Quality of Service Provisioning and Performance Analysis in Vehicular Network

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Remerciements

To my parents

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Summary

Road traffic crashes are one of the world's largest public health and injury problems. Therefore road security has always been the main concern of transportation security stakeholders. During the last decades, public authorities and automotive companies have been involved in the safety improvement of our transportation systems by reducing the consequences of imminent accidents and decreasing the number of road injuries. Nevertheless, most of these preventive measures can only provide passive safety since they focus on the post collision phase. In fact, materials of energy absorption like airbags reduce the impact of an accident but do not prevent it.

This recognition of the inadequacy of these passive measures has oriented industrials to new and innovative perspectives that seek to avoid accidents and detect dangers in advance rather than minimize the damage. In fact, according to relevant studies, $60pers$ of accidents can be avoided if the driver had been alerted half a second before the collision. Drastic steps are already taken by automobile manufacturers to offer to drivers a larger telematics horizon and therefore enhance their range of awareness. If a collision is inevitable, active safety technology can proactively prepare the vehicle for the impact to reduce injuries. For example, vehicles' sensors are employed to measure and assess a vehicle's condition and environment, enabling the issuance of early warnings to drivers. On the other hand, a remarkable and similar step in that direction is achieved by networking research community using vehicular networks within Intelligent Transportation Systems (ITS). Vehicular networking is the enabling technology which allows the realization of the variety of applications and use cases. Given the significant potential to cater for diverse applications and their performance requirements, there has been a growing demand to equip vehicles with multiple connectivity modalities. In order to fully exploit these capabilities, vehicles are required to intelligently select the most appropriate technology for the specific networking scenarios.

Vehicular communications offer great potential for increasing road safety and driver awareness. Nevertheless, benefits are not restricted to safety standpoint but span to further horizons making use of various cooperating technologies. In fact, vehicular applications can be divided into three categories: safety, traffic management and infotainment applica-

tions. Safety applications could be event driven messages, and should have higher priority than periodic and comfort messages. Thus, service differentiation mechanisms and admission control are needed. These mechanisms are applied at MAC layer. Therefore at a first step, the research and industry community standardized a standard for MAC layer in Vehicular Adhoc networks (VANETs).

Currently, two types of communication services are considered: narrowband services and broadband services respectively, carried by IEEE 802.11p technology for narrowband services and LTE for broadband services. Narrowband services cover both the services strict temporal requirement and the data exchange with elastic time constraints for driving assistance. Broadband services are provided for the high-speed information transmission while meeting more or less strict time constraints. Our thesis tackles the performance analysis, design and optimization of resource allocation mechanisms in broadband and narrowband networks.

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Résumé

Les accidents de la circulation sont un des plus grands problèmes de sûreté publique. Par conséquent la sécurité routière a toujours été la principale préoccupation des acteurs de la sécurité des transports. Durant les dernières décennies, les pouvoirs publics et les entreprises du secteur automobile ont été impliqués dans l'amélioration de la sécurité de nos systèmes de transport en réduisant les conséquences des accidents imminents et en diminuant le nombre d'accidents de la route. Néanmoins, la plupart de ces mesures préventives ne peut assurer que la sécurité passive, car ils se concentrent sur la phase post collision. En fait, les équipements comme les airbags rééduisent l'impact d'un accident, mais ne l'empêchent pas.
Cette reconnaissance de l'insuffisance de ces mesures passives a orienté les perspectives industrielles nouvelles et innovantes qui cherchent à éviter les accidents et détecter les dangers à l'avance au lieu de minimiser les dommages. En fait, selon des études pertinentes, 60pers des accidents pouvaient être évités si le conducteur avait été alerté une demi-seconde avant la collision. Des mesures drastiques sont déjà prises par les constructeurs automobiles afin d'offrir aux conducteurs une télématique plus large et donc d'améliorer leur gamme de sensibilisation. Si une collision est inévitable, la technologie de sécurité active peut préparer de manière proactive le véhicule pour l'impact est réduire les dommages. Par exemple, les capteurs de véhicules sont utilisés pour mesurer et évaluer l'état de l'environnement d'un véhicule, permettant l'émission d'alertes précoces aux conducteurs. D'autre part, une étape remarquable dans cette direction est obtenue par la mise en oeuvre des réseaux de véhicules dans les systèmes de transport intelligents. La technologie des réseaux véhiculaires, permet la réalisation d'une variété d'applications. Compte tenu de l'important potentiel pour répondre à diverses applications et leurs exigences de performance, il y a eu une demande croissante pour équiper les véhicules avec de multiples modalités de connectivité.
Afin d'exploiter pleinement ces capacités, les véhicules sont tenus de choisir intelligemment la technologie la plus appropriée pour les scénarios de réseaux spécifiques. Les communications entre véhicules offrent un grand potentiel pour accroître la sécurité routière et la sensibilisation des conducteurs.
Néanmoins, les avantages ne sont pas limités à un point de vue de sécurité, mais à d'autres

horizons de diverses technologies coopérantes. En effet, les applications véhiculaire peuvent être divisées en trois catégories: les applications de sécurité, de gestion du trafic et des applications d'info divertissement qui pourraient être entraînés suite à des messages d'événement, et devraient avoir une priorité plus élevée que les messages périodiques et de confort. Ainsi, les mécanismes de différenciation de service sont nécessaires. Ces mécanismes sont appliqués à la couche MAC. Par conséquent, dans une première étape, le milieu de la recherche et de l'industrie normalisent une norme pour la couche MAC dans les réseaux véhiculaires.
Actuellement, deux types de services de communication sont pris en compte: les services à bande étroite et les services à large bande, respectivement portés par la technologie IEEE 802.11p pour les services à bande étroite et LTE pour les services à large bande. Les services à bande étroite couvrent à la fois la condition temporelle stricte et l'échange des données avec des contraintes de temps élastiques. Les services à large bande sont prévus pour la transmission de l'information à haute vitesse dans le respect des contraintes de temps plus ou moins strictes.

Notre thèse aborde l'analyse des performances, la conception et l'optimisation des mécanismes d'allocation des ressources dans les réseaux à large bande et à bande éétroite.

List of Figures

List of Abbreviations

3GPP	Third Generation Partnership Project
AC	Access Categories
AC-BE	Best-Effort
AC-BK	Background
ACI	Access Category Index
AC-VI	Video
AC-VO	Voice
AIFS	Arbitration Inter-Frame Space
AM	Acknowledged Mode
AP	Access Point
ARP	Allocation Retention Priority
ASTM	American Society for Testing and Materials
BSA	Basic Service Area
BSD	Bucket Size Duration
BSS	Basic Service Set
CA	Cooperative Awareness
CALM	Communications Access for Land Mobiles
CBR	Constant Bit Rate
CCH	Control Channel
CDA	Cooperative Driver Assistance
CDF	Cumulative Distribution Function
CDS	Crash Detection Systems
CFP	Contention Free Period

CoDM	CoDriveMessages
ComS	Communities Services
CoNa	Cooperative Navigation
CP	Contention Period
CP	Cyclic Prefix
CSM	Cooperative Speed Management
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance mechanism
CTS	Clear To Send
CW	Contention Window
DAR	Discrete Autoregressive
DCF	Distributed Coordination Function
DEN	Decentralized Environmental Notifications
DENM	Decentralized Environmental Notification Messages
DGPS	Diferential GPS
DIFS	Distributed Coordination Function
DP	Dynamic Priority
DS	Distribution System
DSRC	Dedicated Short-Range Communication
DwPTS	Downlink Pilot Time Slot
EDCA	Enhanced Distributed Channel Access
eNB	enhanced NodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FEC	Forward Error Correction
FIFO	First In First Out
FTP	File Transfer Protocols
HTTP	HyperText Transfer Protocol
GBR	Guaranteed Bit-Rate

GOP	Group Of Pictures
GP	Guard Period
GPRS	General Packet Radio Service
GPS	General Processor Sharing
GSM	Global System for Mobile Communication
GTP	GPRS tunneling protocol
GUI	Graphical User Interface
HARQ	Hybrid Automatic Repeat reQuest
HC	Hybrid Coordinator
HCCA	HCF Controlled Channel Access
HCCA	Hybrid Coordination Function Controlled Channel Access
HCF	Hybrid Coordination Function
HMI	Human Machine Interface
HSDPA	High Speed Data Packet Access
HSS	Home Subscriber Server
HTML	Hypertext Markup Language
IBSS	Independent BSS
IEEE	Institute of Electrical and Electronics Engineers
IFS	Inter-Frame Space
IP	Internet Protocol
IR	InfraRed
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
ITS-AID	ITS Application Identifier
LBS	Location Based Services
LCA	Lane Change Assistance
LCM	Life Cycle Management
LCP	Logical Channel Prioritization
LDM	Local Dynamic Map
LLC	Logical Link Control
LTE	Long Term Evolution

MAC	Media Acces Control
MANET	Mobile ad hoc networks
MBR	Maximum Bit Rate
MCS	Modulation and Coding Index
MME	Mobility Management Entity
MMPP	MarkovâĂŘModulated Poisson Processes
MSDU	MAC Service Data Unit
NAV	Network Allocation Vector
NGBR	Non GBR
OBU	On Board Unit
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiplex Access
OSI	Open Systems Interconnection
PBR	Priority Bit Rate
PCF	Point Coordination Function
PDCP	Packet Data Convergence Protocols
PDU	Protocol Data Unit
P-GW	Packet-data Network Gateway
PIFS	Point Coordination Function-IFS
P-K	Pollaczek-Khinchin
PMR	Private Mobile Radio
PQ	Priority Queuing
PRB	Physical Resource Blocks
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RHCN	Road Hazard Condition Notification
RHCW	Road Hazard and Collision Warning
RLC	Radio Link Control
RRC	Radio Resource Control
RSU	Road Side Unit
RTS	Request To Send

SAE	System Architecture Evolution
SAP	Service Access Point
SC-FDMA	Single-Carrier FDMA
SCH	Quality of Service
SDF	Service Data Flow
SDU	Service Data Unit
S-GW	Serving Gateway
SIFS	Short-IFS
SOAPS	Spectrum Opportunistic Access in Public Safety
STA	Station
TB	Transport Block
TCP	Transport Control Protocol
TM	Transparent Mode
TTI	Transmission Time Interval
TxOP	Transmission Opportunities
UDP	User Datagram Protocol
UE	User Equipment
UM	Unacknowledged Mode
UMTS	Universal Mobile Telecommunications System
UP	User Priorities
UpPTS	Uplink Pilot Time Stot
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VANETs	Vehicular Adhoc networks
VoIP	Voice over IP
VoLTE	Voice over LTE
WAVE	Wireless Access for Vehicular Environment
WBSS	WAVE Basic Service Set
WSMP	Wave Short Message Protocol
WSMS	WAVE Short Messages
WWW	World Wide Web

Chapter 1

Introduction

1.1 Motivation

Road traffic crashes are one of the world's largest public health and injury problems. Therefore road security has always been the main concern of transportation security stakeholders. During the last decades, public authorities and automotive companies have been involved in the safety improvement of our transportation systems by reducing the consequences of imminent accidents and decreasing the number of road injuries. Nevertheless, most of these preventive measures can only provide passive safety since they focus on the post collision phase. In fact, materials of energy absorption like airbags reduce the impact of an accident but do not prevent it.

This recognition of the inadequacy of these passive measures has oriented industrials to new and innovative perspectives that seek to avoid accidents and detect dangers in advance rather than minimize the damage. In fact, according to relevant studies, 60% of accidents can be avoided if the driver had been alerted half a second before the collision. Drastic steps are already taken by automobile manufacturers to offer to drivers a larger telematics horizon and therefore enhance their range of awareness. If a collision is inevitable, active safety technology can proactively prepare the vehicle for the impact to reduce injuries. For example, vehicles' sensors are employed to measure and assess a vehicle's condition and environment, enabling the issuance of early warnings to drivers.
On the other hand, a remarkable and similar step in that direction is achieved by networking research community using vehicular networks within Intelligent Transportation Systems (ITS). Vehicular networking is the enabling technology which allows the realization of the variety of applications and use cases. Given the significant potential to cater for diverse applications and their performance requirements, there has been a growing demand to equip vehicles with multiple connectivity modalities. In order to fully exploit these capabilities, vehicles are required to intelligently select the most appropriate technology for

the specific networking scenarios.

Vehicular communications offer great potential for increasing road safety and driver awareness. Nevertheless, benefits are not restricted to safety standpoint but span to further horizons making use of various applications. In fact, vehicular applications can be divided into three categories: safety, traffic management and infotainment applications. Safety applications could be event driven messages, and should have higher priority than periodic and comfort messages. Thus, service differentiation mechanisms and admission control are needed. These mechanisms are applied at MAC layer. Therefore at a first step, the research and industry community standardized a standard for MAC layer in Vehicular Adhoc networks (VANETs).

Currently, two types of communication services are considered: narrowband services and broadband services respectively, carried by IEEE 802.11p technology for narrowband services and LTE for broadband services. Narrowband services cover both services with strict temporal requirements and data exchange with elastic time constraints for driving assistance. Broadband services are provided for the high-speed information transmission while meeting more or less strict time constraints.

In order to provide quality of service (QoS) guarantees to narrowband and broadband wireless networks, we believe that vehicular network architecture should well design the following mechanisms:

- Traffic specification module which specifies source traffic characteristics and desired QoS parameters.
- QoS routing algorithm that provides route(s) between source and destination(s) that have sufficient resources to support the requested QoS.
- Call admission control that decides whether a connection request should be accepted or rejected, based on the requested QoS and the network status.
- Resource allocation mechanism which reserves resources such as wireless channels, bandwidth, and buffers at the network elements, which are required to satisfy the QoS guarantees.
- Packet scheduler that schedules packets to be transmitted according to the QoS requirements of the connections.
- Wireless channel characterization which specifies the statistical QoS measure of a wireless channel for example: a data rate, delay bound, and delay-bound violation probability triplet.

More specifically, an end system uses a traffic specification procedure to specify the source traffic characteristics and desired QoS. Then, call admission control decides whether a connection request should be accepted or rejected, based on the requested QoS, the wired link status, and/or the statistics of wireless channels. Afterwards, the network employs QoS routing to find path(s) between source and destination(s) that have sufficient resources to support the requested QoS. For base stations, wireless channel characterization is needed to specify the statistical QoS measure of a wireless channel, e.g., a data rate, delay bound, and delay-bound violation probability triplet; this information is used by call admission control. If a connection request is accepted, resource allocation mechanism assigns resources such as wireless channels, bandwidth, and buffers that are required to satisfy the QoS guarantees. During the connection life time, packet scheduler schedules packets to be transmitted according to the QoS requirements of the connections.

Our research studies tackle traffic specification and modelling, call admission control and packet scheduling in LTE and 802.11p networks. A particular concern was devoted to performance analysis and mathematical modelling of the MAC layer. These studies were conducted in industrial projects as detailed in the following section.

1.2 Context of the Thesis

Our thesis was carried out within the framework of Co-drive and SOAPS projects.

Co-Drive is a French project that is a co-pilot for an intelligent road and vehicular communication system. It aims at validating the pre-industrial cooperative control system between user and vehicle infrastructure. The project architecture is based on an exchange between vehicle and infrastructure through the ETSI protocol stack, or between the vehicle and the traffic information service through GPRS as shown in figure 1.1.

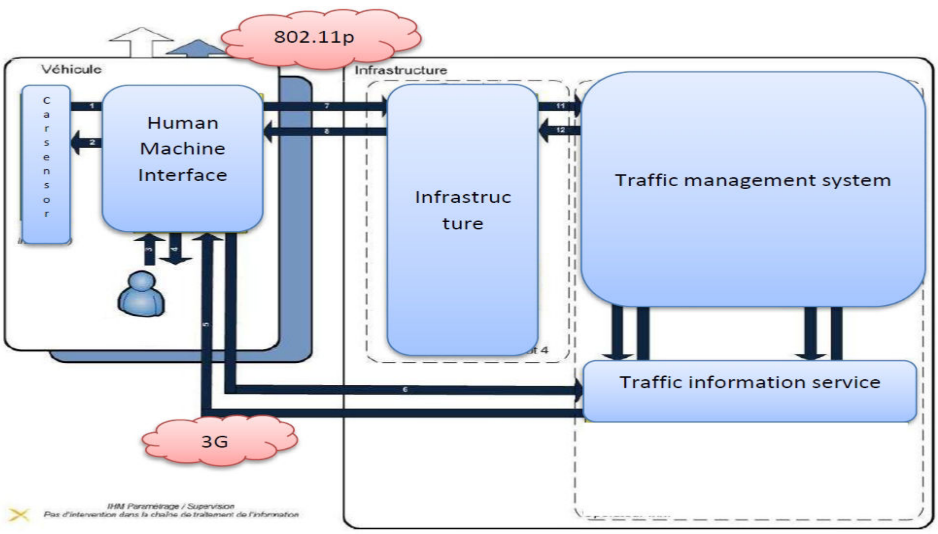

Figure 1.1: CoDrive Architecture

While SOAPS project addresses low layers protocols issues for Broadband Services provision by Private Mobile Radio (PMR) systems using LTE technologies with a particular focus on the improvement of frequency resources scheduling.

1.3 Thesis Contributions

Our thesis addresses the quality of service provisioning and performance evaluation in vehicular networks in the context of IEEE 802.11p and LTE networks. More specifically, we achieved the following contributions:

- Contribution 1-Source traffic Modeling: Since network performance is highly affected by traffic variability, we started our research study by elaborating traffic modeling of vehicular applications. The selected applications fall into safety, traffic management and comfort categories.

- Contribution 2-Class of service mapping study: The panoply of vehicular applications present diverse QoS requirements that should be considered when designing vehicular networks. In fact, an efficient quality of service mechanism, applied in a network, should achieve service differentiation according to traffic specifications. We strongly believe that application mapping to existing network classes of service is a crucial task in broadband and narrowband communication network. It is noteworthy that IEEE 802.11p implements service differentiation using the EDCA mechanism that adopts four access categories, whereas LTE network adopts the radio bearer concept identified by QoS Class Identifier (QCI). In this context, we achieved an original mapping study of the selected vehicular applications to access categories and LTE classes of service.

- Contribution 3-Performance analysis of the protocol stack architecture: We conducted a performance evaluation of the ETSI/ IEEE Wireless Access Vehicular Environment (WAVE) lower layers. This study is of paramount importance; in fact it enabled us to draw conclusions regarding vehicular network performance and thus to propose efficient resource allocation mechanisms that aim at enhancing quality of service.

- Contribution 4-Resource allocation mechanism: Since the vehicles are in communication with multiple heterogeneous radio systems, a global management of radio resources is required; it enables better use of available capacity in the various networks. The developed resource allocation mechanism aims at providing a deterministic or static guarantee to user requests.

- Contribution 5-Cross-layer optimization: In the continuity of the resource allocation mechanism proposal, we pursued our studies and integrated the cross layer in LTE. In this context, we proposed to adapt the bearer priority to the achieved traffic throughput and integrated a RRC-MAC cross-layer scheme. In fact, we believe that cross layer interaction exploits dependencies of protocol layers, thereby fulfilling quality of service demands of various applications. A particular concern is devoted to the RRC-MAC cross layer scheme: the quality of service is highly affected by the MAC layer resource allocation configured by the RRC layer. Performance drastically degrades when the RRC layer does not adopt an efficient scheduling algorithm; whereas good performance is achieved when RRC cooperates with the MAC layer. Therefore, a close coordination between the MAC layer and the RRC layer is required leading to the cross-layer implementation.

In order to validate the proposed mechanisms, we elaborated analytical models using Markov Chain coupled with discrete event simulation batches.

1.4 Organization of the Thesis

The thesis is organized as follows.

Before proceeding with the contributions achieved in LTE and 802.11p networks, we devote Chapters 2 and 3 for presenting the architecture of the tackled networks. More specifically, Chapter 2 addresses vehicular networking architectures. We start by reviewing the different characteristics of vehicular communications then describe the main characteristics of vehicular adhoc networks. Afterwards, we exhibit the general architecture of vehicular networks focusing on the functional entities. In a second step, we overview the various standards that tackle vehicular communications. Since, we contributed in this thesis to quality of service provisioning in vehicular networks, we focus in this chapter on the native QoS mechanisms devised for 802.11p wireless networks and detail the MAC layer in wireless access for vehicular environment.

Chapter 3 is dedicated to LTE functional and protocol stack architecture description in user and control plans. Moreover, we focus on quality of service mechanisms suggested at LTE radio level. We orient our efforts as well towards identifying LTE classes of service.

The chapter 4 is devoted to the study of the applications envisionned in vehicular networks. We mainly tackle the services required by Co-Drive, namely: Warning to a foggy zone, Inter-distance measurement and Road warning event. We bring the focus as well to four services taken into account in SOAPS: Voice, Video, HTTP and FTP. Then, we detail the achieved task 1; we perform an accurate traffic modeling. This will help us to evaluate the performance modeling of the networks in the subsequent chapters.

The third contribution is detailed in chapter 5 and 6. In fact, chapter 5 provides a mathematical modeling of the WAVE physical and Mac layers, while taking into account source traffic models. The study is achieved in a V2I scenario at a large scale and burst scale.

Chapter 6 tackles the virtual collision management proposed by IEEE in vehicular environment. In fact, EDCA virtual collision management is a penalizing process that induces unfairness, priority inversion and quality of service degradation. This chapter describes the performance study of the virtual collision.

Chapter 7 sheds the light on LTE performance. It details the fourth contribution which consists of a mathematical model and performance evaluation of the Medium Access Control (MAC) layer scheduling algorithm. The study while considers source traffic characteristics along with an original applications mapping.

Chapter 8 sheds the light on the fifth contribution. It describes an enhanced scheduling algorithm integrated in a RRC-MAC cross-layer framework. The performance evaluation of proves the performance of the scheduling algorithm. Finally, Chapter 9 addresses our perspectives and the envisionned works that deserve further investigation.

Chapter 2

Vanet Architecture and Overview

2.1 Introduction

In this chapter, we address vehicular networking architectures. We start by reviewing the different characteristics of vehicular communications then describe the main characteristics of vehicular adhoc networks. Afterwards, we exhibit the general architecture of vehicular networks focusing on the functional entities. In a second step, we overview the various standards that tackle vehicular communications. Since, we contributed in this thesis to quality of service provisioning in vehicular networks, we focus in this chapter on the native QoS mechanisms devised for 802.11p wireless networks and detail the MAC layer in wireless access for vehicular environment.

We start the chapter by an overview of different types of vehicular communications in section 2.2, then in section 2.3 we discuss their characteristics. In section 2.4 we describe the main functional entities, after that we present three main standard architecture and protocols in section 2.5 with a particular focus on the QoS mechanisms and physical layer characteristics.

2.2 Vehicular Communications V2I/V2V

In intelligent transport systems, each vehicle takes the role of the sender, receiver and router to disseminate information on the network of vehicles or transportation agency. Vehicular networks are responsible for communication between vehicles moving in a certain environment. A vehicle can therefore communicate directly with other vehicles, this communication is then called Vehicle to vehicle (V2V) or with the infrastructure, and this type of exchange is called thus Vehicle to Infrastructure (V2I) communication [33].

In order to establish communication between vehicles and infrastructure RoadSide Units (RSU), vehicles must be equipped with a radio interface or a vehicle unit OnBoard Unit (OBU), which allows network without short thread scope be trained. Vehicles must also be fitted with equipment that collects detailed location information such as Global Positioning System (GPS) or Differential GPS (DGPS). Infrastructure can be placed at regular intervals, or integrated into existing road infrastructure, for example, road signs, bridges or toll barriers. Indeed, the number and distribution of RSU units depends on the communication protocol used. For example, some protocols require that road units must be distributed uniformly in the road network, while other positioning these units only at intersections.

2.2.1 Vehicle to Vehicle Communications

The configuration of the inter-vehicle communication uses multi-hop broadcast to transmit traffic across multiple hops to a group of receivers. In intelligent transport systems, there are two types of inter-vehicle message: naive dissemination and intelligent distribution. Indeed, in the naive broadcast, vehicles periodically send broadcast messages at regular intervals. Upon receiving the message, the vehicle ignores the message if it is coming from a vehicle behind him. If the message is from a vehicle in front, the vehicle receiver sends its own broadcast message to vehicles behind. This ensures that all vehicles moving in the direction of diffusion receive all broadcast messages. The limits of naive diffusion method are that a large number of messages are generated, thus increasing the risk of collisions of these messages resulting in increased end-to-end transmission delay.

Regarding intelligent broadcasting with implicit acknowledgment, it addresses the problems inherent in the naive broadcast by limiting the number of broadcast messages for a given emergency event. If the vehicle detects an event and receives the same message from vehicles that are behind him, he assumes that at least one of these vehicles received the message, it is going to stop playing. The assumption is that the vehicle behind will be responsible for routing the message to the rest of the vehicles. If a vehicle receives a message from multiple sources, it will considere the first message received only.

2.2.2 Vehicle to Infrastructure Communications

The vehicle to infrastructure configuration is to simply jump diffusion; indeed, the RSU sends a single broadcast message to all vehicles in its coverage area.
The vehicle to infrastructure communication provides a high bandwidth link between vehicles and RSUs; they can be placed every kilometer or less, thereby maintaining high data rates in heavy traffic. For example, during the delivery of dynamic speed limits,

the infrastructure will determine the appropriate speed limit based on internal traffic conditions. It will therefore periodically broadcast a message containing the speed limit and compare geographic areas and directional terms with the vehicle data to determine whether a speed limit warning applies to all vehicles in the neighborhood. If a vehicle violates the required speed limit, a broadcast will be delivered to the vehicle asking the driver to reduce speed.

2.2.3 Routing Based Communications

The routing-based communication is a multi-hop unicast where the message propagates in multi hop until the vehicle carrying the desired data is reached. When a request is received by a vehicle having the desired information, the application at the vehicle immediately sends a unicast message containing the information about this vehicle, which is then responsible for forwarding the request to the source.

2.3 Vehicular Networks Characteristics

Indeed, VANET networks share many characteristics with the MANET, however, there is an important difference between the two networks. In the following, we describe some characteristics [34], as well as various standardization efforts in this area.

Network topology and density: Because of the high mobility of vehicles, the vehicular network topology changes frequently; a vehicle can join and leave the network in a very short time which indicates a wide variation in vehicle density. In addition, the vehicle density can vary from an environment to another (for example, urban or rural environment). Thus, the vehicular networks protocols are facing the challenges of density variation.

Indeed, V2V communications can extend all the way. However, the road network limits the topology of the communication network to one dimension. In fact, obstacles prevent wireless signals to cross between roads, except near intersections

Mobility Model: Vehicle mobility is constrained by the taken paths, the management and the number of traffic lanes; therefore, the vehicle pathways are predictable in advance. Furthermore, the constraints imposed by the obstacles, traffic and the speed limit lights; greatly affect the mobility model and vehicle density.

The vehicles often travel at a very high speed; however, their movements are constrained by the road topology. Moreover, the decision of the driver is related to vehicle performance limitations and to traffic laws. Therefore, the mobility of the vehicle is predictable on the roads.

Large Scale: Vehicular networks are developing at a very large scale; they are based on a diffusion process. Therefore, protocols face collisions and possible interference between communications vehicles.

Security: Data security and privacy remains one of the major problems in vehicular networks. Indeed, the attacks of the network can generate a road accident, which makes its wireless network extremely vulnerable. It is therefore essential to design protocols that secure network access.

2.4 Description of The Functional Entities

The 802.11p network is recommended for wireless access in vehicular network. The architecture of the IEEE 802.11 is composed of several components that interact to provide a wireless network. In this section, we present the functional entities of 802.11p architecture network as shown in Figure 2.1 [1] .

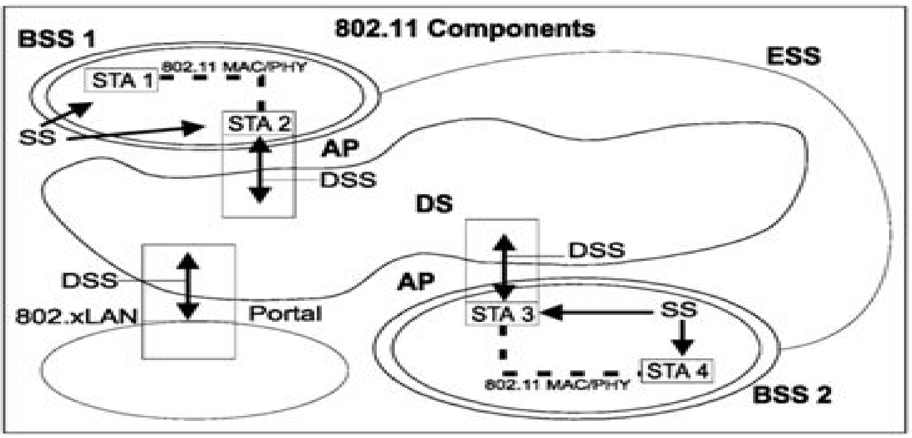

Figure 2.1: Functional entities [1]

2.4.1 Basic Service Set (BSS)

A BSS is a set of stations (STA) under the control of one coordination function. The geographical area covered by the BSS is known as Basic Service Area (BSA). To be a member of the BSS, a station must apply a synchronization procedure. A single Independent BSS (IBSS) form an ad-hoc network without infrastructure.

2.4.2 WAVE Basic Service Set (WBSS)

Two devices (or more) involved in WAVE communication form a WAVE Basic Service Set (WBSS). In order to initiate communication, an RSU or OBU transmits WAVE announcement frames, the equipment that initiated the WBSS is called provider, who receives these frames and establishes communication with the supplier called user. The OBUs and RSUs can be provider or user of a service. A unit can switch from vendor status to the user status of a service but cannot be in both states simultaneously. So there are two types of WBSS:

- A persistent WBSS is announced periodically and may be used to carry a current service indefinitely (ie, Internet access).
- A non-persistent WBSS is announced at the initiation WBSS and will be for a limited time. It is interesting to carry demand services.

2.4.3 Access Point (AP)

The infrastructure networks are established through the Access Point (AP), it is mapped to the RSU unit of the connecting road. The AP has the base station functionality in cellular networks. It represents the entity that allows access to the distribution system through the wireless medium.

2.4.4 Distribution System (DS)

The distribution System (DS) is an architectural component used to interconnect multiple BSSs. This allows the different stations to communicate with other BSS via multiple APs.

2.4.5 Extended Service Set (ESS)

The SSE is the union of several BSS connected by a DS. The stations can communicate within an ESS and move from one BSS to another.

2.5 Available Standards and Protocols

2.5.1 European Telecommunications Standards Institute (ETSI) Architecture

ISO standardization efforts are based on the concept of Communications Access for Land Mobiles (CALM) and ETSI have opened the way for cooperative vehicle systems. ETSI proposal presents a more detailed view of a stack of communication that should be instantiated on personal items, vehicles, roads and its stations ITS, where common OSI layers are surrounded by two plans for the management and security .

This architecture is managed and maintained by the Standard (ETSI) [2] to develop standards and specifications of its services. ETSI architecture (figure 2.2) [2] has four vertical layers (application, facilities, network and transport, and link layer) and two vertical planes: management and safety plans.

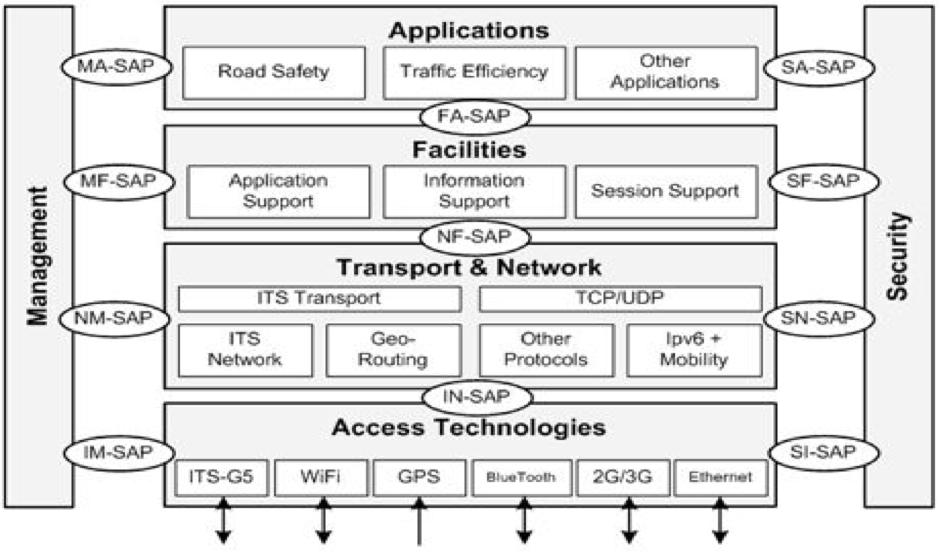

Figure 2.2: Architecture ETSI [2]

2.5.2 Communication Access for Land Mobiles (CALM) Architecture

This architecture is proposed by the ISO standard [3]. The main objective is to develop a CALM standard network protocol that is able to connect vehicles and roadside systems continuously and seamlessly. Thus, CALM provides a multitude of cellular mobile communication media and wireless networks, Dedicated Short-Range Communication (DSRC) or even InfraRed (IR). This reuse (figure 2.3)[3] of the existing communication media can be explained by the fact that the CALM wishes to use the predefined standards. For the routing issue, CALM uses IPv6 as a routing protocol with transfer media.

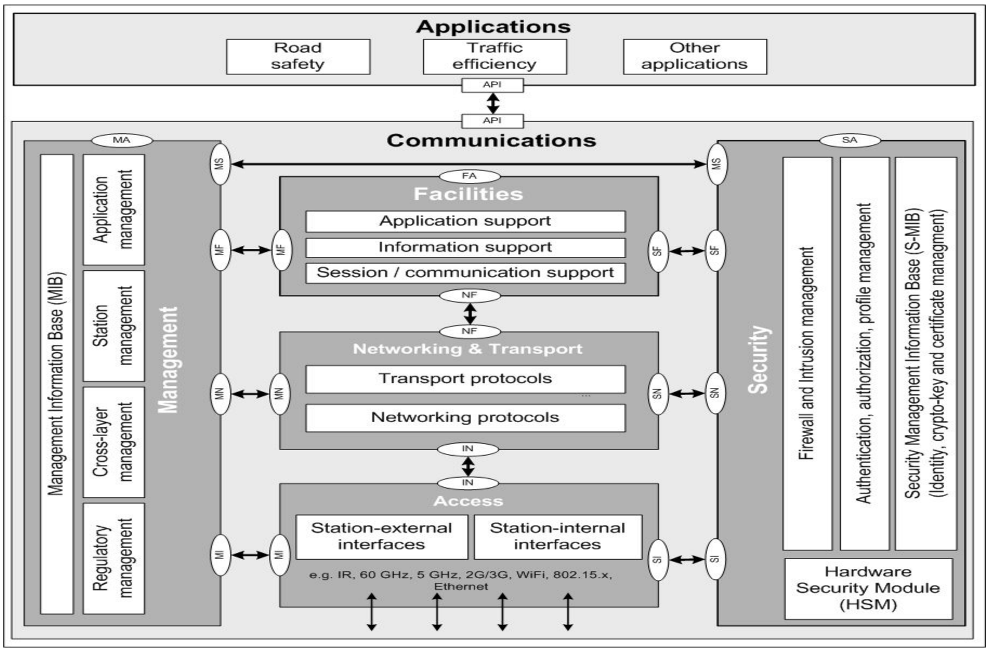

Figure 2.3: Architecture CALM [3]

2.5.3 Wireless Access for Vehicular Environment (WAVE) Architecture

Several standards IEEE P1609.1, P1609.2, and P.1609.3 P.1609.4 (figure 2.4) [1] are developed for vehicle networks forming the WAVE architecture [1], it is based on DSRC standard. In fact, it carries communications in a short range dedicated band in order to issue on unused frequencies of other standards to reduce interference. WAVE recommends the IEEE 802.11p standard which governs the protocols at the MAC layer and physical. IEEE 802.11p standard is based on the IEEE 802.11a physical layer and IEEE 802.11 e for the quality of service. In the following, we will discuss the various components of the WAVE architecture.

The IEEE 1609.1 [35] processes the format of the messages exchanged between vehicles and their neighbors or between vehicles and infrastructure, as well as the necessary data to be stored in vehicles. It is related mainly to VANET applications and specifies the needs of each category in terms of time and data. The IEEE 1609.2 [36] standard describes the security mechanisms required in an automotive environment.

The IEEE 1609.3 [37] standard describes the Wave Short Message Protocol (WSMP) that replaces the TCP / IP stack and manages urgent applications. And high-priority data will be sent in a small time window. The WSMP message can be transmitted on the Control Channel (CCH) and the Service Channel (SCH). The standard therefore provides for the presence of a single channel CCH, reserved for control and safety messages, and up to 6 SCH channels used to transmit non-safety data messages. Indeed, WAVE supports IP and non-IP applications. Short Messages WAVE (WSMS) consume minimal channel capacity, they can be sent over the channels CCH and SCH. Unlike the IP traffic that can be sent on the SCH only, the system management frames are sent on the CCH channel.

Physical and MAC layers are defined by IEEE 1609.4 standards [38]. The standard defines multichannel coordination and describes the process for setting priorities among different traffic. According to the multi-channel coordination mechanism, all stations must monitor the CCH for common time intervals and move to a SCH channel if they want to transmit insecure messages applications.

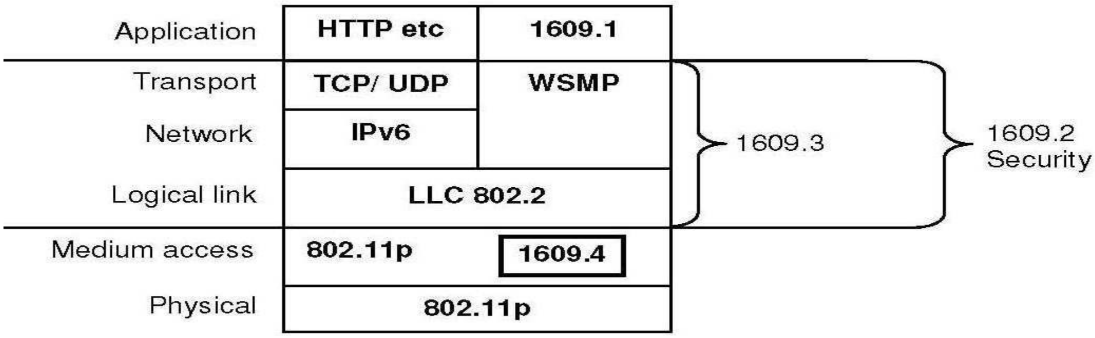

Figure 2.4: WAVE Architecture

WAVE accommodates two protocol stacks: the standard stack (TCP / UDP, IPv6) and the WSMP protocol recommended for wireless access in vehicular environments. More precisely, the data plan incorporates the following protocols:

- The protocol Logical Link Control (LLC).
- The protocol Internet Protocol version 6 (IPv6).
- The protocol User Datagram Protocol (UDP) and Transmission Control Protocol (TCP).
- The protocol WSMP: it allows applications to directly control the characteristics of the physical layer, ie: the channel number and transmission power. The sending application also provides the MAC address of the destination terminal.

In the following, we present the functional architecture of WAVE standard for vehicular networks and the protocol stack adopted by ETSI. In fact, we used both architectures in Codrive project. Specifically, we have adopted a top-down approach starting with the upper layers of the ETSI standard.

The Facilities layer is supported by the standard protocol stack (TCP / UDP, IPv6) and the IEEE 802.11p. This new architecture is intended to transmit specific ITS messages applications on WAVE protocol stack standard. These messages are standardized in two categories Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM). Therefore, road applications are standardized as CAM DENM messages. they are received and interpreted by the Facilities layer before sending them to network and transport layers in which we distinguish between ITS or TCP / UDP transport stack.

2.5.3.1 The Facilities Layer

The Facilities layer is a new paradigm introduced by ETSI. Its main features are merging and management of various data. This layer is also responsible for updating the database dynamically, so that it can be used by applications. The Facilities layer is defined in the standard by a set of modules responsible for interacting with ITS applications and network and transport layers (Figure 2.5).

It provides for ITS applications support to share functions and generic data according to their business needs. We therefore examined the functional architecture and components [39], it summarizes the main features of the facilities layer. Indeed, it focuses on addressing data at this level and the inters-layer communications interfaces through Service Access Point (SAP).

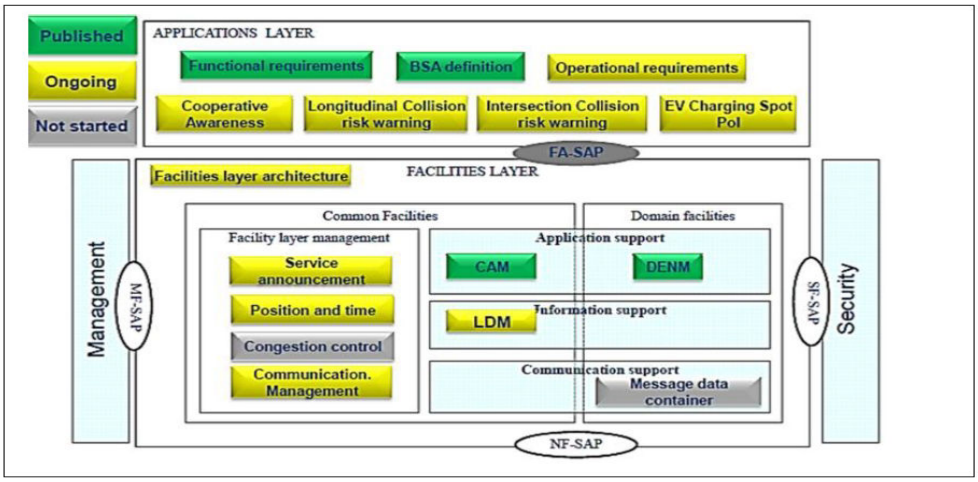

Figure 2.5: Facilities Layer [39]

The Facilities layer consists of two vertical planes: Common and Domain Facilities.

- Common facilities: The plan defines the basic generic services for all ITS applications; Human Machine Interface (HMI) common, the addressing mode; V2X messages; management of CAM messages...
- Domain facilities: It specifies personalized services and functions for a class of ITS applications among these functions: managing expectations queues based on the priority of V2X messages and verification of the relevance of the messages.

Both plans are decomposed into three layers: Application Support, Information Support and Communication Support.

- Application support facilities: this layer carries the ITS services; such as CAM and DENM message manager.
- Information support facilities: it provides data stored and managed in a common database called Local Dynamic Map (LDM) containing the images and information of the road.
- Communication Support facilities: this layer provides services for the communication manager and session.

The Facilities layer has a GUI interface that allows interaction with users, it transmits messages that contain the route information but also location data: longitude, latitude and altitude. The information support contains a temporary database called LDM; it stores the route information dynamically.

This layer allows also the management of messages exchange between applications: construction of CAM or DENM messages, session management messages (request message, response message). Each message is identified by an address and sent to the network and transport layers through Service interfaces Access Point (SAP).

The importance of addressing messages at the application level is to identify ITS applications (using the ITS-AID), and to identify the type of messages sent by applications (using FTM -ID) [39], and allows lower layers to access each application data.

2.5.3.2 Transport/ Network Layer

This layer is responsible for routing packets through the network. It generally implements two protocols: TCP and UDP.

2.5.3.3 MAC Layer

The MAC layer [1] should provide a reliable access to the channel, equitable and effective. We must therefore take into account the different types of applications. For example, safety messages applications must be sent quickly and with very low loss rate. This requires effective sharing of the channel, which is even more difficult because of the high mobility of vehicles and fast topology changes.

The quality of service provisioning for real-time applications with strict time constraints require reliable transmission. This is due to resources fluctuation, high vehicle speeds and physical propagation conditions on the radio channel. The 802.11p standard provides two QoS mechanisms [1]:

- The first mechanism is distributed called Enhanced Distributed Channel Access (EDCA). It transmits traffic according to user priorities (User Priorities) (UPs).
- The second mechanism is centralized and is designated Hybrid Coordination Function Controlled Channel Access (HCCA). It allows the reservation of permissions transmission (Transmission Opportunities (TXOPs)). The following paragraphs detail the two mechanisms built at the MAC layer figure 2.6 [1].

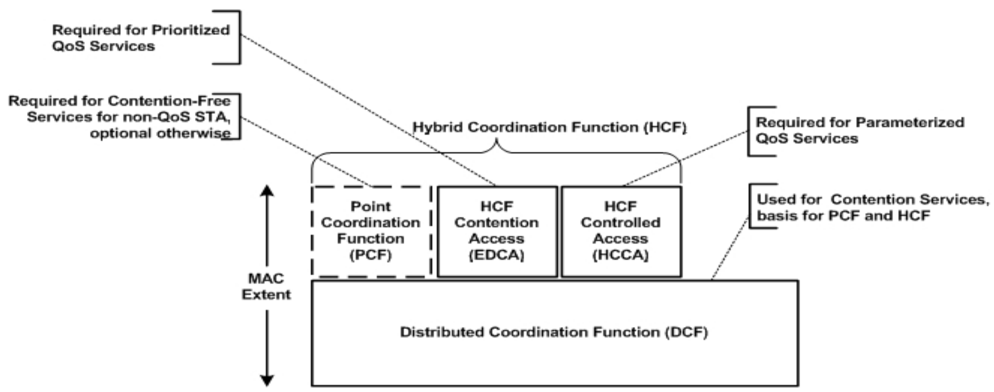

Figure 2.6: MAC Layer [1]

2.5.3.4 QoS Mechanisms of The MAC Layer

The quality of service is the ability to transmit in good conditions a given type of traffic, in terms of availability, throughput, transmission delay, jitter, packet loss rate, it aims to optimize network resources and ensure good performance for critical applications. The guarantee of a good QoS in vehicular conditions that introduce resource fluctuations, high vehicle speeds and difficult physical propagation conditions at the radio channel is not easy. The QoS support begins in a network of the same priority flow aggregation in different classes, the QoS must be maintained throughout the flow crossing through the various layers. To maintain this QoS, the IP layer flows will be mapped on the relevant priorities offered by DiffServ, and then mapped on the QoS offered by the MAC layer.

In fact, the MAC layer provides two types of function: The function Point Coordination Function (PCF) and the Hybrid Coordination Function (HCF) through the Distributed Coordination Function (DCF). CPF mechanisms and HCF DCF will be described in the following.

The medium mode alternates between contention during the Contention Period (CP) and no contention mode during Contention Free Period (CFP). In CP, the stations are competing for access to the transmission medium. During the CFP, the access medium is controlled by the AP; this eliminates any temptation to contention and collision.

Distributed Coordination Function (DCF) DCF in figure 2.7 is the fundamental access method implemented in all stations belonging to the IBSS or to network infrastructure. DCF is based on Carrier Sense Multiple Access with Collision Avoidance mechanism (CSMA / CA). Each station has awaiting MAC Service Data Unit (MSDU), should the access contention to access the channel. This contention will be repeated for all waiting frames in the queue at the MAC layer.

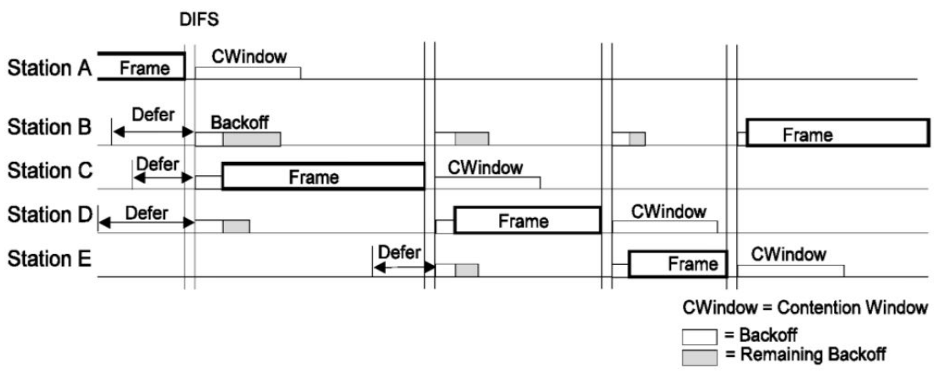

Figure 2.7: Mechanism DCF [1]

The medium access priority is controlled by the use of time slots Inter-Frame Space (IFS) which separate the frames transmissions.

Three IFS intervals are specified in the standard: Short-IFS (SIFS), Point Coordination Function-IFS (PIFS) and Distributed Coordination Function (DIFS). The interval SIFS is lower than PIFS, and lower than DIFS. A station that wishes to issue, should ensure that the channel is free during the DIFS interval before attempting transmission (figure 2.7) [1].

If the channel is free, then the station transmits a data frame. When the frame is transmitted, the frame duration field is used to notify the stations of the time during which the medium is busy. All stations, having received the data frame, update the Network Allocation Vector (NAV) which indicates the time remaining for the current transmission is completed.

In the case where the station detects that the channel is busy, it waits until the channel is free during DIFS. Then, it calculates the backoff length. This period of backoff is decremented as the channel is free for the Contention Window CW period.

- If the backoff reaches zero, the station transmits the frame.
- If two stations have a backoff period equal to zero simultaneously, a collision then occurs. Each station should generate a new backoff time.
- If the channel becomes busy and backoff time has not reached zero, the station freezes the backoff time.

An improvement of this mechanism is developed through the exchange of RTS / CTS frames (Figure 2.8)[1] that aim to minimize collisions. A station that wishes to transmit sends a RTS frame to the AP. It sends a CTS frame broadcast to indicate the reservation of the channel by the concerned station.

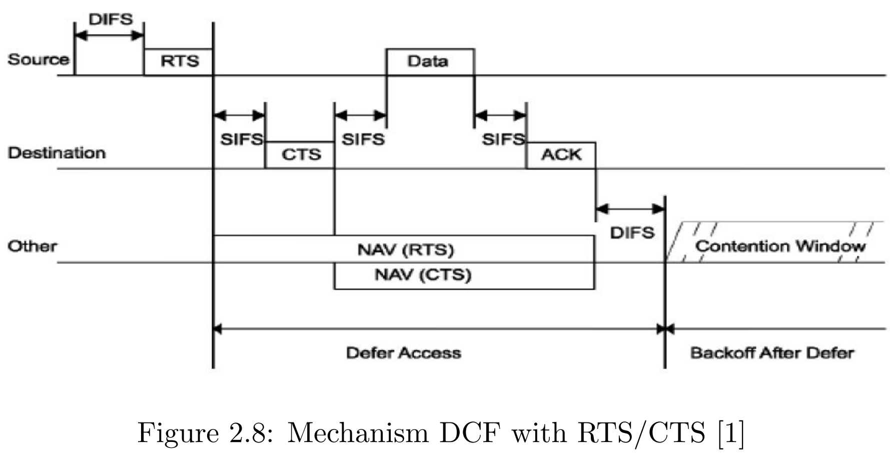

Figure 2.8: Mechanism DCF with RTS/CTS [1]

Point Coordination Function (PCF) The PCF provides a centralized mechanism used only in networks with infrastructure. A Coordinator Point working with the access point performs the polling of active stations and determines the station with the right to transmit.

Hybrid Coordination Function (HCF) The HCF mechanism improves the PCF and DCF functions by integrating QoS mechanisms and specific types of frames. HCF is based on the access method of the EDCA contention channel and on the controlled access method of the HCCA channel.

HCF Controlled Channel Access (HCCA) HCCA mechanism with a hybrid coordinator (HC) is the central body responsible for the quality service provisioning.

HC uses the highest priority level to access the medium in order to initiate frame exchanges and to allocate TXOPs to itself and other stations.

A station sends a request to HC asking for TXOPs (in uplink and downlink transmissions) based on the requirements of its traffic. HC admission control policy allows deciding the acceptance or rejection of the request from the station.
The HC has a global view of the network and known traffic conditions belonging to various categories of service in queues stations. This is the basis for the allocation of TXOPs and transmissions without restraint by the various stations of the traffic carried.

EDCA mechanism The EDCA mechanism provides a distributed method to the wireless medium access with QoS differentiation. Specifically, this mechanism is based on eight different priorities that are matching, in ascending order of the four priorities as shown in Figure 2.9 [1].

Priority	UP (Same as 802.1D user priority)	802.1D designation	AC	Designation (informative)
Lowest	1	BK	AC_BK	Background
	2	—	AC_BK	Background
	0	BE	AC_BE	Best Effort
	3	EE	AC_BE	Best Effort
↓	4	CL	AC_VI	Video
Highest	5	VI	AC_VI	Video
	6	VO	AC_VO	Voice
	7	NC	AC_VO	Voice

Figure 2.9: Mapping of user priorities to the access categories [1]

Eight User Priorities (UP) levels, it is an integer between 0 and 7. Each access class is mapped to one UP accordance to figure 2.9. The quality of service differentiation is obtained by varying the following parameters:

- Arbitration Inter-Frame Space (AIFS): Minimum time interval between the instant when the medium is free, and the start of transmission of the frame.
- Contention window (CW): a gap in which a random number is selected in order to implement the back-off mechanism.
- Transmit Opportunity Limit (TXOP): The maximum amount of time (in milliseconds) during which a station can transmit after receiving a TXOP. In case TXOP is zero, the station can transmit a single MSDU.

The packets are sent to the radio medium according to the DCF, but using a setting own of each category. Indeed, internal collisions can occur, it is possible that two packets in two different queues in a same station have their random wait time ends at the same time. Data packets must indicate whether a quality of service is requested, for this, the quality of service field in the frame control field is activated, it provides information on the quality of service associated with the respective frame such as the priority degree.

2.5.3.5 Physical Layer and Dedicated Short Range Communication (DSRC)

The standard Dedicated Short Range Communication (DSRC) [4] is defined by American Society for Testing and Materials (ASTM) to ensure vehicular communications. WAVE is the standard defined by the IEEE group, this standard is dedicated to V2V and V2I communications and supports IEEE 802.11p, it uses the concept of multi-channels. All channels functionally dividing into one Control Channel (CCH) and 6 Service Channels (SCH).

The physical layer of WAVE [9] is derived from the IEEE 802.11a. It is able to offer a rate between 3 and 27 Mbps on 10MHZ channel (for distances up to 1000 meters) with Orthogonal Frequency Division Multiplexing (OFDM) modulation.

The physical layer is based on seven communication channels of 10 MHz each a length lying in the area 5.850 and 5.920 GHz. WAVE devices must be able to accommodate an architecture that supports a CCH channel and multiple SCH channels to ensure communications for security applications and other Intelligent Transport service.

The control channel is reserved for the transmission of network management messages and high priority messages such as: critical information related to road safety. The six other

channels in figure 2.10 [4] are on the other dedicated to the transmission of data from different services. Finally, note that the protocol should allow unicast and multicast, the different channels can be used simultaneously, however, each station continually alternates between the control channel and service channels. In order to meet safety requirements (collision avoidance) a period containing a CCH and SCH should not take more than 100ms.
The figure shows the channels envisaged for the WAVE standard. A control channel and several service channels are recommended. It should be noted that the entire SCH channel will not be used.

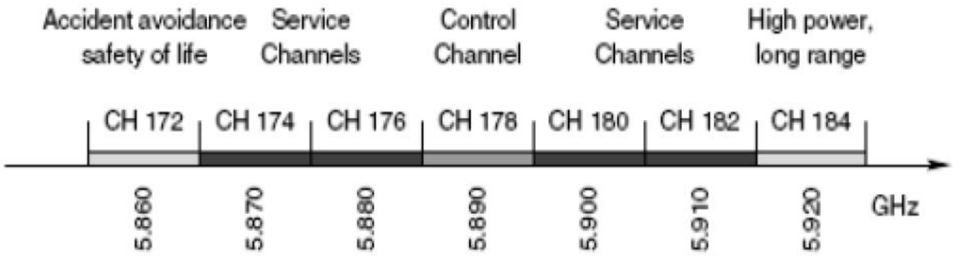

Figure 2.10: WAVE standard channels [4]

According to European standard

- ITS-G5A: Frequency band of 5.875 GHz to 5.905 GHz, dedicated to security ITS applications,
- ITS-G5B: Frequency band from 5.855 GHz to 5.875 GHz, dedicated to comfort ITS applications (non-safety)
- ITS-G5C: Frequency range from 5.470 GHz to 5.725 GHz, dedicated to other types of applications.

The physical layer protocols must address the multiple changes of fading and Doppler frequency caused by nodes mobility. Experimental communications vehicle-to-vehicle used radio and infrared waves. [47] Very high frequency, microwave, and millimeter wave radio waves are examples used for V2V communications. The physical layer protocols must address the multiple changes of fading and frequency caused by nodes mobility. In contrast; both infrared and millimeter waves are only suitable for the targeted communications, while the microwaves provide broadcast communications. In particular, the high frequency communications support low-speed links and, therefore, the tendency is to use microwave.

(DSRC) operates in the 5.9GHz band for the use of public safety and private applications [26]. In the US, the Federal Communications Commission (FCC) has allocated 75 MHz in the band for DSRC 5.850-5.925GHz while the ETSI standard has allocated 30 MHz in the band 5.875-5.905GHz (Figure 2.11). DSRC supports a vehicle speed up to 200 km/h, a nominal transmission range of 300m (up to 1000 m), and the default data rate of 6 Mbps (up to 27Mbps). This frequency band is divided into six service channels (SCH) and a control channel (CCH) with the same bandwidth of 10 MHz each. In the DSRC standard, the whole spectrum is divided into time intervals of 50 ms and messages have two different priorities: low for data broadcast messages transmitted on SCH channels or higher for safety messages or transmitted on the control channel CCH.

If the CCH channel is active, all nodes must stop their communication during the period of CCH to receive and transmit safety messages on the CCH channel. Indeed DSRC standard is proposed to facilitate communication between vehicles and roadside units. In the IEEE 802.11 standard, DSRC is known as the IEEE 802.11p WAVE. WAVE protocols propose changes to the physical layer and MAC of the existing IEEE 802.11 standard to support its applications. This would include the exchange of data between high-speed vehicles and between vehicles and the road infrastructure in the 5.9GHz band. The ultimate goal is to have the WAVE standard as an international standard in the world.

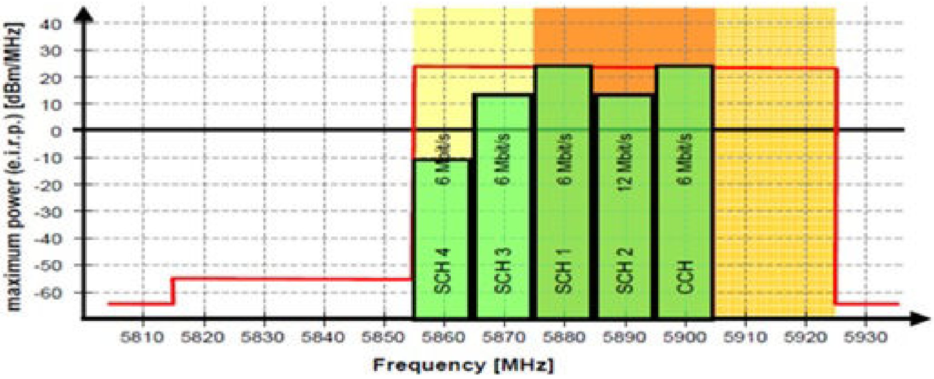

Figure 2.11: European standard channels allocation

2.6 Conclusion

The main goal behind this chapter was to present VANETs networks as a new network paradigm in the research field. Hence, VANETs emerge as a specialized form of MANETs with specific requirements related to the specific characteristics of such networks. A large number of research and standardization efforts have been carried out during last decades and was briefly presented in this chapter. We have also described the most important architectures dedicated to vehicular networks with a special focus on WAVE architecture as it was used as a reference networking stack in the next chapter. Moreover, we classified vehicular applications based on their impact on the road traffic and the requirements of each category in terms of delays and services. We presented for each category some key schemes to well understand the added value of each category. Next chapter will be dedicated to LTE architecture.

Chapter 3

LTE Architecture and Overview

3.1 Introduction

A wide variety of applications for road safety and traffic efficiency are intended to answer the urgent call for smarter, greener, and safer mobility. Although IEEE 802.11p is considered in the standard for on-the-road communications, stakeholders have recently started to investigate the usability of Long Term Evolution (LTE) to support vehicular applications. Therefore, we oriented our efforts towards studying LTE technology. The current chapter is devoted for presenting LTE functional and protocol stack architecture in user and control plants. Moreover, we focus on quality of service mechanisms suggested at LTE radio level.

This chapter is organised as follow: the following section 3.2 describes the main entities of LTE architecture, in section 3.3 we show the QoS concept in LTE followed by section 3.4 where we discuss RLC, MAC, and physical layers in both control plane and user plane.

3.2 LTE Architecture

The result of the 3GPP standardization [5] effort is the Evolved Packet System (EPS) that consists of the core network part, the Evolved Packet Core (EPC) and the radio network evolution part, the Evolved UTRAN (E-UTRAN), also known as LTE. The EPC can also be connected to other 3GPP and non-3GPP radio-access networks. As illustrated in Figure 3.1 [5], the EPC consists of some control-plane nodes, called Mobility Management Entity (MME), control Home Subscriber Server (HSS) and two user-plane nodes, called Serving Gateway (S-GW) and Packet-data Network Gateway (P-GW). The LTE radioaccess network consists of the base stations, denoted as enhanced NodeB (eNb), that are connected to each other through the X2 interface and to the EPC through the S1 interface. The mobile terminal is denoted as User Equipment (UE).

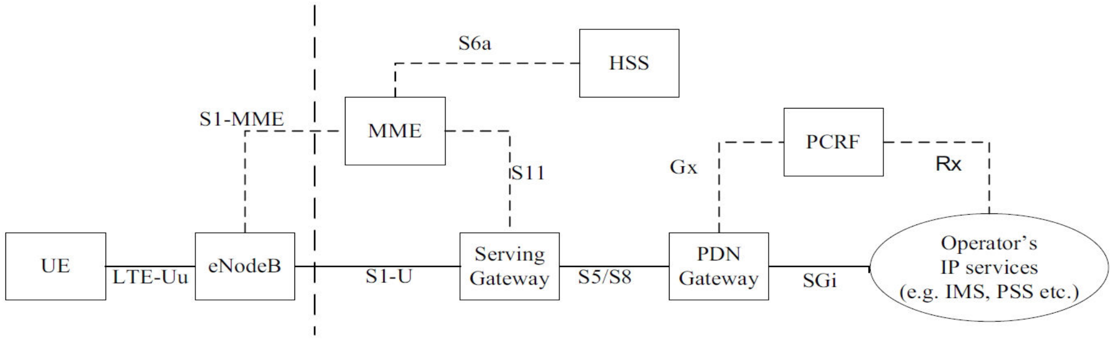

Figure 3.1: Overview of the EPC/LTE architecture [5]

Serving Gateway (S-GW): The S-GWmaintains Service Data Flow (SDF) context for the default/dedicated bearers establishment. It is also in charge of the mobility anchor for inter-eNb and inter-3GPP access mobility Packet.

Packet-data Network Gateway (P-GW): Is the entrance and the exit point for data traffic in the EPC. The P-GW performs policy enforcement and packet filtering for each data flow of each subscriber. It maintains the context for each connection of the mobile device, the traffic flow templates for the active services, the QoS profile and the charging characteristics.

Mobility Management Entity (MME): MME is the central management entity for the LTE accesses. It is responsible for the connection of the UE by selecting the gateway through which messages are to be exchanged and a level of resources for theUE in cases of attachment and handover. It also provides authentication and authorization and location tracking using the HSS and intra-3GPP mobility (e.g. between 2G/3G and LTE).

Home Subscriber Server (HSS): The basic HSS function is the control of user subscription data.

Enhanced Node B (eNb): The Enhanced NodB (eNb) hosts the following functions; Radio Resource Management (RRM) (Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink), IP header compression and encryption of user data stream, selection of an MME at UE attachment, routing of user plane data towards SAE Gateway, measurement and measurement reporting configuration for mobility and scheduling. The eNb is in charge of an important QoS task which is the efficient performance of radio resource allocation.

3.3 Quality of Service (QoS)

The one important benefit of LTE is realised by networks which dynamically accommodate a mix of real and non-real time services. An end-to-end, class-based Qos architecture has been defined for LTE in order to support such a mix of services.

Indeed, the Qos aspect in LTE is very important, for that concern it is composed of two important components, the backhaul and the MAC air interface.
The backhaul part is devoted to an effective processing of packet flows using good policies, it manage the QoS between the eNb and the gateways, this later is in charge of setting the adequate parameters for an efficient packet flows management. The MAC air interface like its name suggest will handle the distribution of the packets in the wireless part of the network, it is therefore located in the eNB.

3.3.1 The Bearer

The QoS mechanism is based on the class-based data flows and bearers concept, as shown in Figure 3.2. Data flows are mapped to bearers, with three individual bearers according to three interfaces (Radio, S1 and S5/S8) combined to provide the end-to end QoS support via the EPS Bearer.

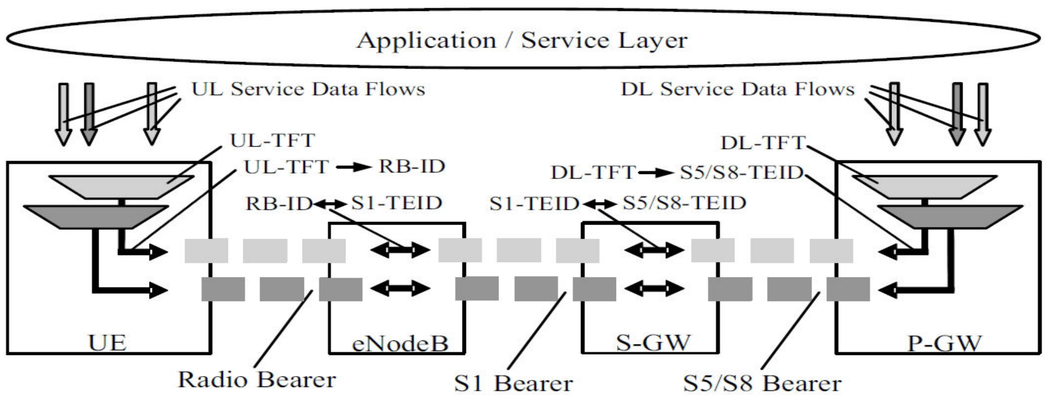

Figure 3.2: Types of Bearers [5]

The class-based QoS approach enables bearers to be mapped to a limited number of discrete classes. Network nodes can be preconfigured for these classes.
The LTE QoS is carried out using a paramount element named Bearer. This element has the very important task of identifying the appropriate QoS processing of the flows between the user equipment and the gateway. Each bearer gives the same packet forwarding treatment common to all flows mapped to that bearer (link layer configuration, queue management policy, scheduling policy ...).
To accommodate with the different QoS constraint, two types of bearers exists: the Guar-

anteed Bit-Rate (GBR) and non-Guaranteed Bit-Rate (non-GBR) [40]. This two bearers are respectively called dedicated and default bearers (Figure 3.2). The bearers are managed at the gateway where they are established, modified and deleted, this tasks are performed by the Policy Controller. This controller takes the management decision based on some important QoS parameters: QoS Class Identifiers (QCI) in table 3.1, Allocation Retention Priority (ARP), Maximum Bit Rate (MBR), Guaranteed Bit Rate (GBR) [41].

The QCI in table 3.1 [42] is a number used to identify the packet forwarding processing, the QCI is forwarded between the terminal and the gateway and allows to determine some important parameters: resource type, priority, packet delay budget and packet loss rate [43], in order to evaluate if a bearer establishment or modification should be accepted or not we use the ARP based on the resource limitation. We remind that the MBR corresponds to the maximum bit rate the bearer should not exceed, while the GBR is the bit rate the user is assured to get [41]. There is 9 QCIs levels standardized in order to have the same vendors understanding of the service characteristics, this allows the operators to have a uniform QOS over the network regardless of the equipment vendor.

QCI	Ressouce type	Priority	Delay Budget (ms)	Packet loss rate	example service
1	GBR	2	100	$10^{-}2$	conversational voice
2	GBR	4	150	$10^{-}3$	conversational video(Live streaming)
3	GBR	5	300	$10^{-}6$	non-conversational video
4	GBR	3	50	$10^{-}3$	real time gaming
5	NGBR	1	100	$10^{-}6$	IMS signaling
6	NGBR	7	100	$10^{-}3$	video(buffered streaming)
7	NGBR	6	300	$10^{-}6$	voice, video (live streaming, interactive gaming)
8	NGBR	8	300	$10^{-}6$	TCP-based (FTP,WWW...)
9	NGBR	9	300	$10^{-}6$	TCP-based (FTP,WWW...)

Table 3.1: QCI profiles [42]

Guaranteed Bit Rate bearers (GBR): A GBR guarantees a minimum bit rate requested by an application. GBR bearers are typically used for applications like Voice over Internet Protocol (VoIP), with an associated GBR value; while higher bit rates can be allowed if resources are available. Each GBR bearer is additionally associated with the following bearer level QoS parameters: GBR that denotes the bit rate that can be expected to be provided by the GBR bearer, and the MBR that limits the bit rate that can be expected to be provided by the GBR bearer(e.g. excess traffic may get discarded by a rate shaping function)[41].

Non-Guaranteed Bit Rate bearers (non-GBR): For these bearers, no bandwidth (resources) are allocated permanently to the bearer, there is no guarantee on any particular bit rate.

3.4 Interactions Between Layers

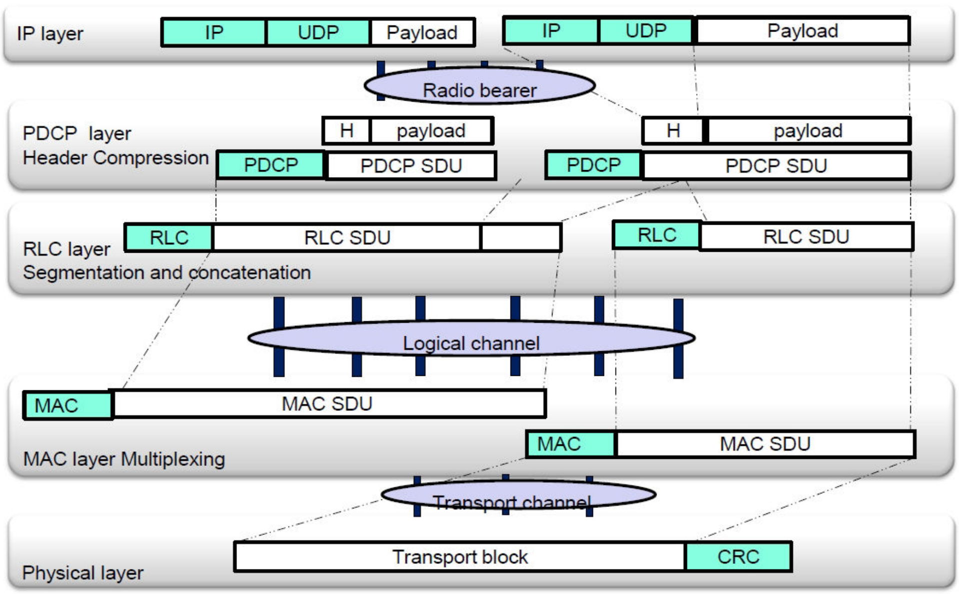

Figure 3.3: Protocol Layers

User Plane: Each time a user sends a data over a LTE network,this data is encapsulated with a header compression, then the packets are tunneled between the eNB and the P-GW over the GPRS tunneling protocol GTP.

The E-UTRAN user plane protocol stack, shown in grey, is formed by the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC) sublayers as shown in figure 3.4 [44].

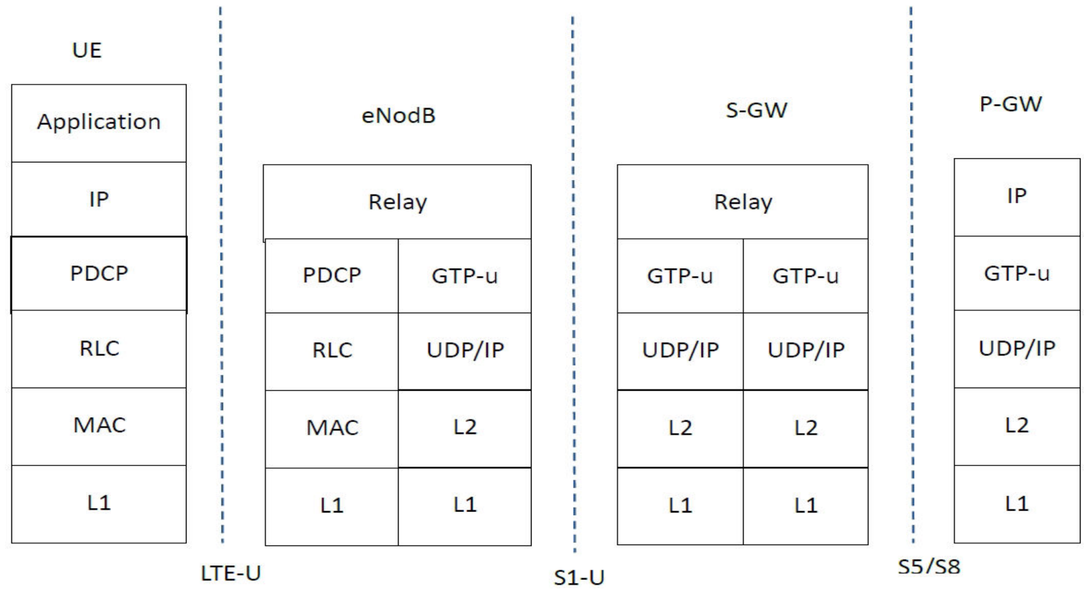

Figure 3.4: User Plane

Control Plane: Figure 3.5 shows the protocol stack of control plane. The lower layers perform the same functions as for the user plane with the exception that there is no header compression function for control plane.
The Radio Resource Control (RRC) protocol is known as Layer 3 in the AS protocol stack. It is the main controlling function in the AS, being responsible for establishing the radio bearers and configuring all the lower layers using RRC signalling between the eNodeB and the UE [44].

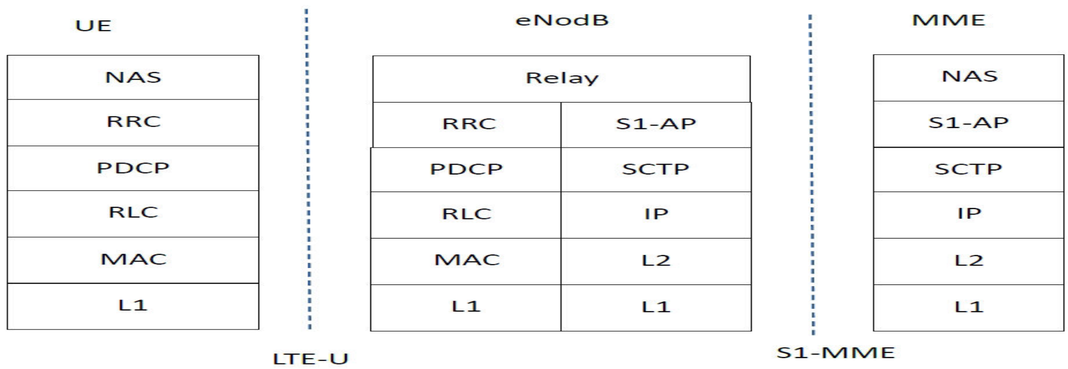

Figure 3.5: Control Plane

Figure 3.3 shows the division into layers, and logical interaction between them (for the UE and eNodB architecture). Two remote peer entities exchange data units called Protocol Data Unit (PDU), consisting of a protocol header and data blocks. These blocks are data units or data segments outputted from the upper layer. The data unit from the upper layers is called Service Data Unit (SDU) in the context of the lower layer. Thus, a PDU is also a SDU to the next lower layer, and so on. This vertical SDU transfer between layers of the same equipment is via Service Access Points (SAP) between logical layers, end they are: radio bearer in the RLC / PDCP, logical channel between LLC and MAC level transport channel between MAC and PHY.

3.4.1 The Physical Layer

The LTE physical layer is based on the Orthogonal Frequency Division Multiplexing (OFDM) to transmit data and control information through the wireless link. LTE OFDM supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) [45] frame structure to separate UL and DL traffic; it also divides the usable bandwidth into several sub-carriers and allocates the resources in time and frequency domain as Resource Blocks (RB). In LTE the downlink is carried with OFDMA [46] while the uplink is a SC-FDMA system [46].

Like the other cellular networks, the 3GPP has standardized the frame structure of the wireless access network. The LTE frame can be sent as a time division duplex or frequency division duplex, the structure of the two frames are different and are called type 1 and 2 frame:

- Type 1: used for the LTE FDD mode systems.
- Type 2: used for the LTE TDD mode systems.

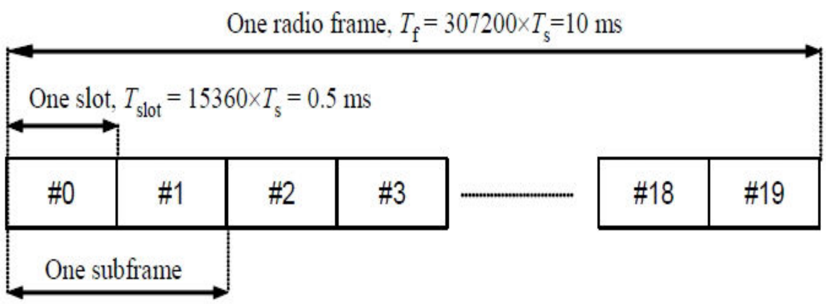

Figure 3.6: Type 1 LTE Frame Structure [6]

Type 1 LTE Frame Structure: The type 1 LTE frame has a length of 10ms. It is divided into 20 individual slots (figure3.6), each slots has a duration of 0.5ms, in this case a slot represents exactly a resource block, which is the smallest radio resource block we can allocate to a mobile user [6].

Type 2 LTE Frame Structure: The Type two frame is composed of 2 half frames of 5ms, each half frame is divided into five subframes of 1ms. According to the switch time, at least one of the half frames contains three field :

- DwPTS - Downlink Pilot Time Slot
- GP - Guard Period
- UpPTS - Uplink Pilot Time Stot.

When the switch time is 10ms, only the first half frame will carry this field, if the switch time is 5ms, both of the half frame are used [6].

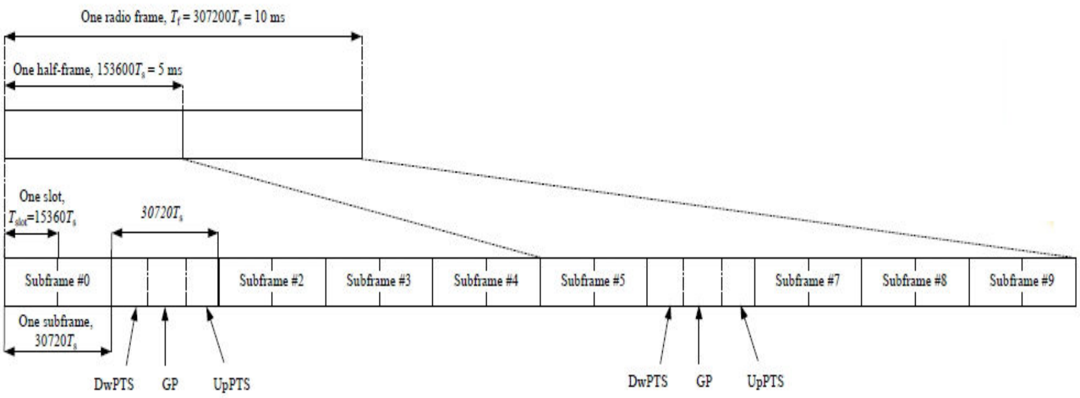

Figure 3.7: Type 2 LTE Frame Structure [6]

Resource Block (RB) A resource block [6] is composed of six or seven symbols by twelve subcarriers, it is represented by a table of 7 rows and 12 lines, each cell is called a resource element of 15 kHz subcarrier by one symbol, this gives the resource block a frequency band of 180 KHz.

The number of symbols N_{symb} is determined by the Cyclic Prefix (CP), if a normal CP is used the RB will have seven symbols, if an extended CP is used we found six symbols.

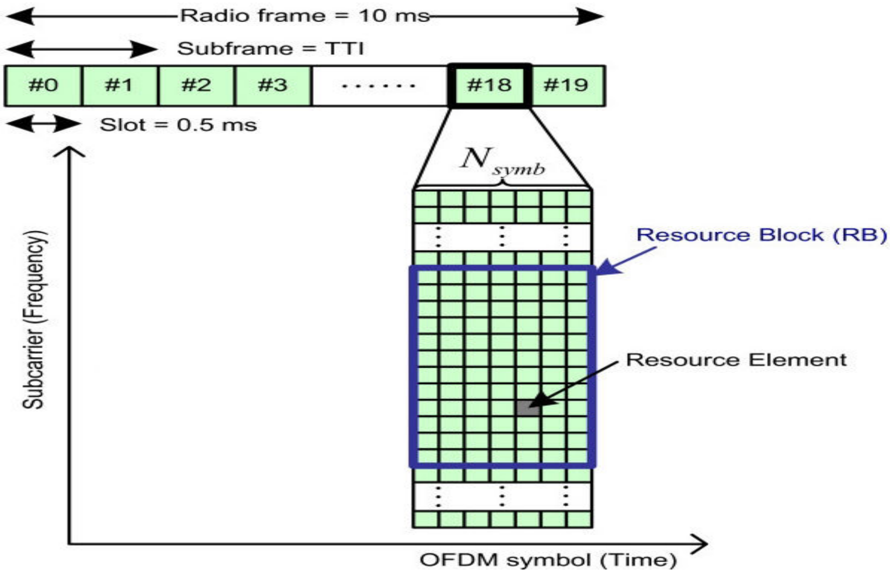

Figure 3.8: Resource block LTE Structure [6]

3.4.2 The Medium Access Control Layer (MAC)

The MAC layer is responsible for scheduling data between the RLC and PHY layer through the logical and transport channels. The MAC layer provides also HARQ and is also responsible for the functionality that is required for medium access, such as scheduling operation and random access.

The main functions of the MAC layer are: scheduling of radio resources between UEs, random access procedure, uplink timing alignment, discontinuous reception, and scheduling information transfer [42] [47].

The MAC Scheduler within the eNodeB is responsible for scheduling the LTE air interface and supporting radio bearer QoS. In fact, the MAC layer is responsible for mapping the QCI to radio bearer is to pre-configured information about priority, packet delay and packet loss.

After passing the IP layer, flows are configured by radio bearer, which aims to define the QoS radio parameters. The PDCP layer responsible for Header Compression, header is reduce to 4 or 6 bytes. PDCP packets are sent to RLC layer which segment and concatenate them to form RLC SDU. The MAC layer is linked to RLC layer through the logical channel and linked to physical layer through transport channel. In fact, it reserves the RLC PDU and multiplexes them to form MAC PDU according to Logical channel prioritization procedure.

After segmentation and concatenation of data in RLC layer, the RLC PDUs are sent to the MAC layer through logical channels. The MAC layer multiplexes these data to form multiples MAC PDU figure 3.9, for that, it applies the Logical Channel Prioritization (LCP) procedure on the different logical channels.

A MAC PDU primarily consists of the MAC header and the MAC payload. The MAC header is further composed of MAC subheaders, while the MAC payload is composed of MAC Control Elements, MAC SDUs and padding.

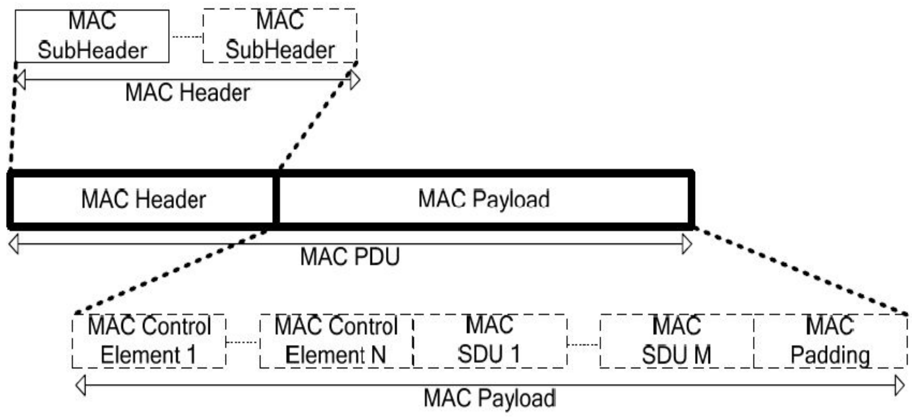

Figure 3.9: MAC PDU stucture [7]

Because LTE is based on OFDM, it is possible to distribute available transmission resources in the frequency domain to different UEs. This allocation can be changed dynamically once per subframe, that is, once per millisecond. The MAC scheduler in the eNB is in charge of assigning both uplink and downlink radio resources.

Downlink scheduling is performed within the eNodeB. The MAC layer decides what data is to be sent and sends it along with allocation information which enables the end UE to receive the data.

Uplink scheduling results in grants being signalled to UEs, indicating what resources the UE can use to transfer data to the eNodeB. The UE is responsible for determining which data is transmitted within the granted resources. Therefore, a resource allocation granted in response to a request caused by one bearer may be used to transfer data from another higher priority bearer, belonging to the same UE, that has subsequently become available for transmission.

3.5 MAC layer: Logical Channel Prioritization (LCP) Procedure Overview

In the literature, several scheduling algorithm already exist, basically defined to meet Qos requirements of each traffic class and strike a balance between bandwidth utilization and provide fairness to the users while guaranteeing a certain quality of service. The LCP [42] [7] procedure lies in the dynamic sharing of resources between different source traffic at asymmetrical loads, this allows in relaxing the traffic congestion conditions. It aims to find an agreement between the services Qos requirement and the overall performances. The RRC layer controls the scheduling of uplink data by configuring the logical channels and helps the MAC layer to apply multiplexing and assembly procedures.
In addition each channel is given a Priority Bit Rate (PBR), and a Bucket Size Duration (BSD). All the PBRs are assigned first in a decreasing order, the higher the logical channel priority is, the higher the PBR will be. This parameter is used to avoid the starvation problem that we find in case of Priority Queuing (PQ). The BSD is used to define the maximum data allowed for a logical channel, it cannot exceed the value set by PBR*BSD, this product is called a Bucket (B). The higher logical channel priority is, the more data a logical channel has and the greater its Bucket will be. We can describe the LCP process on two cycles:

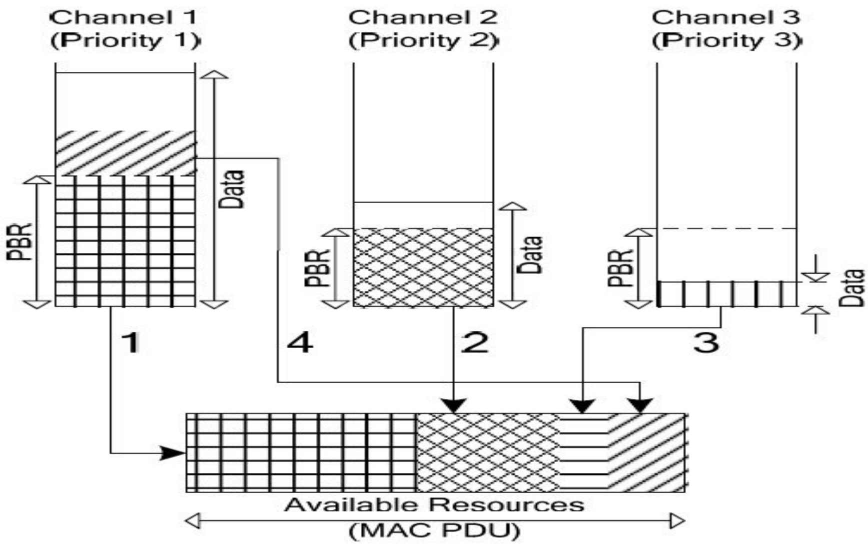

Figure 3.10: LCP procedure [7]

Cycle 1

In a decreasing order, the scheduler allocates the PBR corresponding to each logical channel.

Cycle 2

if any resource remains in the MAC PDU, the scheduler serves each logical channel again in decreasing order up to their configured Bucket. The process ends if all logical channels of higher priority have no more data for transmission, or if there is no more resources in the MAC PDU and the frame duration has expired (See Figure 3.10).

3.5.1 The Radio Link Control Layer (RLC)

RLC layer [44] communicates with the PDCP layer through and with the MAC layer via logical channels. It transmits segments and/or concatenates the PDCP PDUs, and the RLC receiver reassembles the RLC PDUs to reconstruct the PDCP PDUs to fit them into the size indicated by the MAC layer. RLC provides three data transmission modes: Acknowledged Mode (AM), Unacknowledged Mode (UM), or Transparent Mode (TM).
In TM mode no functions are performed and no RLC overhead is added to the PDUs. Since no overhead is added, an RLC SDU is directly mapped to an RLC PDU and vice versa. It is used when the PDU sizes are known a priori. Only RRC messages which do not need RLC configuration can utilize the TM RLC such as for broadcasting system information.
The UM mode provides a unidirectional data transfer, since no feedback path is available, it is then suitable for transport of real-time services especially VoIP because such services are delay sensitive and cannot wait for retransmissions.
Unlik the UM mode, the AM mode provides a bidirectional data transfer service, it is then dedicated for non real-time services such web browsing and file downloading. The most important feature of AM RLC is retransmission.

3.6 Conclusion

This chapter presents an overview of LTE. We described the general LTE architecture and the main components of this architecture, with particular interest to the general QoS architecture and the scheduling mechanism at the MAC layer and the link between MAC, RLC and PHY layers.
We also detailed the LCP scheduling mechanisme. Since the resource allocation is performed at the MAC scheduler interface and since the resource allocation is one target of our thesis, in this chapter we focused on this part to better understand the resource allocation and scheduling.
In next chapter, we adress our contribution based on a study of several applications devised by the industrial projects Co-Drive and SOAPS. We present as well their traffic characterization.

Chapter 4

Vehicular Applications Characterization

4.1 Introduction

Safe navigation support through wireless communications has become an important priority for car manufacturers as well as transportation authorities and communications standards organizations.
While safe navigation has always been the prime motivation behind vehicle-to vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, vehicular networks, provide a promising platform for a much broader range of large scale, highly mobile applications.
Given the role of the automobile as an essential element in the life of nations, placing the intelligence software in cars has the potential to significantly improve the quality of life of the user. This, along with the market demand for reliability, safety and entertainment value in automobiles, has resulted in the significant commercial development and vehicle support networks and applications.
These new applications cover many areas: animation, game mobile Internet, mobile shopping, investigation of crime, civil defense, etc. Some of these applications are classic applications of access to the mobile Internet, downloading files, reading email, etc. Others involve the discovery of local services (for example, restaurants, cinemas, etc.) using the vehicle grid as an ad hoc network. Yet others require close interaction between vehicles such as interactive driving game. In this chapter, we review such emerging applications.
VANET applications are classified by the vehicle's role in managing data: Safety, Traffic Management and Comfort. Based on this, we review various emerging applications proposed in the research community. We mainly focus on three services devised by the industrial projects Co-Drive and Soap. More specifically, we study three services considered by Co-Drive: Warning to a foggy zone, Inter-distance measurement and Road warning

event. We bring the focus as well to three services taken into account in Soap: Voice, Video , HTTP and FTP. Then, we achieve the first contribution in our thesis. In fact, we perform an accurate traffic modeling of the envisioned vehicular applications. This will help us to evaluate the performance modeling of the MAC layer in the subsequent chapters.

In section 4.2, we present an overview of the used ITS classification, then, in section 4.3 we study and characterize three services considered by Co-Drive followed by the study of SOAPS applications in section 4.4. finally we conclude the chapter

4.2 Vehicular Applications

Vehicle networks provide a wide spectrum of applications and services ranging from lane change service, to Electronic Emergency Brake Light, to map download. In the literature, many research studies focused on classifying vehicular applications [9] [10] [11]. We basically adopted the ETSI approach [12] and modified it in order to integrate larger panoply of vehicular applications [13]. Vehicular applications are then classified into three main categories: Safety, Traffic Management and Comfort (Figure 4.1).

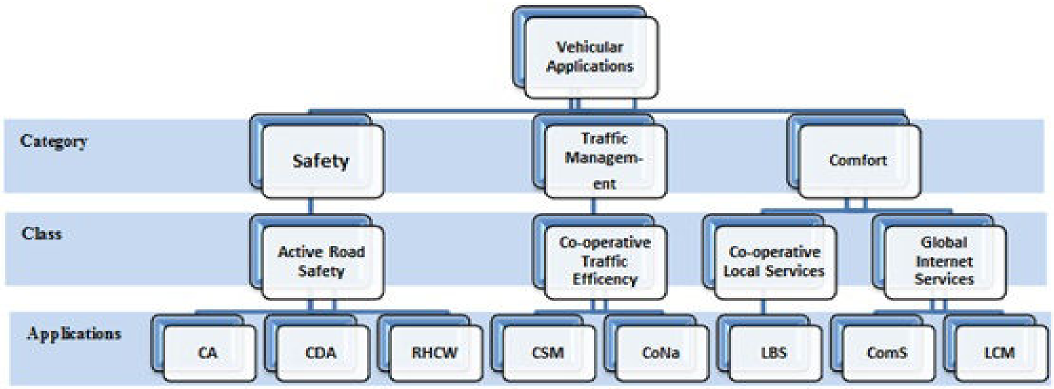

Figure 4.1: Vehicular applications classification.

4.2.1 Safety Category

Safety applications have attracted considerable attention since they are directly related to minimizing number of accidents on the road. Safety category is mapped to Active Road Safety class which aims at providing driver awareness and warning services through Co-operative Awareness (CA), Cooperative Driver Assistance (CDA), and Road Hazard and Collision Warning (RHCW) applications. In fact, active road safety provides awareness functions that deliver information to the driver during normal driving, warn the driver of road hazard conditions and probable accidents and actively assist the driver in avoiding impending accidents. In other terms, safety related applications are responsible of: awareness, warning and assistance.

4.2.1.1 Cooperative Awareness Application (CA)

Cooperative Awareness applications make drivers aware of other vehicles or situations and provide information about the vehicle's surrounding environment. Several applications are offered within this class. Among others are Emergency vehicle indication, Motorcycle approaching indication and Slow Vehicle Advisor. For these applications, an emergency vehicle, a motorcycle, or a slow/stopped vehicle broadcasts messages to approaching vehicles in its neighborhood. The information propagated to road drivers helps them to adapt to road conditions.

4.2.1.2 Cooperative Driver Assistance Application (CDA)

This application provides driver assistance services. Many services fall within this class, among others:

Cooperative driving system: which exploits the exchange of sensor data or other status information among cars. Cooperative driving systems assist drivers for maintaining a safe time-headway distance between vehicles to ensure that emergency braking will not cause rear-end collisions between cars. The headway calculation system adapts a vehicle's headway by accounting for changed environmental conditions, vehicle dynamics, and safety considerations.

Lane Change Assistance (LCA): This application assists the driver in choosing the optimum instant for lane changing and influences the drivers behavior towards improving driving performance.

4.2.1.3 Road Hazard and Collision Warning Application (RHCW)

Road Hazard and Collision Warning applications provide information about imminent collisions due to hazardous road conditions, obstacles and erratic drivers. Crash Detection systems (CDS) rely on radars, sensors or cameras to detect an imminent crash. These systems may warn the driver, pre-charge the brakes, inflate seats for extra support, move the passenger seat to a better position, fold up the rear head rest for whip lash, retract the seat belts removing excess slack and automatically apply braking to minimize the crash severity [14]. Several services are offered within this application, among others:

Cooperative Collision Warning: A vehicle actively monitors kinematics status messages from vehicles in its neighborhoods to warn of potential collision [15].

Electronic Emergency Brake Light: A vehicle braking hard broadcasts a warning message, giving warning notification to endangered drivers about the critical situation with a minimum latency [16].

Road Hazard Condition Notification: When detecting a road hazard (e.g. fog, fluid, ice, and wind), vehicles are notified within the affected area.

Road Feature Notification: A vehicle detecting a road feature (e.g. road curve, hill) notifies approaching vehicles in the neighborhood.

4.2.2 Traffic Management Category

Traffic Management category is mapped to the Cooperative Traffic Efficiency class (Figure 1). Since congestion occurs when the demand for travel exceeds highway capacity, an efficient approach, based on traffic management, is required to reduce congestion [17] [18]. Cooperative Traffic Efficiency provides two applications: Cooperative Speed Management (CSM) and Cooperative Navigation (CoNa).

4.2.2.1 Cooperative Speed Management (CSM) Application

Cooperative Speed Management (CSM) includes two services.

CSM-Speed limits notification: It delivers speed limits notifications that contain current regulatory speed limits and recommended contextual speed limits.

CSM-Traffic light optimal speed advisory: It is responsible for traffic light optimal speed advisory. For this, a road side station provides information about the current traffic light phases, the remaining time before phases changes and the duration for each phase.

4.2.2.2 Cooperative Navigation (CoNa)

With the Cooperative navigation application, a vehicle gets advised for the optimal itinerary and gets assisted in navigation. The CoNa application offers many services among others:

- Traffic Probe: Vehicles aggregate traffic probe information and transmit it to road-side units.

- Free Flow Tolling (TOLL): TOLL save road travelers time, allowing them to drive non-stop through tolling areas. Vehicles are billed automatically as they pass through the tolling area, minimizing delay.
- Vehicle registration, inspection, credentials: Vehicle inspection helps to control the legality of goods/person transportations. The actions of stopping vehicles to verify the validity of the driver's license or to check the physical status of vehicles before entering a road infrastructure are examples of vehicle inspections. A wireless vehicular network allows vehicle data exchange between vehicles and road infrastructures.

4.2.3 Comfort Category

The general aim of this category is to improve passenger comfort. The Comfort category is mapped to Cooperative local services and Global Internet services class.

4.2.3.1 Cooperative Local Services Class

The Cooperative local services class provides Location Based Services (LBS) application which provides:

- Point of Interest notification services include vehicles energy supply station, vehicle maintenance facility, public transport management, rest area, parking, hotel/restaurant, tourism place, local event meeting place, medical center, police station and toll points.
- Service Announcements: Enterprises transmit marketing data to potential customers passing by.
- Content Map or Database Download: A vehicle downloads maps, multimedia from mobile hotspots. These services provide passengers with audio and video data obtained from other vehicles or the infrastructure.
- Real-Time Video Relay: A vehicle transmits and relays real-time video to other vehicles or road-side units.
- Vehicular sharing services distribute data or computations on vehicles.

4.2.3.2 Global Internet Services Class

Global Internet Services class provides Communities Services (ComS) and ITS station Life Cycle Management (LCM) applications. Communities Services applications offer many services:

- Insurance and financial services provide insurance services to the concerned communities, e.g. discount on public transport at given periods of time.
- Fleet management services are dedicated to the related professional fleet, e.g. local intervention base of the professional fleet.
- Cargo monitoring and tracking: Wireless access for vehicular environment fills the gap for seamless and continuous tracking at the cargo-level for transit from indoors to outdoors and from warehouses to containers.
- Remote Vehicle Personalization/Diagnostics: Personalized vehicle settings are downloaded and vehicle diagnostics are uploaded from/to infrastructure.
- Vehicle and RSU data calibration services aim at calibrating of local roadside ITS station by a local operational support ITS station.

4.3 Co-Drive project Vehicular Applications

The work is being conducted in the context of Co-Drive project, we are mainly interested by three types of services belonging to Safety and Traffic Management categories. More specifically, we study the following services (Table 4.1):

Services	Category	Application Class
Service 1: Warning to a foggy zone: Road Hazard Condition Notification	Safety	Active Road Safety
Service 2: Inter-distance measurement: Cooperative driving system	Safety	Active Road Safety
Service 3: Road warning event: Road Feature Notification	Safety	Active Road Safety

Table 4.1: Services Classification

Service 1: Warning to a foggy zone. This service aims at warning the driver in the vicinity of a foggy zone about an imminent danger. It is a type of Road Hazard condition notification (RHCN) services. This service belongs to the Road Hazard and Collision Warning (RHCW) application that falls into the Active Road Safety Application Class. The latter belongs to the Safety Category.

Service 2: Inter-distance measurement. The OBU exploits the exchange of sensor data and sends measurements related to vehicle inter-distance. This service assists drivers for maintaining a safe time headway distance between vehicles to ensure that emergency braking will not cause rear-end collisions between cars. It is a type of Cooperative Driving

System service. This service belongs to the Cooperative Driver Assistance Application that falls into the Active Road safety class. The latter belongs to the Safety Category.

Service 3: Road warning event. The OBU is equipped with a frontal camera which captures and sends a photo upon detection of a road warning event (road curve, hill, road-sign speed,etc); thereby triggering warning and photo messages. This allows the RSU to judge the relevance of the warning event. It is a type of Road feature Notification service. This service falls into the Road Hazard and Collision Warning (RHCW) application that belongs to the Active Road Safety Application class. The latter belongs to the Safety Category.

Since a network performance is highly impacted by traffic variations and traffic statistical distribution, we exhibit the characteristics of each studied service and perform traffic modeling as shown in next sub-sections:

4.3.1 Service 1: Warning to a Foggy Zone Service

When a vehicle detects a dangerous situation (e.g. foggy zone), it will not wait for the periodic transmission of a safety message and issues instead a Decentralized Environmental Notifications (DEN) warning message [19] (figure 4.2). The DENs have very strict temporal requirements and require a high level of QoS. Message transmission continues during the sojourn time of the station in the RSU coverage area.

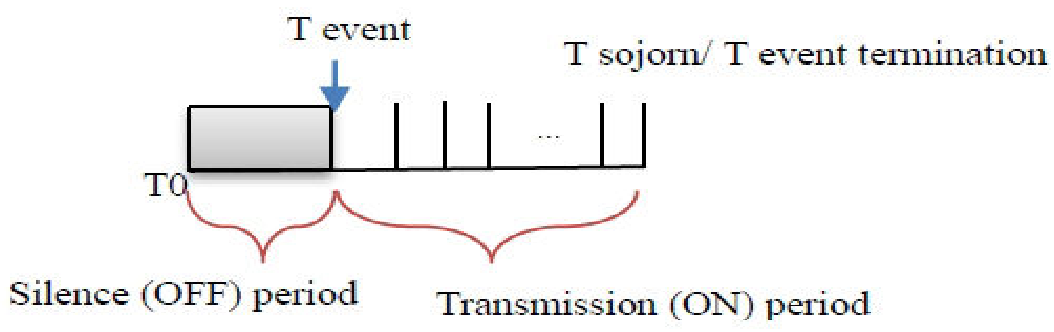

Figure 4.2: Warning service

Since messages are periodically generated in case of the event detection, messages transmission occurs during an activity period (ON period); the remaining time is a silence time interval (OFF period). The ON period lasts until the OBU station leaves the RSU zone or when it stops detecting the dangerous event. Table 4.2 presents the parameters of the warning traffic.

Parameters	Distribution
Message size in ON period	Deterministic :171 bytes
Packet Inter-arrival time	Deterministic: 0.1s
Process arrival	Poisson
ON period duration	Exponential: 60 s
OFF period duration	Exponential: 20 s

Table 4.2: Warning traffic model parameters

4.3.2 Service 2: Inter-distance Measurement Service

Cooperative Awareness Messages (CAM) [20] are transmitted periodically by every vehicle and carry information gathered from on-board sensors (figure 4.3). In the project, we consider CAM messages carrying vehicle inter-distance metric. Each second, the OBU sends a message of 50 bytes size to the RSU with a frequency of 10Hz. The service model parameters are indicated in the following table (Table 4.3):

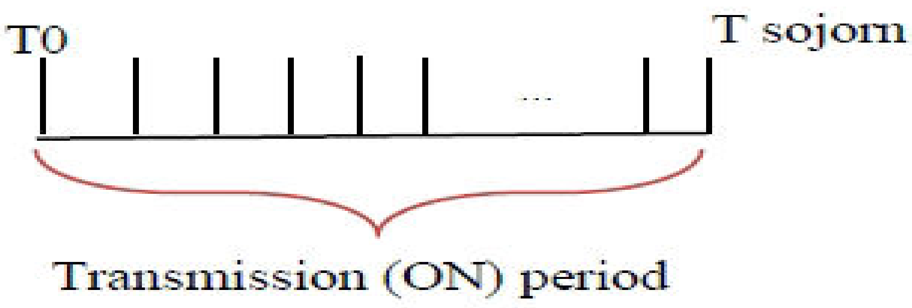

Figure 4.3: Inter-distance Measurement service

Parameters	Distribution
Message size	Deterministic:50 bytes
Inter-arrival time	Deterministic: 0.1s
Process arrival	Poisson

Table 4.3: Measurement service traffic parameters.

4.3.3 Service 3: Road Warning Event

While the car OBU is in the RSU coverage area, it sends a picture upon detection of a road feature warning event. Depending on the application, the picture can be sent in a single block or in several fragments. Contrarily to ITS application messages (CAM, DEN), road warning service is specific to CoDrive project and is called CoDrive Messages (CoDM).

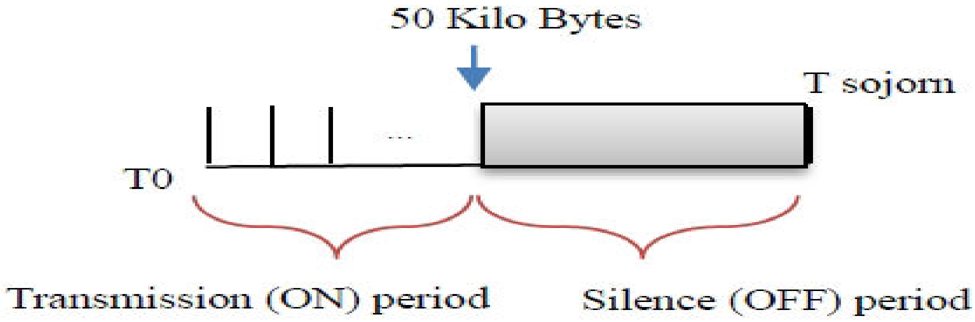

Figure 4.4: Road warning service

Road warning traffic adopts the ON/OFF model; the ON period represents the time in which the car sends photo packets, and the OFF period is the time in which the car is in the coverage area of the RSU but it does not send any packet (figure 4.4). During the ON period, the OBU sends each second a CoDM message of size ranging between 200 and 1200 bytes to the RSU during OBU sojourn time [21], [22], [20]. Table 4.4 presents the parameters of the investigated service.

Parameters	Distribution
Size packet in ON period	Determinist :200 to 1200 bytes
Time inter-arrival	Deterministic : 1 s
Process arrival	Poisson

Table 4.4: Road warning traffic parameters

4.4 SOAPS Project Vehicular Applications

Other applications are considered in this thesis work, they are studied in the project SOAPS context: Voice, video, HTTP and FTP. These services are different from the services considered in Codrive project. Indeed, the technologies used and the needs of the two projects are different.

4.4.1 Voice Source Modeling

The voice traffic, which was initially transported by traditional telecommunication networks like GSM, is now experiencing an important growth in data networks due to the proliferation of Voice over IP (VoIP) services. With the convergence of data and telecommunication networks, and the diversity of offered applications (Telephony, Audio Phony, News, Audio Conferencing, etc.), the voice traffic will be predominantly packetized.

In this section, we propose an overview of the proposed models of packetized voice. We can consider two types of voice: basic voice and VOIP. The common model is a two-state Markov process, known as the ON/OFF model. A voice source is characterized by two alternating periods, the active period (ON period) and the inactive period (OFF period) where the source remains silent [23][24]. Consider the simple 2-state voice activity Markov model show in Figure 4.5. The time spent in ON and OFF states is exponentially distributed with mean a -1 and b -1, respectively.

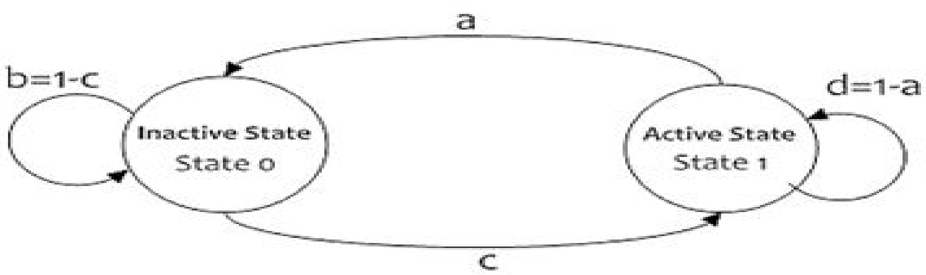

Figure 4.5: 2-state voice activity Markov model

A typical phone conversation is marked by periods of active talking/talk spurts (ON periods) interleaved by silence/listening periods (or OFF periods) [24] as shown in Figure 4.6.

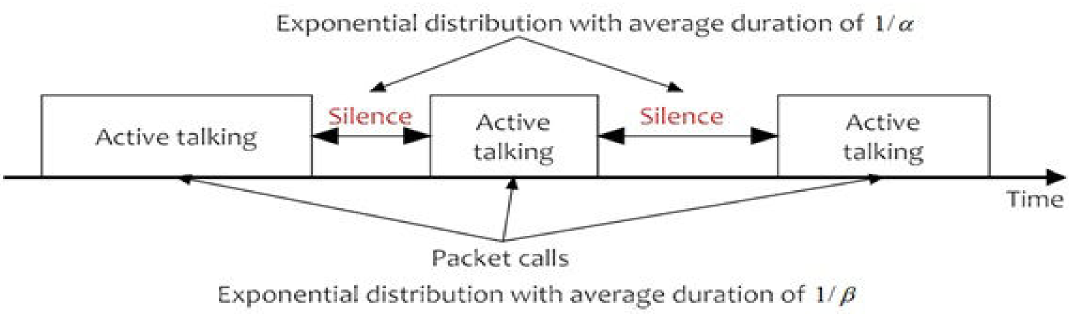

Figure 4.6: Typical Phone conversation Profile

The ON-OFF source model shown in Figures 4.5, 4.6 is the most popular source model for voice. In this model, packets are only generated during talk spurts (ON state) with fixed interarrival time as shown in Figure 4.7 modeling the queue receiving the different sources as it is presented in Figure 4.8.

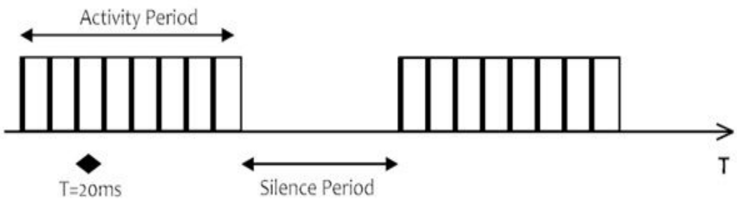

Figure 4.7: Example of generated Voice Traffic

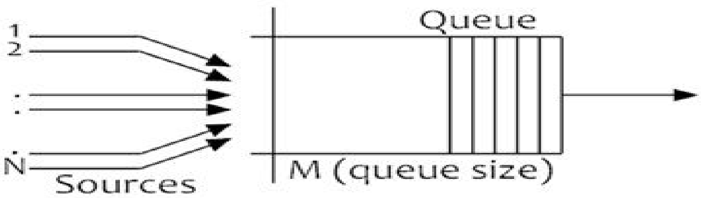

Figure 4.8: Example queuing analysis for ON/OFF models

The duration of the OFF and ON periods are independent exponentials with respective parameters μ and λ. In the ON period, packets are generated at a constant rate $D = \frac{1}{\tau}$. The parameters below are the most commonly used. Packet voice collects multiple samples in once packet knowing that a modern voice encoding schemes also use compression and silent suppression. In the public networks, the typical coder is the Adaptive Multi Rate (AMR).
Here is an example of the packets generated by the AMR codec with activity detection. When active, the voice source generate 244 bits packets with an inter-arrival time τ of 20 ms. This period corresponds to the well-known sampling frequency of 8KHz with 160 samples per packet (coded and compressed). Voice communications in the Private Mobile Radio communications (PMR) are very sensitive and the new-generation Long Term Evolution (LTE) system must achieve at least the same performance than the existing PMR networks. In this last, the speech coder envisaged for VoLTE (Voice over LTE) is Advanced Multi-Band Excitation (AMBE) with a coding rate of 2.45 kbps. It is a proprietary speech-coding standard developed by Digital Voice Systems.

The voice source traffic model parameters are defined in the table below 4.5 .

Parameter	silence period	active period	inter-arrival packets	Packet size
Distribution	Exponential: 325 ms	Exponential: 175 ms	deterministic : 20 ms	deterministic 528 bits

Table 4.5: Voice source traffic modeling

4.4.2 Video Modeling

With the novel compression techniques, the digital video offers multiple applications such as the digital television, video on demand, video telephony, etc. The video coders exploit the spatial and temporal dependencies that exist between consecutive images in order to compress the images. M-JPEG, MPEG-1, MPEG-2, MPEG-4, H261, and H263 are examples of standard video coders.

Video characteristic The video encoder sends a series of packets compressed called elementary packets (Figure 4.9), they are composed of a sequence of pictures I-frames or Intraframes, B-frames or Bidirectionnal coded pictures and P-frames called Group Of Pictures (GOP). Each elementary packet will be fragmented into a set of access unit (AU); a unit may contain several pictures sequences and sound packets.

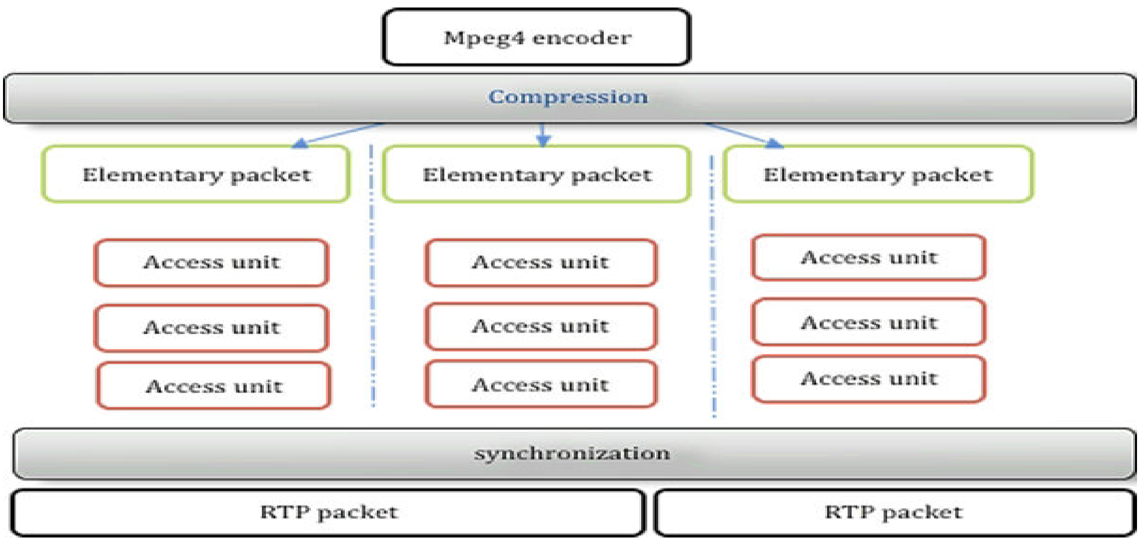

Figure 4.9: Operation of MPEG-4

The following Figure 4.10 shows the basic structure of an elementary packet:

Figure 4.10: Basic structure of an elementary packet

Video uses compression algorithm to reduce the bit-rate. This is achieved by reducing both the spatial and temporal redundancy in the video stream. The spatial redundancies are reduced by transforms and entropy coding, and the temporal redundancies are reduced by prediction of future frames based on motion vectors. This is achieved using three types of frames, these pictures are periodically generated.

In MPEG-4 compressing videos are composed of pictures (frames) that are separated into three different types: I, B, and P e.g: GOP: I B B P B B P B B P BB. I-frames are intraframes that encode the current picture, and based on the discrete cosine transform and entropy coding. B- and P-frames interpolate from previous and future frames knowing that P-frames are Predictive coded pictures, use a similar coding algorithm to I-frames, but with the addition of motion compensation with respect to the previous I-or P-frame; while B-frames are Bidirectionnal coded pictures, similar to P-frames, except that the motion compensation can be with respect to the previous I- or P- frame, the next I- or P- frame, or an interpolation between them. Typically, I-frames require more bits than P-frames. B-frames have the lowest bandwidth requirement as shown in Figure 4.11.

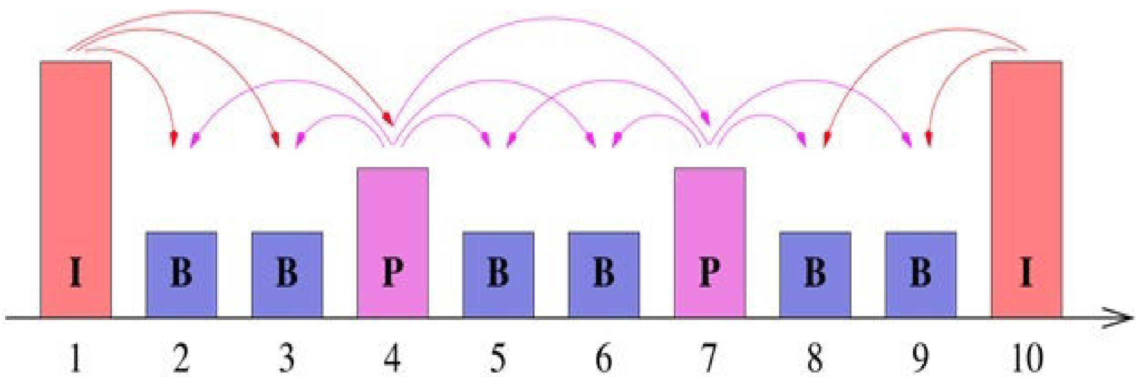

Figure 4.11: Group of Pictures (GOP): IBBPBBPBBI

Typical encoders use a fixed GOP pattern when compressing a video sequence as shown in Fig. 14. The GOP pattern specifies the number and temporal order of P and B frames between two successive I frames. Quite often the fixed GOP pattern is regular in the sense that the number of B frames between two reference frames (I or P) is fixed. Such a GOP pattern can be characterized by two parameters: the I-to-I frame distance (A),

and the I-to-P frame distance (B) knowing that if no P frames are used, then B = A. We can model the video at several levels: arrivals of images, elementary packet arrivals or those of the GOP. Picture Level modeling is very fine, and, elementary packet level is very broad. We then propose a model for the GOP. The bit-rate of MPEG-4 encoder may vary depending on the channel quality. The project provides a flow between [256 ... 3072] Kbps. The pictures are sent with a frequency between [25 ... 30] fps. Each GOP is of the form (12.3), ie: the group contains 12 pictures, organized as follows IBBBPBBBPBBB: there are 3 images B separating other different pictures of P. Example characteristic of Video Streaming traffic model in IEEE C802.16m. Video Traffic (High Definition):
- 30 frames per second
- Frame format: 1920x1080 pixels
- 24 bits per pixel
- Required rate: 1.5 Gbps

Video traffic modeling Several studies have been carried out, and which models video models: Semi-Markov process [25], BMAP [26] [27] [28] Discrete Autoregressive (DAR(1)) model [29], MMPP or even by a queue M/G/ inf : In [30] they modeled the video traffic by a queue type / G / inf, where the arrivals are the GOP according to a Poisson distribution and the service follows a general law. In voice modeling, we were interested in the statistical distribution of the activity periods, which means how the packets are temporally generated. In video traffic, there are no ON/OFF periods because images are periodically generated. The modeling considers the images or Group of Pictures (GOP) size and their correlation [31].

This type of modeling studies the statistical properties of the video rate D(t) [32] that a video flow can be characterized by the mean rate E[D], the variance of the rate Var[D], and the correlation function $corr(\tau) = e - a\tau$. This behavior can be approximated by the MMPP-M+1 process as shown in the Figure 4.12 above.

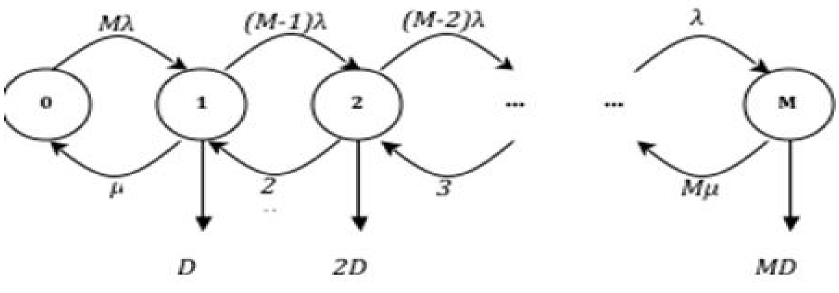

Figure 4.12: Video MMPP model

We will consider M video sources represented to M elementary packets that send a group of pictures at a max rate equal to M.D, arrivals groups of images follow a Poisson process

of rate λ, and they will be served following a Poisson process of rate μ. Each state corresponds to an averaged value of the rate. The MMPP calculations give:
$E[D] = MD\lambda/(\lambda + \mu)$
$Var(D) = MD2.\lambda.\mu/(\lambda + \mu)2$
$Corr(\tau) = e - (\lambda + \mu)\tau$
The following table 4.6 shows the parameters of a video source:

Parameter	I P B frame size	GOP size	GOP inter-arrival	GOP arrival process
Distribution	Lognormal	Lognormal: 1000 byte	Exponential:	Poisson : 0.48

Table 4.6: Video source traffic modeling

We propose an example of what could be generated. Knowing the rate characteristics, we can deduce the MMPP parameters, λ, μ, and D. M is chosen such as M.D will be the maximum rate. Below an example of the values founded in the case of video conferencing witch offer bit rate 3072 Kbps, and GOP size = 1000 byte

4.4.3 Web Browsing (HTTP) Source Traffic Model

HTTP traffic characteristics are governed by the structure of the web pages on the World Wide Web (WWW), and the nature of human interaction. The nature of human interaction with the WWW causes the HTTP traffic to have a bursty profile. The HTTP traffic can be modeled by question-answer model as shown in Figure 4.13. This figure shows the transmission of packets during a typical session of web browsing [31].

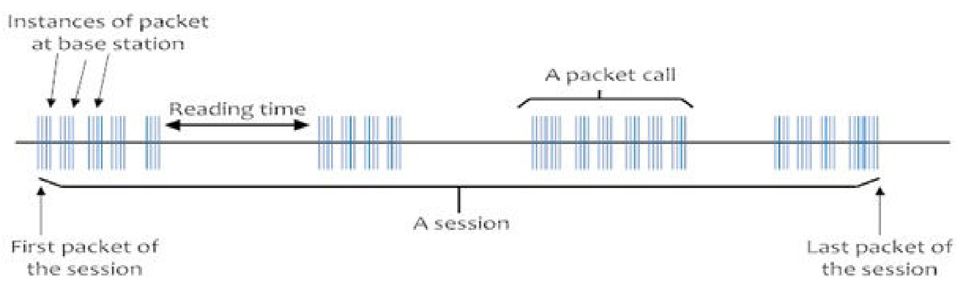

Figure 4.13: Packet Trace of a Typical Web Browsing Session

The session was divided into ON/OFF periods representative web-pages downloads and intermediate readings, where web-page downloads are designated by packet calls. These ON and OFF periods are the result of human interaction where the packet call represents a user request for information and reading time identifies the time to digest the web-page. The ON periods represent the sequence of packets in which the web-page is being transferred from source to destination; while the OFF periods represent the time the user spends reading the web-page before transitioning to another page. This time is also known as Reading Time. As we know, the navigational traffic on the Internet (web-browsing traffic) is self-similar. In other words, the traffic exhibits similar statistics on different time scales. Therefore, a packet call, like a packet session, is divided into ON/OFF periods as shown in Figure 4.14. Unlike a packet session, the ON/OFF periods within a packet call are attributed to the machine interaction rather than human interaction. The amount of information passed from the source to destination during the ON period is governed by the web page structure. A web-page is usually composed of a main object and several embedded objects. The size of the main object, in addition to the number and size of the embedded objects define the amount of traffic passed from source to destination.

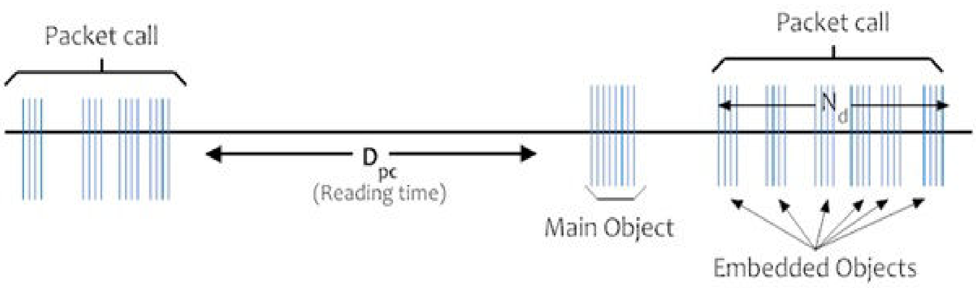

Figure 4.14: Contents in a Packet Call

A web browser will begin serving a user request by fetching the initial HTML page using an HTTP GET request. The recovery of the original (initial) page and each of the constituent objects is represented by ON period within the packet call while the parsing (analysis) time and protocol overhead are represented by the OFF periods within a packet call.

Parameter	Packets inter-arrival	Packet call pre session	Reading time	Packet size
Distribution	Geometric: 0.00195	Geometric: 5 Packets call	Geometric: 412s	Truncated Pareto : α = 1.1 k = 81.5 bytes

Table 4.7: HTTP source traffic modeling

A single user traffic model can be derived frome UMTS networks based on real traffic measurement. The model has three different levels: the session level, the connection level, and the packet level. The main results are:

- The session interarrival time is lognormally distributed with mean m = 0.9681 and variance $\sigma 2$ = 4.3846.

- The session data volume has a lognormal distribution whose parameters depend on the bandwidth class
- The interarrival times and the data volume of connections are lognormally distributed.
- Packets interarrival times are lognormally distributed.
- Packets size follows Truncated Pareto (α, k, m) distribution, where α is a positive parameter, k is the minimum size, and m is the maximum.

The parameters of the HTTP traffic are shown in Table 4.7.
The FTP traffic is modeled similarly to the HTTP traffic. Nevertheless, we consider that there is one packet call per session. The parameters of the FTP traffic are shown in Table 4.8.

Parameter	Reading Time	Packets number per packet call	Packets interarrival	Packet size
Distribution	30 min	Geometric: 200 Packets	Geometric: 0.037	Truncated Pareto : $\alpha =$ 1.1 k = 81.5 bytes

Table 4.8: FTP source traffic modeling

4.5 Conclusion

Vehicular communications offer great potential for increasing road safety and driver awareness. According to relevant studies, 60% of accidents can be avoided if the driver had been alerted half a second before the collision. Nevertheless, benefits are not restricted to safety standpoint but span to further horizons making use of a plethora of cooperating technologies. In fact, vehicular applications can be divided into three categories: safety, traffic coordination and infotainment applications.
In this chapter, we discussed the topic of vehicular applications in the context of 802.11p and LTE technologies. First, we proposed a classification of each application according to ITS standards, then we have proposed a source traffic modeling for each application. In next chapter, we adress our contribution based on IEEE 802.11p performance evaluation.

Chapter 5

Traffic Modeling and Performance Evaluation in Vehicle to Infrastructure 802.11p Network

5.1 Introduction

A key challenging issue that should be addressed in wireless vehicular mobile networks carried by IEEE 802.11p standard is Quality of Service provisioning. In fact, safety applications have critical-delay requirements. The timing requirements can be observed from the fact that it is only relevant to communicate about an upcoming dangerous situation before the situation becomes a fact and perhaps can be avoided. Consequently, special QoS mechanisms should be applied in order to prioritize safety applications.
In the literature, researchers oriented their effort towards studying the quality of service in ITS. Many authors proposed different analytical modeling techniques and simulation in the purpose of evaluating the performance of different ITS scenarios. Nevertheless, the various studies focus solely on the physical and Mac layers, without taking into account source traffic models. As a matter of fact, resource allocation and wireless scheduling are highly impacted by traffic variations and traffic statistical distribution. Therefore, a special attention should be devoted to source traffic modeling when evaluating a quality of service mechanism in wireless vehicular networks. In this chapter, we strive at focusing on traffic flow characteristics while evaluating the performance of a V2I network. The performance evaluation is conducted through accurate simulation runs and mathematical modeling in order to assess the EDCA performance.

In this chapter we use the characteristics of three ITS services: warning to a foggy zone, inter-distance measurement and road warning event defined in section 4.3.

We provide a mathematical modeling of the V2I scenario performance at a large scale and burst scale. The chapter is organized as follows. The following section details the literature survey on quality of service in 802.11p networks. Section 5.3 describes the mathematical modelling of the V2I scenario at a large scale and burst scale. In section 5.4, we provide a performance analysis before concluding the chapter.

5.2 Literature Survey on Quality of Service

One QoS mechanism proposed for the MAC layer in the IEEE 802.11p is the EDCA mechanism. EDCA supports some degree of service differentiation between different types of classes of services, referred to as access categories. The main advantage of EDCA is that the mechanism is completely distributed among stations and thus overcomes the problem of intelligence centralization and vulnerability.

Many research works in the literature tackled the performance of IEEE 802.11p EDCA mechanism. In [33], authors proposed an analytical model for dimensioning the RSU coverage area; the study aims at deriving the minimum contention window, Cwmin, required for a vehicle to connect with RSU during its sojourn time, and that for different classes of average speed. Authors in [48] proposed an analytical model for EDCA performance evaluation. They modelled three access categories with a Markov chain. For each access category, three states are defined: idle state, collision state and success state. Numerical resolution is adopted to determine the throughput. In [49], authors derived the expression of maximum number of transmitters according to the intensity, distance between transmitters and transmission time. In order to perform the analysis of the control channel CCH, authors in [50] modeled the transmission over the MAC layer, with a Markov chain; they distinguished between two states: state 1 refers to the case when no packet is waiting to be sent and state 2 refers to the case when a packet is waiting to be sent. Consequently, they evaluated the throughput expression in a different scenario context. The work published in [51] evaluates the performance of a wireless vehicular network and takes into account the fact that data frames in WAVE are transmitted in broadcast mode. The model has one backoff stage to reflect the fact that there are no acknowledgments. It therefore inherits the characteristics of being only applicable to the saturated case and to systems with only one access category. Additionally, reference [52] analyzes a situation related to broadcast transmissions. Slotted transmissions are considered with fixed-size slots. Further, authors assume that the probability that a station starts transmitting during a given slot is a system parameter with constant value, independent of nodes number, node traffic generation rate, and packet length. In [53], the author proposes formulas to evaluate the throughput and the collision probability in a wireless vehicular environment in which nodes are in a saturation condition. Most of these articles focused solely on the physical and MAC layers, without taking into account the features of wireless vehicular architecture layers and traffic characteristics.

In this chapter, we aim at evaluating vehicular network performance that takes into account the MAC layer and higher layer processing while considering traffic characteristics of three main ITS services.

5.3 Performance Modeling

In V2I communication, OBU and RSU exchange information in uplink and downlink directions. In this chapter, we focus on the uplink communication according to the ETSI standard protocol stack (figure 5.1). At the radio level, MAC and Physical layer correspond to the 802.11p architecture. The facilities layer of this architecture interact with the ITS applications and network/ transport layers.

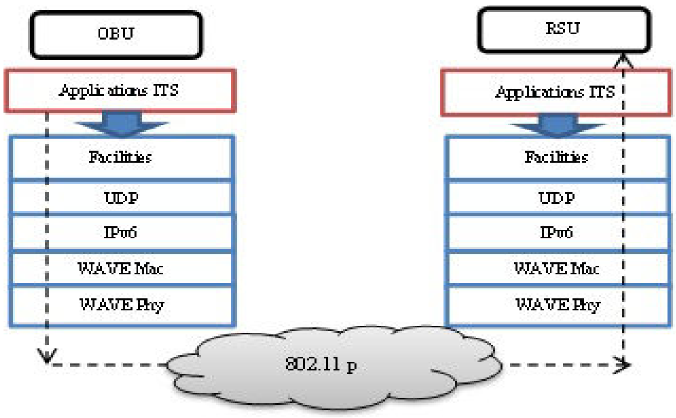

Figure 5.1: Vehicular protocol stack.

More specifically, when the facilities layer receives the applications messages, it determines the messages category (CAM, DEN, CoDM) according to their functional specifications, then for each message it attributes an ITS identifier specified by ITS Application Identifier (ITS-AID) in order to label ITS applications. Moreover, the facilities layer proposes an interface Human Machine Interface (HMI) to interact with the driver, through which he receives messages of services applications. At this stage, we are interested by studying the impact of the ITS architecture on the three envisioned services. Therefore, we proceed in two steps. The first step consists at modeling the facilities/network layer at a large scale. Second, we model the MAC radio layer that manipulates the flows transiting from facilities/network layer. The MAC modeling will be performed at the burst scale.

5.3.1 Facilities and Network Layer Modeling: Large-scale

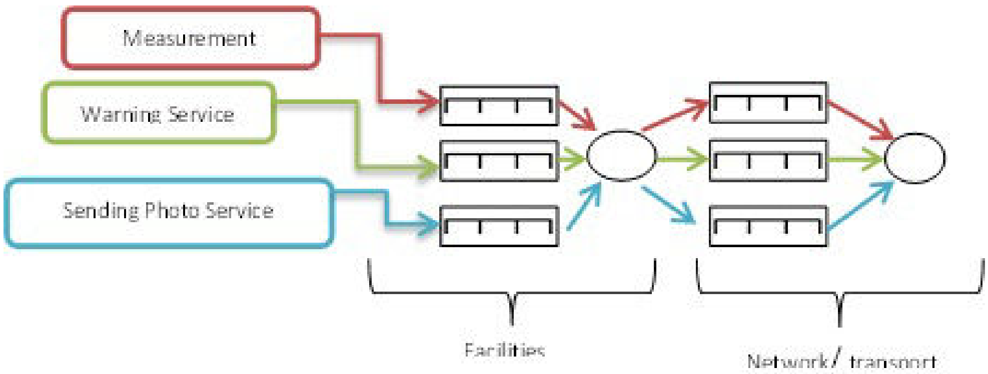

Figure 5.2: BCMP model for facilities and network layers

We adopt the following assumption related to three classes of service.

- r is the class of service (r varies between 1 to 3 in our study),
- Traffic arrival flows are Independent Poisson processes, with intensity (λ_r for service r),
- Service rates follow exponential distribution with parameter μ_r for service r,
- M is the number of OBUs,
- n_i (i=1...M) represents the total number of packets in an OBU_i in a RSU coverage area,
- The system vector state is defined by n=(n1,n2...nM),
- ρ_i is the load of an OBU_i,
- ρ_{ir}, μ_{ir} and λ_{ir} are respectively the load, service rate and mean arrival rate of a service r running on an OBU_i.

The Poisson arrival process and the exponential service rate distribution assumptions enable us to model the system with three M/M/1 queues at each layer (Figure 5.2). Each queue provides services to one class of service. As a result, we model the traffic carried by the upper layers of the architecture with a Product Form Queuing Networks, or BCMP, [54], [55] for which a product-form equilibrium distribution exists. Moreover, we assume that the BCMP network is open. Therefore, the steady-state probability distribution for a single-class (r) load-independent open BCMP network is defined by the product of steady-state probability distributions of queues in isolation. It is given by:

$$\pi(n) = \prod_{i=1}^{M} \pi_i \cdot n_i$$

Whith:

$$\pi_i \cdot n_i = (1 - \rho_i) \cdot n_i! \prod_{i=1}^{M} \cdot \frac{1}{n_{ir}!} \cdot [\frac{\lambda_r e_{ir}}{\mu_{ir}}]^{n_{ir}}$$

And e_{ir}: average visits number of a station OBUi by a class of service r. For each class of service running on an onboard unit i, we derive the performance parameters at the facilities/network layer as follows:

- Mean rate: $D_{ir}= \lambda_{ir}$
- Average number of packets: $L_{ir} = \frac{\rho_{ir}}{(1-\rho_i)}$
- Average sojourn time: $Tir = \frac{L_{ir}}{D_{ir}}$
- Average waiting time: $W_{ir} = T_{ir} - \frac{1}{\mu_{ir}}$

This performance analysis allows us to evaluate the applications flow in the upper layers, and defines the inputs of the underlying layer. At this stage, we pursue our modeling study and perform the MAC radio layer modeling.

5.3.2 MAC Radio layer Modeling

After being processed by facilities and network layer, services packets are passed to the radio MAC layer. In order to implement service differentiation, service packets should have different priorities. Therefore, we propose to map the three services to the EDCA access categories as follows.

Warning service carries critical information and is mapped to the highest priority Access category AC_VO. Measurement service generates important data and is mapped to the AC_BE; the frequent transmission of CAM messages overcomes the unreliability of AC_BE. Finally, road warning service is mapped to AC_BK. The EDCA parameters used in the mathematical study and simulation are resumed in Table 5.1 and Table 5.2.

ITS Service	EDCA Access Categories	Cw_{min}	Cw_{max}	AIFS
Road Warning event	AC_BK	15	511	9
Measurement of inter-distance	AC_BE	7	15	6
Warning to a foggy zone	AC_VO	3	7	2

Table 5.1: CCH EDCA Access categories parameters

ITS Service	EDCA Access Categories	Cw_{min}	Cw_{max}	AIFS
Road Warning event	AC_BK	15	511	7
Measurement of inter-distance	AC_BE	15	511	3
Warning to a foggy zone	AC_VO	3	7	2

Table 5.2: SCH EDCA Access categories parameters

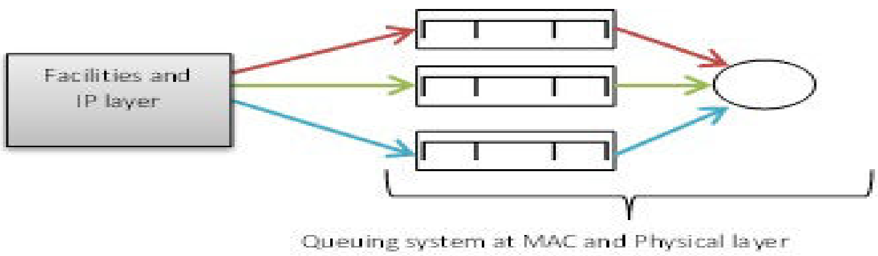

Figure 5.3: M/GI/1 radio model

We model the MAC radio layer with an M/GI/1 multiclass (with three classes of service, as shown in figure 5.3) which adopts a non-preemptive priority policy for each class of service. Packets belonging to a class of service arrive according to a Poisson process. The service follows a general law with Independent arrivals GI. For each service r, we denote by: $E[N_r]$ the number of waiting packets, $E[X_r]$ the average service time, $E[W_r]$ the average waiting time and $E[R_r]$ the unfinished work in the waiting queue server. Using Pollaczek-Khinchin (P-K) Formula we derived the main performance parameters to evaluate the M/GI/1 non preemptive priority system for each service class r as following:

- Average number of packets : $E(N_r) = \rho_r + \frac{{\rho_r}^2(1+C^2)}{2\cdot(1-\rho_r)}$
- Average sojourn time : $E(S_r) = E(X_r) + E(W_r)$
- Average waiting time : $E(W_r) = \frac{E(W_0)}{(1-\rho_r)\cdot(1-\sum_{r=1}^{3}\rho_r)}$

With: C: coefficient of variation, and $E[W_0]$: average waiting delay when the server is busy. It is noteworthy that the average waiting time does not take into account the backoff time. Therefore, we modified the expression in order to capture the backoff effect as follows: $\frac{E(W_0)}{(1-\rho_r)\cdot(1-\sum_{r=1}^{3}\rho_r)} + \sum_{i=0}^{C} w_{min} P(backoffr = i)\cdot i$

Since the backoff window is an integer value, randomly drawn and following a uniform distribution in [1, CW +1] window size, with $Cw \in [CW_{min}, CW_{max}]$, the probability P to draw a backoff window is defined as:

$P(backoff = i) = \frac{1}{1+Cw_{min}}$

5.4 Performance Evaluation

In order to evaluate the performance of the V2I network accommodating OBUs that run three services, we compare the analytical results derived from previous mathematical modeling with simulation.

5.4.1 Simulation Scenario

We conducted an extensive set of simulation runs with Network Simulator NS3. The simulated topology is a one-lane highway of 10 Km. We mainly investigate one RSU with 300m of coverage area (radius). Vehicles are moving according to a random model in one direction way with a mean speed of 20 km/h which corresponds to a traffic jam situation. The vehicle is estimated to stay 3.6 minutes in RSU coverage area.

Each OBU node runs the three modeled services: Warning service (DEN messages with mean Poisson arrival rate $\lambda1$= 10 messages/s), Measurement service (CAM messages with mean Poisson arrival rate $\lambda2$ =10 messages/s and road warning event (CoDM messages with mean Poisson arrival rate $\lambda3$= 1 messages/s).

These services are mapped to EDCA Access categories according to Table 5 and present the traffic models defined in section 4. The envisioned services generate packets which are sent on the service channel SCH number 176, with a constant propagation model. The transmission rate 6Mb/s is controlled by a rate manager algorithm, and a -10db of gain is considered. The vehicle number varies in the range of [5...100] in step of 5 vehicles, which correspond to: 18, 35, 53, 71, 88...354 vehicles/Km^2.

5.4.2 Simulation and Analytic Measurements

Our work aims at determining the maximum vehicles number in the RSU coverage area and the RSU capacity to transmit ITS messages. For this purpose, we are interested by measuring the average packet loss rate and delay. Figure 5.4 shows a comparison between average packet loss rates in function of the vehicle number. Each curve is related to an ITS service (warning, measurement and road warning event).

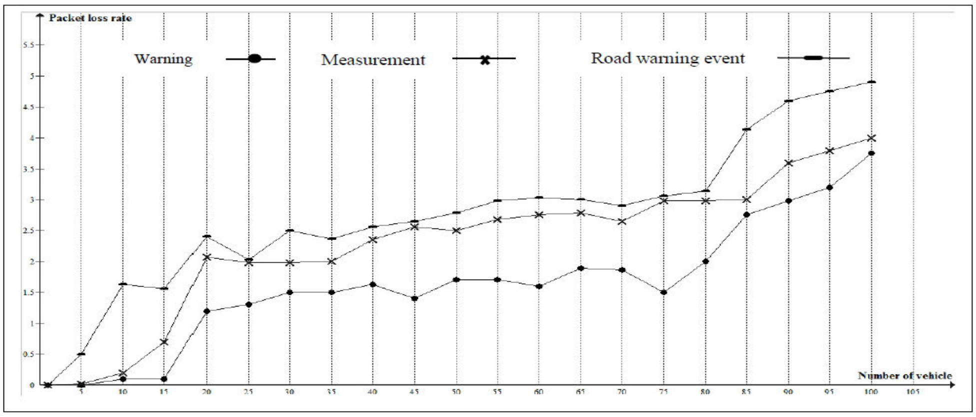

Figure 5.4: Packet loss rate VS vehicles number

First, we note that packet loss rate increases moderately when traffic density varies between 20 and 80 vehicles, but beyond that, the rate increases significantly for all application services. In fact, the more vehicles are associated to a single RSU, the more the vehicles experience backoff process and the higher the collision rate is. Another observation concerns the service differentiation which is well illustrated by the different packet loss rates experienced by the three services. More precisely, road warning service experience higher packet loss rate than that of measurement which is higher than that of warning message. This is mainly due to the different priority levels allocated to the services.

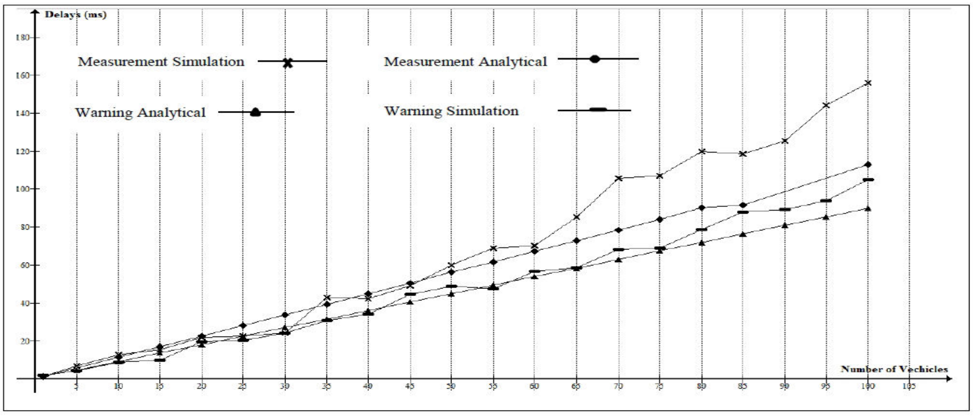

Figure 5.5: End to end delay of measurement and warning service VS vehicles number.

The end to end delay is a QoS parameter of paramount importance in vehicular networks, especially when it concerns warning and measurement messages which carry critical information. It is to be noted that the end to end packet delay corresponds to the sum of transmission and waiting time.

Figure 5.5 illustrates the end-to-end average delay in function of the vehicle numbers for each of the two critical services (warning, measurement). The curves concern analytical

and simulation results. We observe that when vehicles number varies in the range of [5...30] the delay is almost the same for both services. However, it increases significantly for measurement service when vehicle number exceeds 45. The warning delay is more regular in the range [5...80]. This result confirms the EDCA performance which succeeds at prioritizing warning over measurement service.
An important finding concerns the linear curve for analytical measurement, as exhibited in figure 5.5. In fact, backoff evolution is a linear function of road traffic load for different zone ranges (300m, 500m and 900m). Reader may refer to reference [56].

5.5 Conclusion

Wireless vehicular networks perform crucial functions in road safety, detecting and avoiding traffic accidents, reducing traffic congestion as well as improving driving comfort. In this chapter, we shed the light on three ITS services: warning to a foggy zone, inter-distance measurement and road warning event. Since QoS performance is highly sensitive to traffic statistical distribution, we started by modeling the services traffic. Then, we oriented our efforts towards modeling the ETSI high layers (facilities, network) and MAC layer that process packets generated by the three mentioned services. The proposed model is based respectively on BCMP and M/GI/1 queuing model.
We evaluated then the performance of a vehicular network through measuring packet loss rate and end-to-end delay obtained by the mathematical modeling and simulation. Analytical and simulation results confirm the service differentiation and the respect of the critical nature of warning service.
Moreover, we have derived the range of vehicle density at which QoS metrics start to highly increase. In next chapitre, we improve the mobility model and the analytical model by taking into account the virtual collision issue.

Chapter 6

EDCA Virtual Collision Performance Evaluation and Mobility Modeling in V2I Communications

6.1 Introduction

EDCA virtual collision management is a penalizing process that occurs in Intelligent Transportation Systems (ITS). It induces unfairness, priority inversion and quality of service degradation. This chapter tackles the performance evaluation of the virtual collision management proposed by IEEE in vehicular environment and overviews the quality of service in presence of three ITS applications: Warning to a foggy zone, inter-distance measurement and road awareness. We perform a mathematical modelling based on a discrete Markov chain that tackles vehicles mobility. The objective of our study is to show the impact of virtual collision on vehicular network performance and dimension the RSU coverage area.

The convergence of wireless technology and vehicle applications presents network operators with enormous opportunities as well as great challenges. A key challenging issue that should be addressed in wireless vehicular mobile networks is: Quality of Service (QoS) provisioning. Special QoS mechanisms and suitable call admission control should be applied in order to prioritize safety applications. These critical applications imply increased requirements on the wireless communication and the challenge is not only to overcome the unpredictable wireless channel but also to cope with rapid network topology changes together with strict timing and reliability requirements.
The 802.11p standard [57] focuses on describing MAC mechanisms that provide quality

of service to vehicular applications. The standard provides two mechanisms that strive to meet the applications QoS requirements by allocating an adequate Transmission Opportunity (TXOP).

Inter-OBU collision EDCA manages the external collisions using the backoff as follows. A transmitting station senses the medium and ensures that it is idle for a required duration, DIFS, before attempting to transmit. We consider two cases: If the medium is indicated as idle, the transmission may proceed. On the contrary, if the medium is determined to be busy, a station defers transmission until the end of the current transmission. After deferral, or prior to attempting to transmit again immediately after a successful transmission, a station applies the back-off mechanism [58]. During contention, when two (or more) backoff entities counters reach zero at the same time, each backoff entry tries to access the same slot at the same time: it contends then for a TXOP. After detecting the medium idle for AIFS[AC], it starts counting down the backoff counter. A frame transmission is initiated when the backoff counter reaches zero.

Virtual collision In addition to the physical collisions involving queues from two different stations, EDCA manages virtual collisions that involve two queues belonging to the same station. More precisely, whenever the backoff counter of several contending queues within the OBU expire at the same time slot, virtual collision management is achieved as follows: The queue presenting the highest priority wins the right to try to access the medium, whereas remaining queues apply the native backoff procedure adopted for real physical collision. Consequently, virtual collision management may lead to three problems: QoS penalization, unfairness and priority inversion. In order to illustrate the idea, we consider a station having an AC_VO and an AC_VI queue. When both queues go into a virtual collision, AC_VI will have its CW doubled, whereas AC_VO will access the medium.
One direct implication is AC_VI penalization. AC_VI is likely to have urgent packets that will suffer from QoS degradation. Another concern is due to priority inversion. In fact, AC_VI, enduring virtual collisions, may have its CW larger than that of an AC of lesser priority. The other problem is that of fairness. Theoretically, EDCA assigns to each access category a set of parameters that should be the same for all queues of the same priority within one Basic Service Set: in this way, EDCA assigns equal chances to access the medium. Nevertheless, virtual collisions management creates unfairness among the same access category flows.
In this chapter, we mainly tackle EDCA virtual collision problem and elaborate the performance evaluation of MAC layer that manipulates three ITS services: Inter distance measurement, warning to a foggy zone and road awareness services. On the other hand,

we take into consideration a microscopic mobility model that replicates the real behavior of vehicular traffic. In fact, mobility modelling is of paramount importance since it captures the vehicles distribution on highways and impacts vehicular density. The performance evaluation is conducted through accurate simulation runs and mathematical modeling in order to assess the EDCA virtual collision performance. Our contribution adopts a top-down approach. More precisely, we proceed as follows:

- We consider the characteristics of three ITS services defined in chapter 4. We also consider the mapping to the 802.11p access categories according to chapter 5.
- We present an EDCA mathematical modeling of the virtual collision based on a discrete Markov chain. We take into consideration the physical layer parameters.
- We introduce a a car following mobility model and investigate the impact of mobility and different vehicular densities on quality of service.

The chapter is organized as follows. Next section presents a literature survey on EDCA performance evaluation. Section 6.3 focuses on virtual collision mathematical modeling. In section 6.4, we exhibit the mobility modeling. Then we present the computed performance parameters in section 6.5. Section 6.6 brings to the focus the performance evaluation obtained by simulation and analytical model. Section 6.7 ends this chapter by highlighting the different outcomes and findings related to EDCA virtual collision evaluation.

6.2 Related Work

Evaluating the quality of service in vehicular networks is a field that attracted a great number of researchers. Scientific literature regroups various mechanisms and heuristics related to wireless vehicular networks performance evaluation.
Bianchi has evaluated the performance of 802.11b through his ground-breaking work in [59]. Nodes are considered having the same priority and working in saturation mode.
In [60], authors considered the broadcast mode. The model adopts one backoff stage to reflect the fact that there are no acknowledgments, hence frames are not retransmitted since there is no way to know if the initial transmission was successful or not. The model in [60] inherits the characteristics of being only applicable to the saturated case and to systems with a single access category.
In [61], the author evaluated the perfomance of a WAVE saturated environment with constant backoff intervals. In [62], authors considered virtual collisions among different ACs inside each EDCA station in IEEE 802.11e, external collisions among stations, and the impact of high priority ACs AIFSs on low priority ones. They proposed a one dimension markov chain model without considering a mobility model.

The author in [63] described and analyzed a model for the EDCA MAC protocol, taking into consideration the specific conditions of the control channel of an IEEE 802.11p vehicular network. The model captures the details as to how EDCA establishes different priorities among stations and that safety-related information is transmitted using the broadcast address. Authors implemented a 3 dimension markov chain to model the EDCA access categories. Despite the importance of the proposed work, it partially adresses the challenges of EDCA modeling. In fact, authors did not take into account the virtual collision issue, neither the vehicle mobility.

Authors in [62] shed the light on the collision impact on network performance; they considered four classes of service generated by CBR, whereas [63] tackled the effect of successful transmission period on the overall performances. The traffic generated by the services classes in [63] is transactional similar to the classic ON/OFF. While in [64] authors proposed an analytical model in order to study IEEE 802.11e priorities: real time and non-real time trafic were adopted in simulations, without taking into account the virtual collision issue.

In [65] authors proposed an analytical model to compute the saturation throughput and delay of stations in IEEE 802.11e network. The impact of virtual collision analysis is studied in [66]. In [67], authors proposed a three dimensional markov chain model in order to evaluate the IEEE 802.11e network: each state represents an AC in a slot time and the transition probability is represented by the collision probability (virtual and external). Authors in [68] extended the study in [67] and proposed an EDCA markov chain model in IEEE 802.11e network.

The majority of these research studies that analyze the virtual collision is elaborated in the context of IEEE 802.11e. As the reader may notice, 802.11p presents many differences at the MAC layer, physical layer and application layer. Therefore, in this chapter we aimed at focusing on the virtual collision while modelling three ITS services and 802.11p EDCA mechanims and adopting a car-following model that prevents the rear-end collision.

The objective of our study is the dimensionning of the vehicular network: deriving the maximum number of vehicles accomodated by a road side unit and investigating the impact of virtual collision and mobility on vehicular network quality of service .

6.3 Virtual Collision Mathematical Modeling

The virtual collision represents typically the case of access category 2, AC_VI, and access category 3, AC_VO, that will frequently collide.

The analytical model is based on a discrete-time Markov process. The transmission environment is a two-ray propagation model with no hidden terminals, thus packet losses are assumed to occur due to collisions. In the following, we will refer to AC_VI (resp. AC_VO) as AC[2] (resp. AC[3]).

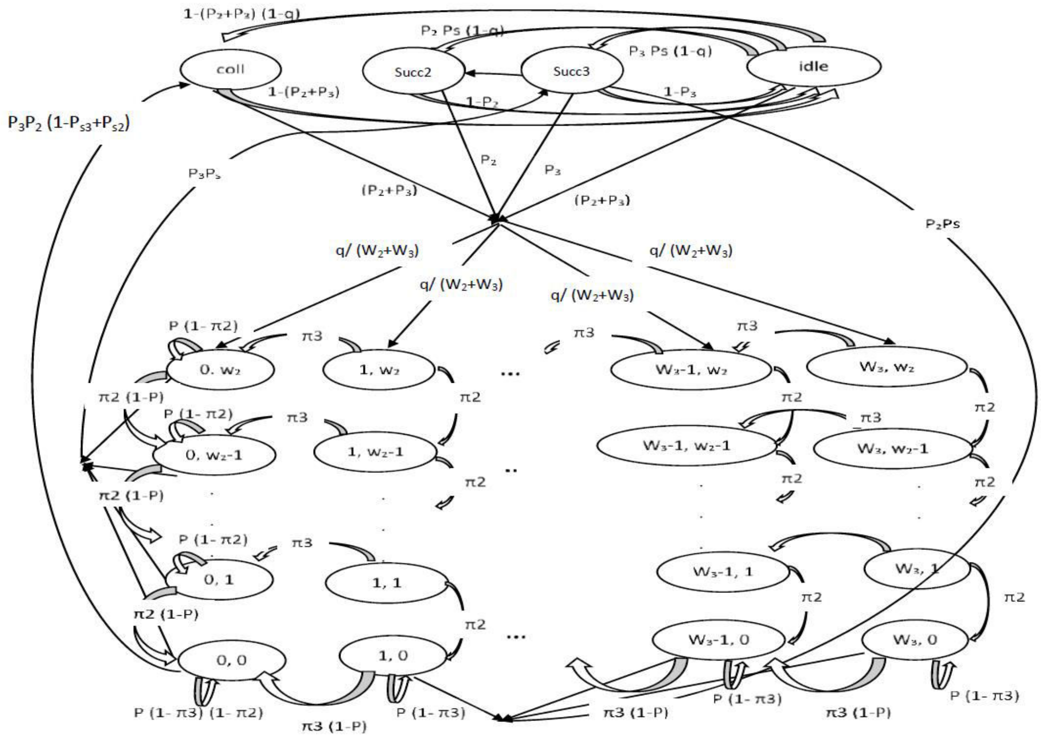

Figure 6.1: Virtual collision Markov chain

Figure 6.1 illustrates the graph associated to the Markov chain. As shown, $Succ_2$ and $Succ_3$ represent the successful transmission states of AC[2] and AC[3] respectively. The access category transits from idle state to $Succ_2$ (resp. $Succ_3$) if AC_VI (resp. AC_VO) transmits successfully. The transition from the Coll state to the idle state illustrates the case of AC_VI (or AC_VO) empty queues.

Upon AIFS expiration, AC[2] and AC[3] start decreasing their backoff counter. The state (W_3,W_2) corresponds to the backoff counters of AC[2] and AC[3] with W2 $\in$ {0... W_{2min}} and $W_3 \in$ {0... W_{3min}}. A station decreases the AC [3] backoff and moves from (W_3,W_2) to (W_3-1,W_2) with a probability π_3 until reaching the state (0, W_2). The transition from (0,W_2) states to Succ3 state occurs in case of a free medium; otherwise the station will freeze its current state.

Transitions from states (W_3,W_2) to (W_3,W_2-1)... to (W_3,0) occur with a probability $\pi - 2$ when AC[2] senses the medium free. When the sate (W_3, 0) is reached, AC [2] will freeze its current state in case of a busy channel or transmits otherwise. The state (0, 0) illustrates the virtual collision. In fact since the backoff counter reaches zero for both access categories, each AC is then ready to transmit. Consequently, AC [2], having the least priority, will have its contention window doubled, while AC [3] will access the medium. We then define two transitions from the (0, 0) state: a transition to coll state and another one to Succ3.

q	Probability that the sensed channel for AIFSN × ts is not free
Pi	Probability that there is a packet in the queue i
Ps	Probability that the packet is successfully transmitted
πi	Probability that no transmission occurs from any access category that presents a higher priority than access category i
P	Probability that the channel is not idle for a slot time σ
τi	Probability that an access category i transmits
σi	Probability of transmission attempt for access category i observed outside an OBU
Pc,i	Collision probability of class i for an EDCA station
Pv,i	Probability that a class collides with higher priority access categories inside the OBU
Pe	Probability of an external collision
Ptr,i	Probability of that an OBU (at least one) transmits in the considered time slot
Ps,i	Probability of successful transmission for access category i in the considered time slot
Cidle,i	Probability that an access category i senses the channel idle
Wi	Minimum contention window size for access category i
Ts,i	Average time of a successful transmission for access category i
Tc,i	Average time of a collision involved in the system for access category i
tPhy	Transmission time of PHY headers
tMAC	Transmission time of MAC headers
tE[Li]	Transmission time of the average payload size, Li, for access category i
Tb,i	Time spent in every backoff attempt for access category i given that the current channel state is busy
Tt,i	Time elapsed during the backoff decrease for an AC[i]
ACK	Transmission time of an ACK message
δ	Propagation delay
tSIFS	SIFS value
tDIFS	DIFS value
Slot	Slot time duration
AIFSi	AIFS value for access category i
E[Bi]	Number of occurrences of backoffs for an AC [i]

Figure 6.2: Model parameters

6.3.1 Model Analysis

The second step towards the performance evaluation is the computation of the steady states probabilities related to the Markov chain. For the reader clarity, figure 6.2 states the symbols adopted for the mathematical model analysis. We denote by:

- $b_{k,j}$ with k ∈ {0...W_3}, j ∈ {0,...,W_2} the stationary distribution of backoff states.
- b_{AC2} (resp. b_{AC3}), the stationary distribution in states $Succ_2$(resp. $Succ_3$).
- b_{idle} the stationary distribution of idle state.
- b_{coll} the stationary distribution of collision state

The model at hand takes into account N vehicles accommodated in a RSU. The probability, π_i, i ∈ {2, 3}, that no transmission occurs from any access category presenting a higher priority than access category i is calculated as follows: $\pi_3 = (1-\tau_3)^N$ and $\pi_2 = (1-\tau_3)^N(1-\tau_2)^N$

Where τ_i the probability of transmission attempt for access category i observed inside an OBU.

By applying the Kolmogorov equations, we obtain the following equations:

$$\begin{aligned}
b_{k,0} =& b_{k,0} \cdot (1-\pi_2) \cdot P \cdot (1-\pi_3) + b_{k-1,0} \cdot (1-P) \cdot \pi_3 + b_{k,1} \cdot \pi_2 \cdot (1-P) \\
b_{k,1} =& b_{k,2} \cdot (\pi_2) \cdot (1-P) \\
b_{k,2} =& b_{k,3} \cdot (\pi_2) \cdot (1-P) \\
b_{k,w_2} =& b_{k+1,w_2} \cdot \pi_3 + b_{k,w_2} \cdot \pi_2 \cdot (1-P) + \frac{b_{coll} + b_{idle} \cdot P_2 \cdot P_3 \cdot q + b_{AC3} \cdot P_3 \cdot q + b_{AC2} \cdot P_2 \cdot q}{W_2 + W_3}
\end{aligned}$$

$$\begin{aligned}
b_{idle} =& (1-P_3) \cdot b_{AC3} + (1-P_2) \cdot b_{AC2} + (1-(P_2+P_3)) \cdot b_{coll} \\
b_{AC2} =& b_{w_2} \cdot P_2 \cdot P_{S2} + b_{idle} \cdot P_2 \cdot P_{S2} \cdot (1-q) \\
b_{AC3} =& b_{w_3} \cdot P_3 \cdot P_{S3} + b_{idle} \cdot P_3 \cdot P_{S3} \cdot (1-q) \\
b_{coll} =& b_{k,0} \cdot (1-P_{S3}+P_{S2}) \cdot P_2 \cdot P_3 + b_{idle}(1-P_2+P_3) \cdot (1-q) Where \\
b_{w3} =& \{b_{0,w2}, b_{0,w2-1}, b_{0,w2-2}, ...b_{0,0}\} \\
b_{w2} =& \{b_{w3,0}, b_{w3-1,0}, b_{w3-2,0}, ...b_{1,0}\} \\
b_0 =& b_{0,0}
\end{aligned}$$

P is the Probability that the channel is not *idle* for a slot time duration.

6.4 Mobility Modeling

Without an authentic mobility model, MAC performance results obtained from mathematical modeling and simulations may not be in phase with performance in a real highway deployment. Therefore mobility models should reflect, as close as possible, the real behavior of vehicular traffic and provide a faithful representation of real world vehicular dynamics. Therefore, at a second step, we oriented our efforts towards elaborating a mobility model that aims at accurately deriving the vehicles density in a RSU coverage area. We assume that the RSU coverage area, with a communication range R, is divided into Z zones (figure 6.3) [69]. We further consider that vehicles move from zone i to zone i+1 with i$\in$ {1,...,Z}. In each zone we elaborate the Markov chain model described previously. The tackled model is a car-following model that aims at avoiding rear-end collisions. More specifically, a vehicle should adapt its speed, μ, and keep the vehicle inter-distance, d, greater than the security distance. Therefore the following equation stands:

$d > \mu.\ T_s$ Where T_s refers to the safety time needed to cross the safety distance. It is noteworthy that controlling vehicles speed implies controlling vehicles arrival rate, B, and inter arrival time, T_d, in the RSU coverage area. In this context, we distinguish between two cases [70].

The first case occurs when the number of arriving vehicles is small. Therefore, the vehicular inter arrival time, T_d, is larger than the security time, T_s. The number of vehicles in the RSU coverage area, N, is then derived as $N = \frac{2 \cdot B \cdot R}{\mu}$.

The second case is when the number of arriving vehicles in the RSU coverage zone is large. In this case, the vehicular inter arrival time T_d, is less than the safety time, T_s. As a consequence, the vehicular inter distance becomes less than the security distance. Therefore, vehicles have to decelerate in order to avoid a rear end collision.

We then model the system with a single server Poisson arrival queue. If a vehicle finds another one being served, the new vehicle will wait until all vehicles have been served, i.e. the distance between any two following vehicles is greater or equal than security distance. Then vehicles will move according to new speed limits which illustrate the new speed limits. We define then the new maximum speed $V_{max}[new]$ and minimum speed $V_{min}[new]$ as follows:

$V_{max}[new] = V_{max} e^{\epsilon \frac{E[B]}{\mu}}$

and $V_{min}[new] = V_{min} e^{\epsilon \frac{E[B]}{\mu}}$

Where ϵ is the ratio of vehicles that apply the safety distance rule and V_{max} and V_{min} are the speed limits. The new average speed, μ[new], is then calculated as follows:

$\mu[new] = \frac{V_{max}[new] + V_{min}[new]}{2}$

The vehicles number in this case is:
$N = \frac{2 \cdot B \cdot R}{\mu}, if E[S] = 0$
$N = \frac{2 \cdot B \cdot R}{\mu[new]}, if E[S] \neq 0, B \cdot E[S]_{new} < 1$
$N = \frac{2 \cdot B \cdot R}{10}, if E[S] \neq 0, B \cdot E[S]_{new} > 1$

Where E[S] is the mean service time and E[B] is the mean server busy time.

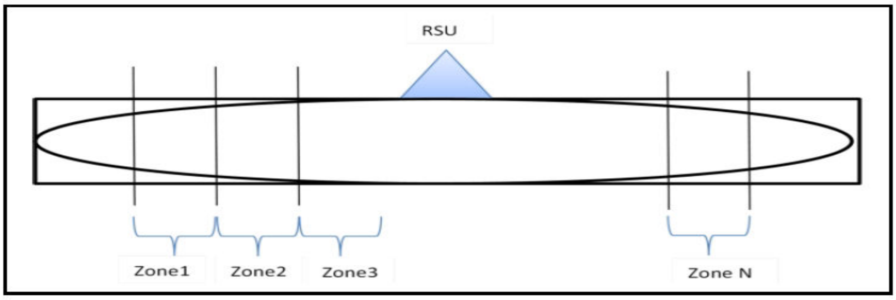

Figure 6.3: RSU coverage zone

6.5 Performance Parameters

In order to evaluate the EDCA performance, we computed the average access delay and the offered throughput for each access category i. These parameters were retrieved from simulation runs and numerical resolution of mathematical modeling.

6.5.1 Throughput Calculation

A node will transmit a packet when it reaches state (0,0) or when it is in state *idle* and senses a free chanel for $AIFS \cdot ts$. Therefore, we can compute τ_i, the probability that an access category i transmit, with i ∈ {0, 1, 2, 3} as: $\tau_i = b_{k,0} + b_{idle} \cdot ((P_2 + P_3) \cdot (1 - q))$

Since collisions are external or virtual, the collision probability of an access category i, $P_{c,i}$ can be expressed as follows [6]: $P_{c,i} = P_{v,i} + (1 - P_{v,i}) \cdot P_e$

Where $P_{v,i}$ define the probability that a class i collides with higher priority access classes inside the EDCA station and P_e denotes the probability of an external collision. $P_{v,i}$ can be expressed as follows:

$$
\begin{aligned}
P_{v,3} =& 0 \\
P_{v,3} =& \tau_3 \\
P_{v,1} =& 1 - (1 - \tau_3) \cdot (1 - \tau_2) \\
P_{v,0} =& 1 - (1 - \tau_3) \cdot (1 - \tau_2) \cdot (1 - \tau_1)
\end{aligned}
$$

In order to derive the external collision probability, σ_i, we first compute the probability of transmission attempts for AC[i] observed outside an EDCA node such that:

$$\begin{aligned}\sigma_3 =& \tau_3\\ \sigma_2 =& \tau 21 \cdot (1-\tau_3)\\ \sigma_1 =& \tau_1 \cdot (1-\tau_3)\cdot(1-\tau_2)\\ \sigma_1 =& \tau_0 \cdot (1-\tau_3)\cdot(1-\tau_2)\cdot(1-\tau_1)\end{aligned}$$

Then, the total transmission probability for an EDCA node is:

$$\sigma_t = \sum_{i=0}^{3} \sigma_i$$

This will in turn allow us to compute the probability of external collision P_e namely:

$$P_e = 1 - (1-\sigma_t)^{N-1}$$

At this stage, we calculate $P_{tr,i}$ the probability that at least one station transmits in a time slot, and $P_{s,i}$ the probability that an AC[i] transmission attempt is successful. The following equation allows us to compute the transmission duration, where E[Li], the average payload size:

$$\begin{aligned}P_{tr,i} =& 1-(1-\sigma_i)^N\\ P_{s,i} =& \frac{1}{P_{tr,i}} \cdot N \cdot \tau_i \cdot (1-\tau_i)^{N-1} \cdot \prod_{\substack{j\neq i\\ j=1}}^{3}(1-\tau_j)^N\end{aligned}$$

At this stage, we derive the throughput S_i as:

$$\frac{P_{s,i} \cdot P_{t,i} \cdot E[L_i]}{(1-P_{tr,i} \cdot Slot + \sum_{k=0}^{3}(P_{tr,k} \cdot P_{s,k} \cdot t_{s,k}) + P_{tr,i} \cdot P_{c,i} \cdot T_{c,i}}$$

Where, Slot is the slot time duration.

6.5.2 Delay Calculation

The end to end delay, D_i, is defined as the time taken for packets to be sent from vehicle to infrastructure. D_i is equal to the sum of waiting time and transmission time. For an access category i, let us denote by:

- E[B_i] the number of occurrences that the access category needs to backoff.
- $T_{t,i}$ the time elapsed during the backoff decrease.

- $T_{s,i}$ the average time of successful transmission.

D_i is computed then as following:

$$D_i = E[B_i] \cdot T_{t,i} + T_{s,i}.$$

In the following, we strive at calculating each term of the Di equation.

$T_{s,i}$ takes into account the transmission time of physical, MAC headers, ACK messages, SIFS, AIFS, slot time duration and payload size of L_i. Thus,

$$\begin{aligned} T_{s,i} = & t_{phy} + t_{MAC} + tSIFS + \delta + ACK + \\ & tE[L_i] + tAIFS[AC_i] + Slot \end{aligned}$$

Since the backoff window is an integer value, randomly drawn and following a uniform distribution in [1,C_W+1] window size, with $C_W \in [C_{Wmin}, C_{max}]$, the number of occurrences the AC has to back off is defined as

$$E[B_i] = \sum_{i=0}^{C_{wmin}} P[backoff = i] \cdot i = \frac{C_{wmin}}{2}$$

$T_{t,i}$ represents the time elapsed during the backoff decrease for one AC[i].

$$\begin{aligned} T_{t,i} = & \prod_{i \neq 1}^{3} (1-\tau_i)^N \cdot Slot + T_{c,i} \cdot (1 - \prod_{i=1}^{3} (1-\tau_i)^N) + \\ & Tb_i + P_{c,i} \cdot T_{c,i} + \sum_{i=0}^{3} P_{tr,i} \cdot P_{s,i} \cdot T_{s,i} \end{aligned}$$

The first part in this expression corresponds to an idle channel before the transition. In this case, the state transition time takes one slot time. The second part corresponds to the situation in which the channel was previously occupied and just being released: it can be occupied by a collision or a successful transmission. It is noteworthy that $T_{c,i}$ is the average time of a collision involved in the system for access category i.

$$T_{c,i} = t_{phy} + t_{MAC} + tE[L_i] + tAIFS[AC_i] + Slot$$

In the following, we calculate the expression of Tb_i: the time spent in every backoff attempt for AC[i], given that the current channel state is busy. Indeed, the backoff counter decreases just before the end of AIFS duration. Thus, the channel may become busy after the AC has waited longer than a DIFS but shorter than its AIFS [6]. We denote then by $Diff_i$ the difference in the number of time slots between $AIFS_{min}$(DIFS) and $AIFS_i$ where tAIFS [ACi] is the AIFS transmission time.

$$DIFF_i = \frac{AIFS_i - AIFS_{min}}{Slot}$$

We need the $Diff_i$ expression in order to calculate Tb_i:

$$Tb_i = [\frac{Cidle_i \cdot (1 - Cidle_i^{Diff_i - 1})}{1 - Cidle_i} - (Diff_i - 1) \cdot Cidle^{Diff_i}]$$
$$\cdot Slot + \sum_{i=0}^{3} P_{tr,i} \cdot P_{s,i} \cdot T_{s,i} + P_{c,i} \cdot T_{c,i}$$

Where: $Cidle_i$ represent the probability that one access category i senses the channel idle.

$$Cidle_i = (1 - \sigma_t)^{N-1} \prod_{\substack{j \neq i \\ j=1}}^{3} (1 - \tau_i)$$

6.6 Performance Evaluation

In order to evaluate the performance of the mathematic model, MAC parameters are adopted from the latest IEEE 802.11p standard [1] and listed in figure 6.4. We then achieved a numerical resolution using Matlab. Moreover, an extensive set of simulation runs were conducted with Network Simulator NS3. The objective is to assess the accuracy of the mathematical modeling by comparing the simulation results with numerical results and to evaluate virtual collision performance.

AIFS[AC3]	58 µs (SIFS + 2slot)
AIFS[AC2]	71µs (SIFS + 3slot)
AIFS[AC1]	84µs (SIFS + 4slot)
AIFS[AC0]	84µs (SIFS + 4slot)
t_{PHY}	64 µs (192bits / 3Mbps)
t_{MAC}	43 µs (256bits / 6Mbps)
ACK	101 µs (192bits + 14bytes / 3Mbps)
Slot	13 µs
tSIFS	32 µs
$T_{s,i}$	$t_{Phy} + t_{MAC} + tSIFS + \delta + ACK + tE[L_i] + tAIFS[ACi] + Slot$
$T_{c,i}$	$t_{Phy} + t_{MAC} + tE[L_i] + tAIFS[ACi] + Slot$

Figure 6.4: IEEE 802.11p MAC parameters

6.6.1 Scenario Description

We considered a one-lane highway of 10 Km. We mainly investigated one RSU with 300m of coverage area (radius). Vehicles move with a mean speed μ of 20 km/h; this speed corresponds to a traffic jam situation. Each OBU node runs three modeled services:

Warning service (DEN messages with mean Poisson arrival rate $\lambda 1= 10$ messages/s), Measurement service (CAM messages with mean Poisson arrival rate $\lambda 2 =10$ messages/s and road awareness (CoDM messages with mean Poisson arrival rate $\lambda 3= 1$ messages/s). These services are mapped to EDCA Access categories stated in section 3 and present traffic models. The envisioned services generate packets that are sent on the service channel SCH N 176, with a constant propagation speed. The transmission rate 6Mb/s is controlled by a rate manager algorithm, and a -10db of gain is considered. The vehicle number varies in the range of [5...100] with a step of 5 vehicles, which correspond to [18, 35, 53, 71, 88...354] vehicles/Km^2. We capture three metrics, the end to end delay of two critical services (warning, measurement), the offered throughput and the packet loss ratio. For the mobility tests, we investigate the number of vehicles according to various speed values spanning from 20 km/h to 180 km/h. Moreover, we measure the signaling traffic (number of received messages RX) sent from OBUs to the RSU.

6.7 Performance Analysis

Figure 6.5 illustrates the end-to-end average delay in function of the vehicle number for each of the two critical services, namely warning and measurement. Indeed, the end to end delay is of paramount importance in vehicular networks, especially when it concerns warning and measurement messages which carry critical information. We note that when vehicle number in the range of [1... 25], the end to end delay is almost the same for the two services. However, it increases significantly for measurement service when vehicle number exceeds 30. The result confirms the EDCA performance which succeeds at prioritizing warning over measurement service.

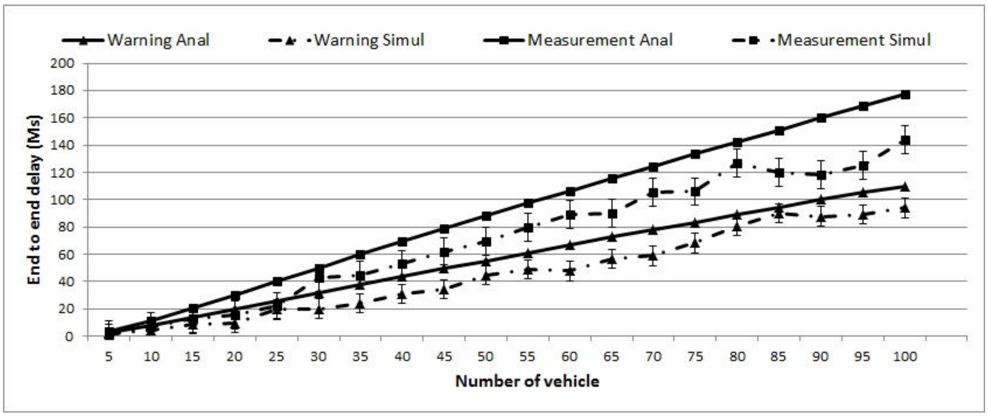

Figure 6.5: Average end to end delay

Figure 6.6 shows simulation and analytical results of the overall throughput of the three ITS services. First we observe that the overall throughput is the highest for warning service since this service experiences the highest priority.

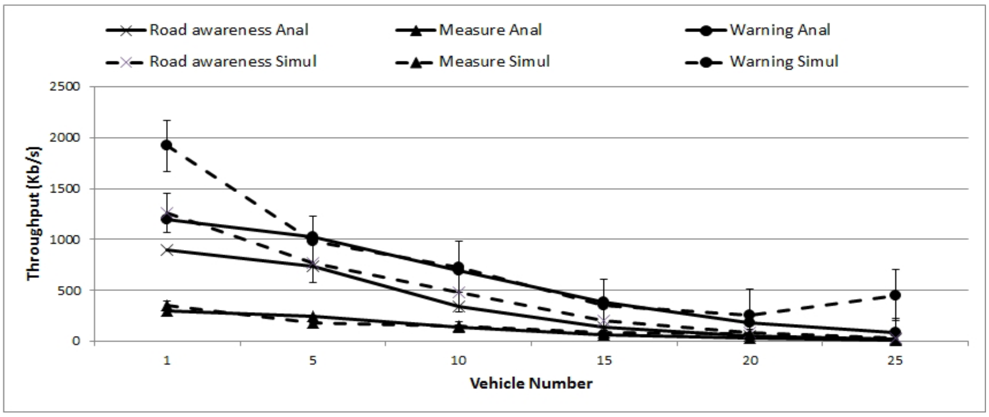

Figure 6.6: Average Throughput

Although measurement service presents a higher priority than road awareness, the latter exhibits a higher throughput. This can be explained by the fact that road awareness incurs sending photos which have larger payload size than packets generated by measurement service. In addition, the measurement access category is forced to double its backoff window to avoid virtual collision with warning access category which causes a window size close to that of the photo access category.
It is noteworthy that when the vehicle number increases, the overall throughput decreases for all applications. Indeed, the more vehicles are present in the RSU coverage area, the higher collision rate will be; and thus the smaller throughput will be obtained.
Figure 6.7 displays average packet loss rates in function of the vehicle number. One can deduce that packet loss rate increases moderately when traffic density varies between 20 and 80 vehicles, but beyond that, the rate increases significantly for all application services. In fact, the more vehicles are associated to a single RSU, the more vehicles experience backoff process and the higher the external collision rate is, in addition to the virtual collision.
Another observation concerns the service differentiation: road awareness service experiences higher packet loss rate than that of measurement and warning message. As one can see, packet loss rates become comparable between measurement and road awareness services; in fact virtual collision management induces doubling of measurement service backoff window and thus impacts its performance.
We observed via the delay and the loss rate measurements that the performance parameters decreased moderately when the vehicle number is in the range of [60...70]. Beyond that, the performance degrades significantly. This validates the analytical measurement and thus allows getting the dimensioning rules.
Finally, we were concerned with the impact of mobility model on the received messages. We are mainly interested by deriving the maximum number of OBUs accommodated by

a RSU with different traffic situations (jam, fluid traffic). Figure 6.8 indicates that the number of vehicles decreases with the speed: in fact, speed affects the vehicular density and thus sojourn time in the RSU coverage area. It can be easily deduced that in traffic jam (speed = 20 Km/h), the number of vehicles reaches 90. Contrarily to traffic situations with mean speed of 180 Km/h that induce 10 vehicles connected to a RSU.

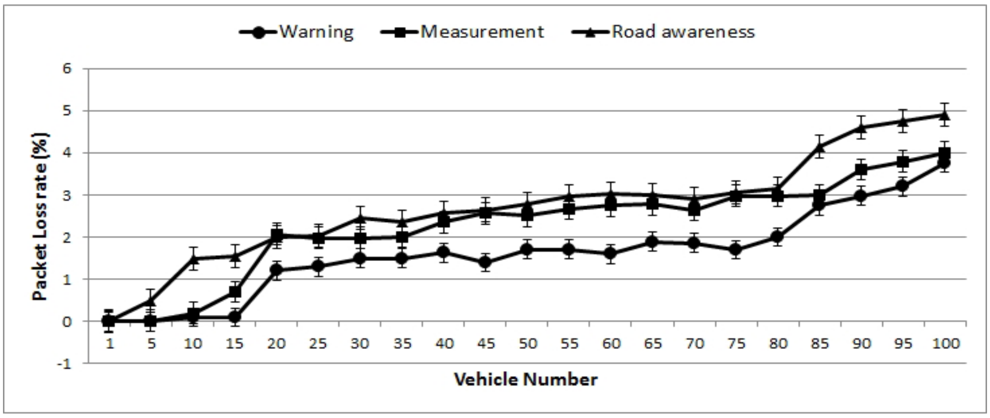

Figure 6.7: Loss rate

Moreover, Figure 6.8 visualizes the variation of received messages according to vehicular speed. The lower the speed is, the higher the number of vehicles is and consequently the higher is the number of collisions. Therefore, the higher is the number of retransmissions. This is confirmed by Figure 6.7 that displays the packet loss rate in function of vehicle number. Finally, when comparing simulation runs to mathematical model results, the overall figures show that mathematical results are closely approximated by simulation results.

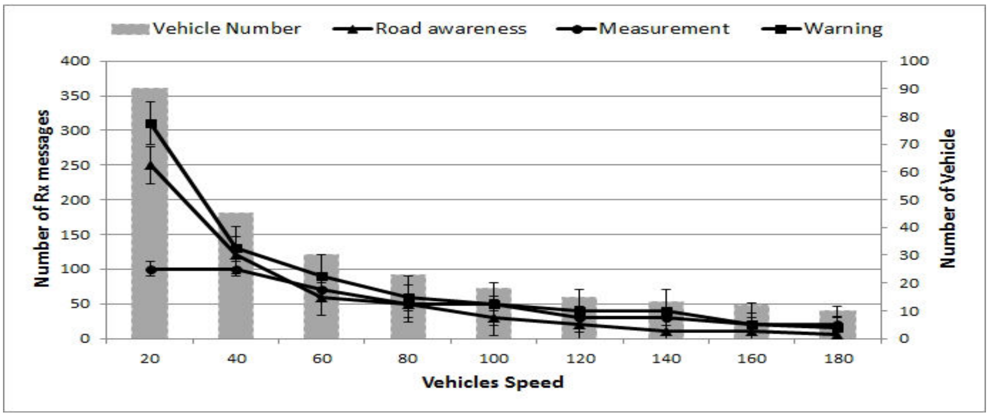

Figure 6.8: Received messages and vehicle number

6.8 Conclusion

Virtual collision is a very frustrating phenomenon that occurs frequently in EDCA mechanism. In this chapter, we oriented our efforts towards evaluating the performance of the virtual collision in presence of three safety services: warning to a foggy zone, inter-distance measurement and road awareness.

In a first step, we proposed an original mapping for WAVE access categories and contributed to their traffic modeling. Then we pursued our studies and elaborated a mathematical modeling based on a two-dimension Markov chain. The model takes into account a car-following model that ensures the adoption of the safety distance. Accurate simulation was performed and compared against mathematical results.

This study permitted to attain three objectives. First, mathematical modeling matches to a certain extent simulation results. Secondly, EDCA virtual collision management mechanism has proven to achieve service differentiation despite of the mechanism main problem: priority inversion. Finally, we have succeeded to draw RSU dimensioning rules in presence of a jam traffic situation.

The following chapter sheds the light on LTE performance. It consists of modeling and performance evaluation of the scheduling mechanism at MAC layer.

Chapter 7

MAC-LTE Scheduler Modeling and Performance Evaluation in LTE Network

7.1 Introduction and Related Work

Long Term Evolution (LTE) is the most recent evolution of mobile phone standards; it has been proposed to provide higher throughput and better spectral efficiency. However with the increasing of services applications supported by each device in LTE networks, the resources sharing function is one of the key challenging issues. In this context, Logical Channel Prioritization (LCP) is referred. In this chapter, we propose a mathematical model and performance evaluation of the MAC layer scheduling algorithm while considering the source traffic characteristics, thus an original applications mapping. Our study highlights the impact of the Radio Resource Control (RRC) configuration on the overall performance during the Transport Block (TB) construction. Our analysis is based on a numerical study of a discrete time Markov chains and validated by an extensive simulation runs.

Different techniques have been introduced in the literature to overcome the challenges of resource allocation with respect of the quality of service constraints.
Authors in [71] propose an analytical model for the time varying cell capacity in LTE and study its impact on the admission control algorithm with no QoS differentiation. In [72], authors address the problem of the resource sharing, where they propose a model at two levels. Using a Markov Decision approach, they propose an algorithm "QoS-aware Two-level Scheduling Algorithm" to optimize the resource allocation and to define the amount of data sent by the traffic source. For the simulations, they took a video traffic source.

The work in [73] proposes a cross-layer algorithm for resource optimization. It is based on the transmission rate, the packets waiting time in the queue and the size of the queue at the MAC level. The proposed model is used to derive the equations of these parameters. Then, the authors evaluate the performance of their algorithm by measuring the bandwidth utility. For this, they use an ON/OFF transmission rate of a voice traffic source. In [74], the authors propose a model to evaluate the performance of the LTE network. They present an analytical model based on a Markov chain, where a state represents the number of users associated to one MCS (Modulation and Coding Scheme). The authors consider two scenarios: the first model with a single class of service and without service differentiation, the second model with two Non-Guaranteed Bit Rate (NGBR) service classes, and QoS differentiation. To validate their model, they choose a download file service, and compare the analytical and simulation results to evaluate the download delays. Authors in [75] present a semi analytical MAC layer model. The model elaborates the allocation resource issue, and focuses on packet delay Qos parameter.

Most of these works propose an analytical model at radio layer, and discus different issues. Some of them carry out the resource allocation problem without taking into account the features of MAC scheduling and the source traffic characteristics. In this chapter, we aim at evaluating the network performance that takes into account the MAC layer processing while considering the source traffic characteristics. We focus on the modeling of the LCP procedure for resource allocation at MAC layer in the context of SOAPS (Spectrum Opportunistic Access in Public Safety) networks [76]. We shed the light as well on the impact of the RRC configuration on the resource allocation by measuring the Transport Blocks filling, as well as its impact on the network performance while guaranteeing a certain quality of service for each traffic. SOAPS project addresses low layers protocols issues for broadband services provision by Private Mobile Radio (PMR) systems using LTE technologies with particular focus on the improvement of frequency resources scheduling.

The rest of the chapter is organized as follows. In section 7.2, we propose an original application mapping, then, we describe the system model and our proposition in section 7.3. In section 7.4, we elaborate the simulation and numerical models followed by performance evaluation results, before concluding the chapter.

7.2 Applications Mapping and Source Traffic Modeling

The QoS radio architecture is based on the concept of mapping data flows to radio bearer and configuring several service classes. Each bearer is defined by several QoS profile parameters: QoS Class Identifier (QCI), Allocation and Retention Policy (ARP), Guaranteed Bit Rate (GBR), and Maximum Bit Rate (MBR) [77]. Table 3.1 in [77] shows the 3GPP standardized QCI profiles, divided into four Guaranteed Bit Rate classes and five classes of Non-Guaranteed Bit Rate.

Our work considers four applications defined in SOAPS project, real time (voice and video) and non-real time (HTTP and FTP) applications. We exhibit the characteristics of the real-time studied service and perform traffic modeling as shown in section 4.4

In this particular study, we considered four services: Video, Voice, FTP and HTTP. As highlighted in Chapter 4. Since voice and video present very strict temporal requirements, they are then mapped to the GBR QCI number 1 and 2 respectively according to the table 6.1.7 in [77].

7.3 System Model

In this section, we elaborate an analytical model using a Markov chain to evaluate the overall network performances and the TB filling during Transmission Time Interval (TTI) duration. The main feature of this model is to observe the system state and determine the probability distribution of the number of waiting packets. In an uplink transmission, one transport block is sent during one TTI, we will monitor the system state at the end of TB_n and just before the beginning of TB_{n+1} as proposed in [78]. Each logical channel is modeled by one FIFO queue, where the state of the system is defined by the number of packets waiting for transmission at each queue i. We assume that the header and control elements are already allocated at each MAC frame n. We consider the following parameter notations:

- PBR^i Priority Bit Rate of the logical channel i.
- B^i Bucket of the logical channel i (the maximum data allowed for a logical channel).
- A_n^i arrival in logical channel i during frame n.
- Q_n^i number of packets in logical channel i during frame n.
- Z_n^i output of logical channel i during frame n.
- L_n^i number of packets that can be used in a logical channel i during frame n.
- $output^i$ the sum of output that a channel can send.
- C the frame size.
- C^i the logical channel size (queue buffer).

where:

$$L^i \leq \quad B^i;\ \forall i \in [1 \ldots N]$$

and

$$PBR^i < B^i;\ \forall i \in [1 \dots N]$$

7.3.1 Waiting in Queues

Clearly, we consider a discrete-time $M/D/L^i/C^i$ queue. We further assume that the services take place after the arrivals and they are deterministic for each queue. A classic way to study these queues is to write the recurrence equations of Lindley:

Proposition 7.1. the number of packets in queue i is governed by the following equation when the queue buffer capacity C^i is finite:

$$Q_n^i = \ ((Q_{n-1}^i + A_n^i) - Z_n^i)^+;$$

$$or : Q_n^i = (inf(B^i; Q_{n-1}^i + A_n^i) - Z_n^i)^+;$$

Where $(Y)^+$ indicates the maximum value of $(0, Y)$ and $inf(a; b)$ represents the minimum between a and b.

7.3.2 Stationarity

The stationary state of our model is studied as well, we denote by ρ_i the queue i load , λ_i the intensity of the packets arrivals, and $E[len_i]$ the service rate ; with $\rho_i = \frac{\lambda_i}{E[len_i]}$. The system is considered stable if and only if:

$$\forall i \in [N \dots 1] \ \ \rho_i < \ 1$$
$$and, \sum_{i=N}^{1} \lambda_i < \ C$$

7.3.3 Analytical Resoluion

At this stage, we exhibit the analytical resolution. Then, we will describe the terms Z_{n+1}^i and Q_{n+1}^i. For this, we take two queues, queue 1 and queue 2 which represent two data logical channels. We assume having two services one for real-time services GBR and the second for non-real time NGBR mapped on the data logical channels described above.

We define $\mathbb{1}_{A>B}$ that equals 1 or 0 according to the following condition:

$$\mathbb{1}_{A>B} = \begin{cases} 1\ if\ A > B \\ 0\ if\ B \geq A \end{cases}$$

As described in section 3.5 the frame is constructed in two cycles:

7.3.3.1 Cycle 1 (Initial state)

first, the scheduler allocates the PBR corresponding to each logical channel:
Queue1

$$
\begin{aligned}
Z^1_{n+1} = &\quad inf(C, PBR^1).\mathbb{1}_{(Q^1_n+A^1_{n+1})>PBR^1} \\
+ &\quad inf(C, [Q^1_n + A^1_{n+1}]).\mathbb{1}_{(Q^1_n+A^1_{n+1})\leq PBR^1} \\
Q^1_{n+1} = &\quad [(Q^1_n + A^1_{n+1}) - Z^1_{n+1}]^+
\end{aligned}
$$

Queue2

$$
\begin{aligned}
Z^2_{n+1} = &\quad inf((C - Z^1_{n+1}), PBR^2).\mathbb{1}_{(Q^2_n+A^2_{n+1})>PBR^2} \\
+ &\quad inf((C - Z^1_{n+1}), [Q^2_n + A^2_{n+1}]). \\
&\quad \mathbb{1}_{(Q^2_n+A^2_{n+1})\leq PBR^2} \\
Q^2_{n+1} = &\quad [(Q^2_n + A^2_{n+1}) - Z^2_{n+1}]^+
\end{aligned}
$$

Throughout this cycle, the number of packets that can be used in each queue i during the frame n is equal to:

$$L^i_n = \quad inf(PBR^i, Q^i_n + A^i_n)$$

We denote by $output_1$ the sum of the outputs of each queue for the construction of the frame (n +1) during the cycle 1, where: $output_1 = \sum^1_{i=N} Z^i_{n+1}$.

7.3.3.2 Cycle 2

We derive first at this stage the number of packets that can be used in each queue i as follow:

$$L^i_n \quad = \quad inf([B^i - Z^i_n]^+; Q^i_n + A^i_n)$$

Now, we define the equations of this two queues for the service of the remaining packets:

Queue1

$$\begin{aligned} Z^1_{n+1} &= inf([C - output_1]^+, Q^1_n + A^1_{n+1}). \\ & \mathbb{1}_{(Q^1_n + A^1_{n+1}) \leq L^1_n} \\ &+ inf([C - output_1]^+, L^1_n).\mathbb{1}_{(Q^1_n + A^1_{n+1}) > L^1_n} \\ Q^1_{n+1} &= [inf(B^1; Q^1_{n-1} + A^1_n) - Z^1_{n+1}]^+ \end{aligned}$$

Queue2

$$\begin{aligned} Z^2_{n+1} &= inf([C - (Z^1_{n+1} + output_1)]^+, Q^2_n + A^2_{n+1}). \\ & \mathbb{1}_{(Q^2_n + A^2_{n+1}) \leq L^2_n} \\ &+ inf([C - (Z^1_{n+1} + output_1)]^+, L^2_n). \\ & \mathbb{1}_{(Q^2_n + A^2_{n+1}) > L^2_n} \\ Q^2_{n+1} &= [inf(B^2; Q^2_{n-1} + A^2_n) - Z^2_{n+1}]^+ \end{aligned}$$

For both queues, we define the probability distribution of the number of packets transmitted at the end of the frame $n+1$ by:

$$\begin{aligned} P(Z^1_{n+1} = i) &= P[inf([C - output_1]^+, Q^1_n + A^1_{n+1}) \\ & = i/(Q^1_n + A^1_{n+1}) \leq L^1_n]. \\ & P[(Q^1_n + A^1_{n+1}) \leq L^1_n] \\ & + P[inf([C - output_1]^+, L^1_n) \\ & = i/(Q^1_n + A^1_{n+1}) > L^1_n]. \\ & P[(Q^1_n + A^1_{n+1}) > L^1_n] \\ P(Z^2_{n+1} = i) &= P[inf([C - (Z^1_{n+1} + output_1)]^+, \\ & (Q^2_n + A^2_{n+1})) = i/(Q^2_n + A^2_{n+1}) \leq L^2_n]. \\ & P[(Q^2_n + A^2_{n+1}) \leq L^2_n] \\ & + P[inf([C - (Z^1_{n+1} + output_1)]^+, \\ & L^2_n) = i/(Q^2_n + A^2_{n+1}) > L^2_n]. \\ & P[(Q^2_n + A^2_{n+1}) > L^2_n] \end{aligned}$$

The expression of *Kolmogorov-Smirnov* equation is derived as follow:

$$P_{n+1}(x_1, y_1) = P(Q^1_{n+1} = x_1, Q^2_{n+1} = y_1) \quad (7.3.1)$$

We replace the terms Q^1_{n+1}, and Q^2_{n+1} in 7.3.1:

$$= \sum_{x=0}^{\infty}\sum_{y=0}^{\infty} P([inf(B^1; Q^1_{n-1} + A^1_n) - Z^1_{n+1}]^+ = x_1/$$
$$Q^1_n = x, Q^2_n = y).P([inf(B^2; Q^2_{n-1} + A^2_n) - Z^2_{n+1}]^+$$
$$= y_1/Q^1_n = x, Q^2_n = y).P(x, y)$$

Although we proposed a description of the logical channel prioritization. However, this approach is analytically not tractable, due to the queues coupling. At this stage, we pursue our study and propose the numerical model.

7.3.4 Numerical Model

In order to evaluate the numerical model, we propose different scenarios that we explain in section 7.4. All the results are given with a confidence interval of 95% with 300 executions. For each value, we consider the TDD (Time-Division Duplexing) mode. In this mode, a transport unit can hold 10 TB. We vary the number of possible TDD transmissions (the number of frames to generate corresponds to $NB_{TDD} \times 10$) and we analyze the average number of waiting packets in each queue and the average size of the transport blocks. We denote by SF the average frame size (see section 7.4).

7.4 Performance Evaluation

In order to evaluate the performance of the LTE MAC layer, and to validate the efficiency of our model, we conducted extensive simulation runs on Matlab simulator; We consider Uplink transmission on 3 MHz channel bandwidth and we adopt OFDM modulation with 16-QAM and a MCS index equal to 19. The frame duration is fixed to one $TTI = 1ms$. In fact the transport block size is equal to 5352 bits with controlling overhead (see [79]). We assume that a part of the frame is allocated to the control elements, and the remaining space for the data logical channels allocation. We assume that the user runs the four services modeled in section 7.2: Voice, video, HTTP and FTP services. So, the simulated queuing system is defined by four FIFO queues. Once the RRC layer configures the logical channel parameters: PBR and BSD, we computed the following performance parameters: the average offered throughput, queuing delay, queue length as well as the probability distribution of number of packets and the transport block filling. Different scenarios are considered.

7.4.1 Simulation and Numeric Measurements

In the following scenarios we take into account the source traffic parameters of GBR (Voice, video) and NGBR (HTTP, FTP) services, as well as different RRC configuration of LCP parameters PBR and BSD.

7.4.1.1 Scenario 1

In this scenario we investigate the Bucket variation between the four services described above. We assume the following LCP parameters in table 7.1, the PBR and BSD are affected in decreasing order according to service priorities.

	Voice	Video	HTTP	FTP
PBR (Kb/s)	64	32	16	8
Bucket (Byte)	2400	600	200	50

Table 7.1: Scenario 1 parameters

Figure 7.1 shows the offred throughput measurement. The curves show that the throughput increases when the affected bucket rises, except for voice service because of its low requested PMR traffic load ([80]). During the frame duration, the queue size does not exceed the affected Bucket, in this case we can ignore this parameter and assume that the GBR services don't need a source flow control. However the throughput offred by HTTP and FTP services is lower than the requested one and don't exceed 1592 Kb/s. In fact, this is due to the configured Bucket; the authorized data in HTTP and FTP queues is very limited, even if the requested throughput is higher or the transport block is not completely full.

7.4.1.2 Scenario 2

In the first scenario we found that the Bucket controls the traffic source, and limits the throughput for the NGBR services, consequently, the transport blocks are not full, and the overall performances are decreased. We then propose the second scenario. We investigate the same performances parameters when we increase the Bucket value for all services. We took the same PBR value, and we change the BSD value; see table 7.2.

	Voice	Video	HTTP	FTP
PBR (Kb/s)	64	32	16	8
Bucket (Byte)	19200	4800	1600	400

Table 7.2: Scenario 2 parameters

We observe in figure 7.1 that the video and voice throughput does not change in comparison with the first scenario, while the HTTP throughput increases. However the FTP throughput is limited to the configured PBR even if its bucket value is higher. In fact HTTP service is assigned higher priority than FTP to access the entire remaining resources after GBR allocation. In this scenario the transport block is completely full, but the FTP performances are drastically degraded. We propose then the third scenario.

7.4.1.3 Scenario 3

In this case we change the PBR values, always in respect of priority order; however, the BSD values change as follow: voice transmits its bucket in 300 ms, video in 150 ms, HTTP in 50 ms and FTP in 100 ms (table 7.3). Clearly, FTP is less prior that HTTP, however they have the same requested throughput but FTP needs some fairness to ensure better performances. For that we propose that HTTP and FTP have the same Bucket.

	Voice	Video	HTTP	FTP
PBR (Kb/s)	128	64	32	16
Bucket (Byte)	4800	1200	200	200

Table 7.3: Scenario 3 parameters

NB_{TDD}	SF (octets)
1	654.503 ± 1.64342
5	654.430 ± 0.70362
10	655.131 ± 0.50318
20	655.317 ± 0.35503
50	655.370 ± 0.22302
100	656.343 ± 0.15791

Table 7.4: Average frame size

In comparison with the other scenarios (see figure 7.1), we can see that the GBR throughput performances does not change. However, FTP performances clearly improve, despite that HTTP performances are still better than FTP. This is due to PBR parameter, the minimum amount of pending data allowed for HTTP service is higher than FTP.
In addition to the overall performances evaluation, we investigate the transport block filling during the frame duration, contrarily to the first scenario, the transport block are completely full, consequently the resource allocation are optimized. We conclude that with this configuration, the overall performances have improved with respect of Qos requirements and FTP fairness.

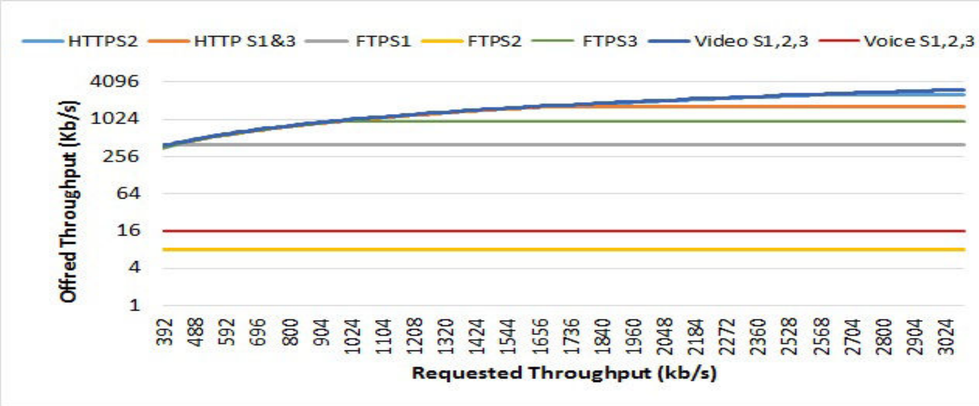

Figure 7.1: Comparison: Throughput

We investigate also the impact of each configuration on the queue length and waiting delay. Figure 7.5 exhibits the average queue length for FTP and HTTP services. One can see that when the bucket gets small value, FTP is assigned lower priority to access the remaining resources after GBR allocation, and thus higher queue length. The greater the bucket is, the higher the NGBR queue length will be, and hence the longer a packet will wait in the queue.

However the GBR queue length is small (reaches zero) and it is not affected by the bucket value. Indeed the higher the priority service is, the smaller the queue length will be, which reduce the waiting time (figure 7.3).
Now, using this configuration we will validate our model and will compare the numerical and simulation results by measuring the transport block filling and the probability distribution of number of waiting packets. We note from results shown in Table 7.4 that the transport blocks are completely filled during this scenario. We compared the numerical and simulation results, and we we noticed the matching between them, this validates our proposal model.

In figure 7.2 we compare between simulation and numeric probability distribution of number of waiting packets in the system.
Indeed, the GBR services are completely served with respect of quality of service constraints, so the probability that their queues are empty equal to 1. However, since the HTTP service is less prior than voice and video one, the probability that its queue is empty reaches 0.7, where the FTP one reaches 0.1 and this for both analytical and simulation results.

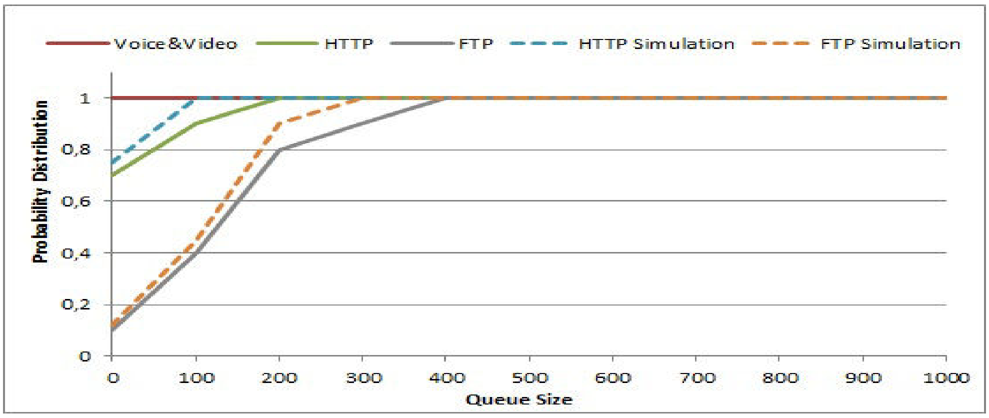

Figure 7.2: Cumulative Distribution Function Queues.

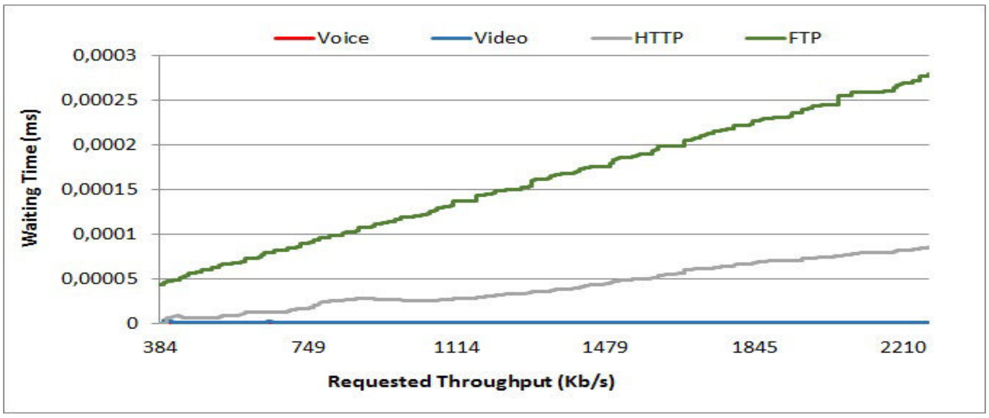

Figure 7.3: Scenario 3: waiting delays

7.4.1.4 Scenario 4

We shed the light in this scenario on a comparison between scenario 3 and Priority Queuing service policy (PQ). In fact, with PQ, the GBR service classes are served until their queue gets empty, then the NGBR service class will have the right to be transmitted, there is a strict priority between the four classes of service.

Figure 7.4 shows a comparison in term of throughput evaluation between PQ and LCP scheduling in the third configuration since it is the best one. We can see that the GBR performances don't change; we focalize then on HTTP and FTP classes.

HTTP offred throughput in scenario 3 of LCP scheduling is lower than PQ. In fact with a strict priority HTTP transmits until its queue gets empty or there are no remaining resources, however in LCP procedure, the scheduling mechanism keeps some fairness between services and limits the HTTP performance in order to maintain a minimal amount of resources to the FTP, which explain the difference between the two scenarios. PQ policy induced starvation problem to the FTP service whenever the highest priority flow continues. Regarding the queue length (consequently waiting delay), PQ achieves better

HTTP Qos guarantees (Figure 7.5). However, it induces FTP degradation performances since PQ provides strict priority. The two policies provide the same GBR services, they achieve their Qos guarantees.

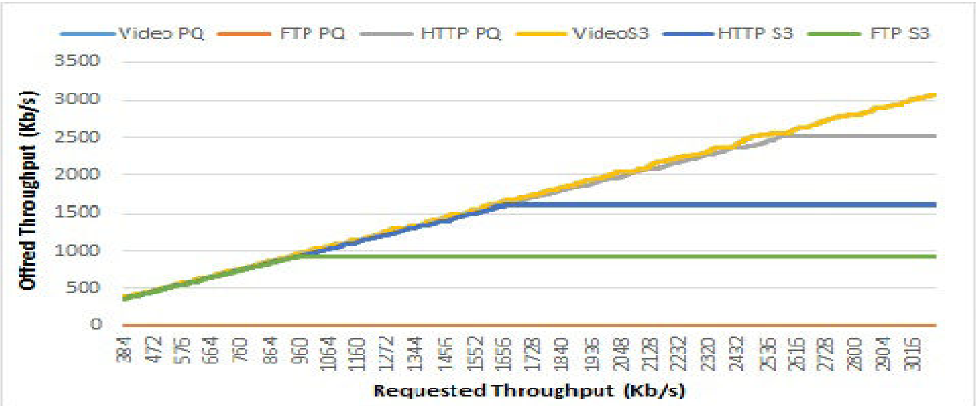

Figure 7.4: Comparison Scenario3 vs PQ: Throughput

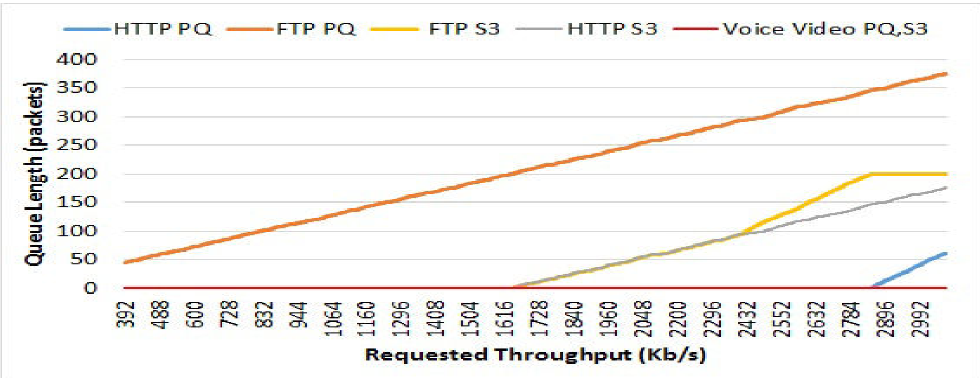

Figure 7.5: Comparison Scenario3 and PQ: Queue Length

7.5 Conclusion

We proposed an analytical model of MAC layer in LTE technology in order to evaluate the network performances. We have seen that multiple parameters are taken into account in the proposal model, they can influence directly the overall performances. With simulation, we compared the most important results captured by numerical model, through measuring the distribution probability of number of packets in queues and the transport block filling ratio. Simulation and numerical results confirm the service differentiation and respect of critical nature of GBR services, thus the fairness of NGBR services. The throughput, the waiting delays and the queue length are measured too, we chose different performances evaluation scenarios, and it turns out that performances change in each configuration.

Performance can drastically degrade if the RRC layer does not manage efficiently resource allocation. Otherwise efficient RRC resource allocation mechanism notably improves and avoids starvation problem that is incurred by PQ scheduling. We propose then in next chapter a cross-layer algorithm to allow the RRC layer to take a pre-decision before the allocation process.

Chapter 8

Cross-Layer Scheduling Algorithm in LTE Multiservice Networks

8.1 Introduction and Related Work

Long Term Evolution (LTE) networks are expected to provide enhanced quality of service (QoS) guaranteed services and a high capacity. In this chapter, the focus is on the packet scheduling of data generated by exhaustive classes of service. The performance of a new scheduling algorithm, based on a RRC-MAC layer interaction, is proposed. Channel prioritisation is adapted to traffic achieved throughput, thus rising the priority of penalized traffic and preventing non real time class of service starvation. Performance results show that the proposed algorithm is effective in enhancing fairness, throughputs and reducing the waiting packet delay. The cross-layer scheduling algorithm aims to find an agreement between fairness and services QoS requirements.

Emerging technologies like LTE as defined by the 3rd Generation Partnership Project (3GPP) [5] offer high data rate capabilities to mobile users and strives to deliver a true mobile broadband experience. Motivated by real time video services which are expected to be the main revenue generators in the near future, development of efficient fair resource allocation techniques is a key issue for researchers and operators.

In wireless multiservice networks tackling uplink transmissions, there is a stressing need to avoid starvation of low priority class of service. To address this need in LTE, each user equipment is provided with an uplink rate control function that handles uplink resources sharing between radio bearers. This uplink rate control function is known as logical channel prioritization procedure (LCP). LCP is executed whenever a new transmission occurs, i.e. a transport block needs to be generated. One proposal for resource allocation is to assign resources to each bearer, initially in priority order, until each one has received a ressource allocation equivalent to the minimum bearer data rate. Then, the remaining resources are allocated to bearers in priority order.

In this chapter, we propose to enhance the LCP procedure by adapting the bearer priority to the achieved traffic throughput and integrating a RRC-MAC layer interaction. In fact, we believe that cross layer interaction exploits dependencies of protocol layers, thereby fulfilling quality of service demands of various applications. A particular concern is devoted to the RRC-MAC cross layer scheme: the quality of service is highly affected by the MAC layer resource allocation configured by the RRC layer. Performance drastically degrades when the RRC layer does not adopt an efficient scheduling algorithm; whereas good performance is achieved when RRC cooperates with the MAC layer[81] . Therefore, a close coordination between the MAC layer and the RRC layer is required leading to the cross layer implementation.

Different cross-layer frameworks and scheduling algorithms were proposed in the literature. Authors in [71] tackled users resource sharing issue in the IEEE 802.16 network. They proposed a cross-layer scheduling algorithm that takes into account different channel conditions. Moreover, they derived an utility function that aims at achieving users fairness.

The work in [73] proposed a cross-layer algorithm for resource optimization. It is based on the transmission rate, the packets queue waiting time and the queue size at the MAC level. Then, the authors evaluated their algorithm performance by measuring the bandwidth utility.

Authors in [82] integrated a new scheduling algorithm in HSDPA by applying a cross layer design. Resource allocation takes into account radio conditions and classes of service requirements. In addition, authors introduced the adaptability concept; more precisely, users packets which are rejected with regular algorithms due to the lack of codes can be scheduled with their algorithm since adaptation is performed.

Authors in [75] presented a scheduling algorithm based on a cross layer communication. They considered the waiting time as a QoS criteria that triggers the resource allocation process. Besides the scheduler takes into account physical layers parameters.

Article [72] tackled resources sharing problem between several services. In this perspective, authors proposed a polling-based scheduling algorithm. The proposed algorithm does not take into account the channel conditions nor the service parameters.

In [74], authors proposed a scheduling algorithm dedicated to LTE networks. The scheduler allocates resources according to users priorities and thus performs users differentiation. In the cited paper, authors did not take into account the impact of the RRC layer on the

MAC layer resource allocation algorithm.

In [8], authors studied a scheduling algorithm for LTE downlink communication at MAC level. The algorithm integrates MAC logical channel prioritization and service differentiation. More specifically, the algorithm prioritizes Guaranteed Bit Rate (GBR) services over the remaining services. Moreover, authors assumed that a portion of resources, namely α, is reserved solely for the usage of GBR class of service. Therefore, the reservation strategy combined with the prioritization scheme induces starvation for low priority class of service. This paper [83] recommends a cross layer approach for resource allocation based on Quality of Experience (QoE) for multi-service downlink Long Term Evolution (LTE) systems. They mainly focused on physical parameters and application characteristics.

Using the cross layer technique, authors in [84] proposed an algorithm that allocates resource blocks to different traffic flows (real time and best-effort traffic). The objective is to maximize the expected total user satisfaction under different services constraints.

[85] proposed a cross layer interaction between application and MAC layer in LTE network. Authors analyzed the coexistence of Forward Error Correction (FEC) scheme in application layer and Hybrid Automatic Repeat reQuest (HARQ) at MAC layer to avoid redundancy and useless retransmissions at LTE downlink.

In this chapter, we raise the scheduling issue at MAC level in a LTE network providing quality of service to various real time and non real time classes of service. More specifically, we design a scheduling algorithm that meets requirements of each traffic class and strikes a balance between fairness and bandwidth utilization while guaranteeing a certain quality of service level to each traffic flow. The proposed scheduling algorithm is a part of a cross layer framework that adopts the interaction between RRC and MAC layers. In fact, monitoring and providing knowledge about low layer conditions to higher layers allow designing more sophisticated resource allocation and optimization algorithms. Moreover, channel prioritization is adapted to traffic achieved throughputs. In this context, users, experiencing good channel condition and satisfactory average throughput, should be assigned a low priority and thus adapt their throughput in order to satisfy penalized users. Consequently, fair resource allocation mechanism is achieved and non real time classes of service starvation problem avoided.

The remainder of the chapter is organized as follows.

- We define a dynamic priority function that achieves fairness to various classes of service in section 8.3.1.
- We design a priority-based scheduling algorithm based on a cross-layer RRC-MAC

interaction in section 8.3.2.

- Section 8.4 is devoted for performance analysis through a LTE simulation before concluding the chapter.

8.2 LTE Classes of Service

The present study manipulates four services with various traffic specifications: HTTP,FTP, voice and Video. The source modelling of each traffic is achieved in section 4.4.

Class of service mapping At this stage, we address class of service mapping applied to the envisionned services identified in the previous subsection. Since the voice and video services have very strict temporal requirements, they are then mapped to the GBR QCI number 1 and 2 respectively according to Table 3.1.

On the other hand, HTTP and FTP services are mapped to NGBR services. This is due to the fact that these non real time services do not require strict delay. As a consequence HTTP can be handled by the class of service with QCI 8. In order to perform service differentiation, we map FTP (lower priority than HTTP) to NGBR class of service with QCI 9.

8.3 Cross Layer Scheduling Algorithm

The RRC layer controls the scheduling of uplink data by configuring the logical channel prioritization and helps the MAC layer to apply multiplexing and assembly procedures. More precisely, with the legacy LCP standard, RRC assigns a priority to each logical channel according to the mapping of service classes (section 8.2).

With our proposed scheduling procedure, the channel prioritization will change according to the traffic assigned rates; therefore, traffic queues suffering from a low rate will have an increased priority in order to prevent starvation. Thus, we propose to assign a dynamic priority to the different bearers in order to take into account the achieved throughputs as will be detailed in next subsection.

8.3.1 Dynamic Priority

In an attempt to achieve a trade-off between fairness and efficiency, we define a Dynamic Priority function $DPi(t)$ for each logical channel i. The service with the highest dynamic priority value is enabled to transmit and thus will be assigned the highest priority. We then define the Dynamic priority function defined as the user instantaneous data rate divided by its current average throughput. The latter is evaluated through an exponential weighted low-pass filter. The dynamic priority function and average throughput are computed as follows :

$$DPi(t) = \frac{Ri(t)}{Ti(t)}$$
$$Ti(t) = (1 - \frac{1}{Tc}) \cdot Ti \cdot (t-1) + xi \cdot \frac{1}{Tc} \cdot Ri(t)$$

When the average throughput of a queue i is low, the average value of $DP_i(t)$ will be high and the queue will be likely to be granted the right of transmission even if the traffic queue falls into a low priority class of service.
The scheduler changes the queues priority order according to dynamic priority value (the higher the DP value is, the higher its bucket value will be). However the scheduler maintains a higher priority bit rate value for GBR services than other services.

8.3.2 Cross Layer Interaction and Resource Allocation

Before presenting the resource allocation procedure, we first define the parameters manipulated in the algorithm. We assume that the header and control elements are already allocated at each MAC frame n, and we consider m logical channel modeled by m FIFO queues. We consider the following parameter notations:

- i: the number of logical channels $i \in \{1..\text{m}\}$.
- PBR^i: Priority Bit Rate of the logical channel i.
- BSD^i_n: Bucket Side Duration used to define the maximum data allowed for a logical channel i during frame n. It is noteworthy that the allocated resource $PBR^i * BSD^i$ cannot exceed the Bucket (B^i).
- B^i_n: Bucket of the logical channel i during frame n.
- L^i_n: number of bits sent on a logical channel i during frame n.
- C: The frame size.
- Ti: The average throughput of the logical channel i.
- Ri: The actual served rate of the logical channel i.
- xi: equal to 1 if the logical channel i is scheduled and 0 otherwise.
- Tc: a parameter varying between 800 and 1000.

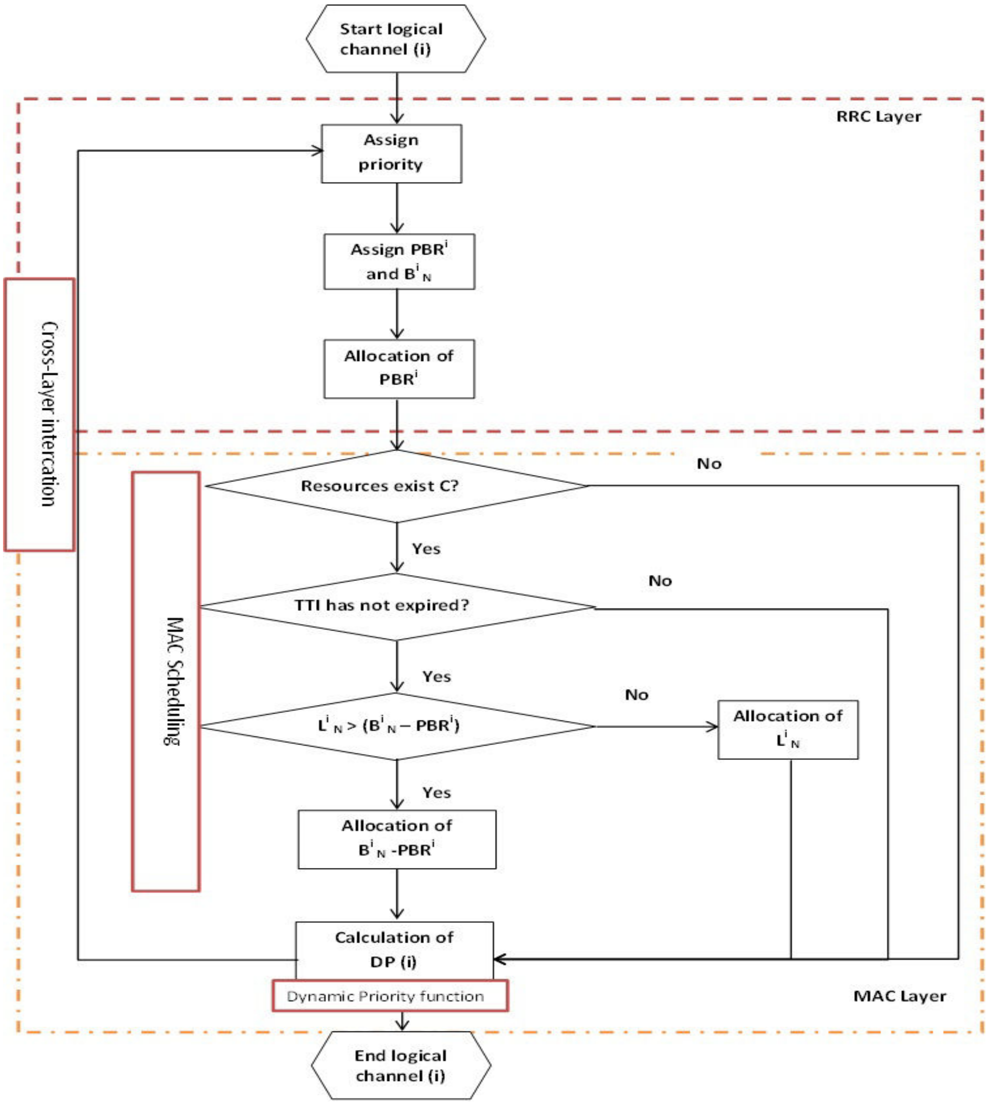

Figure 8.1: Block diagram of the Cross-Layer Scheduling algorithm

8.3.3 Cross Layer Interaction

8.3.3.1 Step 1: RRC Resource Allocation

The cross layer RRC/MAC interaction starts with the RRC resource allocation (figure 8.1). In fact, during a frame n the RRC layer allocates the PBR^i, and the B^i_n for the different queues starting with the queue having the highest priority . The higher the logical channel priority is, the higher the PBR will be, the more data is assigned to a logical channel and the greater its Bucket will be. Initially, RRC considers a static priority and assigns resources according to the initial mapping and priority levels. It is noteworthy that the RRC resource allocation satisfies the following condition:

$$\sum_{i=1}^{m} min(L_n^i, B_n^i) \geq C$$

This condition allows us to fix the bucket value and thus overcome the transport block filling problem that can be found in some RRC configurations [81].

```
Function Initialization (RRC layer)
    For i = 1..m
        Assignment of priority according to the initial mapping;
        Assignment of PBR^i_init;
        Checking the condition ∑ min (L^i_n, B^i_init) > C
        Assignment of B^i_init;
    End For
End Function

For J = 1..N (Number of Transport Blocks)

    Function Scheduling (MAC layer)

        For i = 1..m
            For J= 1...1
                B^i_j = B^i_init;
            End For

            • Cycle 1:
            PBR^i_init are first assigned in a decreasing order; the higher the logical
            channel priority is, the higher the PBR^i_init will be, the more data is
            assigned to a logical channel;
            • Cycle 2:
            If any resource remains in the current frame, the scheduler serves each
            logical channel again in decreasing order up to their configured Bucket
            (B^i_j )
        End For

    Function DP
        For i = 1..m
            Computation of DPi;
        End For

    Function Logical Channel Reconfiguration (Feedback to RRC layer)
        For i = 1..m
            % the initial value PBR^i_init is maintained %
            Assignment of priority according to DPi results;
            Checking the condition ∑ min (L^i_n, B^i_init) > C
            Assignment of (B^i_j );
        End For

End For
```

Figure 8.2: The Cross-Layer Scheduling algorithm

8.3.3.2 Step 2 : MAC Scheduling

If any resource remains in the current frame, the MAC scheduler serves each logical channel in decreasing order up to their configured Bucket. The process ends if all logical channels of higher priority have no more data for transmission, or if there is a lack of resources.

8.3.3.3 Step 3: Updating the Dynamic Priority

The MAC layer computes the dynamic priority of each queue according to its assigned rates; thus upgrading penalized queues and achieving fairness. Then the MAC layer sends the dynamic priority values of the different queues to the RRC layer. This feedback enables the RRC layers to update the resource allocation. The procedure executes then step 1. Figure 8.2 summarize the different steps of the proposed algorithm

8.4 Performance Evaluation

In order to evaluate the performance of the LTE MAC layer and validate the efficiency of our scheduling algorithm, we conducted 400 extensive simulation runs on Matlab simulator. We considered an uplink transmission on 3 MHz channel bandwidth and adopted OFDM modulation with 16-QAM and a Modulation and Coding Index (MCS) index equal to 19. The frame duration is fixed to one $TTI = 1ms$, one a transport block (TB) is sent every TTI and the transport block size is set to 5352 bits with controlling overhead ([79]). We assume that a part of the frame is allocated to the control data. Each user runs four services modeled in section 8.2: Voice, video, HTTP and FTP services. We take into account the source traffic parameters proposed in section 4.4. The GBR logical channel transports voice and video packets, and the NGBR handles HTTP and FTP traffic, as described in section 8.2.

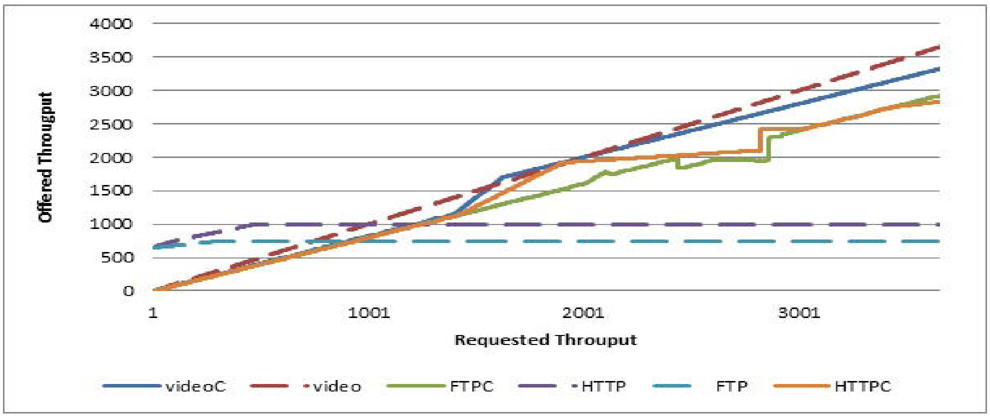

Figure 8.3: Offered Throughput

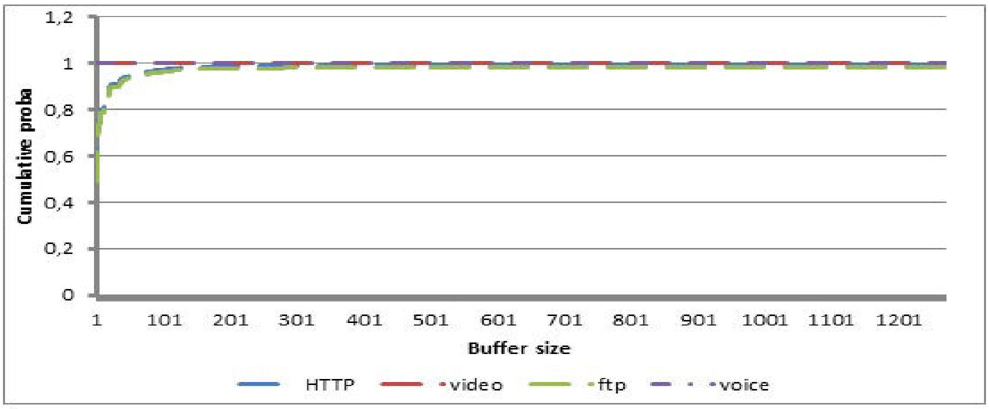

Figure 8.4: Cumulative Distribution Function with LCP procedure

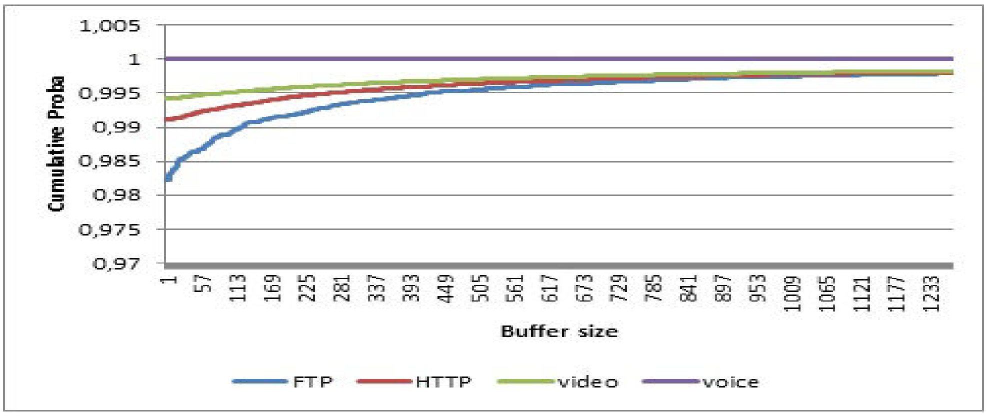

Figure 8.5: Cumulative Distribution Function with Cross-Layer algorithm

Figures 8.3, 8.4 and 8.5 compare the offered throughput and the queue cumulative distribution functiom retrieved with the LCP scheduler and the cross layer scheduler. We draw the following interpretations:

- One can see that the offered throughput increases when the requested throughput rises, except for voice service due to its low requested PMR traffic load [80].
- The Video offered throughput with the cross layer scheduler is slightly lower than that of the LCP scheduler case. This can be explained by the fact that the cross layer scheduler dynamically adapts queues priorities to the DP function.
- Service differentiation is achieved with the cross layer scheduler. In fact, video performance is better than that of NGBR services. Moreover, HTTP QoS parameters outperform that of FTP.
- The throughput offered to HTTP and FTP services in case of LCP procedure is lower than the requested (lower than 1000 Kb/s) contrarly to our algorithm. This is

due to the limited configured bucket. With the RRC/MAC cross layer scheduler, the bucket allocation is based on the requested throughput, the size of transport blocks and DP function that provides fairness to different classes of services preventing starvation.

- With the LCP procedure, the cumulative distribution function (CDF) of GBR services is 1. Indeed, GBR services are served with respect of their quality of service constraints, leading to empty waiting queues. Contrarly to HTTP and FTP services which present a CDF that reaches 0.5 with the LCP procedure (figure 8.4). Nevertheless, with the cross layer scheduling algorithm the CDF rises for HTTP and FTP; this is interpreted by a better service of NGBR queues reflected by a low number of waiting packets.

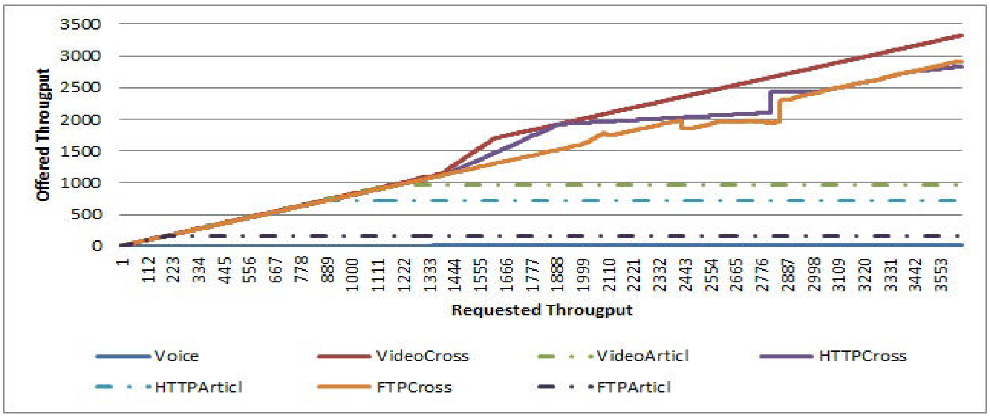

Figure 8.6: Offered Throughput with Cross-layer algorithm and [8] algorithm

Another set of simulation runs are carried out in order to compare the performance of the cross layer algorithm and the resource allocation proposed in [8] (section 8.1). We adopted the same parameters set in [8]. Figure 8.6 exhibits the offered throughputs retrieved with both algorithms.
We note that the cross layer algorithm achieves high throughputs. Besides, one can see that the FTP traffic suffers from starvation with the algorithm proposed in [8]. This is a major concern in a LTE network that tackles different classes of service and is supposed to provide fairness. Therefore, we conclude that the interaction between RRC and MAC layer, in the framework of cross layer design, adapts resource allocation to the different classes of service requirements. Moreover, the dynamic priority function helps to promote penalized queues and settles a balance between fairness and quality of service provisionning.

8.5 Conclusion

We proposed a new scheduling algorithm based on RRC-MAC layer interaction in LTE technology. We have seen that multiple parameters are taken into account in the proposal algorithm.

First, we proposed a source traffic modeling of four services with various traffic specifications, we manipulated two GBR services and two NGBR services. With simulation we evaluated the overall performances considering these services, we captured the offered throughput, the distribution probability of number of packets in queues and beside that we observed the transport block filling.

We compared our proposal with LCP scheduling procedure and with existing works. Performance analysis shows that the proposed algorithm is effective in enhancing fairness, throughputs and reducing the waiting packet delay.

It is noteworthy that our study brings the focus to multiservice scheduling dedicated to LTE networks. In our future works, we aim at investigating multiservice and multiuser scheduling in beyond 4G networks. This will confirm the benefits of the cross layer scheme coupled to efficient scheduling algorithm

Chapter 9

General Conclusion and Future Directions

During the past years, automotive industry and road safety stakeholders have strived to enhance vehicular active safety in the pre-crash phase. Active safety refers to technology assisting in the prevention of a crash. Active systems include braking systems traction control systems and electronic stability control systems, that interpret signals from various sensors to help the driver control the vehicle. Additionally, forward-looking, sensor-based systems and collision warning/avoidance/mitigation based on wireless networks systems are also considered as active safety systems under this definition. In this context, vehicular networks disseminate urgent messages related to assistance, warning and information applications.

In this thesis, we focused on wireless networks in vehicular environments, namely 802.11p and LTE networks. More specifically, we achieved the following contributions:

- We started our research by deriving authentic mathematic traffic modelling of vehicular applications. The selected applications fall into safety, traffic management and comfort categories.
- We proposed and justified the mapping of the selected vehicular application to access categories in 802.11p network and LTE classes of service.
- We conducted a performance evaluation of the ETSI/ WAVE lower layers. This study enabled us to draw conclusions regarding vehicular network performance and thus to propose efficient resource allocation mechanisms that aim at enhancing quality of service.
- We proposed and modelled a a resource allocation mechanism that performs a global

management of radio resources. The performance analysis showed that it enables better use of available capacity in the various networks. The developed resource allocation mechanism aims at providing a deterministic or static guarantee to user requests.

- In the continuity of the resource allocation mechanism proposal, we integrated the cross layer scheme in LTE. In this context, we proposed to adapt the bearer priority to the achieved traffic throughput and integrated a RRC-MAC cross-layer scheme. Performance analysis shows that cross layer interaction exploits dependencies of protocol layers, thereby fulfilling quality of service demands of various applications. At this stage we addressed the challenge of multi-service scheduling and resource allocation. In near future we plan to work on an improvement of our cross-layer algorithm by introducing multi-user multi-service solution.

In order to overcome V2V failure recovery delays and the limitations of routing techniques, a novel framework based on LTE D2D (Device to Device) was recently proposed in the literature. In fact, V2V communication over LTE is inherently D2D communication in which vehicles establish direct communication without the help of any network infrastructure. More precisely, LTE applicability is claimed in vehicular environments for the following reasons:

- Coverage and Mobility: LTE will rely on a capillary deployment of eNodeBs organized in a cellular network infrastructure offering wide area coverage. This would solve the 802.11p issue of poor, intermittent, and short-lived connectivity and would make LTE particularly indicated for V2I communications even at high node speeds. The LTE infrastructure exploitation would also represent a viable solution to bridge the network fragmentation and extend the connectivity in those scenarios where direct V2V communications cannot be supported due to low car density (off-peak hours, rural scenarios, etc.) or to challenging propagation conditions (e.g., corner effect due to building obstructions at road intersections).

- Position based routing: The absolute geographical location of vehicles introduces new type of transmission based on their geographical position.

- Capacity: LTE offers high downlink and uplink capacity that potentially supports several vehicles per cell. Such values are higher than 802.11p, which offers a data rate up to 27 Mbps.

In our future works, we plan to continue studying resource allocation and QoS guaranteeing aspects in LTE D2D scenarios. In fact, these are the most challenging and important issues in D2D communications. On the other hand, several challenges still need to be resolved such as D2D mode switch, D2D interference management, signaling overhead trade-off, cross-layer optimization with joint time, frequency and space-domain resource allocation and vertical handover.

Moreover, the coexistence of multiple access technologies allows us to move towards a new perspective that is Heterogeneous Networks (HetNets) due to its capability to support high speed connections, flexibility of resource management, and integration of distinct access technologies. We plan in future work to expand the HetNets properties to support vehicular communications.

Chapter 10

Publications, Presentation and Projects Reports

Publications

- Naila Bouchemal, Rola Naja and Samir Tohme. EDCA Virtual Collision Performance Evaluation and Mobility Modeling in V2I Communications. In Proc. Twentieth International IEEE Symposium on Computers and Communications (ISCC 2015), July 2015, Cyprus.

- Naila Bouchemal, Rola Naja, Mahmoud Mobarak and Samir Tohme. EDCA Modeling and Performance Evaluation in V2I Communications. In Proc. IEEE Fifth International Conference on Digital Information and Communication Technology and its Applications (DICTAP2015), April 2015, Lebanon.

- Naila Bouchemal, Rola Naja and Samir Tohme. Traffic Modeling and Performance Evaluation in Vehicle to Infrastructure 802.11p Network. In Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, Springer, vol. 129, 2014, pp 82-99.

- Naila Bouchemal, Nora Izri and Samir Tohme. MAC-LTE Scheduler Modeling and Performance Evaluation in LTE Network, In Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2014), Washington, 2014, DOI: 10.13140/2.1.1280.4480.

- Naila Bouchemal, Rola Naja and Samir Tohme. Cross-Layer Scheduling Algorithm in LTE Multiservice Networks. Submitted to NTMS 2015.

Projects Reports

- Naila Bouchemal and Samir Tohme. Applications ITS ET Architecture Général 802.11p, Deliverable D2.1, CoDrive Project, November 2011.
- Naila Bouchemal and Samir Tohme. Dimensionnement et évaluation des performances du réseau 802.11p dans Co- Drive, Deliverable D3.3, CoDrive Project, March 2012.
- Naila Bouchemal and Samir Tohme. La couche Facilities et les messages CAM/ DENM, Présentation, CoDrive Project, December 2012.
- Naila Bouchemal and Samir Tohme Allocation des canaux selon la norme européenne, Deliverable D3.2, CoDrive Project, April 2013.
- Naila Bouchemal and Samir Tohme. Dimensionnement et évaluation des performances du réseau Ethernet dans Co- Drive, Deliverable D3.5, CoDrive Project, June 2013.
- Naila Bouchemal, Amine Adouane and Samir Tohme. Definition and specification of test scenarios, Deliverable D1.2.1, SOAPS Project, October 2013.
- Joint physical-application-network layers studies for conversational voice and video transmission optimization, Deliverable D3.2.2, Naila Bouchemal, Amine Adouane, Samir Tohme, SOAPS Project, July 2014.
- Naila Bouchemal and Samir Tohme. General Architecture of the Telecommunication System, Deliverable D2.3.1, SOAPS Project, August 2014.
- Naila Bouchemal, Amine Adouane and Samir Tohme. Joint physical-application-network layers studies for conversational voice and video transmission optimization-Simulation results, Deliverable D3.2.3, SOAPS Project, April 2015.

Presentations

- Naila Bouchemal. Cross-Layer Scheduling Algorithm in LTE Multiservice Networks, IEEE Comsoc Workshop Lebanon Communications Research Day LCRD, Lebanon, April 2014.
- Naila Bouchemal. MAC-LTE Scheduler Modeling and Performance Evaluation in LTE Network, Doctoriales 2014, University of Versailles, December 2014.
- Naila Bouchemal. MAC-LTE Scheduler Modeling and Performance Evaluation in LTE Network, Séminaire DigiCosm , University of Versailles, October 2014.
- Naila Bouchemal. Modéle analytique des flux de trafic dans Vanet, Doctoriales 2012 , Poster, University of Versailles, December 2012.

Bibliography

[1] Ieee standard for information technology-telecommunications and information exchange between systems-local and metropolitan area networks-specific requirements - part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications. *IEEE Std 802.11-2007 (Revision of IEEE Std 802.11-1999)*, pages C1–1184, 12 2007.

[2] European Telecommunications Standards Institute. Intelligent Transport Systems (ITS); Communications Architecture. EN 302 665 V1.1.1, ETSI, September 2010.

[3] International Organization for Standardization. Intelligent transport systems - Communications access for land mobiles (CALM) âĂŞ Architecture. Technical report.

[4] European Telecommunications Standards Institute. Intelligent Transport Systems (ITS); Users and applications requirements; Part 1: Facility layer structure, functional requirements and specifications. TS 102 894-1 V1.1.1, ETSI, August 2013.

[5] J.B. Kenney. Dedicated short-range communications (dsrc) standards in the united states. *Proceedings of the IEEE*, 99(7):1162 –1182, july 2011.

[6] P3gpp ts36.300. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Overall Description.

[7] Anritsu Company. Lte resource guide, 2009.

[8] Stefania Sesia, Issam Toufik, and Matthew Baker. *LTE: the UMTS long term evolution*. Wiley Online Library, 2009.

[9] Wei Hong Fu, Qing Liang Kong, Wei Xin Tian, Cheng Wang, and Li Li Ma. A qos-aware scheduling algorithm based on service type for lte downlink. *Applied Mechanics and Materials*, 347:2468–2473, 2013.

[10] Vettath Pathayapurayil Harigovindan, Anchare V Babu, and Lillykutty Jacob. Ensuring fair access in ieee 802.11 p-based vehicle-to-infrastructure networks. *EURASIP Journal on Wireless Communications and Networking*, 2012(1):1–17, 2012.

[11] ISAT Nevers and Mr François COLET Examinateur Renault. Réseaux véhiculaires: Dissémination, routage et collecte de données: Modèles et algorithmes.

[12] The Institute of Electrical and Electronics Engineers. IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE)-Resource Manager. Technical report, October 2006.

[13] The Institute of Electrical and Electronics Engineers. IEEE Standard for Wire- less Access in Vehicular Environments - Security Services for Applications and Management Messages. Technical report, April 2013.

[14] The Institute of Electrical and Electronics Engineers. IEEE Standard for Wire- less Access in Vehicular Environments (WAVE) - Networking Services. Technical report, April 2010.

[15] The Institute of Electrical and Electronics Engineers. IEEE Standard for Wire- less Access in Vehicular Environments (WAVE) - Multi-channel Operation. Technical report, February 2011.

[16] Klaus Ingemann Pedersen, Troels Emil Kolding, Frank Frederiksen, István Zsolt Kovács, Daniela Laselva, and Preben Elgaard Mogensen. An overview of downlink radio resource management for utran long-term evolution. *Communications Magazine, IEEE*, 47(7):86–93, 2009.

[17] Hannes Ekstrom. Qos control in the 3gpp evolved packet system. *Communications Magazine, IEEE*, 47(2):76–83, 2009.

[18] Etsi ts 136 321 v9.0.0 (2009-10), lte evolved universal terrestrial radio access (e-utra); medium access control (mac) protocol specification (3gpp ts36.321 version 9.0.0 release 9).

[19] Technical Specification Group Radio Access Network 3GPP. Technical Specification Group Services and System Aspects; GPRS Enhancements for E-UTRAN Access (Release 8). Technical Report Technical report, 3GPP TS 23.401., 3GPP.

[20] Yannick Bouguen, Eric Hardouin, and François-Xavier Wolff. *LTE et les réseaux 4G*. Editions Eyrolles, 2012.

[21] Basic Transmission Scheme. Lte: the evolution of mobile broadband. *IEEE Communications magazine*, page 45, 2009.

[22] Technical Specification Group Radio Access Network 3GPP. Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement (Release 6). Technical Report Technical report, 3GPP TS 25.892, 3GPP.

[23] David Martín-Sacristán, Jorge Cabrejas, Daniel Calabuig, and Jose F Monserrat. Mac layer performance of different channel estimation techniques in utran lte downlink. In *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, pages 1–5. IEEE, 2009.

[24] Kashif Dar, Mohamed Bakhouya, Jaafar Gaber, Maxime Wack, and Pascal Lorenz. Wireless communication technologies for its applications [topics in automotive networking]. *Communications Magazine, IEEE*, 48(5):156–162, 2010.

[25] Hariharan Krishnan, Fan Bai, and Gavin Holland. Commercial and public use applications. *Vehicular Networking*, pages 1–28, 2010.

[26] Jun Luo and Jean-Pierre Hubaux. A survey of inter-vehicle communication. Technical report, 2004.

[27] European Telecommunications Standards Institute. Technical Specification Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 1: Functional Requirements. TS ETSI TS 102 637-1 V1.1.1, ETSI, August 2010.

[28] Rola Naja et al. *Wireless vehicular networks for car collision avoidance*, volume 2013. Springer, 2013.

[29] Francisco J Martinez, Chai-Keong Toh, J-C Cano, Carlos T Calafate, and Pietro Manzoni. Emergency services in future intelligent transportation systems based on vehicular communication networks. *Intelligent Transportation Systems Magazine, IEEE*, 2(2):6–20, 2010.

[30] Fan Bai, Tamer Elbatt, Gavin Hollan, Hariharan Krishnan, and Varsha Sadekar. Towards characterizing and classifying communication-based automotive applications from a wireless networking perspective. In *Proceedings of IEEE Workshop on Automotive Networking and Applications (AutoNet)*, pages 1–25, 2006.

[31] Yunpeng Zang, Lothar Stibor, H-J Reumerman, and Hui Chen. Wireless local danger warning using inter-vehicle communications in highway scenarios. In *Wireless Conference, 2008. EW 2008. 14th European*, pages 1–7. IEEE, 2008.

[32] Shinji Inoue, Kazuya Shozaki, and Yoshiaki Kakuda. An automobile control method for alleviation of traffic congestions using inter-vehicle ad hoc communication in lattice-like roads. In *Globecom Workshops, 2007 IEEE*, pages 1–6. IEEE, 2007.

[33] Brijesh Kadri Mohandas, Ramiro Liscano, and Oliver WW Yang. Vehicle traffic congestion management in vehicular ad-hoc networks. In *Local Computer Networks, 2009. LCN 2009. IEEE 34th Conference on*, pages 655–660. IEEE, 2009.

[34] European Telecommunications Standards Institute. Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specification of Decentralized Environmental Notification Basic Service. TS ETSI TS 102 637-3 (V1.1.1), ETSI, August 2010.

[35] European Telecommunications Standards Institute. Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of applications; Part 2: Specification of Cooperative Awareness Basic Service. TS ETSI TS 102 637-2 (V1.2.1), ETSI, August 2010.

[36] Alexander Paier, Daniele Faetani, and Christoph F Mecklenbrauker. Performance evaluation of ieee 802.11 p physical layer infrastructure-to-vehicle real-world measurements. In *Applied Sciences in Biomedical and Communication Technologies (ISABEL), 2010 3rd International Symposium on*, pages 1–5. IEEE, 2010.

[37] Katrin Bilstrup, Elisabeth Uhlemann, Erik G Strom, and Urban Bilstrup. Evaluation of the ieee 802.11 p mac method for vehicle-to-vehicle communication. In *Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th*, pages 1–5. IEEE, 2008.

[38] Abdelnaser Adas. Traffic models in broadband networks. *Communications Magazine, IEEE*, 35(7):82–89, 1997.

[39] Balakrishnan Chandrasekaran. Survey of network traffic models. *Informe téc*, 2009.

[40] Sebastian Kempken and Wolfram Luther. Modeling of h. 264 high definition video traffic using discrete-time semi-markov processes. In *Managing Traffic Performance in Converged Networks*, pages 42–53. Springer, 2007.

[41] Alexander Klemm, Christoph Lindemann, and Marco Lohmann. Traffic modeling of ip networks using the batch markovian arrival process. In *Computer Performance Evaluation: Modelling Techniques and Tools*, pages 92–110. Springer, 2002.

[42] Ji-An Zhao, Bo Li, Chi-Wah Kok, and Ishfaq Ahmad. Mpeg-4 video transmission over wireless networks: a link level performance study. *Wireless Networks*, 10(2):133–146, 2004.

[43] Paulo Salvador, António Pacheco, and Rui Valadas. Modeling ip traffic: joint characterization of packet arrivals and packet sizes using bmaps. *Computer Networks*, 44(3):335–352, 2004.

[44] Aggelos Lazaris, Polychronis Koutsakis, and Michael Paterakis. On modeling video traffic from multiplexed mpeg-4 videoconference streams. In *Next Generation Teletraffic and Wired/Wireless Advanced Networking*, pages 46–57. Springer, 2006.

[45] Hassan HASSAN. Generic modeling of multimedia traffic sources. 2005.

[46] Jahangir H Sarker. Models for video traffic. *Helsinki University of Technology*.

[47] Rola Naja. *Gestion de la mobilité et allocation de ressources dans les réseaux multi-services sans fil*. PhD thesis, Télécom ParisTech, 2003.

[48] Jose R Gallardo, Dimitrios Makrakis, and Hussein T Mouftah. Mathematical analysis of edca's performance on the control channel of an ieee 802.11 p wave vehicular network. *EURASIP Journal on Wireless Communications and Networking*, 2010:5, 2010.

[49] Anh Tuan Giang and Anthony Busson. Modeling csma/ca in vanet. In *Analytical and Stochastic Modeling Techniques and Applications*, pages 91–105. Springer, 2012.

[50] Faouzi Kaabi, Pasquale Cataldi, Fethi Filali, and Christian Bonnet. Performance analysis of ieee 802.11 p control channel. In *Mobile Ad-hoc and Sensor Networks (MSN), 2010 Sixth International Conference on*, pages 211–214. IEEE, 2010.

[51] Xianbo Chen, Hazem H Refai, and Xiaomin Ma. Saturation performance of ieee 802.11 broadcast scheme in ad hoc wireless lans. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 1897–1901. IEEE, 2007.

[52] Ashwin Rao, Arzad Kherani, and Anirban Mahanti. Performance evaluation of 802.11 broadcasts for a single cell network with unsaturated nodes. In *NETWORKING 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet*, pages 836–847. Springer, 2008.

[53] Stephan Eichler. Performance evaluation of the ieee 802.11 p wave communication standard. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 2199–2203. IEEE, 2007.

[54] Jean-Yves Le Boudec. *A BCMP extension to multiserver stations with concurrent classes of customers*, volume 14. ACM, 1986.

[55] Chan-Woo Park and Hyo-Seong Lee. A multi-class closed queueing maintenance network model with a parts inventory system. *Computers & Operations Research*, 38(11):1584–1595, 2011.

[56] Serkan Öztürk, Jelena Mišić, and Vojislav B Mišić. Reaching spatial or networking saturation in vanet. *EURASIP Journal on Wireless Communications and Networking*, 2011(1):1–12, 2011.

[57] Institute of electrical and electronics engineers (2007). ieee standard for information technologyâĂŤtelecommunications and information exchange between systemsâĂŤlocal and metropolitan area networksâĂŤspecific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications.

[58] Institute of electrical and electronics engineers vehicular technology society (2006). ieee 1609.4 draft standard for wireless access in vehicular environments (wave) - multichannel operation.

[59] Giuseppe Bianchi. Performance analysis of the ieee 802.11 distributed coordination function. *Selected Areas in Communications, IEEE Journal on*, 18(3):535–547, 2000.

[60] Xianbo Chen, Hazem H Refai, and Xiaomin Ma. Saturation performance of ieee 802.11 broadcast scheme in ad hoc wireless lans. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 1897–1901. IEEE, 2007.

[61] Stephan Eichler. Performance evaluation of the ieee 802.11 p wave communication standard. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 2199–2203. IEEE, 2007.

[62] Ching-Ling Huang and Wanjiun Liao. Throughput and delay performance of ieee 802.11 e enhanced distributed channel access (edca) under saturation condition. *Wireless Communications, IEEE Transactions on*, 6(1):136–145, 2007.

[63] Jose R Gallardo, Dimitrios Makrakis, and Hussein T Mouftah. Performance analysis of the edca medium access mechanism over the control channel of an ieee 802.11 p wave vehicular network. In *Communications, 2009. ICC'09. IEEE International Conference on*, pages 1–6. IEEE, 2009.

[64] Yang Xiao. Performance analysis of priority schemes for ieee 802.11 and ieee 802.11 e wireless lans. *Wireless Communications, IEEE Transactions on*, 4(4):1506–1515, 2005.

[65] Juki Wirawan Tantra, Chuan Heng Foh, and Adel Ben Mnaouer. Throughput and delay analysis of the ieee 802.11 e edca saturation. In *ICC*, pages 3450–3454, 2005.

[66] Hua Zhu and Imrich Chlamtac. Performance analysis for ieee 802.11 e edcf service differentiation. *Wireless Communications, IEEE Transactions on*, 4(4):1779–1788, 2005.

[67] Zhen-ning Kong, Danny HK Tsang, Brahim Bensaou, and Deyun Gao. Performance analysis of ieee 802.11 e contention-based channel access. *Selected Areas in Communications, IEEE Journal on*, 22(10):2095–2106, 2004.

[68] Mohamad EL MASRI. Revisiting the markov chain model of ieee 802.11 e edca.

[69] Tom H Luan, Xinhua Ling, and Xuemin Sherman Shen. Provisioning qos controlled media access in vehicular to infrastructure communications. *Ad Hoc Networks*, 10(2):231–242, 2012.

[70] Khalid Abdel Hafeez, Lian Zhao, Bobby Ma, and Jon W Mark. Performance analysis and enhancement of the dsrc for vanet's safety applications. *Vehicular Technology, IEEE Transactions on*, 62(7):3069–3083, 2013.

[71] Mehri Mehrjoo, Mehrdad Dianati, Xuemin Sherman Shen, and Kshirasagar Naik. Opportunistic fair scheduling for the downlink of ieee 802.16 wireless metropolitan area networks. In *Proceedings of the 3rd international conference on Quality of service in heterogeneous wired/wireless networks*, page 52. ACM, 2006.

[72] Yuming Jiang, Chen-Khong Tham, and Chi-Chung Ko. A probabilistic priority scheduling discipline for multi-service networks. *Computer Communications*, 25(13):1243–1254, 2002.

[73] Richard Musabe and Hadi Larijani. Low complexity cross-layer scheduling and resource allocation for voip in 3g lte. *International Journal On Advances in Telecommunications*, 6(1 and 2):24–33, 2013.

[74] Yasir Zaki, Thushara Weerawardane, C Gorg, and Andreas Timm-Giel. Multi-qos-aware fair scheduling for lte. In *Vehicular technology conference (VTC spring), 2011 IEEE 73rd*, pages 1–5. IEEE, 2011.

[75] Mohsen M Tantawy, Adly S Tag Eldien, and Rokaia Mounir Zaki. A novel cross-layer scheduling algorithm for long term-evolution (lte) wireless system. *Canadian Journal on Multimedia and Wireless Networks*, 2(4):57–62, 2011.

[76] Soaps project:http://www.soaps2.fr/joomla/index.php.

[77] 3rd generation partnership project; technical specification group services and system aspects; policy and charging control architecture (release 8", 3gpp ts 23.203 v8.11.0, 29 september 2010 (2010-09-29). Available in http://www.qtc.jp/3GPP/Specs/23203-8b0.pdf.

[78] Rola Naja, Melhem El Helou, and Samir Tohmé. Wimax double movable boundary scheme in the vehicle to infrastructure communication scenario. volume 67, November 2012.

[79] Lte; evolved universal terrestrial radio access (e-utra); physical layer procedures (3gpp ts 36.213 version 9.2.0 release 9). Available in `http://www.etsi.org/deliver/etsi_ts/136200_136299/136213/09.02.00_60/ts_136213v090200p.pdf`.

[80] Alina Alexandra Florea. *Optimisation de la transmission de phonie et vidéophonie sur les réseaux à larges bandes PMR*. PhD thesis, Institut National des Télécommunications, 2013.

[81] Naila Bouchemal, Nora Izri, and Samir Tohme. Mac-lte scheduler modeling and performance evaluation in lte network. In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*. IEEE, 2014.

[82] Rola Naja and Samir Tohmé. Supporting intelligent terminals by cross-layer adaptation over hsdpa network. *Journal of Engineering and Technology Research*, 1(7):133–142, 2009.

[83] Peiwen Tang, Ping Wang, Ning Wang, and Van Nguyen Ngoc. Qoe-based resource allocation algorithm for multi-applications in downlink lte systems. In *2014 International Conference on Computer, Communications and Information Technology (CCIT 2014)*. Atlantis Press, 2014.

[84] Richard Musabe and Hadi Larijani. Cross-layer scheduling and resource allocation for heterogeneous traffic in 3g lte. *Journal of Computer Networks and Communications*, 2014, 2014.

[85] Eilwoo Baik, Amit Pande, and Prasant Mohapatra. Cross-layer coordination for efficient contents delivery in lte embms traffic. In *Mobile Adhoc and Sensor Systems (MASS), 2012 IEEE 9th International Conference on*, pages 398–406. IEEE, 2012.