulations.

5.3.1 Vehicle -to-Infrastructure

This sub-section will evaluate the performance of a V2I network without the impact of propagation phenomena; like fading log-normal shadowing and Rayleigh fading. The reason for evaluation of the network performance of existing RAA and ACARS is for application in data transfer and road safety etc. V2I is one the networking platforms for future vehicular applications [1]. Hence, it is a vital network analysis to implement. Analysis will be based on the results obtained from the simulations which are shown using plots from MATLAB. Figure 5.5 shows the V2I network configuration. This configuration has vehicles on both side of roads acting as clients, while the RSU as a server.

In this scenario, all vehicles act as clients, with a fixed base station acting as a server. This scenario is very typical in cities and highways having road-side units (e.g., kiosks and cafes) with wireless services. This scenario consists of a road of length 1000 m with multiple lanes. The base station is located at the middle of the road. Vehicles select their speeds uniformly over the range:

$$v = [\overline{V} \times 0.75, \overline{V} \times 1.25] km/h \tag{5.18}$$

where v is speed of vehicle, and $\overline{V}$ is the average speed of vehicle. All vehicles start at the same time at the beginning of the road and move towards the end of the road, crossing the server on the way. Once a vehicle is in the range of the server, it establishes a connection immediately. Simulation was done with different number of vehicles and speeds. In Figure 5.6 on page 112, the vehicles in communication range drive past the AP and any vehicle in range can then communicate with the AP. This figure explains the process that occurs from the transmitter to the receiver. It shows the propagation phenomena, the interferences that occur during transmission, and also the processes it undergoes before packets are received.

It was also assumed, that the vehicle arrival process is Bernoulli with parameter p. That is, with probability p, a vehicle will enter range of the AP during one time interval (one slot) and with probability $(1p)$ no vehicle will enter the range during that slot. Table 5.3 shows the different traffic types and their delay requirements. This is important because, delay is an important issue is road safety application. Packet size is in *bytes* and latency is in *msec*.

Table 5.3: Typical Data Traffic.

Application	Pkt size	Latency	Traffic	Msg	Priority
ICWA	~ 100	~ 100,	Event	300	Safety
CCW	$\sim 100/\sim 100K$	~ 100,	Periodic	-	Safety
WZW	$\sim 100/\sim 1K$	~ 100,	Event	50-300	Safety
CCW	$\sim 100/\sim 100K$	~ 100,	Periodic	-	Safety
TVSP	~ 100	~ 100	Event	300-1000	Safety
TC	~ 100	~ 50	Event	15	Non-Safety
SA	$\sim 100/\sim 2K$	~ 500	Periodic	0-90	Non-Safety
MD	>20 M	N/A	N/A	0-90	Non-Safety

Intersection Collision Warning/Avoidance is (ICWA), Cooperative Collision Warning (CCW), Work Zone Warning (WZW), Transit Vehicle Signal Priority (TVSP), Toll Collection (TC), Service Announcement (SA), Movie Download (MD).

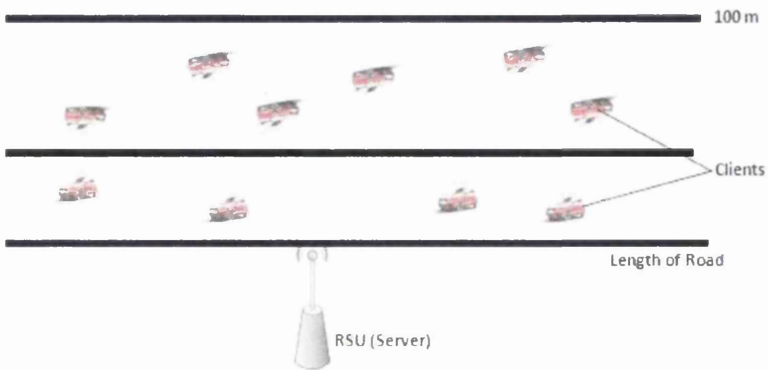

Figure 5.5: Network Configuration.

Figure 5.6: Vehicles with Short Range Communication devices drive past an 802.11 Access Point.

5.4 Simulation Results and Analysis

This section will analyse the network design with communication range set, without communication range set in the presence of no propagation or fading effects. It will also evaluate the results with different values of γ and σ as shown in Tables 4.2 and 4.3 respectively.

Discussions of results will be based on results obtained from plots generated from the simulations. This section will also discuss and analyse different metric parameters, and performances of various RAAs used in the simulations. In this research, few environments have been simulated for time constraints, and not all the environments listed in Table 4.4. The behaviour of various rate schemes without communication range set was also analysed.

In this section, simulation was done for $\gamma = 2$, $\sigma = 0dB$, and $P_t = 50$ mW.

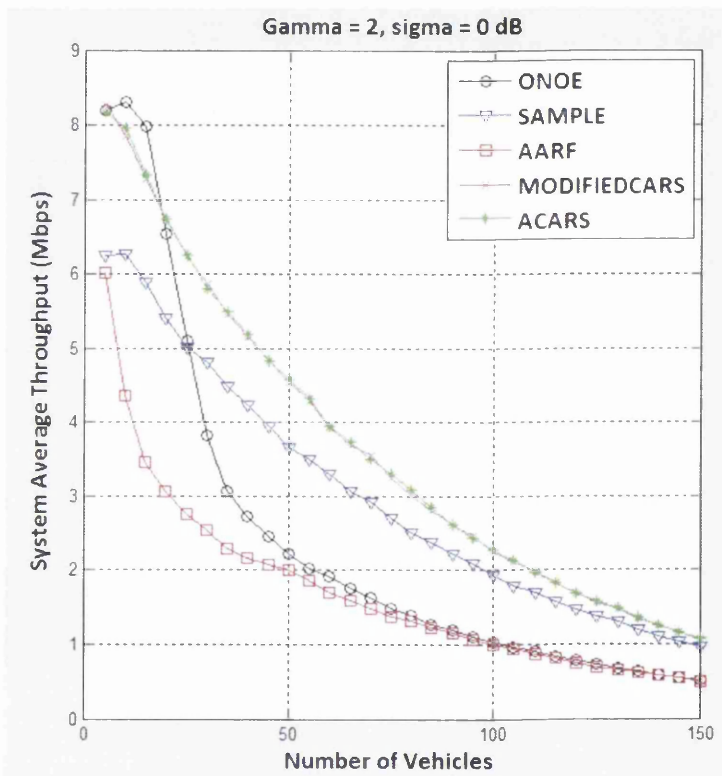

Figure 5.7: Average System Throughput vs Number of Vehicles.

As the number of vehicles increases in the network, more vehicles contend for network resources which affects the performance of all RAAs. From Figure 5.7, it is observed that ONOE can hardly accumulate 10 credits to scale up at 24 Mbps but at improving channel condition, it quickly probes at 27 Mbps, and when it senses that the channel quality is deteriorating, it either stops probing or retracts to lower bit rate immediately. This behaviour of ONOE affects its overall optimal throughput performance as compared to the other RAAs. In this figure, AARF and ONOE perform worst than the others. There is no significant difference between ACARS and MODIFIEDCARS, but both of them performed best, the reason may be because there are no fading processes to actually differentiate these two RAAs in this network configuration. Compared to the results of CARS [14]in page 11, it is observed that AARF, SampleRate all dropped in throughput performance, this should because of the integration of power control scheme in proposed algorithm. The implementations of these RAAs in [14] was without power control, so there should be fluctuation in the results as the algorithms struggle to cope with power control mechanism which they were not originally designed for.

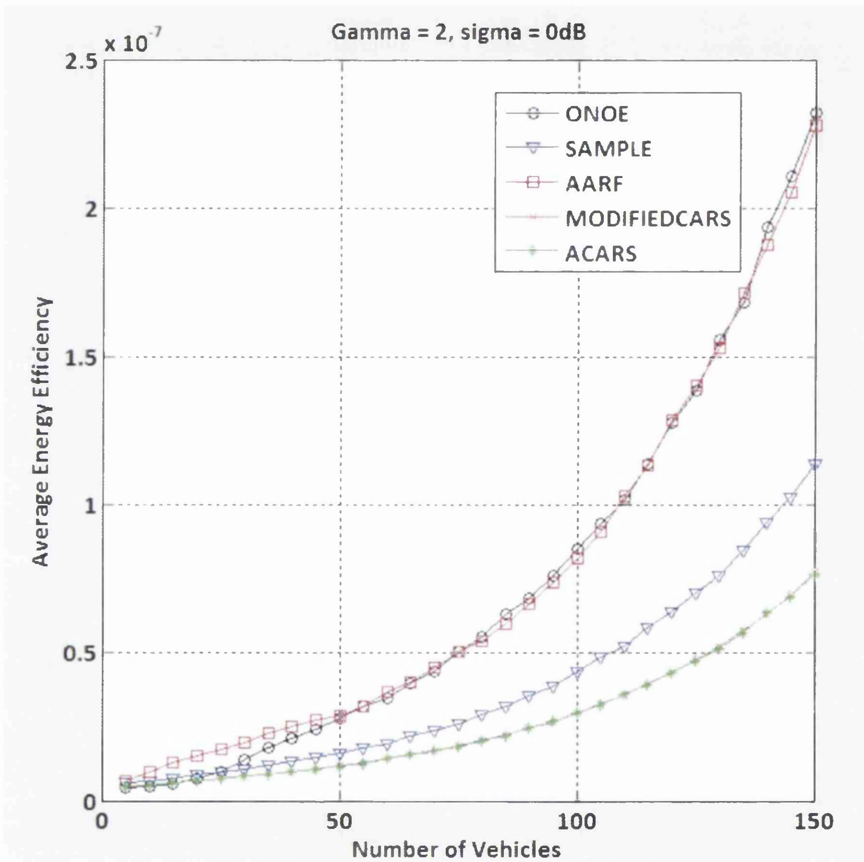

Figure 5.8: Average Energy Efficiency vs Number of Vehicles.

One of the reasons for integration of power control scheme into the ACARS RAA is for energy efficiency; so as to reduce power consumption in vehicular networks. From Figure 5.8, ACARS and MODIFIEDCARS show low energy consumption compared to the other RAAs. The reason may be because ACARS was built from MODIFIEDCARS and should have similar characteristics. Observation shows that AARF and ONOE performed poorly in this regards because they could not cope with this power control scheme.

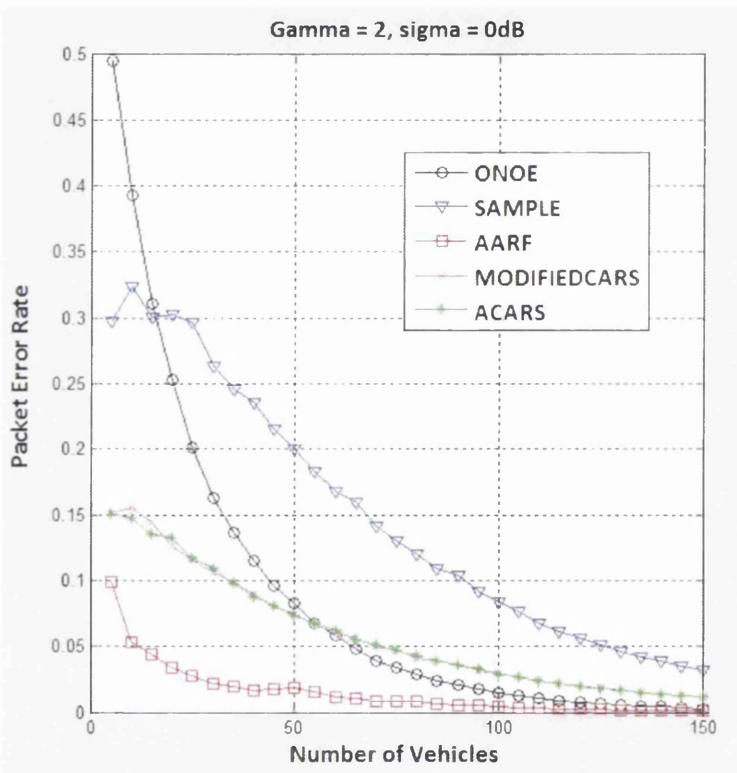

Figure 5.9: Packet Error Rate vs Number of Vehicles.

AARF performs better than the other RAAs as observed from Figure 5.9, with SampleRate having the worst performance. The PER for ACARS and MODIFIEDCARS is still better. It is observed that at 150 nodes, there is not much difference between the performances of ACARS, MODIFIEDCARS, and ONOE. Packet error rate is a factor that is proportional to success probability and throughput. If many packets are in error, it affects the successfully received packets, and hence will affect the overall throughput performance of the network. Also, the lower packet delivery ratio is an indication of poor connectivity in the network due to increased average distance imposed by constraint movement of vehicles within communicate range so as to communicate with the RSU, and by the increased interference due to node clustering.

When simulating a high way environment in vehicular network operation, these two main parameters are very important; the end-to-end latency (airtime) of a packet travelling across the medium, and the success rate of packets sent. A high success rate (above 70% for example) is required for QoS and safety applications.

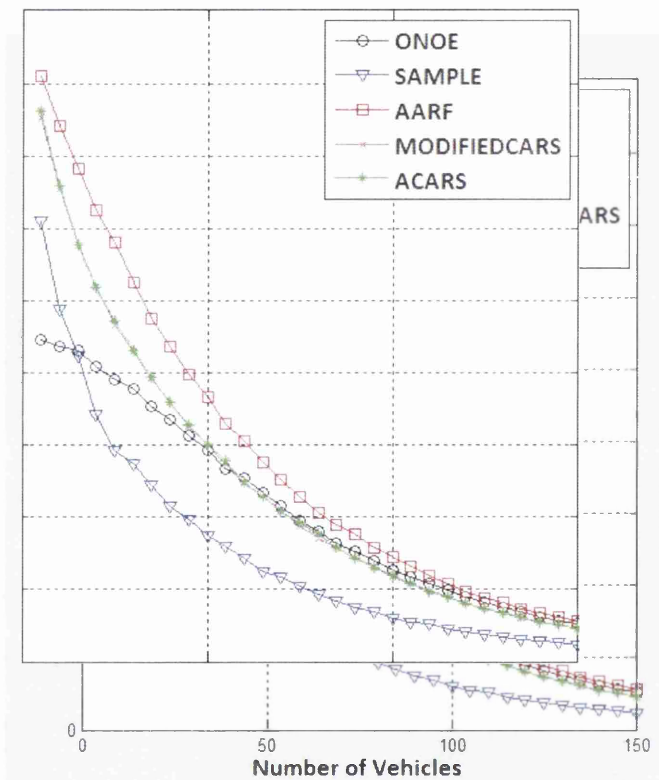

Figure 5.10: Success Probability vs Number of Vehicles.

Packet success rate is a metric that provides the QoS that can be attained in a network. ITS and safety applications relies on appropriate level of packet success rate. The rate of packet success in a collision avoidance application is proportional to the velocity and density of the vehicles involved. From simulation result in Figure 5.10, it is observed that AARF, ACARS, and MODIFIEDCARS attained a success rate above 70% below 50 vehicles in the network, but drops as the number of vehicles increase. This is not strange because, as congestion increases, there is tendency for increase in collision, and this eventually affects the number of successfully received packets. From this scenario, ONOE and SampleRate perform poorly, and could not attain the expected success rate even at below 10 vehicles in the network. Reason could be because of their peculiar behaviour in response to channel conditions which many not have favoured their good performances.

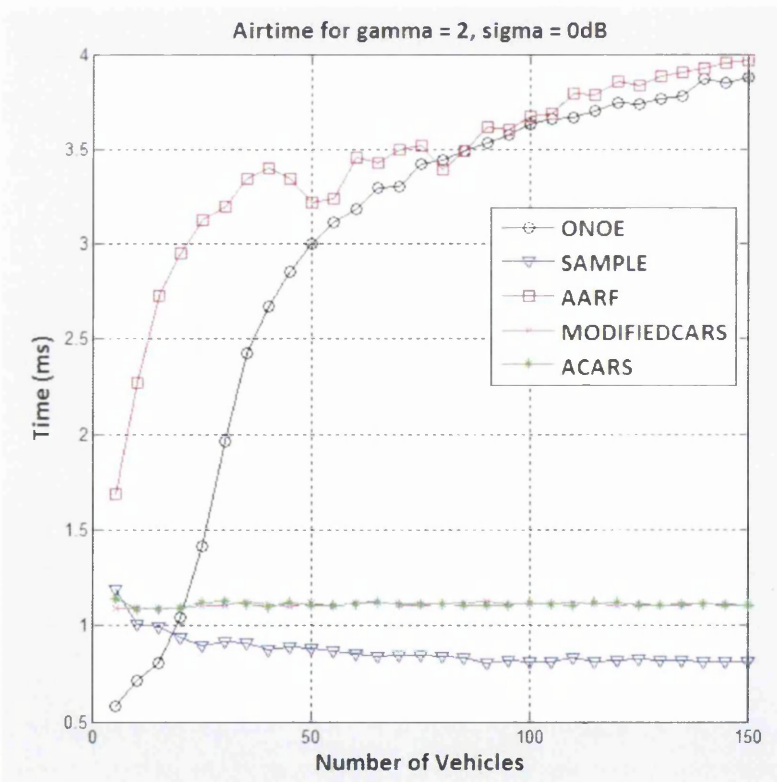

Figure 5.11: Airtime vs Number of Vehicles.

Vehicles that transmit data onto a shared medium will have to contend for access; this means that data will take time to leave the transmitting station, and get to the receiver. The application of VANET to safety systems relies on data being sent and received within a time frame, set by the specific application. So analysing the time it takes individual packets to be sent and received explores the operating parameters of these applications. For example, a collision avoidance application requires the packets containing location and heading data, to be sent and received with a very low latency (below 100 ms could be accepted), so that vehicles have time to compute a safe velocity and heading to avoid collision with the vehicles around them. Latency in a collision avoidance application is proportional to the velocity and density of the vehicles involved.

From Figure 5.11, AARF and ONOE perform so poorly compared to the others. SampleRate has the lowest delay, with the best performance, while ACARS and MODIFIEDCARS almost over-lap each other without any significant difference. SampleRate could tolerate some random channel errors and did not drop its transmission rates frequently may be the reason for its good performance. This metric parameter is very important in QoS and safety application in VANET.

From this figure, there is fluctuation (it increases and decreases) in airtime as the number of vehicles increase. This is because, as the number of vehicles increase, the duration needed per vehicle to upload the stream is extended due to greater medium contention. This allows the vehicles to upload more packets using higher rates while they are closer to the server, which minimizes the transmission airtime and the number of retransmissions. As the number of vehicles continue to increase, the number of packets transmitted per vehicle when it is near the server reduces due to the contention. Hence, vehicles continue their uploads while they are moving away from the server. As vehicle moves away from the server, vehicles switch to lower data rates to cope with the change in link conditions.

Simulation was done for $\gamma = 3$, $\sigma = 0dB$, and $P_t = 40$ mW. This analysis is for results obtained with values of γ which is path loss exponent, σ is shadowing deviation, and P_t is transmit power.

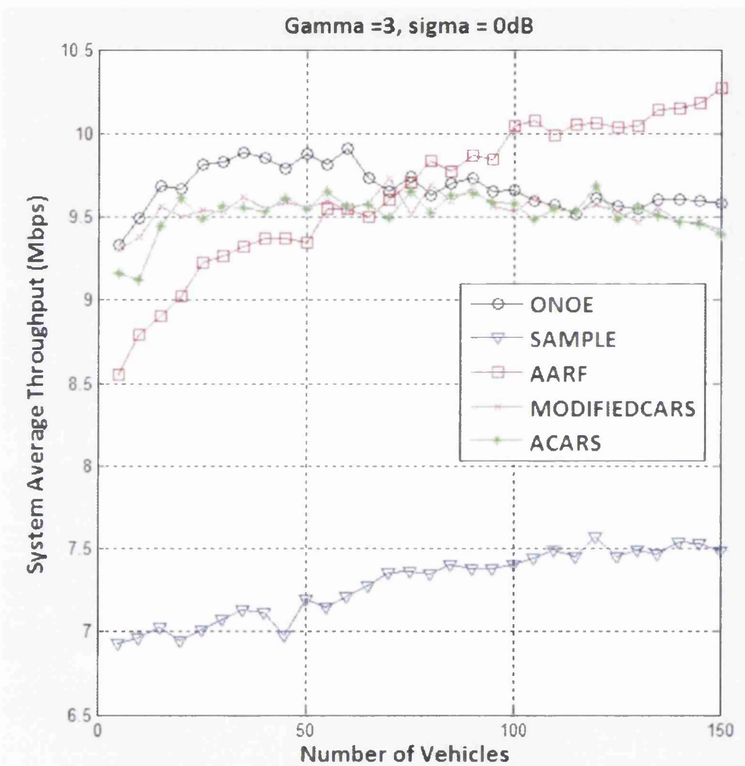

Figure 5.12: Average System Throughput vs Number of Vehicles.

ONOE is a credit-based RAA, it spends much time longer; 10 seconds on each bit rate before it increases rate, and then scaling up to the highest bit rate of 27 Mbps, therefore does not perform well in this scenario. AARF and ONOE have same poor performances compared to the others as seen in Figure 5.12. AARF waits for 10 consecutive successful transmission attempts before increasing rate and also because it a transmitter-based RAA, it cannot adapt faster in selecting the proper transmission rate to match the channel condition, this may be one of the reasons for its low performance. ACARS and MODIFIEDCARS shows no significant differences in performance as both of them showing an over-lap; although out-perform others. It is observed from this figure that SampleRate increases its performance gradually and had a better trend than when vehicles were less on the network. It struggles to compete with ACARS and MODIFIEDCARS compared to when network was less congested. Observation from this figure shows that, SampleRate works better in more congested network than in a sparse network. Tendency may be that if the number of vehicle is increased more than 150, it may perform better than ACARS and MODIFIEDCARS. This will be investigated in future work since it was not done in this research because of time constraint.

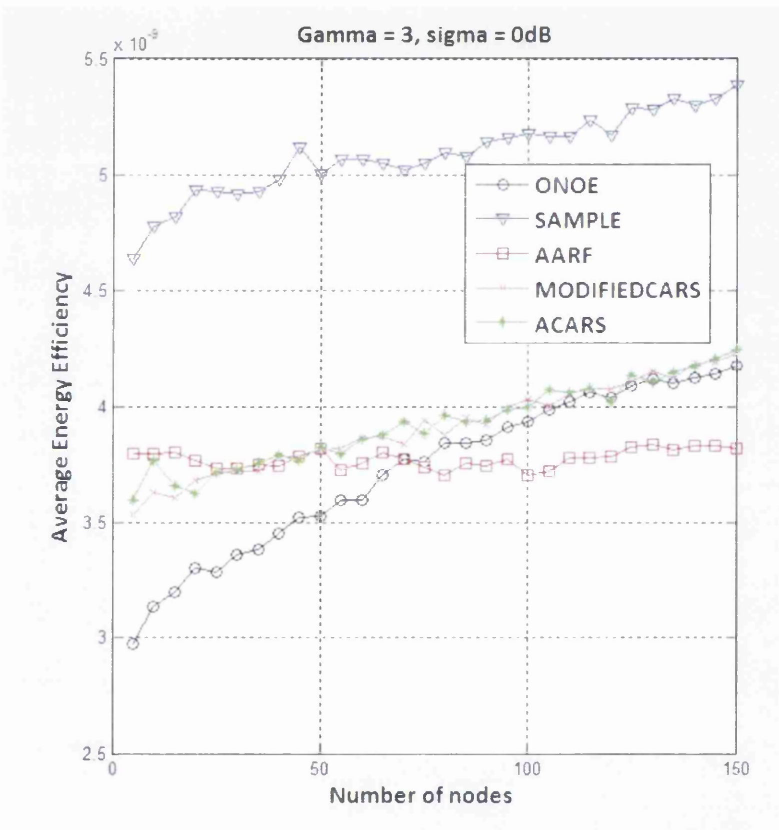

Figure 5.13: Average Energy Efficiency vs Number of Vehicles.

Similar to the results obtained, ACARS and MODIFIEDCARS from Figure 5.13 have more energy efficiency compared to the others, which means it is reliable for less energy consumption in vehicular communications, which is one of our aims in the design of ACARS. AARF and ONOE performed poorly among all.

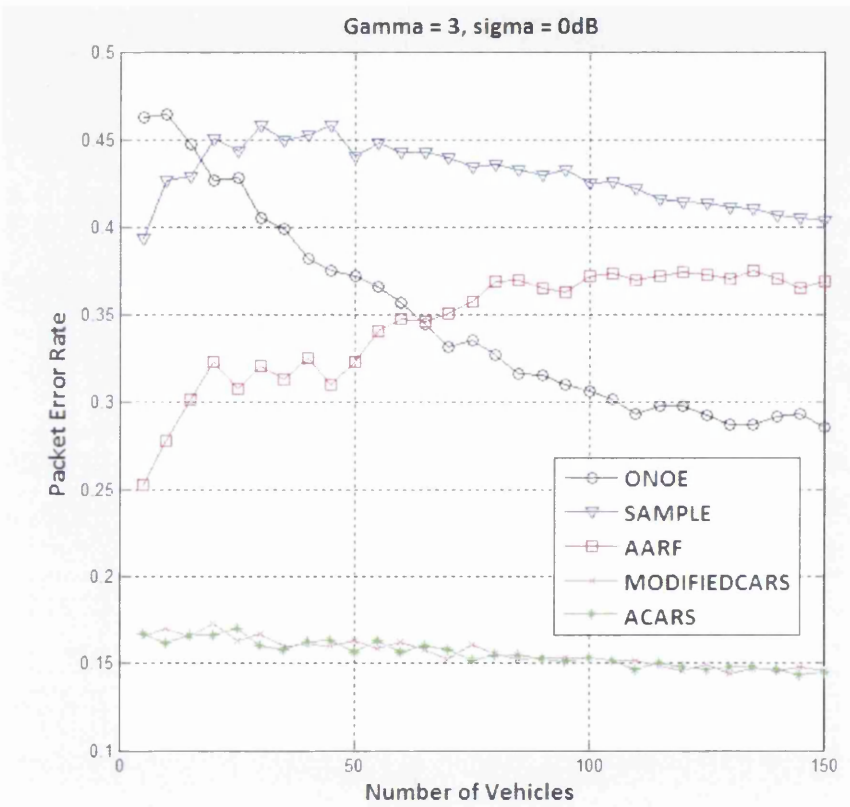

Figure 5.14: Packet Error Rate vs Number of Vehicles.

From Figure 5.14, AARF obtained a low PER which is a good indicator of this metric that leads to a good overall system throughput. This is because, PER and success rate are directly proportional to system throughput. If there are many packets in error, then the throughput will degrade and same as successfully received packets. From this figure, it is quiet difficult to distinguish between the performances of ACARS and MODIFIEDCARS as they over-lap each other. SampleRate from this figure performs poorly compared to the other rate selection algorithms.

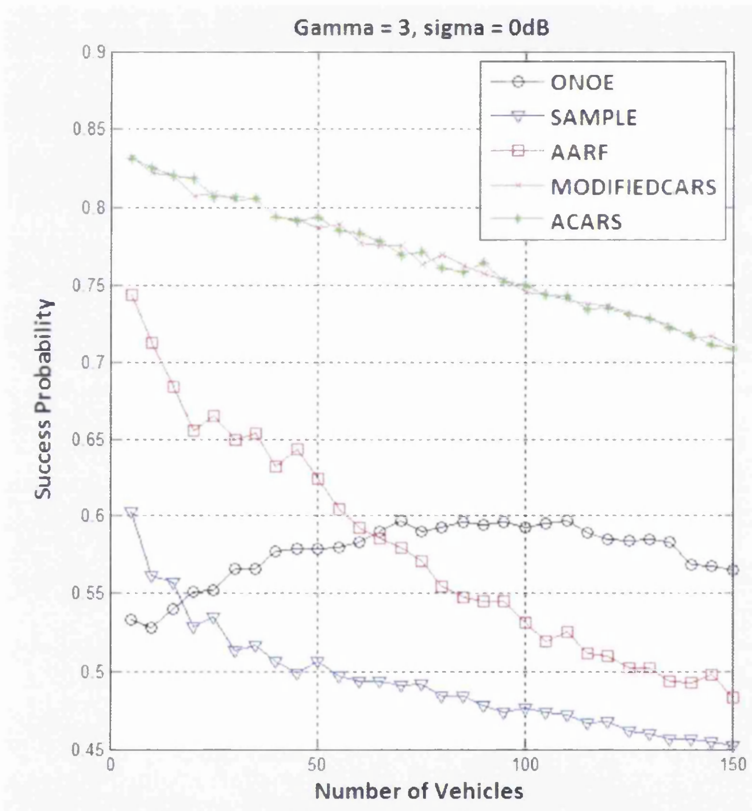

Figure 5.15: Success Probability vs Number of Vehicles.

From Figure 5.15. AARF out-performs other RAAs with a better success rate, because its PER in Figure 5.9 on page 129 was less than all the other RAAs. ACARS and MODIFIEDCARS still compete with each other without a significant difference in their performance. SampleRate rate performs worst in this regard, as ONOE over-laps in performance with ACARS and MODIFIEDCARS.

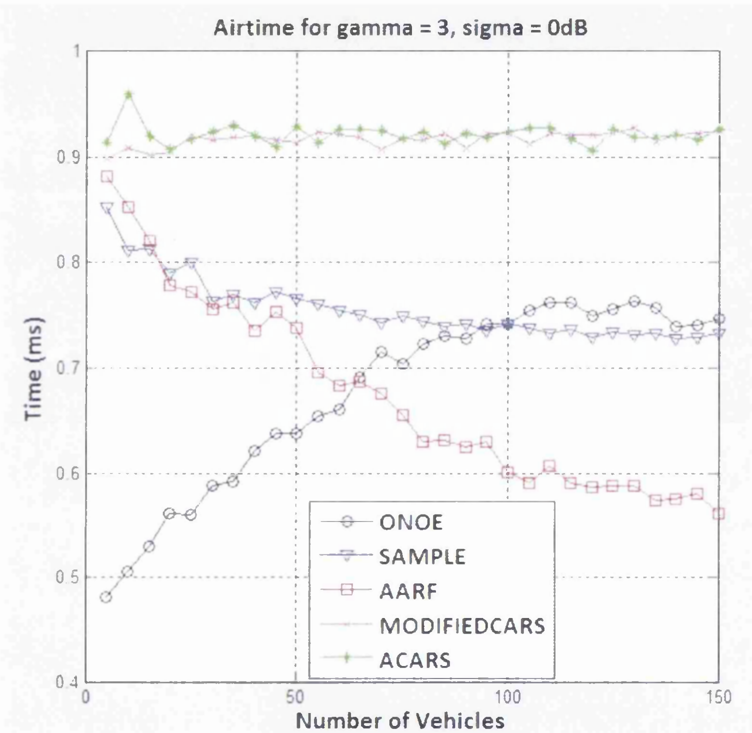

Figure 5.16: Airtime vs Number of Vehicles.

The MAC layer in a traffic safety application is unlikely to need many different service classes or transfer rates. Instead, to guarantee that time-critical communication tasks meet their deadlines, the MAC method must first of all provide a finite worst case access time to the channel. Once channel access is a fact, different coding strategies, diversity techniques and retransmission schemes can be used to achieve the required correctness and robustness against the impairments of the un-predictable wireless channel. However, if the MAC scheme does not provide an upper bound on the maximum delay before channel access, it is not possible to give any guarantees about meeting deadlines. Information that is delivered after the deadline in a critical real-time communication system is not only useless, but implies severe consequences for the traffic safety.

For these reasons, delay metric is very vital in vehicular communications because there is deadline during which a transmission attempt is needed, and when a packet is supposed to be delivered. From Figure 5.16, SampleRate has the best airtime. AARF and ONOE perform worst in this scenario. It is also observed from this figure, that there is much difference between the performance of SampleRate and these two schemes. On the other hand, ACARS and MODIFIEDCARS also struggle with each other in competing, but with careful look, there is a little difference in better performance for ACARS.

This section consists of results obtained from simulations for $\gamma = 5$, $\sigma = 0dB$, and $P_t = 40$ mW. Analysis is made here for other values of γ which is path loss exponent, σ is shadowing deviation, and P_t is transmit power.

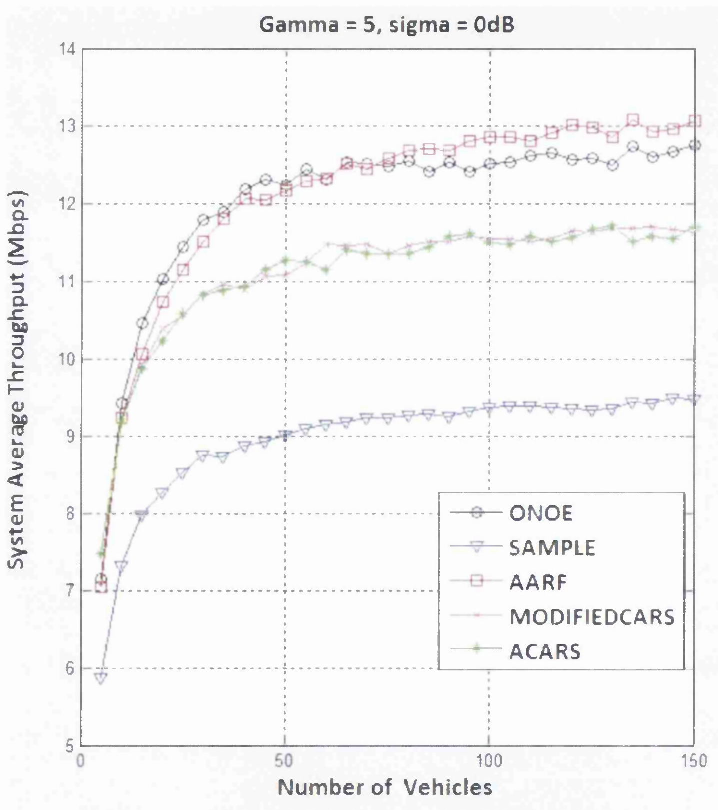

Figure 5.17: Average System Throughput vs Number of Vehicles.

From Figure 5.17, AARF probes it packets faster in order to change it rates, and hence performs better than all other rate selection schemes in this scenario. SampleRate performs worst, because it drops to lower rate more frequently compared to ONOE. ACARS performs better than MODIFIEDCARS in this regards because it can easily estimate SNR to the PHY layer.

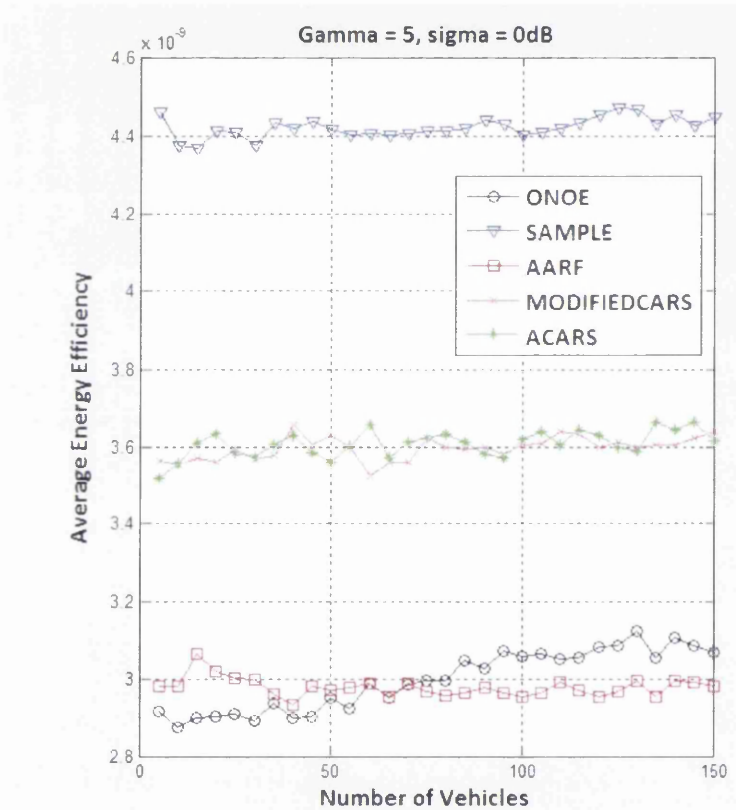

Figure 5.18: Average Energy Efficiency vs Number of Vehicles.

AARF from Figure 5.18 probes faster and performs better having low energy consumption than the other RAAs. The poor performance of SampleRate can be best explained by its heuristic implementation. It cannot tolerate some random channel variations, and drops to lower rate more frequently. Although ACARS has lower energy consumption than MODIFIEDCARS, but could not perform as better as AARF and ONOE in this regard.

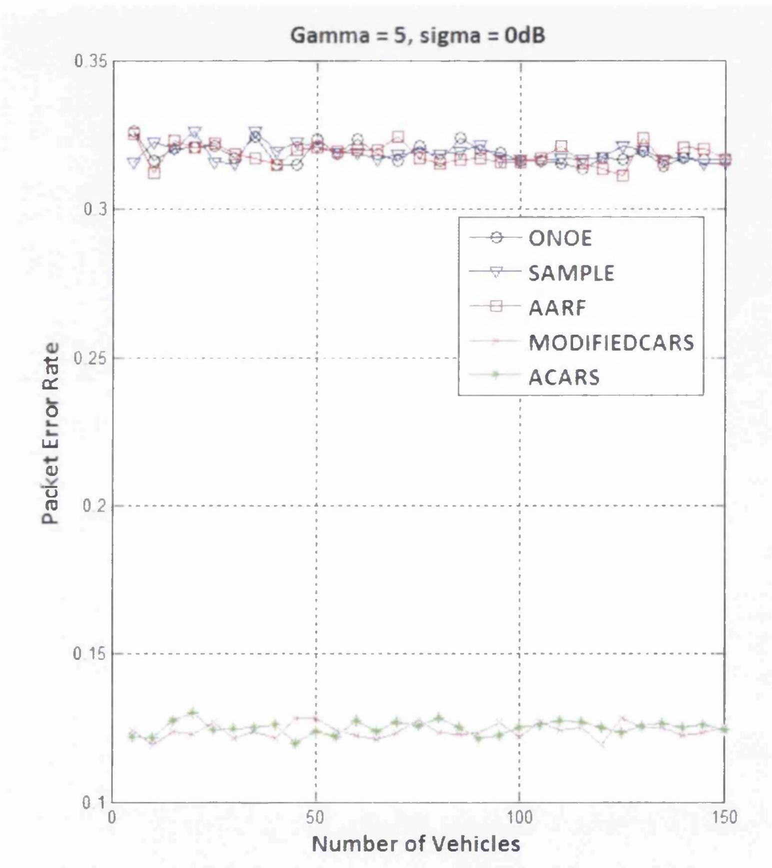

Figure 5.19: Packet Error Rate vs Number of Vehicles.

ACARS has the lowest PER from Figure 5.19 followed by MODIFIEDCARS. From this figure, AARF, ONOE and SampleRate compete with each other as the number of vehicles increase. From careful look, AARF has the highest PER; although there is not much differences between the three of them. ONOE must have spent much time trying to increase its bit rate, and AARF may have been very slow in probing the packets so as to increase in its rate, while SampleRate may not have maintained the expected transmission time for each rate, by updating it after each transmission. These reasons may have resulted to their in ability to perform well in this scenario compared to ACARS and MODIFIEDCARS which have similar behaviours.

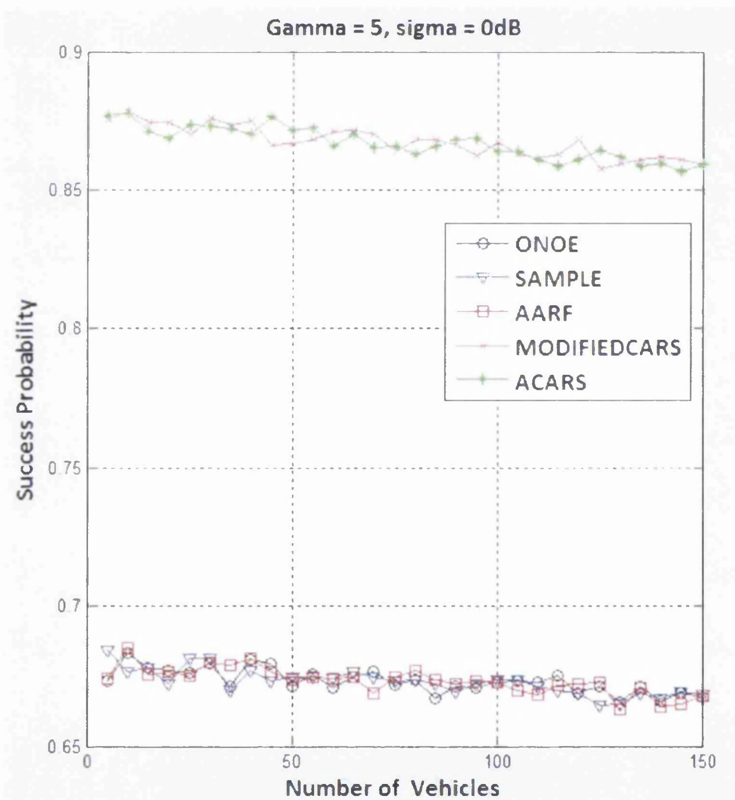

Figure 5.20: Success Probability vs Number of Vehicles.

From Figure 5.20, ACARS has the highest success probability compared to the other rate selection schemes. AARF performs poorly compared to the other schemes. From careful observation, AARF, ONOE, and SampleRate competes with each other above 100 nodes. Successfully received packets is an indication of good system throughput. This is because, if more packets are successfully received, it means that there were less collision and corruption, hence less PER.

5.5 Network Analysis with no Communication Range set

In this section, analysis on the network with different environmental factors and without setting any communication range will be considered. In this case, communication range ($\vec{C_R}$) is not an input parameter to the mobility function ($\vec{V}_{Mob}$). This means that all vehicles can participate in communicating with the RSU.

This section will also evaluate the impact of different environment factors, and also with no communication restriction on various rate selection schemes; by using some of the path loss exponent and shadowing deviation values for these analyses. Results obtained in this section was done for $\gamma = 3$, $\sigma = 0dB$ and $P_t = 40$ mW. Result obtained from simulation is evaluated here.

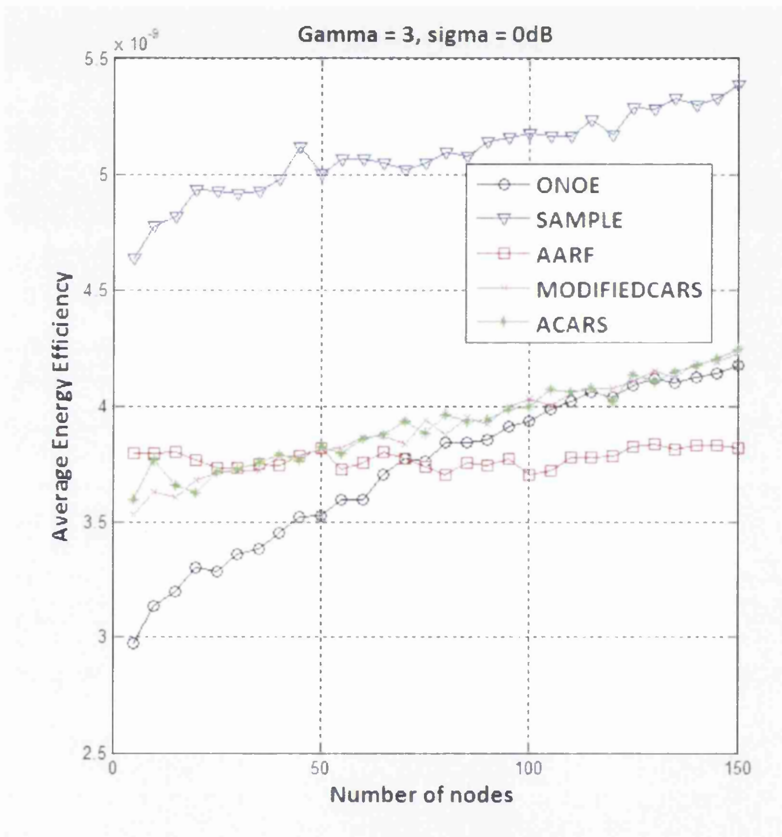

Figure 5.21: Average Energy Efficiency vs Number of Vehicles.

AARF has poor energy efficiency than all other rate selection schemes from Figure 5.21. From this figure, SampleRate performs better than the other rate schemes, followed by ACARS. ONOE struggles to increase its efficiency at higher vehicle density. This trend is different from that of AARF that degrades its efficiency as the density of the vehicle increases.

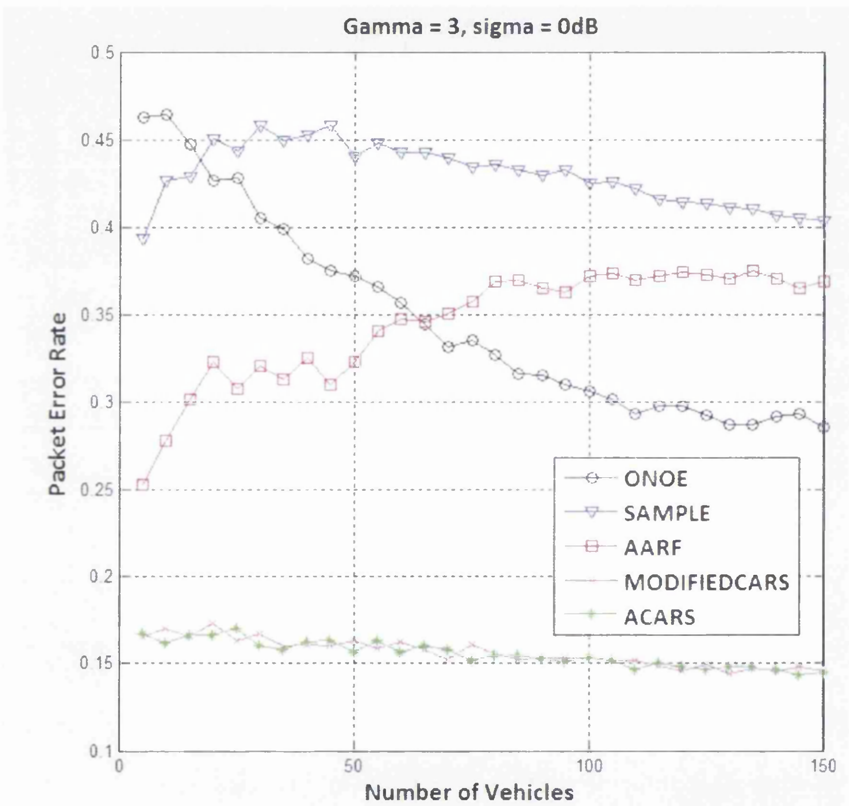

Figure 5.22: Packet Error Rate vs Number of Vehicles.

The rate at which packet is in error affects the over throughput performance of the system. From Figure 5.22, ACARS, has a low PER rate, which helps in the overall system throughput performance for this algorithm. On the other hand, SampleRate performs very poorly compared to all other rate selection schemes. MODIFIEDCARS struggles to compete with ACARS as can be seen from this figure. It also performs better that AARF, ONOE and SampleRate in this scenario.

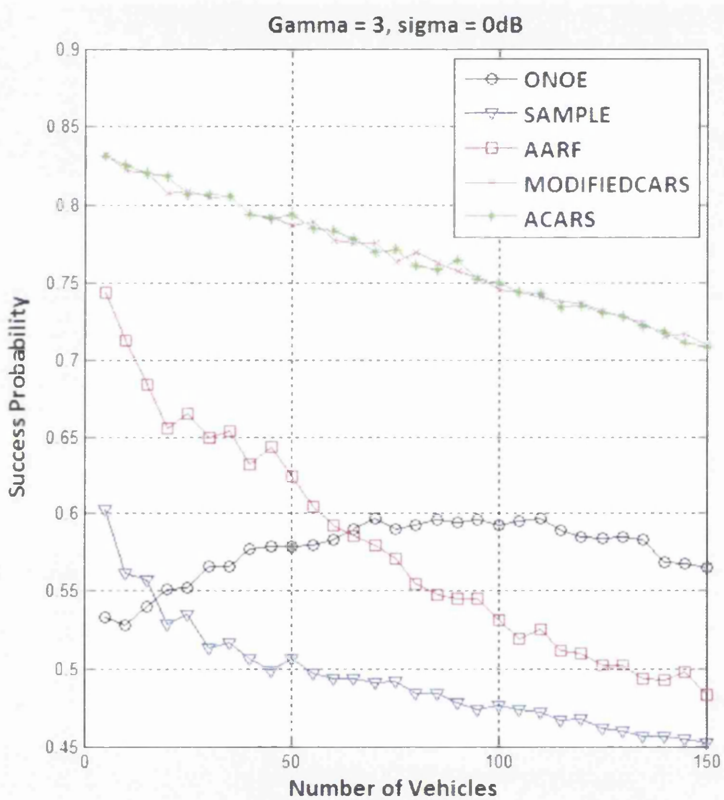

Figure 5.23: Success Probability vs Number of Vehicles.

Furthermore, in Figure 5.23, the success probability for both ACARS and MODIFIEDCARS are better than the others. Success rate is proportional to network throughput. If the success rate is high, then the overall system throughput will be better. SampleRate performs poorly compared to the other rate selection schemes. The channel condition in this scenario may have greatly been affected by its ability to choose an appropriate transmission time in order to change rate. The performance measure between ACARS, SampleRate, and MODIFIEDCARS is so large. AARF also degrades faster as the number of vehicles increase. It is observed in this scenario, how network congestion greatly affects AARF and ONOE.

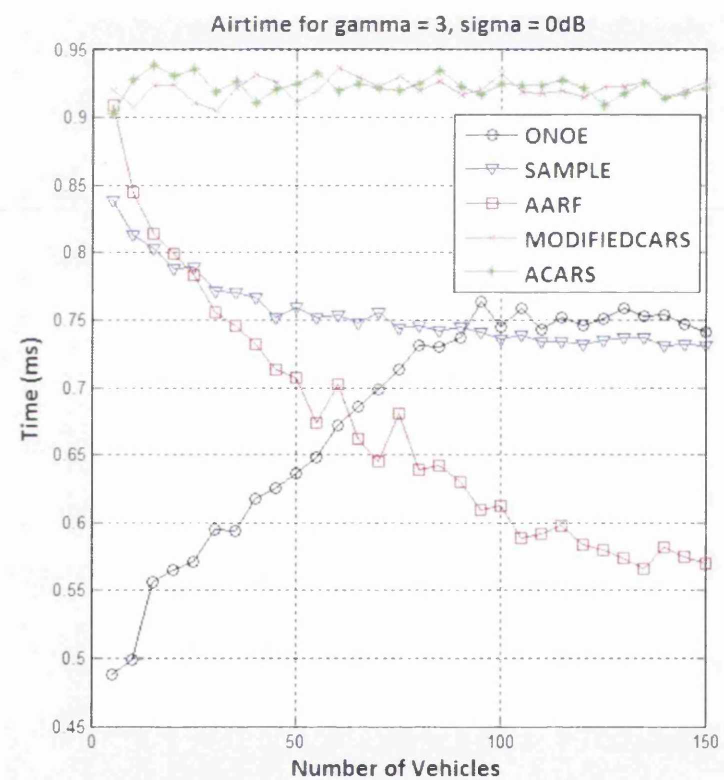

Figure 5.24: Airtime vs Number of Vehicles.

From Figure 5.24, ACARS and MODIFIEDCARS have high delay, although it is below the recommended delay for real time applications. But the delays for these two RAAs are higher than the others. Reason may be because both spend much time before changing rate in this circumstance thereby increasing the waiting time. AARF performs better than all other rate schemes. ONOE has strange trend of reducing delay as number of vehicles increase as seen in Table III in [14].

5.6 General Discussion

From the results obtained in this chapter, it can be observed that the network configuration is similar to the one in [14], where no fading process was considered as shown in Tables 5.4-5.8. From these results, there is no much significant difference between ACARS and MODIFIEDCARS, because it is a no-fading configuration. These observations are seen in almost all of the metric performances carried out in this chapter. From results obtained in this chapter, ACARS offers no advantage over MODIFIEDCARS because of the no-fading condition considered here.

5.6.1 Summary of Some Results Obtained

In this section, some results obtained in some metric analyses from simulations are summarised in tables for quick understanding of the trend of various RAAs.

Table 5.4: Average Throughput (Mbps) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	5.90	8.10	7.90	9.50	6.80
30	2.60	6.10	6.10	6.09	5.10
50	1.85	4.15	4.15	2.00	3.50
70	1.35	3.15	3.15	1.40	2.80
90	0.98	2.20	2.20	1.00	1.98
120	1.15	1.45	1.45	0.80	0.80
150	0.50	0.85	0.85	0.50	1.80

Table 5.5: Packet Error Rate vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.05	0.15	0.14	0.38	0.30
30	0.03	0.09	0.10	0.15	0.27
50	0.02	0.06	0.07	0.08	0.17
70	0.01	0.04	0.04	0.03	0.13
90	0.01	0.03	0.03	0.02	0.07
120	0.01	0.02	0.02	0.02	0.04
150	0.00	0.01	0.01	0.00	0.35

Table 5.6: Average Energy (10^{-3}) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.20	0.10	0.10	0.15	0.10
30	0.30	0.15	0.15	0.20	0.17
50	0.40	0.17	0.17	0.30	0.20
70	0.60	0.18	0.18	0.59	0.30
90	1.10	0.40	0.40	1.10	0.50
120	1.95	0.60	0.60	1.97	1.10
150	4.30	1.42	1.42	4.40	2.10

Table 5.7: Success Probability vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.72	0.66	0.66	0.42	0.50
30	0.56	0.40	0.40	0.32	0.24
50	0.32	0.28	0.28	0.26	0.06
70	0.22	0.18	0.18	0.18	0.10
90	0.16	0.13	0.13	0.14	0.08
120	0.09	0.07	0.07	0.08	0.06
150	0.04	0.03	0.03	0.03	0.02

Table 5.8: Airtime (10^{-3}) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	2.50	1.20	1.20	0.70	1.00
30	3.50	1.25	1.25	2.30	0.80
50	3.60	1.28	1.28	3.20	0.70
70	3.70	1.29	1.29	3.49	0.71
90	3.80	1.29	1.29	3.60	0.80
120	4.00	1.30	1.30	3.80	0.82
150	4.10	1.31	1.31	3.90	0.82

5.7 Chapter Summary

Throughput performance depends on the number of active stations, total load offered to the system and CW_{min}. However, performance can be substantially enhanced if the exponential back-off window adopted in the CSMA/CA DCF protocol is substituted by an adaptive contention window. This will depend on the number of contending stations and optimized to maximize the throughput of the system. It is observed from this research that CW_{min} depends on network scenario (contending stations. Hence, high CW_{min} is not good for small number of contending stations.

This chapter has demonstrated the behaviour of RAAs without fading processes. It has also given idea and area of concern to look at in future. Chapter 6 will be dealing with fading processes. The results obtained in this chapter have shown the impact of mobility and context-information on RAAs. Apart from no-fading demonstrated in this chapter, the simulation results also demonstrate mobility in RAAs.

From all the simulated results, it can be observed that no RAA is perfect. There is no scenario that a particular RAA out-perform in all metric analyses. These show that every RAA has limitation, and that each RAA performs better in the condition it was actually design for. It struggles in performance when it comes to the condition(s) it was not design for. Results also show that channel condition can degrade and affect the performance of each RAA, and that mobility have impact on rate selection speed especially at increase of inter-node distance and speed.

6

Realistic Analysis of ACARS Algorithm

This chapter will present network analysis on vehicle communications with mobility and propagation phenomena. It will also evaluate the impact of mobility on vehicles, the effect of propagation phenomena, and the impact of power control. This chapter will also consider analyses on the impact of communication range and without communication range.

Analyses in this chapter deals with real world concept of vehicular networks, unlike in Chapter 5. Some of the probabilistic concepts are addition of fading to the algorithms, because in the real world, vehicles are affected by the propagation phenomena as they travel from one environment to the other. The power control concept is also applicable to a real world scenario where wireless networks need power to sustain communication in vehicular networks. They need to consume less energy in order to sustain service and communicate with each other or the RSU depending on the type network. This chapter will also analyse the case of no communication range set, and their performances of various rate selection algorithms, because in real world, vehicles are not given restriction in area to move and distance they must be or cover. In this deign, mobility is implemented to demonstrate a real world concept in which vehicles ought to move and not remain stationary like an office network. This chapter will also analyse results from simulations in MATLAB. The results will be use to compare the performance of existing RAAs with proposed algorithm with the impact of propagation phenomena, communication range effect, and transmit power control. Results will also be used to evaluate their performance based on the results obtained for different RAAs.

Controlling the communication range by adjusting the transmission power can be used to mitigate the adverse effects of high density condition. Hence, the choice of communication range has a direct impact on the fundamental property of VANET. In the simulation, RSU also coordinates the communication range within which vehicles transmit to regulate the power control scheme for energy consumption.

Controlling the transmit power in mobile communications is a very efficient means to control the QoS and the capacity of wireless networks [57]. In environments where the channel varies slowly, existing power control schemes are designed to operate in such networks, but when it comes to channels like vehicular networks, it does not perform well because user channels change very quickly and these methods fail in such scenario. Power adjustment is needed in this case rather than tuning the instantaneous SINR.

Power control is vital because, it is a means of balancing received power levels or balancing or guaranteeing Signal-to-Interference Ratios (SIRs). It aims to minimize energy consumption subject to maintaining a transmission rate. A centralized power control scheme is proposed for mobile communication systems with shadowing and fast Rayleigh fading. The essence of power control is to minimize the total transmit power with constrains on outage probability for each user on network, and with constrains on individual transmit and received signal powers [65]. Here, a transmitter sending data via an AP through a communication channel is considered. As the vehicles change speed and locations, there are interferences such as tall building and trees which interfere with the received signal power. Since the goal is to ensure QoS for information transmission rate or average delay while conserving energy, this thesis implements a power control scheme with fast fading, so that energy distribution and conservation can be utilized by vehicles. In addition to this robust algorithm, this research focuses on the performance of power control on existing and proposed rate algorithms.

Power control affects the performance of the physical layer in two ways. First, power control impacts the traffic carrying capacity of the network. More so, choosing a high transmission power will lead to a reduction in the number of forwarding nodes needed to reach to the intended destination, and this creates excessive interference in a medium that is commonly shared. On the other hand, choosing a lower transmission power reduces the interference seen by potential transmitters, but packets will require more forwarding nodes to reach their intended destination [63]. Second, power control also affects the network connectivity or configuration. A high transmission power increases the connectivity of the network by increasing the number of direct links seen by each node, but the trade-off is reduction of network capacity [63][94]. The objective of minimizing the maximum transmit power rather than the total over all nodes is because, battery life is a local resource, and so collective minimization has a little practical value [94].

Current rate selection algorithms are dominated by probe-based approaches that search for the best transmission rate using trial-and-error. In mobile environments, probe-based techniques often perform poorly because, they inefficiently search for the moving target presented by the constantly changing channel. An adaptive rate selection algorithm that uses signal strength to select the transmission rate has been proposed in this thesis.

6.1 Network Connectivity

Physical connectivity alone does not provide nodes with end-to-end connectivity. A routing protocol is imperative in providing nodes with the means of communicating with each other in a multi hop environment. The transmission range used has an impact on the rate of signalling packets required to discover and maintain these pipes of connectivity over time in the presence of a node's mobility. The choice of the common transmission power used impacts the number of signalling packets required by the routing protocol. The use of a low common transmission power increases the number of intermediate nodes between source-destination pairs. These intermediate nodes move in and out of existing routes, which requires the routing protocol to take periodic actions to repair these routes in time. It is expected that the lower the common transmission power used, the higher the number of signalling packets required by the routing protocol to discover and maintain routes. These signalling packets consume capacity, and power resources in the network. On the other hand, choosing a low common transmission power hoping to increase network capacity, as suggested seen in literature, may generate too many signalling packets in the presence of node mobility, and therefore, a higher transmission power may be desirable [63].

At the network layer, reducing the transmission range as a means to increase network capacity could be harmful to the available capacity remaining for the nodes. The trade-off between network connectivity, and network capacity presents an interesting paradigm: is it possible to maintain low overhead for the routing protocol while at the same time provide higher capacity to the nodes in the network?. Following the design and performance of common-range transmission MANET-type routing protocols, the answer is 'no', unless a different method for discovering, and maintaining routes that departs from common transmission range broadcast technique is used. Recently, there has been some initial work in this area [95] that provide variable-range transmission support for routing protocol operation.

Most Ad-Hoc network designs simply borrowed MAC protocols designed for wireless LAN operation. IEEE 802.11 standard as well as most CSMA MAC protocols use a common-range transmission which are not flexible enough to exploit the spectral reuse potential of the network. In general, nodes transmitting with lower transmission power levels may not be noticed by nodes transmitting with higher transmission power levels, and as a result, collisions may be difficult to avoid. Fortunately, there are some new proposals in MAC design that overtake this limitation and take advantage of the spectral reuse potential acquired when using dynamic power control [95].

From research, communication range is proportional to SNR. Simulation was done by setting a SNR_{min}, and without communication range. Once the network detects a connection with a vehicle, it begins communication, and the values of the SNR_{min} is added to the SNR generated from BER table in MATLAB. In doing so, the SNR is increased, and a high SNR is an indicator of good channel quality.

The trade-off are, too high transmit power reduces forwarding nodes and increases connectivity, but reduce network capacity, and also low transmit power reduces the interference seen by potential transmitter, but require more forwarding nodes to reach their intended destination.

6.1.1 Wireless Channel Models

In a mobile communication system, a signal transmitted through a wireless channel will undergo a complicated propagation phenomena that involve diffraction, multiple reflections, and scattering mechanisms. In most cases, a Line-of-Sight (LOS) path between the mobile and the base station is hardly in existence due to a very dense propagation environment between the mobile and the base station [56]. Table 6.1 shows the different power classes that are available in wireless networks. It also shows the maximum output power that each power class can accommodate.

Table 6.1: Power classes in IEEE 802.11 Wireless Networks.

Power class	Maximum output power(dBm)
Class A	0
Class B	10
Class C	20
Class D	28.8

6.1.2 Fast Handover in Vehicle-to-Infrastructure Communications

A vehicle entering a RSUs transmission range needs to be integrated into the communication schedule of the RSU as soon as possible. Only then will it be polled for data by the RSU, and be part of the collision-free communication required by real-time safety applications. The centralized approach requires the RSU to know about and identify the vehicles currently residing within its transmission range and their communication needs. This makes a connection setup between vehicle and RSU necessary. One option is to let the vehicles send out Connection Setup Requests (CSR) as soon as they can hear the RSU. Even if the RSUs along a road might be widely spaced, we can view this chain of connection setup and disconnection as a series of handover procedures. We thus consider just one protocol components: fast connection setup with a RSU [26][96]. Figure 6.2 shows how hand over is implemented between mobile nodes and access routers which is same as RSU or AP in this network.

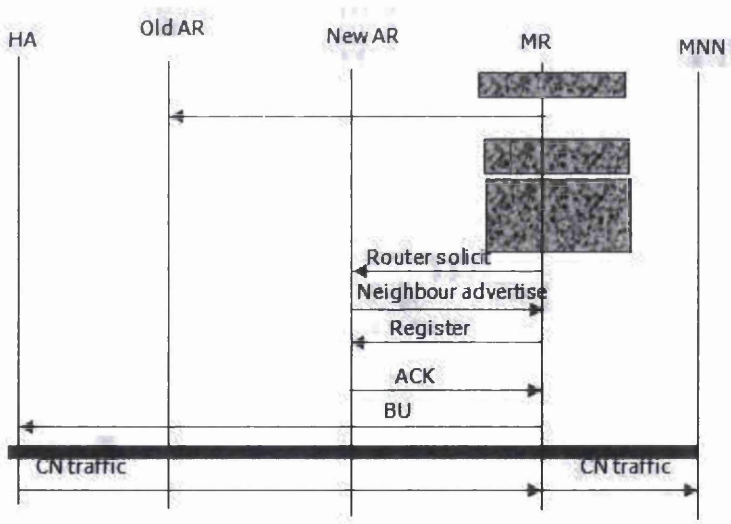

Figure 6.1: IP Layer Hand-off Protocol for Mobile Networks.

6.1.3 Mobility in Rate Adaptation Algorithms

IEEE 802.11 wireless networks traditionally involve communication between stationary devices. They are increasingly being used by mobile devices such as 802.11 phones, PDAs, embedded devices etc. Mobility issues are more challenging in RAAs because of the rapid channel variations in link conditions. In such dynamic environments, it is expected that fast gain and accurate channel information is necessary in order to effectively utilize the channel.

Many of the RAAs reviewed in Chapter 2 were implemented without mobility model. The few of them that implemented mobility are CARA, CARS, and CHARM etc. In the design of ACARS, mobility model was integrated into the algorithm to depict the real world vehicular movement. In the analysis of the results from Chapter 5, some RAAs struggle with performance of the network demonstrating the impact of mobility on existing rate selection schemes and the proposed RAA.

6.1.4 Probabilistic Models of Radio Propagation

Probabilistic models allow a more realistic modelling of radio wave propagation. A probabilistic model takes a deterministic model as one of its input parameters in order to get a mean transmission range [24]. Probabilistic model is a means to demonstrate a more real life scenario in simulation. For example, allowing vehicles to communicate and transmit without restriction in area coverage. This is more realistic in the real world in vehicular communications.

Rayleigh: The Rayleigh propagation model is applicable in a situation when there is no LOS, and only multipath components exist. This model incorporates intensive variations in received signal power because multiple paths can either combine constructively or destructively. The amplitude, delay and phase shift of these components greatly depends on the environment.

Log-Normal Shadowing: The Log-normal shadowing model uses a normal distribution with variance σ to distribute reception power in the logarithmic domain.

Fast Fading: Fast fading occurs due to scattering from nearby objects, and thus is termed small-scale fading. Generally, fast fading can be observed up to half-wavelength distances. When there is no direct path (LOS), a Rayleigh distribution tends to best fit this fading scenario, thus fast fading is sometimes referred to as Rayleigh fading [62].

6.2 Deterministic Models of Radio Propagation

Deterministic models (like free space, two-ray ground) are often used in VANET research. They greatly increases the runtime performance of a simulation, this is the reason they describe real conditions insufficiently. A probabilistic model could better account for the variance in real world situations, which enables vastly different communication between two nodes having the same TransmitterReceiver (T-R) separation [24]. Another observation is that in VANET simulation, nodes are often dimensionless. The vehicles have no influence on radio propagation. It seems reasonable though, that in practice, the large metal bodies of vehicles provide a wide range of effects on propagation. Vehicles often block LOS between two communicating vehicles, making multipath components dominant. Also, vehicles can function as wave-guides or as reflectors, thereby increasing the transmission range beyond what could be expected based on free space propagation.

A deterministic model allows for computing the RSS, based on actual properties of the environment such as the distance between a transmitter T, and the receiver R. These models range from simple (only account for distance between nodes) to very complex where they also account for multipath propagation in the environment modelled exactly as the area of deployment.

6.3 Network Analysis

This section will analysis the simulation results using different metrics that were earlier explained. Some other new terminologies will be explained in this section as well. The received signal strength of a wireless is given as:

$$RSS = P_{tx} + G_{tx}PL + G_{rx} \tag{6.1}$$

where RSS is the received signal strength, P_{tx} is the transmit power, G_{tx}, G_{rx} are the transmit and receive antenna gain, and PL is the path loss. Thus, a transmitter that knows the quantity $P_{tx} + G_{tx}PL + G_{rx}$ can calculate RSS at the receiver. P_{tx}, G_{tx}, and G_{rx} are properties of the transmit and receive hardware and are generally fixed. Their values can be obtained from the hardware and provide to the transmit side rate selection algorithm, although in practice, it is not necessary to know the individual values for G_{tx} and G_{rx}.

Practically speaking, this means that if the "transmitter" knows the transmit power used by the "receiver", it can estimate the path loss (in both directions) by observing the RSS for packets it receives from the "receiver", taking antenna gains into account. Equation (6.2) is for path loss.

$$PL = P_{tx} + G_{tx} + G_{rx} - RSS \tag{6.2}$$

where P_{tx} in this case is the transmit power of the "receiver". For the purposes of rate selection, the antenna gains can simply be considered a fixed part of the path, so that equation (6.2) becomes:

$$PL = P_{tx} - RSS \tag{6.3}$$

where PL is path loss, P_{tx} is transmit power, and RSS is received signal strength.

6.4 Power Measurement

Minimizing energy consumption is an important challenge in mobile networking. The wireless network interface is often a device's single largest consumer of power. Since the network interface may often be idle, turning the radio off when not in use could save this power. A good power-saving coordination technique for wireless Ad-Hoc networks, should have the following characteristics; it should allow as many nodes as possible to turn their radio receivers off most of the time, since even an idle receiver circuit can consume almost as much energy as an active transmitter. Furthermore, the back-bone formed by the awake nodes should provide as much total capacity as the original network, since otherwise congestion may increase.

The power saving protocol determines when to turn a node's radio on or off. It depends on the low level MAC layer to support power saving functions, such as buffering packets for sleeping nodes. IEEE 802.11 Ad-Hoc power-saving mode uses periodic beacons to synchronize nodes in the network. Beacon packets contain timestamps that synchronize nodes clocks. A beacon period starts with an Ad-Hoc Traffic Indication Message window (ATIM window), during which all nodes are listened, and pending when traffic transmissions are advertised. A node that receives and acknowledges an advertisement for unicast or broadcast traffic directed to it must stay on for the rest of the beacon period. Otherwise, it can turn itself off at the end of the ATIM window, the available channel capacity is reduced. When the 802.11 MAC layer sends a packet, it may or may not be able to send it immediately, depending on which ATIMs have been sent and acknowledged in the immediate and preceding or current, ATIM window. If the packet arrives at the MAC during the ATIM window, or if the advertisement for the packet has not been acknowledged, it needs to be buffered [97].

By contrast, existing power control schemes generally focus on capacity and quality issues. Power control is employed as a means of balancing received power levels or balancing or guaranteeing Signal-to-Interference Ratios (SIRs), typically at the maximum possible common SIR; it is sometimes integrated with other network management tasks such as base or channel assignment [98]. For cellular systems in particular, the point is to minimize co-channel interference (as, for example, under Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Packet Reservation Multiple Access (PRMA), or related protocols) and/or near far effects (as under spread-spectrum schemes such as Code Division Multiple Access (CDMA)) [66]. The minimum power level to be transmitted by node i such that at least the minimum received power level is achieved at node j for a given network configuration is given by:

$$P_{tij} = P_{max} \times \wp_{min} / P_{rji} \tag{6.4}$$

where P_{tij} is power transmitted by node i such that the transmission range does not exceed node j, P_{rji} is power received by node j when node i transmits at maximum power P_{max}, and $\wp_{min}$ is minimum received power.

6.5 Results and Discussions

This section will explain the results obtained from simulations, and make comparison using several metric analysis for existing RAAs and the proposed rate adaptation scheme. Both cases of setting a communication range in the presence of propagation phenomena, and also analysing the network configuration without restricting vehicles within a communication range will be considered. From the simulation model, $\vec{C_R}$ is one of the input parameters to the $\vec{V}_{Mob}$ function, in the case of no $\vec{C_R}$, $\vec{C_R}$ is not included as an input to the mobility function. The reason is to analyse the impact of $\vec{C_R}$ set in the network.

Results were obtained by simulating for $\gamma = 5$, $\sigma = 8dB$, and $P_t = 40$ mW. These parameters will be used in analysing results obtained from simulation.

The results obtained here are based on values of γ which is path loss exponent, σ is shadowing deviation, and P_t is transmit power. The impact of setting communication range in the network, and also the effect of environmental factors are evaluated. One of advantages of communication range set is that, less vehicles are available to contend for network resources at a given time which increases system throughput performance.

6.5.1 Rate Selection

Before sending packet to a specific destination, the sender first invokes the path loss prediction algorithm to estimate the current path loss to the destination. It then uses its own transmit power and the noise level at the receiver (provided by the receiver to obtain an estimate of the SINR at the receiver). The SINR-estimate is finally used to determine a set of transmission rates through lookup in a table with SINR-thresholds for the intended receiver.

Using PER packet, the driver can specify several transmission rates, used in the original transmission, and each of the possible retransmissions in the order specified by the driver. For the first transmission, the driver picks the highest rate supported for the estimated SINR value, in order to maximize the channel throughput. For retransmissions, lower rates are selected according to the schedule described in the implementation section. There are two reasons for switching to lower rates fairly quickly. First, for the network to deliver the packet and if the first transmission fails, then the first rate may have been too high. Second, a successful delivery result in an ACK, which provides more up-to-date information on the SINR. Updated SINR information will benefit later packets.

Numerous efforts have addressed the problem of transmission rate selection. These approaches have been broadly categorized into probe-based, SINR-based, and hybrid techniques, though in many cases, hybrid elements are present in probe and SINR-based algorithms. Probe-based rate selection algorithms leverage successful packet reception as an implicit indicator of reception conditions at the receiver. These algorithms typically use in-band probing via user data packets. IEEE 802.11 ACKs provide the transmitter with knowledge that reception occurred; ACK-timeouts are taken as an indication that reception did not occur, though this may not be the case if it is the ACK packet that is lost. The advantage of probe driven approaches is simplicity, and the ability to implicitly take into account complex factors affecting reception. A key disadvantage is the speed at which channel information can be obtained. From the transmitter's perspective, each transmission attempt yields either a success, or a perceived failure. Another major disadvantage of probe-based rate adaptation is the inability to distinguish the causes of perceived transmission failure; all the transmitter knows is that it did not correctly receive an ACK. A packet loss could be the result of a missing ACK or a collision caused by a hidden terminal, neither of which would justify reducing the transmission rate.

In contrast to probe-based approaches, SINR-based approaches use signal metrics provided by the wireless devices to select the transmission rate. This scheme typically relies on the RTS/CTS mechanism to provide instantaneous receiver-side SINR information to the transmitter. In theory, knowing the SINR at the receiver would allow the transmitter to directly set the transmission rate without wasting precious time probing. However, the use of the RTS/CTS mechanism is to communicate the receiver SINR to the transmitter, it introduces significant overhead. Moreover, relying on a single unfiltered SINR measurement can potentially result in poor rate selection.

Furthermore, the hybrid technique is a combination of both the probe and SNR-based techniques. This is because, it uses the elements of both of these schemes. In this technique, both the server and client are needed to participate in the rate control process.

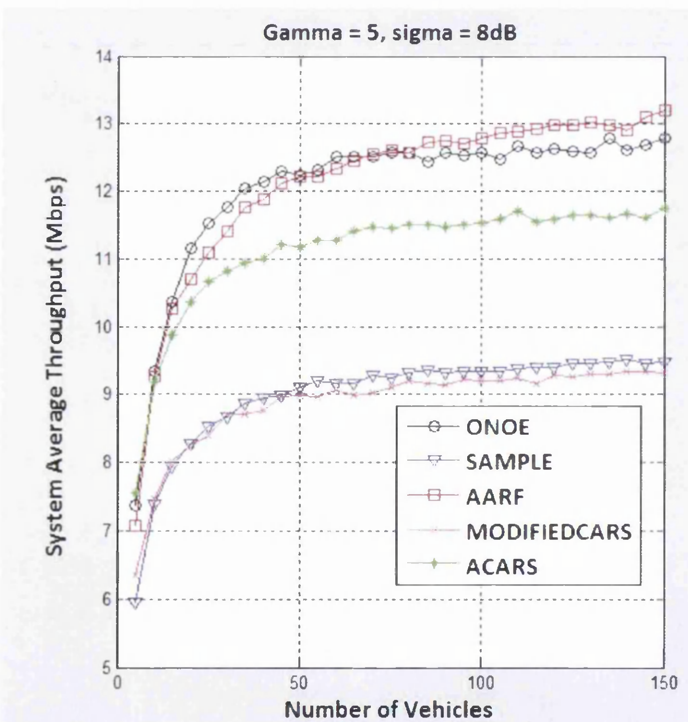

Figure 6.2: Average System Throughput vs Number of Vehicles.

Figures 6.2 shows the effect of path loss exponent in the network performance and capacity. Since one of the importance of PC is to increase network capacity, from the result in this figure, AARF out-performs other rate selection schemes, while MODIFIEDCARS performs poorly compared to all the other schemes. Also from this figure, AARF as a probe-based algorithm is able to adapt fast to this environmental condition in changing its bit rate than other schemes, but MODIFIEDCARS could not perform in the bad channel condition. As shown in Table 4.2 and 4.3, the values of both γ and σ depends on the environment. From these tables, these simulations cover a good number of environments as listed in the tables.

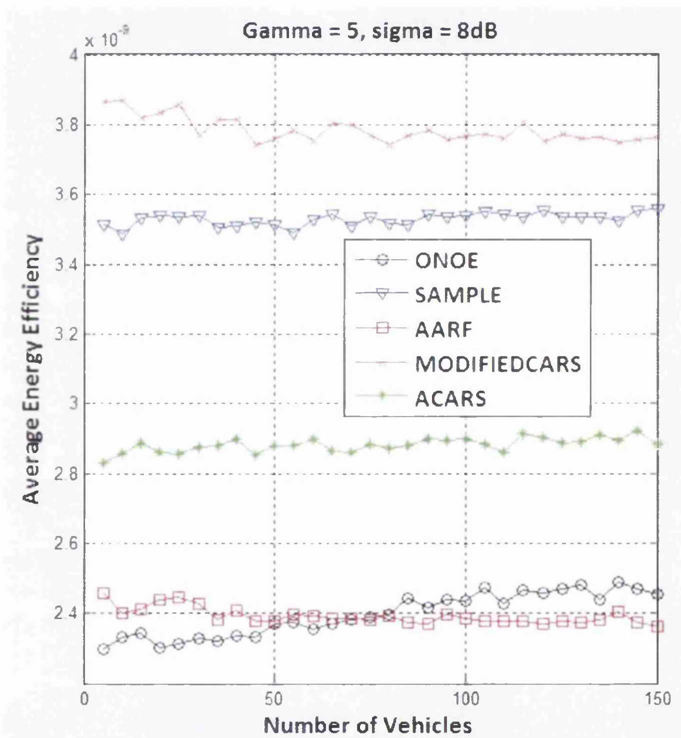

Figure 6.3: Average Energy Efficiency vs Number of Vehicles.

From Figure 6.3, results show significant reduction in energy consumption in the case of AARF compared to other RAAs. AARF has timeout mechanism that results in probing the channel at least every 15 packets. Other rate selection schemes have low performance because they could not adapt to the fast channel variations, and as a result have many disturbances causing typical packet losses, and the behaviour of these losses are prone to burst which affect the final outputs. The performance of MODIFIEDCARS is poor compared to ACARS as there is a big difference between both of them.

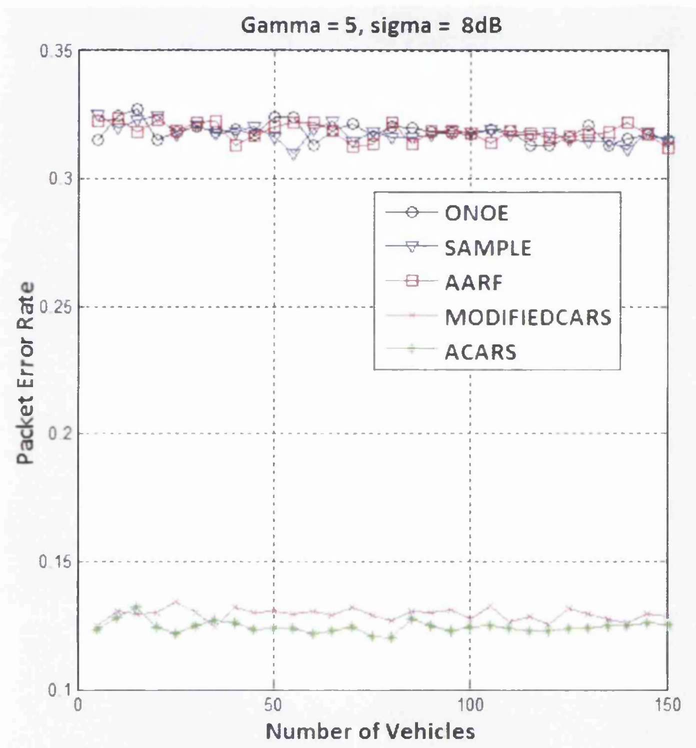

Figure 6.4: Packet Error Rate vs Number of Vehicles.

From Figure 6.4, result shows that ACARS has significant improvements using this scheme to alleviate the challenge of hidden stations common to all wireless and mobile networks and RAAs. As earlier mentioned, this scheme causes additional over head in cause of solving the problem, which is the trade-off in adopting a RTS/CTS mechanism in RAAs. This may probably be the cause of low performance for other RAAs especially AARF. From this figure, ACARS and MODIFIEDCARS perform better than the other rate schemes. The PER for these rate selection schemes are quiet lower than the other. The differences in their performances, compared to AARF, ONOE and SampleRate show a huge difference.

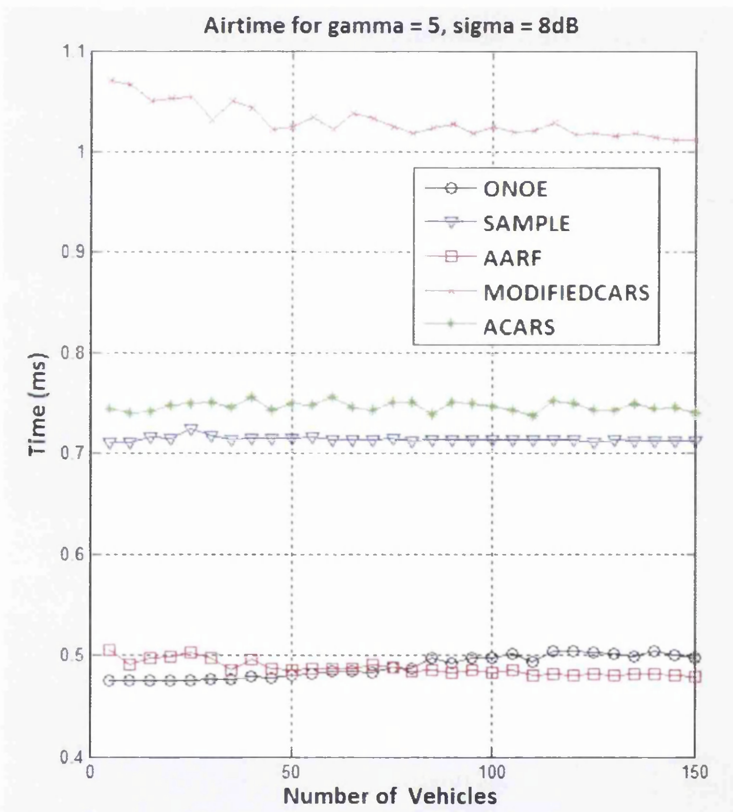

Figure 6.5: Airtime vs Number of Vehicles.

From Figure 6.5, the airtime for MODIFIEDCARS is very high compared to the other rate selection schemes. It has poor performance in terms of the delay in this scenario. ACARS did not perform well compared to AARF, ONOE, and SampleRate, but its delay is more than 1 ms.

This section contains results simulated using $\gamma = 2$, $\sigma = 6dB$, and $P_t = 40$ mW. Analyses of results will be based on these parameters used in simulation.

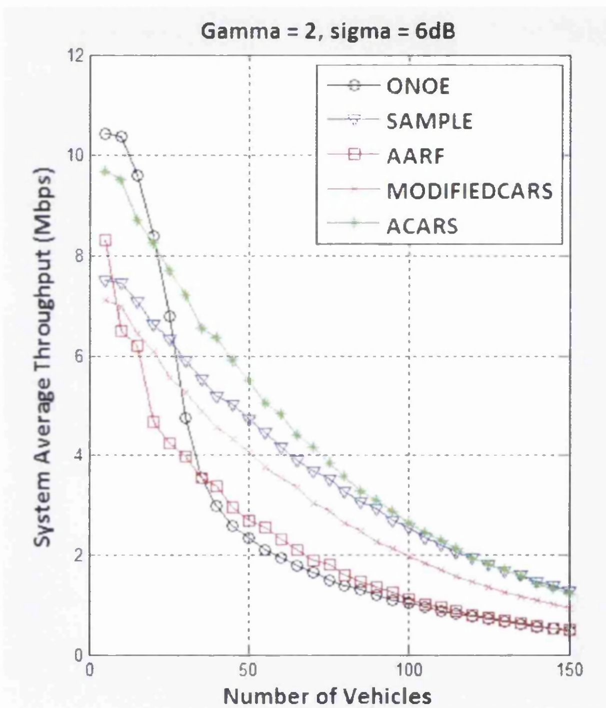

Figure 6.6: Average System Throughput vs Number of Vehicles.

As seen in Figure 6.6, ACARS adapts to the fast variation of channel conditions, and also estimate SNR to the PHY layer to improve its performs as an SNR-based rate adaptation scheme. From this figure, it out-performs other rate selection schemes, especially with significant difference between MODIFIED-CARS. There is almost an over-lap between ACARS and SampleRate at 150 vehicles. This shows that SampleRate improves its performance as the channel condition degrades, while other rate selection schemes struggle in performance. SampleRate also performs better because, it tolerates some random channel errors, and does not drop to lower transmission rates as frequent as AARF. AARF and ONOE have poor performance and degrade consistently as the number of vehicles increase. This result also shows the impact of mobility on these RAAs as they struggle to cope with the varying speeds of the vehicles and the propagation phenomena.

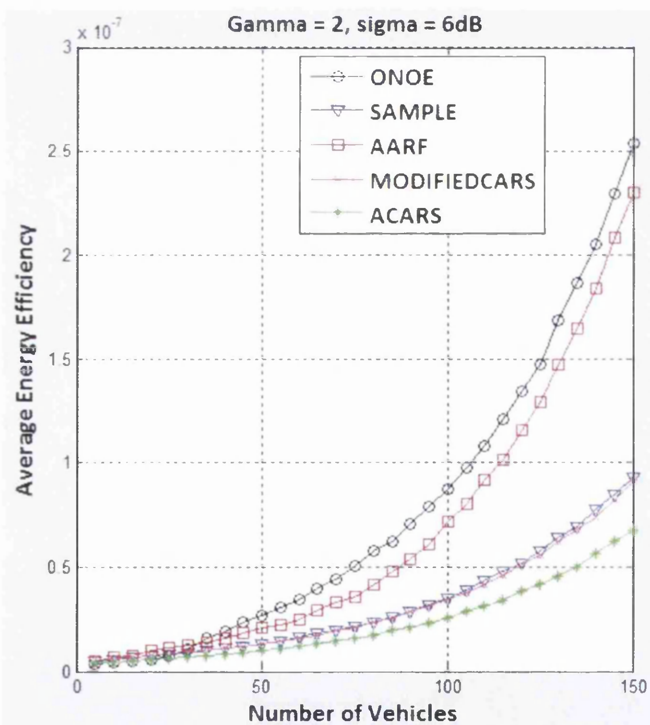

Figure 6.7: Average Energy Efficiency vs Number of Vehicles.

The power of each transmitter in a wireless network is related to the resource usage of the link. Since the links typically occupies the same frequency spectrum efficiency, they mutually interfere with each other. Proper resource management is thus needed to utilize the radio resource efficiently [87]. This relation is a summary of it: $C(t) = p(t) + g(t)$. where $C(t)$ is signal power, $p(t)$ is transmit power, and $g(t)$ is channel variation or power gain.

Consider a general network with m transmitters using the powers $p_{i(t)}$, and m connected receivers. For generality, the base stations are seen as multiple transmitters (downlink) and multiple receivers (uplink). The signal between transmitter i and receiver j is attenuated by the power gain g_{ij}. Thus the receiver connected to transmitter i will experience a desired signal power $C_i(t) = p_i(t) \times g_{ii}(t)$ and an interference from other connections plus noise $I_i(t)$. The SIR at receiver i can be defined by:

$$i(t) = C_i(t)/I_i(t) \tag{6.5}$$

where $i(t)$ is thermal noise, i and j are users, $I_i(t)$ is noise, and $C_i(t)$ is signal power.

One of the goals in the design of ACARS is low energy consumption. From Figure 6.7, it can be seen that ACARS has the lowest energy consumption compared to the other rate selection algorithms. This may be because, it can estimate SNR to the PHY layer. Hence, it is efficient in fast adaptation of varying channel condition compared to the others. ONOE did not perform very well in this regard, as it has very poor performance compared to the other RAAs. Other RAAs may not have performed well in this regard, because they were not designed for this purpose, hence struggle in performance with the integration of power control scheme. ACARS has good power control management as a result of AP coordination, hence, it can be used to improve QoS, effective data transfer, control congestion and collision avoidance for road safety.

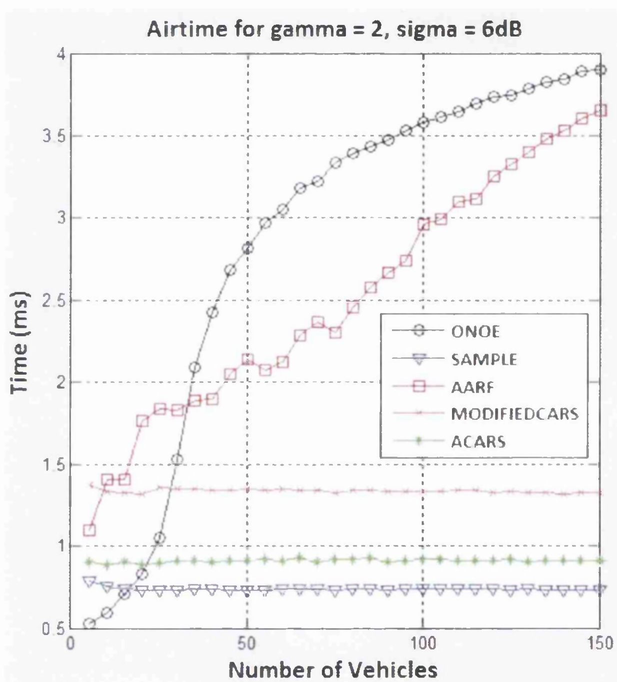

Figure 6.8: Airtime vs Number of Vehicles.

In a highly mobile vehicular network, delay is an important metric for real-time application. This is of concern because, vehicles only stay in the transmission range of a RSU for a relatively short time span (approximately 20 s for a transmission radius of 400 m and a vehicle speed of 40 mps). ITS safety applications benefit from very short connection setup times with guaranteed delay bounds, so that the deadlines of the real-time data traffic are not compromised. Hence, any rate selection scheme that should be adopted for this purpose should be able to meet up with the delay requirements. From Figure 6.8, SampleRate attains the lowest delay by maintaining the expected transmission time for bit rate changes, and updates it after each transmission. The next performance is followed by ACARS, which tends to change its rate by fast estimation of SNR to the PHY layer. The performance of AARF, and ONOE are very poor in this scenario, this could be because, AARF cannot send a probe packet faster as a probe-based rate selection algorithm, and ONOE as a credit-based rate selection scheme, must have stayed longer on each bit rate before changing rate.

ACARS overcomes the challenges in vehicular environments, such as short duration of the connection, and the fast change in link conditions, which prevent other schemes from selecting the optimum data rate. SampleRate out-performs AARF scheme in exploiting higher data rates. This is due to the enhancements in SampleRate that uses data rate with the minimum average transmission time. It also probe for higher date rates periodically. Using optimum higher data rates allow ACARS scheme to reduce the network load, as indicated in the transmission airtime.

Simulation was done for $\gamma = 4$, $\sigma = 8dB$, and $P_t = 40$ mW. The results obtained here is achieved with the above parameters.

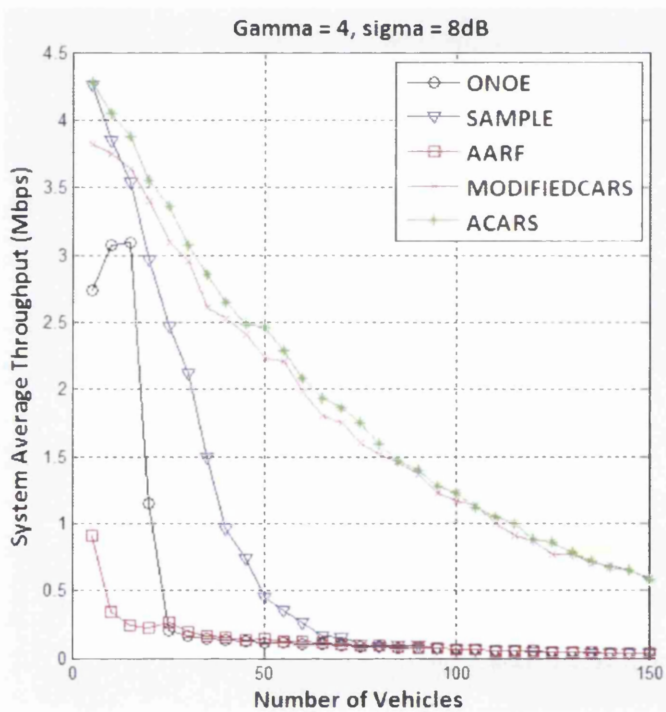

Figure 6.9: Average System Throughput vs Number of Vehicles.

Figure 6.9 shows that ACARS out-performs all other RAAs. This is an outdoor (for shadowing deviation), and free space(for path loss exponent) environment. This shows the impact of propagation phenomena on these rate schemes. Observation shows that AARF, ONOE and SampleRate degrade poorly compared to ACARS and MODIFIEDCARS in this scenario.

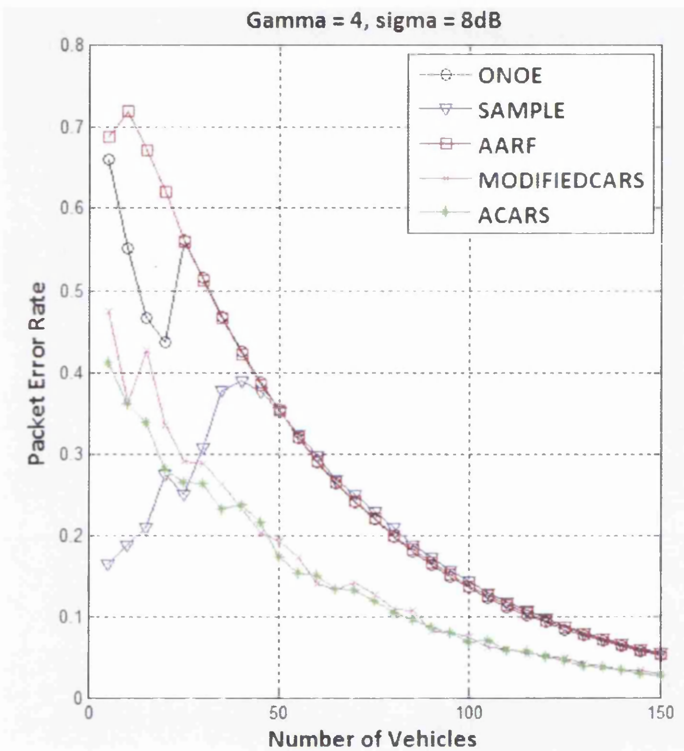

Figure 6.10: Packet Error Rate vs Number of Vehicles.

From Figure 6.10, ACARS has the lowest PER from careful look. Although there is much competition with MODIFIEDCARS as observed from this figure. Since PER is a prediction of the overall system throughput, if the PER is high, the overall system throughput performance will be low and vice-versa. From this figure, AARF, ONOE, and SampleRate over-lapped each other making no distinctive performance above 100 nodes. MODIFIEDCARS gradually degrades its performance as the number of vehicles increases, while ACARS has similar trend with MODIFIEDCARS as the number of vehicles increase. This result indicates that ACARS has less number of packet corruption and collisions which are all characteristics of PER.

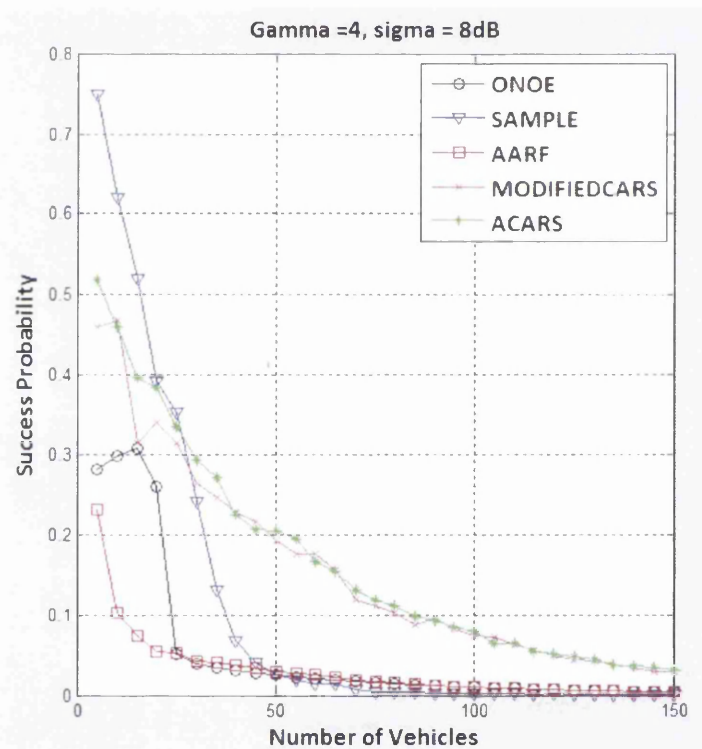

Figure 6.11: Success Probability vs Number of Vehicles.

The rate of successfully received packet is an indication of the level of packet collision and corruption in a network. From Figure 6.11, result shows that ACARS has the highest success rate; although with much competition with MODIFIEDCARS in this scenario. SampleRate from careful look seems to have the worst performance, while AARF and ONOE over-lapped each other without significant difference between them. Collision rate due to congestion and packet corruption may have resulted to the poor performance of these rate selection algorithms. However, ACARS and MODIFIEDCARS show better improvements than the rest of them.

6.6 Network Analysis With Fading and no Communication Range Set

This section will analyse the impact of fading, and without communication range set. It will also implement the real-world application of vehicular communications where vehicles can communicate without restriction. Also, from network concept, increasing transmit power increases SNR, which increases communication range. In this scenario, a minimum SNR is set for each vehicle to transmit. With these minimum SNR, the over SNR for that node will increase, since this value is added to the SNR obtained from the PER table. For different simulation values, there will evaluation of the performance metrics for various rate selection algorithms. Also in this section, a real world scenario will be simulated using the value indicated from [24]. This will also help to analyse a probabilistic behaviour of the network.

This section contains results simulated for $\gamma = 2$, $\sigma = 7dB$, and $P_t = 40$ mW. These parameters will be used in analysing results obtained in this section. From Figure 6.12, it is observed that the behaviour of various RAAs differ from the network configuration with communication range set. In this setup, vehicles are not restricted to a certain range of communication. This is the typical scenario of the real world vehicular concept. From this figure, results show that MODIFIEDCARS performs poorly compared to all other RAAs with these settings.

AARF performs better than all others by probing fast in this channel condition to increase its bit- rates. ACARS and ONOE compete in performance as ONOE tries to decrease its bit-rate upon severe packet loss, while ACARS tries to estimate SNR to the PHY layer in this regard which fully relies on information from the RTS/CTS mechanism.

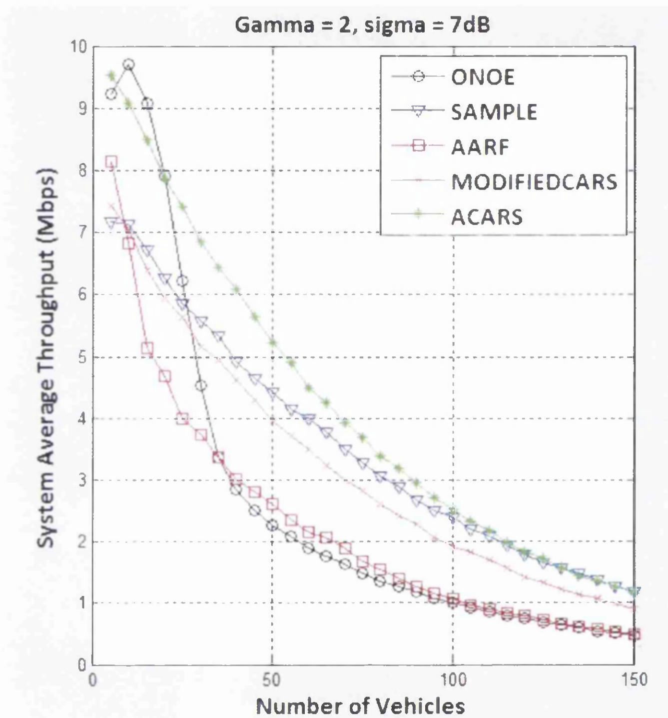

Figure 6.12: Average System Throughput vs Number of Vehicles.

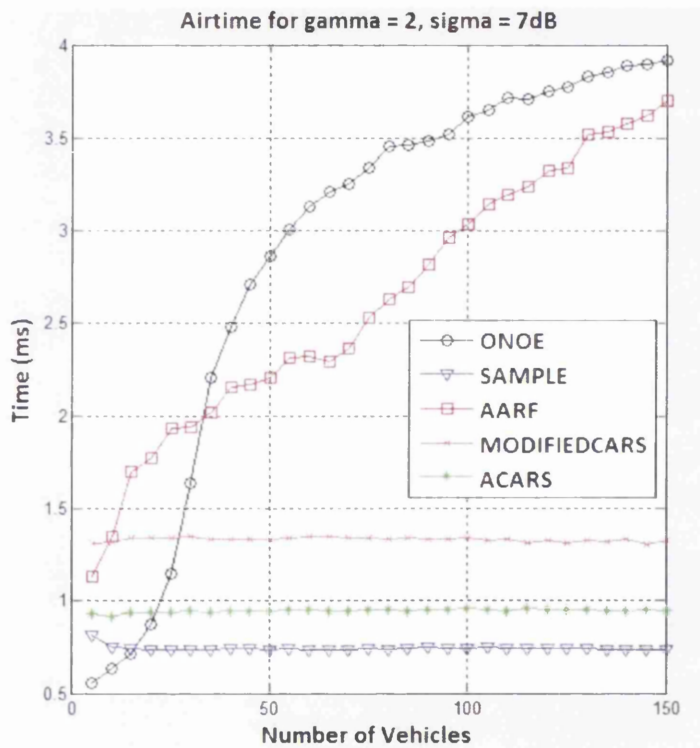

Figure 6.13: Airtime vs Number of Vehicles.

MODIFIEDCARS also performs poorly from Figure 6.13 followed by ACARS, while AARF out-performs all other RAAs using probing to access new rate. From observation, SampleRate did not make much difference in performance between a sparse and dense network. It is nearly like a straight line in this regard. There is also fluctuation for ONOE as the number of vehicles increase.

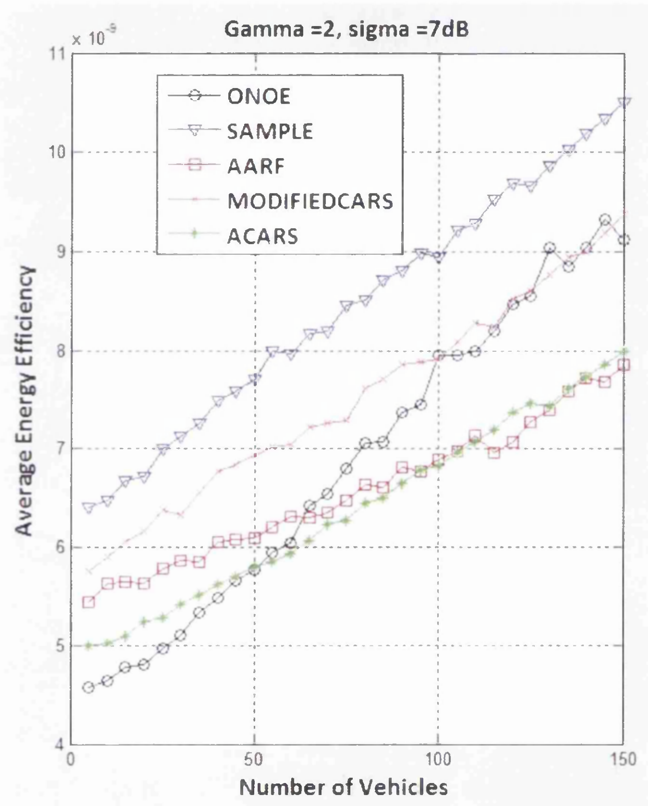

Figure 6.14: Average Energy Efficiency vs Number of Vehicles.

MODIFIEDCARS still performs poorly from Figure 6.14. Its energy consumption is high in this regard, and may not be ideal for congestion control and Qos etc. AARF out-performs all other RAAs with is probing mechanism. ACARS struggles in performance with ONOE, but as the network becomes more congested, it improves its performance better than ONOE; although not with much differences. But it was able to sustain its performance as the network becomes denser. This shows that ACARS should be ideal for QoS application, and network congestion control. ACARS is enable to quickly estimate SNR to the PHY layer to improve its performance in power management, by getting information from the RTS/CTS mechanism to provide instantaneous receiver-side SINR information to the transmitter. It will also be ideal for road safety application.

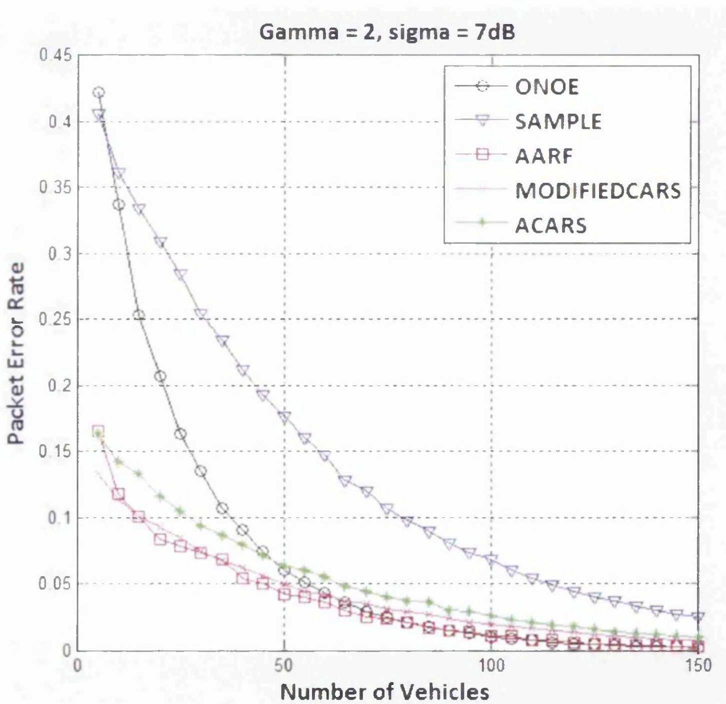

Figure 6.15: Packet Error Rate vs Number of Vehicles.

From Figure 6.15, ACARS out-performs other rate selection schemes competing with MODIFIEDCARS. From this figure, result shows that SampleRate performed badly by having high PER compared to AARF. This result also shows the rate at which packet collision and corruption occurs in this scenario. This means that, if less packets are corrupted and collides, the over all system PER will be low and vice-versa. From ACARS and MODIFIEDCARS algorithms, it can also be seen from their implementations, that PER is a parameter needed in order to get the maximum bit rate to transmit with. This shows that PER is very important in the implementation of both ACARS and MODIFIEDCARS.

Results obtained here were simulated with $\gamma = 2.56$, $\sigma = 4dB$, and $P_t = 40$ mW. Discussion on results obtained will be based on the values of these parameters used in simulation.

From [24], a real world simulation values were chosen as above. Simulation is done with these values to analyse the behaviour of rate selection schemes.

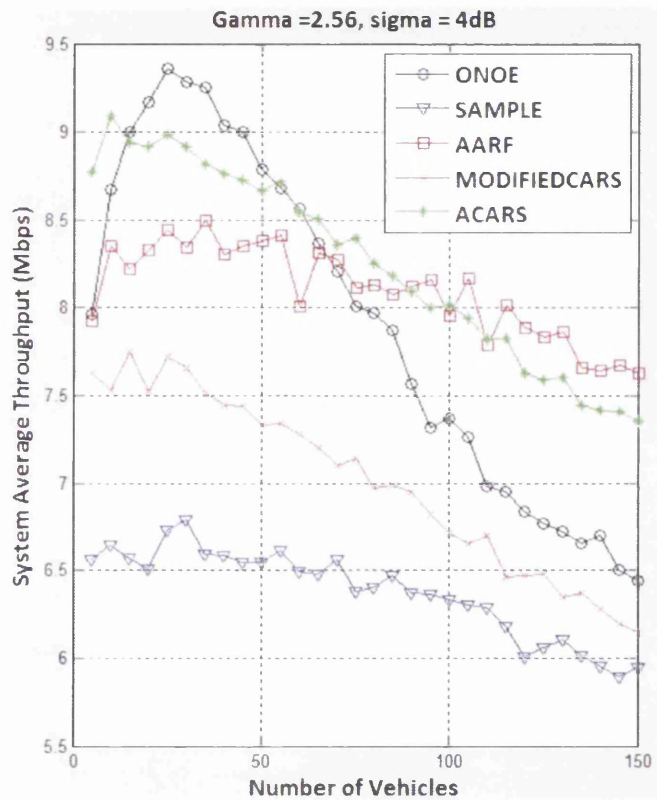

Figure 6.16: Average System Throughput vs Number of Vehicles.

From Figure 6.16, results shows that AARF out-performs all other rate selection schemes, while SampleRate did not perform well in this scenario. ACARS performs better than MODIFIEDCARS with much significant difference. From this figure, observation shows that AARF and ACARS can be very useful in real-world concept where no communication range was set and also simulating with the values of γ and σ respectively.

From Figure 6.17, result shows that AARF have the least energy consumption compared to all other rate selection schemes. ACARS also has low energy consumption compared to SampleRate, ONOE and MODIFIEDCARS. SampleRate performs poorly than all other rate selection schemes, reason should be that it cannot cope with the environmental condition in changing its bit-rate.

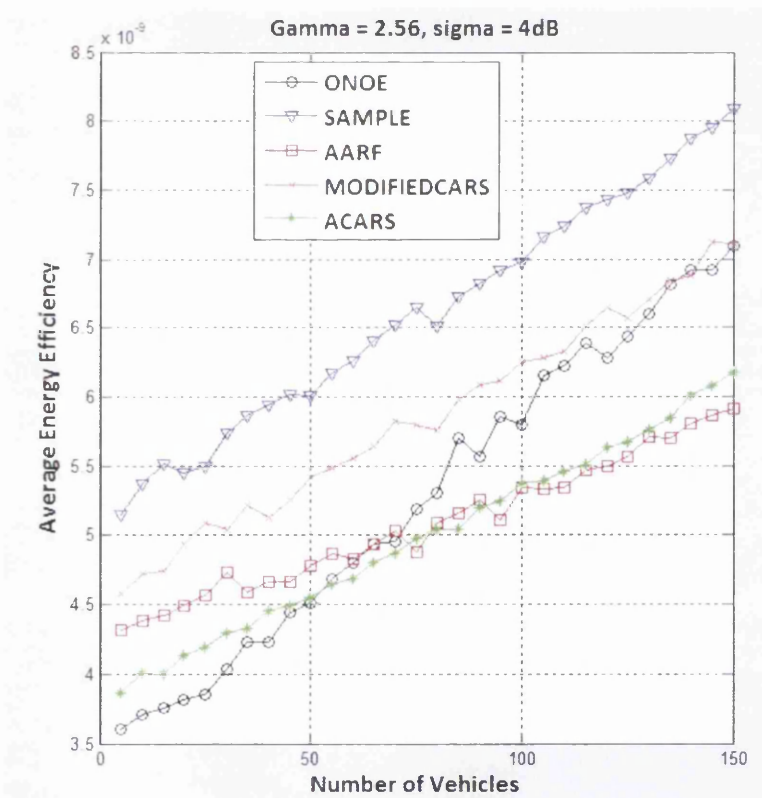

Figure 6.17: Average Energy Efficiency vs Number of Vehicles.

6.6.1 Summary of Some Results Obtained

In this section, some results obtained in some metric analyses from simulations are summarised in table for quick understanding of the trend of various RAAs. Tables 6.2-66 summarize some of the metrics used in analysing simulated scenarios in this research.

Table 6.2: Average Throughput (Mbps) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	5.60	8.80	7.00	9.60	6.80
30	3.70	6.80	5.20	4.00	5.30
50	2.30	5.00	4.00	2.20	4.10
70	1.80	3.60	3.00	1.40	3.20
90	1.40	2.80	2.40	1.20	2.50
120	0.80	1.80	1.40	0.80	1.60
150	0.60	1.20	0.90	0.60	1.20

Table 6.3: Packet Error Rate vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.72	0.36	0.37	0.56	0.19
30	0.52	0.28	0.29	0.52	0.31
50	0.36	0.17	0.19	0.36	0.36
70	0.24	0.14	0.16	0.24	0.25
90	0.18	0.09	0.08	0.18	0.19
120	0.19	0.08	0.07	0.19	0.19
150	0.08	0.06	0.06	0.08	0.08

6.6 Network Analysis With Fading and no Communication Range Set

Table 6.4: Average Energy (10^{-7}) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.20	0.10	0.10	0.20	0.10
30	0.25	0.15	0.16	0.25	0.20
50	0.27	0.16	0.17	0.30	0.18
70	0.39	0.17	0.18	0.48	0.19
90	0.60	0.19	0.20	.070	0.38
120	1.40	0.40	0.49	1.39	0.60
150	2.49	0.80	0.95	2.70	1.25

Table 6.5: Success Probability vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	0.10	0.48	0.49	0.30	0.62
30	0.07	0.29	0.28	0.04	0.26
50	0.06	0.20	0.19	0.05	0.05
70	0.07	0.12	0.11	0.07	0.06
90	0.10	0.09	0.09	0.10	0.01
120	0.02	0.06	0.06	0.02	0.02
150	0.01	0.04	0.04	0.01	0.01

Table 6.6: Airtime (10^{-3}) vs Number of Vehicles.

Veh.No.	AARF	ACARS	MODIFIEDCARS	ONOE	SAMPLERATE
10	1.62	0.90	1.40	0.70	0.80
30	2.10	0.95	1.35	1.80	0.71
50	2.45	0.98	1.38	2.98	0.60
70	2.60	0.97	1.39	3.80	0.61
90	3.05	0.98	1.39	3.55	0.62
120	3.49	0.99	1.39	3.70	0.61
150	3.60	1.00	1.38	3.98	0.60

6.7 Chapter Summary

This chapter can be summarized with this salient features observed in the channel measurements.

- *RSSI* measurements are fairly accurate, though there is a small amount of noise inherent in the measurement;
- The dynamics of large-scale path loss depend heavily on the environment. It can be relatively fixed when the devices are stationary and there is little movement in the area. Large-scale path loss can become more variable when there is more movement and it becomes highly dynamic and can change abruptly for mobile devices . Adapting rapidly to these changes can greatly improve performance;
- Small-scale fading due to movement increases as line-of-sight and dominant rays decrease. Fades occur on a variety of time-scales. Rate adaptation algorithms can benefit from adapting to slower fades, but fades also occur on a very small time-scale that a rate adaptation algorithm is unlikely to be able to adapt to successfully.

From simulation results obtained so far as shown in Tables 6.2-6.6, it show that integrating power control into both existing RAAs increases the performance of all rate selection algorithms. Although much direct comparisons cannot be made with ACARS and simulated RAAs because, the results obtained in the simulations have additional parameters like fading, power control etc. that were not used in the results shown in Table III in [14]. Another fact observed from simulation is that these existing RAAs can perform better with the integration of some of these techniques that has been implemented. From [14], SampleRate and AARF were all implemented without range checking, fading and power control. But from results, it means that they can still perform better if much modification is done with proper implementation.

From this research, studies have been made on how SNR measurement can be used to estimate the channel quality. It is clear that different transmission rates have different SNR thresholds. Generally, higher rate requires higher SNR in order to be sustained.

The most important element of SNR when selecting a rate is the *RSS*. This quantity can be estimated at the receiver using the RSSI, but must be known at transmitter where the transmission rate is selected . From the results obtained in this chapter, conclusion can be made that, different environmental factors have adverse effect on the performance of RAAs. It is also observed from the results that different RAA work better in different environments and not just a particular RAA performing better in all different environments. This chapter has also studied the impact of communication range set and when there is no communication range set for the various algorithms. From some of the results obtained especially in Figure 6.17 without communication range and In same environmental condition, the configuration without communication range set has better throughput for ACARS achieving 9.2 Mbps for 150 nodes and 1.5 Mbps for one with communication range set for 150 nodes.

Rate adaptation algorithms offer an effective means to facilitate system throughput improvement in IEEE 802.11-based wireless networks by exploiting the PHY layer multi-rate option upon dynamic channel conditions. The key insight learnt from the results obtained in both Chapters 5 and 6 is that the RAAs have to infer different loss behaviours and take adaptive reactions accordingly.

7

Conclusions and Future Work

In this chapter, the main findings and contributions of this thesis will be summarised. This chapter will also considers the outlook for future work, critical evaluation of this work, and references to similar work in this field are shown to underline the contribution of this thesis.

7.1 Summary of the Thesis

The common challenges of all RAAs include [14][34]: (1) Not able to adapt quickly to the rapid to the variations caused by fading and vehicular mobility; (2) Not able to distinguish losses due to environment from losses due to hidden stations; (3) Not able to estimate link quality from transmission window.

From the implementation of ACARS, two out of the three challenges mentioned above have been handled. ACARS algorithm can adapt to variation of propagation phenomena. Results from Chapter 5 show that ACARS and MODIFIEDCARS has same results in almost all the analyses, because there is one propagation phenomena considered, while in Chapter 6, results show that ACARS has better performance (e.g. low energy consumption, high throughput put, low delay.) compared to existing RAA in the presence of propagation effects as observed in many of the simulation results. For example in Figure 6.7 on page 159, ACARS has a low energy consumption of about 0.80×10^{-7} Joules as against a high energy consumption of 2.70×10^{-7} Joules achieved by ONOE. It also had low energy consumption than MODIFIEDCARS in this scenario for 150 vehicles.

It has also been demonstrated that ACARS provides lower PER and higher throughput than others, because it can effectively estimate SNR to the PHY layer which is a good indicator of channel quality. This handles the second challenge faced by all RAAs. Figure 6.16 on page 171 shows that the PER of ACARS has 0.06 compared to 0.08 for SampleRate in a 150 vehicular simulation.

Furthermore, the ACARS implementation adopts the RTS/CTS scheme in order to handle the challenge of hidden node problem that leads to collision faced by all wireless and mobile nodes. Implementing this scheme enables ACARS to handle the challenge on how to differentiate between losses due to environment and losses due to hidden stations.

This thesis has introduced the ACARS algorithm as another SNRbased RAA that considered some of the challenges faced by existing RAAs, by integrating these challenges in its proposed scheme. It is a robust algorithm that adapts effectively to different environmental factors. ACARS can be applied to road safety from the results obtained. This is because the minimum acceptable delay for road safety applications is 100 ms. The airtime from results in Chapters 5 and 6 are less than this value, which means that, vehicles can effectively communicate with each other to minimize packet or vehicle collisions. This also shows that ACARS is efficient in the collision avoidance application of the DSRC target.

7.2 Main Contributions

Rate adaptation offers an effective means to facilitate system throughput improvement in 802.11-based wireless networks by exploiting the PHY layer multi-rate option upon dynamic channel conditions. It is expected that RAAs should be able to adapt to rapid channel variations, handle hidden station problem, estimate link quality etc. From the results, it is shown that ACARS adapts to varying channel conditions and can achieve good performances for various environments.

The main contributions of this thesis are:

1. One of the key contributions in this thesis is the implementation of a new SNR-based RAA. ACARS is an SNR-based RAA that estimate SNR to the PHY layer to enable it to be effective in packet delivery probability. With this feature, ACARS performed better than compared existing RAAs is observed from results obtained.

2. Another key contribution in this thesis is the integration of power control into the design of ACARS algorithm. From the literature, it has either been rate adaptation analysis, or power control analysis. With the literature referenced so far in this thesis, there was none that had a combination of these two. These two techniques were combined in the design and implementation of ACARS. From this implementation and the results obtained, ACARS minimizes energy consumption which is one of the major challenges of wireless mobile nodes. It can also reduce network congestion; enhance QoS with this power control scheme.

3. Finally, the contribution of this thesis is to propose a robust RAA for collision avoidance and road safety. Since road safety is one of the major concerns of the IEEE 802.11 standards, reason for introducing 802.11p for vehicular communication. This contribution shows that ACARS can be properly utilized in the CCH channel of the seven channels available in the DSRC service divisions.

7.3 Critical Evaluation

The major focus of this thesis has been to perform high fidelity simulations in vehicular networks. Simulation was done using several path loss exponent which represent different environments and also several shadowing deviation values. Mobility model has also been implemented in proposed algorithm, which many of the existing RAAs lack, as observed in publications. Mathematical calculations were integrated into MATLAB code to implement the ConstSpeed mobility model. With this model, the impact of context-information on existing RAAs was evaluated, and then implemented ACARS and other existing RAA. Appropriate parameters were also used in this simulation, such as noise power, shadowing deviation, transmit power etc.

7.4 Future Work

This section discusses some future directions for research topics presented in this thesis. The current implementation only focused on few context-information parameters. It will be nice investigating ACARS on other parameters like traffic density, acceleration of the vehicles, environmental factors like location, weather, type of road, type of road user etc. Implementing these factors will give a better design and more realistic analysis of ACARS for applications in safety and non-safety demands of DSRC.

In ACARS implementation, context-information parameters were implemented through mathematical modelling and calculations. It was not with Global Positioning System (GPS), which can give accurate readings about location, time, distance between neighbouring vehicles etc. It will be more realistic and likely achieve better performance if such measuring devices will be used in ACARS implementation.

This research did not consider the case of communication outage in vehicular communications. In the real world, there will be some points in time when the vehicle may be in an environment with a tunnel, the duration in which the vehicle may lose communication with each other in such scenario depends on the length of the tunnel. It will be another challenge to investigate this issue in ACARS implementation and evaluate its performance.

There are four types of traffic mentioned in Chapter 2, known as access categories. In ACARS implementation, this research generally considers packet transmission involving data transfer without analysing each data type. This is why the values of AIFS is used in the simulation, because values of AIFS indicate which traffic is in use at given point in time. For future research, these traffic types will be considered, in order to evaluate their performances in ACARS implementation.

In the design of ACARS in Chapter 4, only one AP in the network is considered. There is need to extend ACARS to multiple APs, and a deterministic solution to enhance the handover procedures is needed via a fast, proactive handover mechanism that will improve the performance of the network.

Since random access MAC protocol of 802.11p is a protocol to depend on, there is no guarantee that a vehicle will be integrated into the collision-free infrastructure-based communication within a given delay interval. There is need for an alternative way to let the RSU know that a new vehicle has entered its communication range. In this case, many RSUs are needed depending on the network capacity. This is a limitation of ACARS, because it was not modelled in the proposed algorithm.

This research only considered a V2I scenario, reasons as stated in Chapter 2. It will be necessary to have a V2V scenario as in [14] where vehicles can communicate to each other without the need of an AP. This network scenario will be investigated in the future. In a V2V network scenario, all vehicles on same side of road acts as clients and the ones on the opposite act as servers. From [14], there was no comparison between V2I and V2V scenarios in terms of any performance metrics. But it will be interesting to evaluate the performances of these two network scenarios and conclusions can be drawn. This will be an opportunity for future research.

Appendix A

A.1 Conference Publications

From this research work in Chapters 3, 4, the following publications were made for various conferences. Results from this research is demonstrated in Chapters 5 and 6 and were used in these publications. These publications were made, so that others can read about this findings in RAAs and vehicular communications. Attending these conferences, were also a time to network with other people in similar area of research and sharing ideas and also receiving challenges and making amends were work was not properly done.

- K. S. Nwizege, J. He, K. S. Kim, and P. Igic. "Performance Evaluation of Adaptive Context Aware Rate Selection Algorithm (ACARS) for Road Safety Applications in Vehicular Network", EMS2013, IEEE Conference, 20-22 November, Manchester , 2013.

- K. S. Nwizege, M. Macmammah, M. Shedrack, F. M. Good, and G. I. Ikhazuangbe.
"Performance Evaluation of Propagation Model on Rate Algorithms in Vehicular Networks", CICSYN2013, IEEE Conference 5-7 June, Madrid, 2013.

- K. S. Nwizege, J. He, M. Shedrack, F. M. Good, and M. Macmammah. "Analyze Impact of Context Aware of Rate Adaptation Algorithm in Vehicular Communication", UKSIM2013, IEEE Conference 9-12 April, UK, 2013.

- K. S. Nwizege , J. He, and M. Shedrack. "Optimizing Rate Algorithms in Wireless Networks", EMS2011, IEEE Conference 16-18 November, Madrid, 2011.
- K. S. Nwizege, F. M. Good, A. Taneh, and S. Neenwi."Performance Analysis of Adaptive Rate Mechanism for IEEE802.11p in DSRC for Road Safety Application in Vehicular Networks", CIMSIM2011, IEEE Conference, 20-22 September, Malaysia, 2011.

Appendix B

B.1 Journal Publications

From this research, the following journal papers were published.

- K. S. Nwizege, and J. He. "ACARS: Adaptive Context Aware Rate Selection Algorithm for DSRC in Vehicular Networks", IJSSST V13, April, 2013.

- K.S. Nwizege, M. MacMammah, and G. I. Ikhazuangbe."Performance Evaluation of Path Loss Exponents on Rate Algorithms in Vehicular Networks", IJESE, Volume-1, Issue-10, August, 2013.

Appendix C

C.1 Publications not Part of this Research

The publications listed in this section are not directing related to this research , but still in wireless communication and computer technology.

- K. S. Nwizege. "Evaluation of Quality of Service (QoS) Support for Real-Time or Mission Critical Services over IEEE 802.11e Wireless Networks", EMS2011, IEEE Conference 16-18 November, Madrid, 2011.
- K. S. Nwizege, F. Chukwunonso, C. Kpabeb, and M. Shedrack. "The impact of ICT on Computer Applications", EMS2011, IEEE Conference 16-18 November, Madrid, 2011.

Appendix D

D.1 Parameters

D.1.1 Scenario Parameters

Road Length(m) - The length of the studied road/highway used is 1000 m.
Obstruction Location - The area where propagation processes occur using path loss exponents and shadowing deviations (for Chapter 4).
Vehicular Density (vehicles per metre) - How many vehicles are present on a given section of road of a set length, where the density assumes uniform separation.
Number of Vehicles - The number of vehicles present in a simulated system regardless of any other parameter.
Vehicle Velocity (m/s, mph, kph) - The speed at which vehicles are travelling. This can be an average across the field or per vehicle depending on the implementation.
Number of Lanes - How many lanes the road contains and if the direction of travel is the same or opposing.
Simulation Time (s) - The amount of time that passes in a simulation.
Antenna Height (m) - The height at which the radio antenna is positioned, for use in the Two-Ray Ground Reflection propagation model.

D.1.2 Application Parameters

Packet Transmission Rate (Hz) - The number of packets that are transmitted per second according to a preset distribution.
Transmission Method - A model that describes the way in which data is transmitted, according to either stochastic or probabilistic functions, or both.
Packet Size (b) - The size of the data packet being sent across through the network equipment, in most cases this represents the payload and not the added data from encapsulation at the layers of the OSI model.

D.1.3 MAC Layer Parameters

MAC Model - The particular model that represents the MAC layer, with specific functions for each of the IEEE 802.11 standards.
RTS-Timeout (ms) - As specified in the particular IEEE 802.11 standard, the RTS-timeout represents the time to wait until a RTS authorisation is received from a possible recipient.
CTS-Timeout (ms) - As specified in the particular IEEE 802.11 standard, the CTS-timeout represents the time to wait until a CTS authorisation is received from a possible recipient.
ACK-Timeout (ms) - Acknowledgement messages are sent to advise of a successful packet reception, in Ad-Hoc and infrastructure-based networks, where the timeout is the time a sending station waits before assuming a packet has been lost in transmission.
SIFS (ms) - The short inter-frame spacing time refers to the minimum interval between receiving a data and sending an acknowledgement, to mitigate fluctuations on the medium due to interference etc.
DIFS (ms) - The distribution (coordination function) inter-frame space is the time allowed for DCF activity in the MAC layer to sense the medium and determine it's state.
Slot Time (ms) - The slot time is twice the theoretical time taken to send a single pulse between sender and receiver, and enable the MAC layer to calculate

how long it will require the medium for.

D.1.4 PHY Layer Parameters

Transmission Power (dBm, W) - The Equivalent Isotropically Emitted Power (EIRP) of a radio signal from a transmitter's antenna measured in decibel metres (dBm) or Watts (W).
Centre Frequency (MHz, GHz) - The central frequency represents the centre of the used channel in a frequency range, i.e. the 5.9 GHz frequency specified for DSRC ranges from 5.860-5.920 GHz in 10 MHz channels (real range is therefore 5.850-5.925 GHz).
Transmission Range (m) - A pseudo-realistic distance within which a transmitted packet should be received. Inaccurate due to the complex calculation of packet reception according to propagation path loss and interference or noise on the medium, but useful for defining a constraint on calculating packet success in a simulated network.
Wavelength (m) - The wavelength is the distance between the period of a single waveform (the distance between two peaks in a sinusoidal wave) and is calculated by $\lambda = C/f$ where C is the speed of light and f is the centre frequency λ is wavelength.
Propagation Model - The propagation pathless model calculate the loss of energy of a radio wave as it travels away from the transmitter, further explained in Chapters 2, 4, 5 and 6.
Error-Rate Model - The error rate model calculates the success of any packet reception through a stochastic (dependent on the medium SNIR/Noise level) and a probabilistic method, to accurately represent the chance of loss on a utilised medium.
Energy Detection Threshold (dBm, W) - The energy detection threshold is the power level sensed on the medium that enables the PHY layer to switch from **IDLE** to **BUSY** period (full details of the PHY layer is discussed in Chapters 2 and 4). This value is device-dependent and varies according to the sensitivity of

the network device.

D.2 Performance Metrics

Average Energy Efficiency - The average of the transmit power over the sum of the bits. It is this parameter that we use in analysing energy consumption in existing rate adaptation algorithm and ACARS.
Collision Probability - The rate which collision occur during network transmission.
Packet Error Rate - This gives the rate at which transmitted packets that are not corrected received occur. This parameter affects throughout.
Number of Transmitted Packets - These show how transmitted packets are influenced bu number of nodes, speed , distance etc.
Average Speed (m/s, mph, kph) - The average speed is a mean calculation of all the speeds in a simulation, which gives an overall perspective on the flow of vehicles along a highway.

Vehicle Flow Profile - The flow profile is the percentage of $CarsEntering/CarsLeaving$. This metric shows how many vehicles are being held in the simulated system, due to congestion, and also shows the percentage of vehicles that have successfully traversed the obstruction around which congestion develops. In our simulation model, we can determine the number of vehicles in communication range and those out of range.

Vehicular Throughput - Vehicular throughput is a more commonly used metric than a vehicle flow profile; it represents the actual throughput of vehicles at a given position in the simulated system.

Packet End-to-End Latency (ms, ns) - The packet end-to-end latency is a measurement of a number of actions. In this thesis, the end-to-end latency of a packet is the time from entering the transmitting stations MAC layer to the packet leaving the receiving stations PHY layer, thereby encompassing the DCF function, the physical encoding and transmission on the medium and the time taken to receive data of the medium by the receiver. The definition of end-to-end latency varies through the literature and so should be well-studied if using for comparison.

Average Latency (ms, ns) - The average latency is a mean calculation of the individual end-to-end latencies gathered in a simulation. In this thesis only successfully received packets provide an end-to-end value as any dropped packets could supply an incomplete traversal of the actions that are measured, skewing the average. In this thesis, we have used airtime to evaluate our delay or latency.

Packet Success Rate (%) - The packet success rate is a percentage of packets sent and packets successfully received, as reported by the transmitter and receiver. This rate takes into account packets that are lost through collision on the medium and errors in reception and is not related to packets that are not receivable (i.e. outside the range of detection).

Airtime - The duration it takes to receive a successful packet at destination. It means same analysis as delay or latency. Network congestion, collision avoidance, QoS all depend on this parameter.

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