MASTER THESIS

Efficiency of broadcasting in vehicular networks by means of 5G device-to-device communications

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Summary

The surge of concepts of the connected world, IoT, IoV, smart cities and many more, drive academic and industrial research activities from various relevant domains towards a unified direction. Generally labeled as heterogeneous networking, hosting different technologies, interoperating with each other, to fulfill demands of a wide range of innovative applications.

Intelligent Transportation Systems (ITS) in the domain of vehicular networking, as an integral part of such a smart ecosystem, are subject to rapid developments. Data broadcast, as the main communication type in vehicular networks, is of significant interest of research community. IEEE 802.11p/1609 is known as the standard communication protocol suit for vehicular networks. However, it does not have any MAC-layer acknowledgment scheme for broadcast communication. Considering the lack of this feature, challenges arise to provide reliable communication and keep the performance of such systems and applications reasonable. Many works have been proposed in the literature to improve reliability of vehicular broadcast. However, it has not been possible so far to provide ultra-reliable broadcast communication in vehicular networks and it is important for many applications, including safety-critical applications.

In this regard, 5G, as the next generation of the mobile networking system, is a promising solution to be utilized for improving vehicular communications. 5G will not be just an enhancement of the current fourth generation of mobile networks, LTE/LTEA, but rather an end-to-end system, realizing a fully mobile and connected society. Such a system will enable diverse use cases with extreme range of requirements, which can be reflected in the proposed architecture. Transportation is one of the main verticals in the focus of 5G. Taking into account this vertical, two main points are directly related to vehicular communication, Device-to-Device (D2D) and Machine Type Communication (MTC). These two emerging technologies of wireless cellular systems, are in the core of the 5G system.

D2D refers to the direct communication between vehicular users without the interaction of any base station. This is mainly used for broadcasting messages among the vehicular devices.Resource management is fundamental aspect of D2D communication as it affects directly its performance. It can improve the system efficiency by making more suitable allocations depending the scenarios on which the message broadcasts are done. In this work, we study two types of resource allocation methods for LTE D2D and analyze their performance difference. We mainly focus on resource efficiency and delivery success rate.

Acknowledgements

This is the final project of my two-year Telecommunications Engineering Master program. It has been developed in the University of Twente, more specifically in the Design and Analysis of Communication Systems (DACS) group.

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This paragraph is dedicated to all the new and special friends that I made during my exchange semester in Enschede, who, in their own way, made my stay in the Netherlands unforgetable. They also gave me strength and motivation to make an extra effort to obtain the best results. Even if they were not physically there, I would also like to thank my family and friends who unconditionally supported me.

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Nora Sarrionandia Uriarte

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List of acronyms

D2D	Device-to-Device
MTC	Machine Type Communication
ITS	Intelligent Transport System
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
MAC	Medium Access Control
IoT	Internet of Things
IoV	Internet of Vehicles
ProSe	Proximity-based Services
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service

Chapter 1

Introduction

There has been a considerable increase in the demand of high data rates among wireless networks since the integration of multiple services and new applications into cellular communications. Satisfying the basic demands of cellular users as they were known until now is not enough anymore. The mobile networking system is facing capacity and quality challenge with respect to significantly increasing traffic volume and innovative applications. D2D communication is proposed as a means of offloading the infrastructure. That is, devices in close proximity of each other can bypass the base station and directly communicate. This will decrease the management load on the base station. This new technology can be used for vehicular broadcast when a certain node wants to send a message to the cars nearby its location.

Intelligent Transport System (ITS) paradigm is proposed as a solution for the increasing need for mobility and connected vehicles. The current inefficiencies in the infrastructure, like the lack of sensors that inform the status of the roads or any possible danger, brings up problems like critical situations for vehicles and pedestrians, high pollution and many more situations that can be solved with the future Internet of Vehicles (IoV). For vehicular communications, data broadcasting is the main type of delivering information.

Nevertheless, the current technologies fail to meet the expected performance for vehicular communications regarding reliability. The most known and used technologies for broadcast in vehicular networks are IEEE802.11p and 4G. On the one hand, the first standard, based on Orthogonal Frequency Division Multiplexing (OFDM), has no need for infrastructure coverage, as the data can be transmitted without any control information. On the other hand, starting from the release 12 of the mobile networking system, the concept of Proximity-based Services (ProSe) has been proposed. It is mainly focused for public safety applications and hence it fails to meet the performance requirements of safety critical applications due to the limited mobility support and scalability constraints in dense scenarios.

Even though Long Term Evolution (LTE) is designed to accommodate high data rates, the increasing bandwidth demand is creating a bottleneck in the system. Motivated by these requirements, 5G has been proposed. The main objectives of this new technology are the increase of cellular network capacity, spectral efficiency and lower energy consumptions [1]. One of the three services that it provides is the uMTC, and its core, which is based in D2D communications.

D2D communications are capable of making direct communication between two devices located in close proximity of each other. From the resource usage point of view they can be categorized in two modes: Inband and Outband.

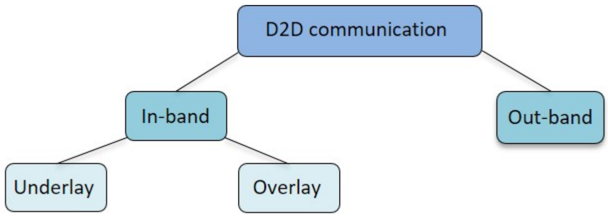

Figure 1.1: D2D communication modes.

D2D communication can be classified into two main categories as it can be seen in the Figure 1.1, from resource utilization point of view. They can either reuse the resources from the cellular network (i.e. inband D2D) or use the ones from unlicensed spectrum (i.e. outband). The second one is out of our scope because service providers have no control over them and a minimum Quality of Service (QoS) can not be guaranteed.

In the inband mode the area for carrying out the communications belongs to the coverage of a base station or eNodeB. In conventional cellular communication, the base station acts as a relay between end points. That is, data goes in uplink from the sender to the base station, and in downlink from the base station to the receiver.

This way, the only type of information that bypasses the infrastructure is the control signaling. In D2D communications the level of control assistance from infrastructure can vary, and this results in a trade-off between control overhead and the performance of D2D communications.

Nevertheless, D2D users transmit the data using direct communication links. By doing this, D2D communications allow to skip high data streams to pass by the base station. Moreover, the throughput and the power efficiency are significantly improved.

In the inband mode the white spaces in the spectrum that are not used by the cellular users, are used by the D2D users. This leads to create interference both to D2D and cellular users. In regards of that, resource management becomes an essential factor because it directly affects to its performance. The in-band D2D can be further divided into underlay and overlay schemes [2]. The underlay in-band

D2D refers to the case where the radio resources are shared between the cellular users and D2D users. In conventional cellular communication Resource Blocks (RB) are mostly assigned per user basis, by the base station. This implies orthogonal (i.e., not interfering) resource allocation for users. The same way can be adopted for underlay D2D resource allocation, where only unused RBs are considered for allocation to D2D users.

However, taking into account the ever-increasing number of users and lack of resources in the close future, efficient spectrum utilization and accordingly the reuse of the RBs come into prominence. This may lead to interference between transmissions using the same resources. As a means of avoiding interference, dedicated resources may be considered for D2D communication. This is called the overlay in-band D2D. The base station defines these resources and either accordingly allocates them (i.e. scheduled mode) or users may access them randomly on their own (i.e. autonomous mode).

We consider the current fourth generation of the mobile networking system as the baseline and focus on the network management aspect of resource allocation. In this work, we study two resource allocation modes for overlay D2D broadcasting: scheduled and autonomous. In both cases the resources are dedicated for D2D users as they belong to the overlay mode. However, in the Scheduled mode the base station is the entity in charge of making the assignation of the resources for each users. In the autonomous mode in the contrary, the users are the ones that can access to the resources on their own.

1.1 Research questions

In order to measure and analyze the efficiency of D2D communication systems and the control overhead that it carries, the Resource Block Allocation methodology is studied, as it is the basis to determine the most important parameters related to its performance. Therefore, the next research questions are posed for their resolution.

- Which are the alternatives for 802.11p and 4G? Is there any other technology that can be used to carry out the D2D communication?
- Is the mobile networking system a promising approach for vehicular communication?
- How do we measure the efficiency of the developed resource allocation methods?
- Which are the parameters that have direct or indirect effect in the performance of device to device communication?

- Which are the possible scenarios on which D2D communications can be carried out?
- How can we improve the reliability of the system for the transmission of broadcast information?
- How do we implement the solution to improve the performance of broadcasting in vehicular networks?

1.2 Approach and Contributions

In the present documentation, the design and implementation of Resource Block Allocation for D2D communications will be exposed, as well as the measurement of the resource availability used for control, and the efficiency of the system. This has resulted in the following contributions.

- We have designed and implemented a scenario in Matlab that simulates a real communication environment.
- We have designed and implemented two methods for resource block allocation:
  - Dedicated spectrum
  - Shared spectrum
- We have developed two types of dedicated spectrum RBA:
  - Scheduled mode
  - Autonomous mode
- We have developed a resource availability detection script to determine the resource blocks used for control and the ones that are not used.
- We have developed a script to measure the system efficiency regarding interference and the amount of resource blocks wasted because of it.
- We have evaluated the performance of the system taking into account the aforementioned parameters.

1.3 Outline

This thesis is structured as follows. In the Chapter 2 the background and related work is explained to understand the concept of device to device communication.

Here different technologies and their approaches are analyzed, including Internet of Things (IoT), ITS, 4G, Machine type communications...

In the Chapter 3 the approach of the thesis is explained. Furthermore, the current shortcomings are highlighted as well as the ways to address them. Moreover, in Chapter 4 the design and implementation of this approach is presented.

In Chapter 5, we evaluate the system performance, in terms of relevant indicators such as the number of broadcast groups in the scenario or the size of the transmitted messages. Finally, the conclusion is going to be posed followed by the future work that can be done to go on with the research.

Chapter 2

Background and Related Work

Due to the contribution of IoT technology, the possibility of merging different telecommunications technologies with the direct aim of creating new services arises. To cope with the exponential growth of mobile broadband data traffic, the 3GPP has proposed LTE-Advanced standard as a candidate for the fourth generation cellular wireless systems. The aim of this standard is to provide high data rates over a larger areas, which means more users per cell. To satisfy these requirements, the enhancements of Release 11 and beyond are the next ones:

- Extremely high network capacity with significant decrease in cost per bit
- Better spectrum efficiency and user experience throughput
- Energy efficiency and conservation
- Scalability and flexibility to optimize system for various environments
- Low end-to-end latency

Considering these points, D2D communications underlaying an LTE-Advanced network is a candidate feature to provide peer-to-peer services and thus enable MTC enhancements.

D2D communication is a radio technology that enables two devices to communicate directly without the usage of the network infrastructure. This new solution gains momentum for the promising benefits mentioned before. In fact, some operator started considering this technology as a key requirement for the current (i.e. 4G) and future (i.e. 5G) cellular systems.

Basically, the motivation behind this choice is to eliminate the interference among cellular and D2D users within the well known Smart Cities. With the introduction of this concept and Vehicular Networking for a safer environment, vehicular safety applications are developed. These applications rely on the exchange of broadcast messages among nearby devices.

Recently, the research community started to investigate the ability of LTE to support cooperative safety applications due to its high capacity and high data rate.

To understand the direction of this research and its context, it is necessary to analyze firstly some essential concepts and their relation to D2D communications in vehicular networks. That is why smart cities play a very important role on the development of this scenarios as well as the technologies which will lead to the creation of them.

2.1 Smart Cities

Nowadays one of the main problems that citizens need to confront every day is traffic. Urban car congestions are becoming bigger with the development of economy and living standards. Most of the citizens own a car and avoid using the public transport. For the time being, most of the countries in the world are suffering a rapid growth of traffic amount, which is increased by limited road resources and unscientific management means. As some traditional applications can hardly work effectively in alleviating this problem, some new approaches are needed in dealing with such matters. [3]

Smart cities, as a trend of internet development in future, may turn upside down our daily life in that all the people, devices at work, home or on the roads can communicate with each other in real time. It integrates some modern techniques, and introduces new services and opportunities to either, machines and human beings. Ensuring that our cities are creative, connected and sustainable is a major challenge but also a great opportunity to improve the lives of billions of people along with the health and future of the planet itself.

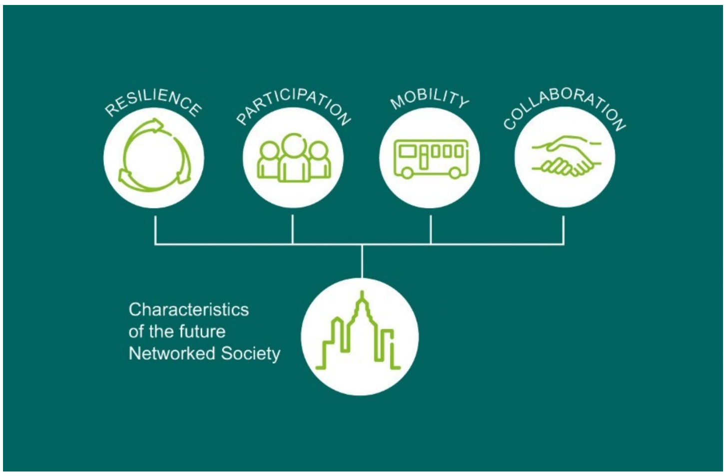

Figure 2.1: Characteristics of Smart Cities.

Here the concept of Information and Communication Technologies (ICT) is introduced, as they are proven as enablers of change and have a big potential to continue to promote sustainable growth [4]. The future networked or connected society, which goes beyond the smart cities of today, has the following characteristics as its basis: resilience, participation, mobility, and collaboration. This is shown in the Figure 2.1.

As innovation companies invest in ICT, it is both smart and reasonable to make a long-term prediction of the relationship between cities performance and ICT maturity. Every study made until the moment show that the current scattered correlation will evolve into a picture where ICT is increasingly correlated with the cities performance. As a clear example, Ericssons Networked Society City Index can be used. This technology provides an inspiring contribution to urban development around the world. This index examines and ranks 41 world cities, providing a framework where the ICT maturity can be measured in relation to social, economic and environmental progress. It can also be used to exploit emerging possibilities associated with a connected world.

In fact, by the analysis of the information the use of physical infrastructure as base stations could be more efficient. Not only the roads and other physical assets, but the design of new communication systems and new applications regarding the distribution and utilization of the resources.

In this context clustering would be a strong choice to make. By engaging effectively with local people and making decisions by use of open innovation processes and participation, improving the collective intelligence of the city's institutions, with emphasis placed on vehicular participation and co-design. Learn, adapt and innovate and thereby respond more effectively to changing circumstances by improving the intelligence of the moving users. It resides in the increasingly effective combination of digital telecommunication networks, ubiquitously embedded intelligence, sensors and tags, and software (the knowledge and cognitive competence).

These forms of intelligence in smart cities have been demonstrated in three ways [5]:

- Orchestration intelligence: Where cities are able to create institutions and community-based problem solving and collaborations.
- Empowerment intelligence: Cities hand over facilities in trial, open platforms and smart infrastructure in order to cluster innovation in certain districts.
- Instrumentation intelligence: Where the infrastructure is made smart through real-time data collection, with analysis and predictive modelling across city districts. There is much controversy surrounding this, particularly with regards to surveillance issues in smart cities.

With the purpose of achieving these goals, some mayor changes should be done in the cities. These are implemented through a common IP infrastructure firstly, that is open to researchers to develop applications. There are also wireless meters and devices like cars that can transmit broadcast information to other users to become aware of their environment. These kind of vehicles are known as intelligent transportation systems.

2.2 Intelligent Transportation Systems

With popularity of cars for private purposes, urban traffic is getting more and more messy and crowded through the years. Many traffic administration departments have formed a consensus that expanding roads, optimizing traffic lights, public transport priority and any other traditional or modern transportation management means can be complicated to implement. Consequently, ITS has been proposed for relieving the traffic pressure.

ITS are vital to increase safety and tackle growing emission and congestion problems. They can make transportation safer, more efficient and sustainable by combining various information and communications technologies to the vehicles. Moreover, the integration of existing technologies can create new services with a high potential.

In the coming years, digitalization of all means of transport, and ITS in particular, are expected to grow considerably. The European Commission is trying to use more ITS solutions to accomplish more adequate administration objectives regarding the transport network. ITS will be used to develop trips and operations on limited and mixed modes of transport. [6]

This technology includes telematics and all types of communications between vehicles, and between vehicles and infrastructure or fixed locations. As far as automotive systems are concerned, there already are some standardizations related to them, such as the Dedicated Short-Range Communications or DSRC [7] which provides communications between the vehicles and the roadside units. There are also some Wireless Communication Systems [8] dedicated to ITS providing network connectivity to transports and interconnect them using radio links. And, last, Continuous Air interface Long and Medium range [9] provides continuous communication between a vehicle and the roadside units. For this, heterogeneous communication systems are used, including the cellular one and the 5 GHz.

In this study, we are going to focus on this type of heterogeneous networks. Nevertheless, ITS can be extrapolated to another areas of application, i.e. Railway systems for high speed railways, as well as conventional raylways when interoperating across national boarders, or Aeronautical systems such as air traffic control systems and onboard telephony. [10]

ITS systems vary considerably in technologies that can be applied, from basic management systems such as a regular car navigation to integrate live data and feedback as parking guidance, weather information, etc. Furthermore, predictive techniques are being developed to allow advanced modelling. Even though the ITS is planned globally, the characteristics for the European union are different from the rest. For instance the frecuency rance (5855-5925 MHz), the number of channels (Seven 10MHz channels). Moreover, the modulation used is OFDM.

The protocol stack defined for ITS [11] is also different in the European Union, as the ETSI and CEN are working together in order to develop a batch of specifications. Furthermore, its architecture is based on the ISO/OSI reference model. [12]

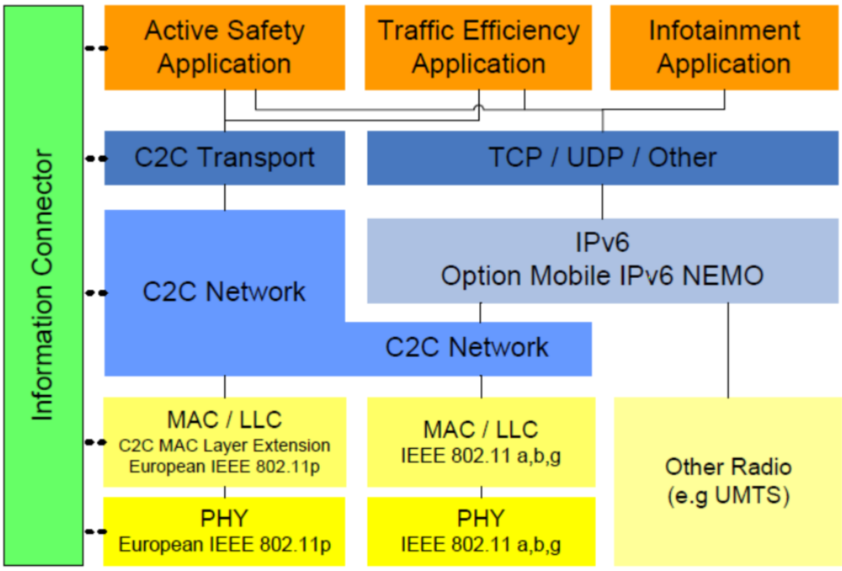

Figure 2.2: ITS Protocol stack.

Starting from the bottom, in the Figure 2.2, the yellow boxes display the ITS access technologies. This pile covers some communication media and related protocols for the physical (IEEE 802.11p) and data link (Medium Access Control (MAC)/LLC) layers.

The blue ones make reference to the ITS network and transport layer. These protocols are the ones which are in charge of data delivery among central stations and from the station to other nodes from the network. Therefore, they use routing protocols that include the path that the data should follow from the source to the destination through intermediate nodes efficiently.

Consumer to consumer transport protocols also provide end-to-end communication of the data depending on the application that will be used and the ITS facilities. Those facilities provide some functions to support the aforementioned applications, such as data storage structures, different types of addressing and finally the ability of stablishing and maintaining communication sessions.

Nevertheless, one of the most important facilities is the management of services. It includes the discovery and downloading of services as if they were modules for their posterior management at the station. Some aspects as the reliability of the link, collision control and avoidance of congestion are taken into account. In the near future, as in other areas of communication in smart cities, IPv6 is supposed to be developed, but some issues regarding its interoperability with IPv4 are holding up the deployment. The protocols used in this layer are the next ones:

- GeoNetworking protocol to use it over different ITS access technologies
- Transport protocol over Geonetworking
- Internet protocol IPv6
- Internet protocol IPv4
- User Datagram Protocol (UDP)
- Transmission Control Protocols (TCP)
- Other network protocols
- Other transport protocols (SCTP)

On the top of the figure the orange boxes can be found. These ones refer to the application layer, on which ITS applications are collected. The most studied for the past few years is the first one referring to Active Safety or road safety. Although the traffic efficiency is also very important inside the field of Intelligent Transportation Systems, as it is one of the main objectives to reach by improving the performance of vehicular systems.

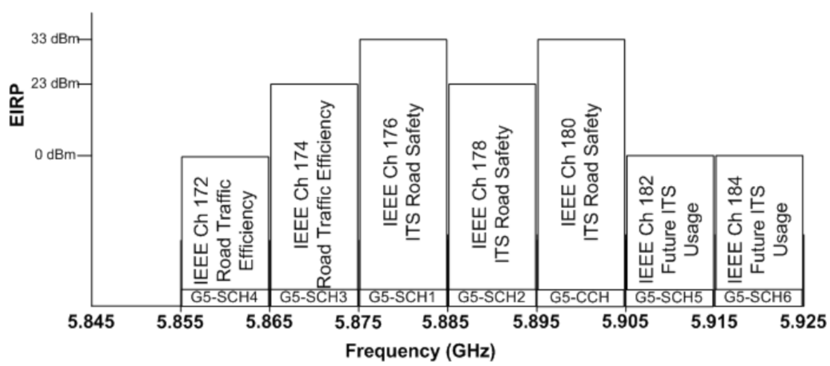

Figure 2.3: ITS Frecuecy division.

As for the frequency division for these applications, in the Figure 2.3 the bigger spectrum usage for the Road Safety part can be clearly seen. There are also some frequencies saved for the future development of new applications within the frame of ITS.

Currently, for applications like Road Safety, technologies as IEEE 802.11p and ProSe in 4G are used. Both providing D2D communications have a completely different solution for a single application.

2.3 IEEE 802.11p

Over the last years, the automobile industry was trying to define a new protocol that could have influence on vehicle safety. The idea was to create a standard that could be used for future inter-vehicular communication, as well as for vehicles to roadside units. Although the possibility of including other types of devices such as smartphones, bicycles, etc. is also a point of interest. Vehicular environments have a set of new requirements on the current communication systems, as for the applications they are supposed to support, they need a very low latency, high reliability and some other aspects that are needed to be considered. Undoubtedly, this type of communication will play an important role in traffic management, as they are capable of alerting the presence of other devices in the near areas, in order to avoid any possible fatality. [13]

Parameters	20 MHz Bandwidth	10 MHz Bandwidth	5 MHz Bandwidth
Bit rate (Mbit/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27	1.5, 2.25, 3, 4.5, 6, 9, 12, 13.5
Modulation mode	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Code rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Number of subcarriers	52	52	52
Symbol duration	4 s	8 s	16 s
FFT period	3.2 s	6.4 s	12.8 s
Subcarrier spacing	312.5 kHz	156.25 kHz	78.125 kHz

Table 2.1: IEEE 802.11p parameters

IEEE 802.11p can operate in different frequencies and bandwidths. Due to these variations, the technology has several parameters that are susceptible of suffering changes. In the Table 2.1 the three bandwidths are analyzed with their main metrics in order to compare the behavior of the technology.

All these numbers are specified to create the most accurate type of communication, hence, the measurements made in several studies show that, in the channels used, there is not high interference with other devices which operate in adjacent spectral bands. [13]

Another critical parameter in IEEE 802.11p is the Spectrum Quality. Here, the transmitters spectrum is measured and also if there is any emission out of the transmission band. The expected results should be under an established threshold to prevent creating distortion in the neighbor transmission channels. The parameters that are taken into account for these measurements are the next ones:

- Transmit power
- Occupied bandwidth
- Out-of-band measurements (spurious emissions)

With these parameters [13] the shortcomings of IEEE 802.11p are exposed. First the offset that the center frequency has compared to the ideal center frequency. Second, the symbol clock error, where the difference between the clocks of the transmitter and the receiver is saved. If those two parameters are combined, they can create high constellation errors, leading to a failed connection between stations.

The correction of these precise metrics is specially designed for vehicular environments. In moving scenarios the impact of these errors is huge for the signal quality on the receptor. Apart from the usual fading, Doppler shifts can appear depending on the relative speed of the sender and receiver. For these critical scenarios IEEE 802.11p does not have specifications, but some organizations such as C2C and ETSI have proposed some fading parameters to make the performances more realistic. [13]

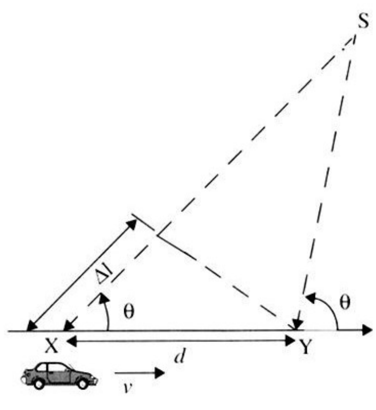

Figure 2.4: IEEE 802.11p Doppler shift.

Doppler shifts directly depend on the driving conditions of the vehicle. The effect is not the same in a vehicle which is being driven in a city center and in a vehicle which is moving with a very high speed in a highway. In the first case buildings and other kind of obstacles have a bi effect, and in the second one the velocity of the automobile. The most important five cases would be:

- Rural Line of Sight: Clear environment with no buildings or blind spots.
- Urban Approaching Line of Sight: Urban environments with buildings but not blind spots.
- Urban Street Crossing Non Line Of Sight: A couple of vehicles approaching in a blind intersection.
- Highway Line of Sight: Multiple cars with direct sight in a highway.
- Highway Non Line of Sight: Multiple cars in a highway with an obstacle in between them.

Several companies have been trying to reduce traffic problems by analyzing those five scenarios and taking action on them. Undoubtedly, Intelligent Transportation Systems using IEEE 802.11p is one of the best solutions proposed for this challenge, as its MAC and Physical layers are based on this technology. Nonetheless, some other aspects as reliability, interference and channel congestion are needed to improve to get better wireless communications. In the mentioned urban environments, there is a big scalability constraints, because service cant be provided if more users than the amount expected request it. Trying to solve these problem, more base stations could be installed, however, the hidden node problem would appear, and consequently, there would be a highly limited mobility support. [14]

2.4 Floating car and cellular data

Nowadays, the connection between vehicles is not very developed due to the inefficient and expensive solutions made by the communication companies. Consequently, the main users are police, ambulances to sum up, security and health services. They pick up the information from static objects placed in the roadsides like traffic cameras or inductive loops, and radio stations transmit it in the licensed range of the FM frequency band. Nevertheless, there are some shortcomings related to the communication. On the one hand, the navigation device from the vehicle needs to process the information, and that can cause a significant delay, because they are created by people and not automatically generated. On the other hand, the transfer rate is still very low (60 bps), so not many messages can be sent simultaneously. [15]

A gateway to these problems can be Floating Car and Cellular data. This is a method to specify, for a determined area or road, traffic flow depending on localization data, time information, vehicle velocity and direction of travel. By doing this traffic analysis, routing quality can be also predicted, as the vehicle would work like a stationary sensor for the network. Moreover, the throughput of this communication can reach the 360bps without any overhead.

The information collected is the main source for the operations made by the ITS, so the vehicles, thanks to their integrated devices, would be the only agents. There would be no need of static sensors that act currently on our roads.

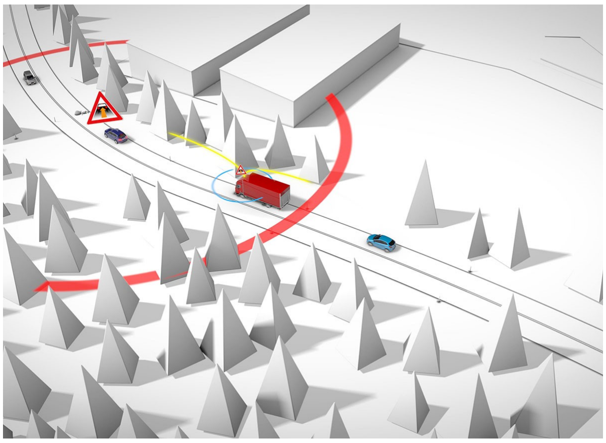

Figure 2.5: ITS information transmission.

Two types of floating car data can be differentiated: Cellular Floating Car Data and GPS based Floatin Car Data. The first one makes reference to cellular networks, and it is the closest one to the research topic of this thesis. The main advantage that this option shows is that there is no need of any extra sensor (mentioned above), as the mobile phones themselves are turned into the only hardware needed for collecting the data.

All the information, such as the location of the devices, is gathered from the cellular network. Due to the high amount of these gadgets in our society, it is expected that each citizen will own at least 4, the quality and accuracy of the data from the network is extremely high. Regarding the GPS based Floating Car Data, the idea of collection the information is similar, but the devices in charge must have GPS module, because they will establish the communication with the provider by using the on-board radio. Hence the location obtained will be much more precise, and the calculations will provide better results. [16]

Generally, the information transmitted consists on:

- Physical and time position of the device
- Unique ID of the device

- Floating Car Data mode
- Generic information of the device for accuracy

A couple of companies are already developing this idea as a technology, i.e. Google and Waze [17]. Both are using current static sensor on the roadsides, but also smartphones to get, as mentioned before, more accurate results. The main requirements to carry out this communication are the next ones: the complete message size per vehicle is 45 bytes, and the information is sent at 1MHz.

The base station is the responsible of integrating the information provided by the rest of the devices to use it for the applications proposed as estimation of speed for road sections, or to calculate the time of arrival. In this case, the vehicle to vehicle communication is used as backup in case the devices that need the information are out of range or the base station in charge can not get them. Their communication system is based in IEEE 802.11a/b/g interface. [18]

There are three requirements regarding the floating car data that must be mentioned when these kinds of applications use our smartphones as bridges:

- Privacy: generally, smartphone owners do not like the idea of using their devices by third parties and they are interested on keeping their privacy. Nevertheless, it is compulsory to use them as they are creating the backbone for floating car data network.
- Autenticity: the service providers need to be sure that the data received is correct. The information can be altered by hackers or malicious users that are sending incorrect location, so this ones should be taken out of the calculations. The bigger number of users in the network, the worse can be the effect of wrong information.
- Reliabilty: the communication through the cars must be reliable in order to get accurate results and not waste the resources used for the transmissions.

The protocols already implemented are request/response protocols. The procedure depends on the device that is used in each case. If the smartphone used has a GPS module, it will directly send specific data to Google, and it will get back the information about the location and the surroundings. But if it does not have any module, the information will be taken from the cellular network and this can add some undesired latency. The positioning will also be less accurate, and if there are many devices with the same characteristics, the computational volume will increase and the possible errors will also grow, so the reliability of the system would not be as good as it should be. [16]

2.5 4G mobile networking system

The Long Term Evolution or LTE has been the first technology which has grown the most in the area of cellular technology. In the gap of five years, more than one hundred countries implemented and used this standard, totaling three hundred and sixty deployed commercial networks. Moreover, regarding its success, a new technology known as LTE-Advanced is being developed by using some existing enhanced components and also some new ones. The main characteristics of LTE can be shown in the next table. [19]

Category	Max data rate uplink (Mbps)	Highest Modulation Scheme	Duplexing	Channel bandwidth (Mbps)
Release 11	From 50 to 100	16QAM	FDD/TDD	5, 10, 15, 20

Table 2.2: LTE characteristics

Initially, these networks were defined as homogeneous networks as the cells used to cover the areas were the communication was being done had the same characteristics as their size. Nowadays, however, as the technology has been developed, different cell types and sizes appeared and constructed the heterogeneous networks. Depending on the requirements of the area where these cells are installed one kind or another is going to be used.

The fact that their user capacity can be varied gives a high flexibility to the system and also puts a wider scope introducing many parameters that will affect the efficiency of the system regarding lower power consumption, better QoS The most used types of cells are the Macro cell, with a radius of one kilometer to thirty kilometers, Micro cell, with a radius of two hundred meters to two kilometers and finally the Pico cell, with a radius of four meters to two hundred meters. Nevertheless, for the last few years the phemto cells are being developed for indoor environments i.e. offices, isolated rooms where the signal power is not enough. [20]

Even though the creation of new scenarios poses many challenges in real life, because every cell has a different propagation environment. The main parameters that have been considered to make these communications more efficient are for example the improvement of mobility robustness. In this study we focus on the vehicular networks, and one of the main points is that the vehicles or devices are in constant movement and that makes the communications more complicated as the latency of the link needs to be very low in order to have a successful transmission.

Furthermore, this aspect is related with reducing the signaling load and finding a balance between the amount of data that needs to be sent with the control information for stablishing the communications in the network. In the ideal scenario, by applying these changes, there would be an enhancement in the throughput per user. Although there are different approaches that lead to resource sharing between several cells controlled by one base station that includes all of them.

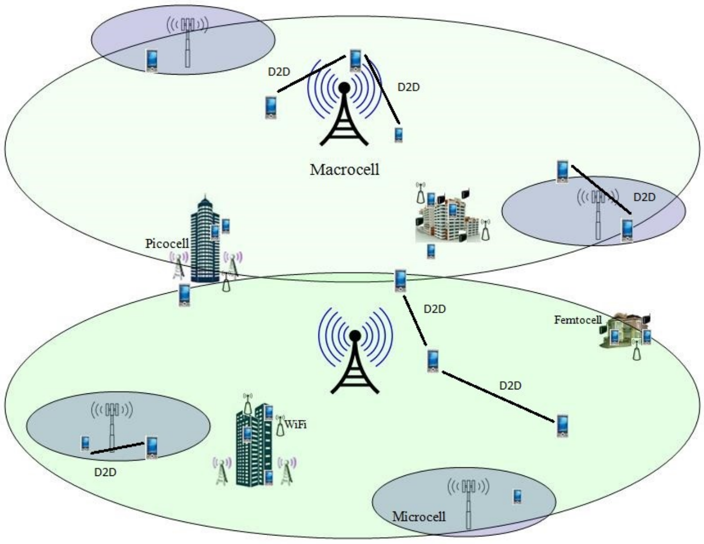

Figure 2.6: LTE Advanced Heterogeneous Network.

Currently, for critical communications systems or public safety the standard used in Europe is known as TETRA. This technology is able to support point to point and also point to multipoint or broadcast like in the Figure 2.6. Nevertheless, this is only used by police, firefighters, ambulances and it has many shortcomings regarding latency in dense scenarios and traffic bottleneck in the base station. Due to these problems, and with the last improvements of LTE, most network and mobile operators are considering it as a substitute for future communications as D2D. One of the most known companies that decided to endorse LTE were the APCO, NPTSC and NENA, and the main requirements that they are seeking for are [19]:

- Reliability in changing scenarios
- Resilience under tough circumstances
- D2D communication
- Broadcast communication
- Communication without interacting with base station

First time D2D terminology was introduced in the 3GPP documentation was in the Release 12 [19]. Here, ProSe were specified and their aim was to allow devices from a determined are to communicate directly with each other reducing this way the network load, use in a more effective way the under utilized cellular network and finally make the communication in no-link areas possible. The idea was to create a commercial model out of the already developed public safety applications that will provide mobility and services continuity with a direct impact on its performance.

D2D communication would be divided in two steps. First the network discovery is done for the nodes to know which are the closest users and the base station makes the resource allocation. Once this process is finished the direct communication between the users, without the control from the base station starts.

However, the discovery of the devices can be only done when in the first moment they are in coverage, i.e. inside the range of the base station. Afterwards, the users can continue the data exchange even if they are out of coverage of the eNodeB. Moreover, it was decided that for ProSe applications only uplink resources were going to be used with TDD. As far as the multiple access scheme is concerned, SC-FDMA was chosen as it is the one currently used for LTE. This are also the basis that we are going to use for the thesis.

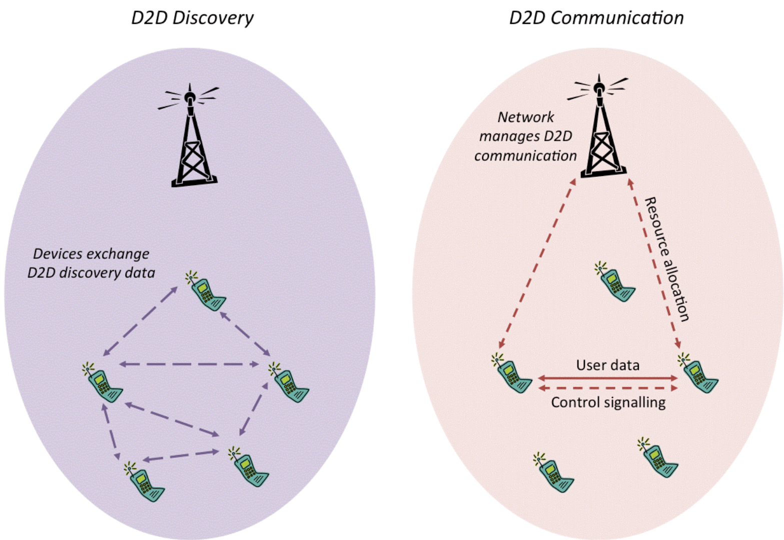

Figure 2.7: D2D Communication.

All the information about the standard is already preconfigured in each device. This means that before any device is used in the roads, they already have the information for carrying out any communication in case the link fails. Once that the discovery is done, the user has all the authorizations needed to carry on the communication. This preconfiguration allows the procedure of resource allocation. Because of the preconfiguration, they know which are the resources that they can use for the transmission of the information and which ones are occupied by other users. In case the reuse of the resources is allowed, there will be a higher chance of getting a resource.The devices will use this saved information to transmit the control information on the PSCCH [19] in the next format.

Modulation and Coding Scheme (MCS)	5 bit
Time Resource Pattern (T-RPT)	8 bit
Timing Advance Indication	5 bit
Group Destination ID	8 bit
Resource Block Assignment and Hopping Flag	5-13 bit
Frequency hopping flag	1 bit

Table 2.3: Control Information format

The sidelink control information is sent in two subframes occupying only two resource blocks every time a reconfiguration of the allocation is done. The method for the resource allocation is defined by the time repetition pattern or bitmap, and this is the method that will be followed in this study. It determines which subframes are going to be used within a transmission for sending D2D data. As it has been specified before TDD is being used, and in the 3GPP Release 12 is determined that the length of the bitmap will be 8 bits, creating this way up to 128 different time repetition patterns. The information will be sent four times in order to make the transmissions more reliable regarding interference.

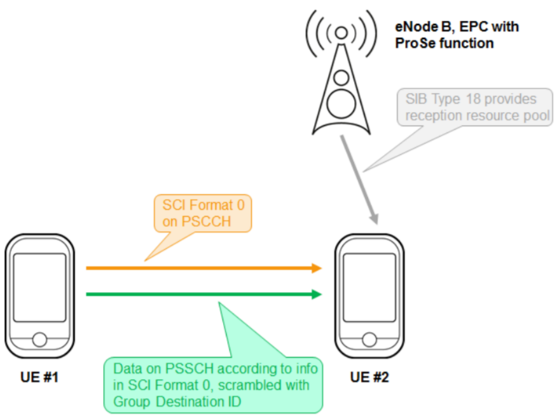

Figure 2.8: D2D transmission scheme.

2.6 5G

One of the main goals of the network and telecommunications companies is to make the internet work faster and in a more efficient way. Smartphones, watches, houses, even cars are expected to be fully connected. In order to achieve that without the links collapsing, a new wireless technology must be implemented. There is where 5G is introduced. Hence, it can be expected that 5G will be gradually introduced on the market within a few years. Although the tecnology is not fully specified, its main characteristics and trends can be discerned. For instance, that the mobile broadband will be at the heart of 5G.

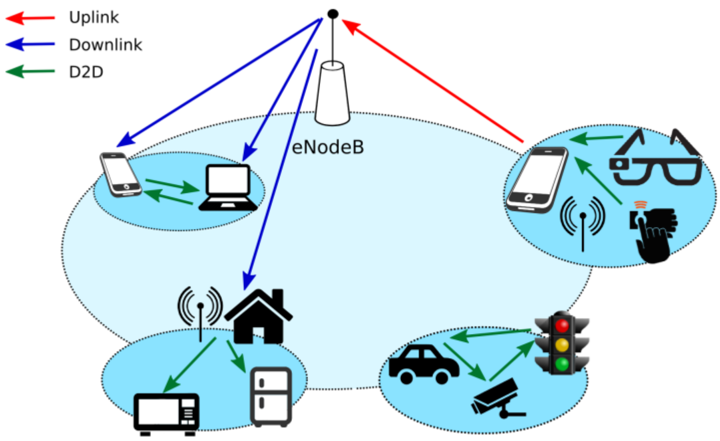

Figure 2.9: D2D communications in 5G IoT networks.

In a similar way as 4G and 3G [21], this is a wireless connection designed for the proliferation of mobile devices connected to the internet and their needs, as shown in the Figure 2.9. Currently, there are 6.4 thousand millions of devices owned and the number is expected to grow until 20.8 thousand million. 5G is being built on the basis of 4G LTE, and it will allow many applications such as healthcare, cellular communications, vehicular communicationsto improve their critical aspects as it can be seen in the Figure 2.10. These trends pose significant challenges to the underlying communication system, as information must reach its destination reliably within an exceedingly short time frame beyond what current wireless technologies can afford. There are three main services [22] that it will provide:

- Enhanced Mobile Broadband
- Massive Machine Type Communications
- Ultra-reliable and Low Latency Machine Type Communications

The numerous initiatives conducted by mobile and wireless communication leading enablers of the twenty-twenty information society (such as METIS European project [23], 5G-PPP association [24], Networld2020 platform [25], etc.), confirm the role of D2D in various scenarios such as vehicle-to-vehicle communications, national security and public safety, cellular network offloading, or service advertisement...

In this thesis we are focusing on vehicular broadcast, that is why 5G plays an important role. Within the ultra reliable and low latency communications [26] all the characteristics that we are seeking for are covered. Currently, the systems for vehicular communications use dedicated spectrum, but with a medium access method that does not provide guaranteed service. This motivated the study of the benefits that 5G uMTC can provide to vehicular communications. It would also support applications with hard requierements on reliability.

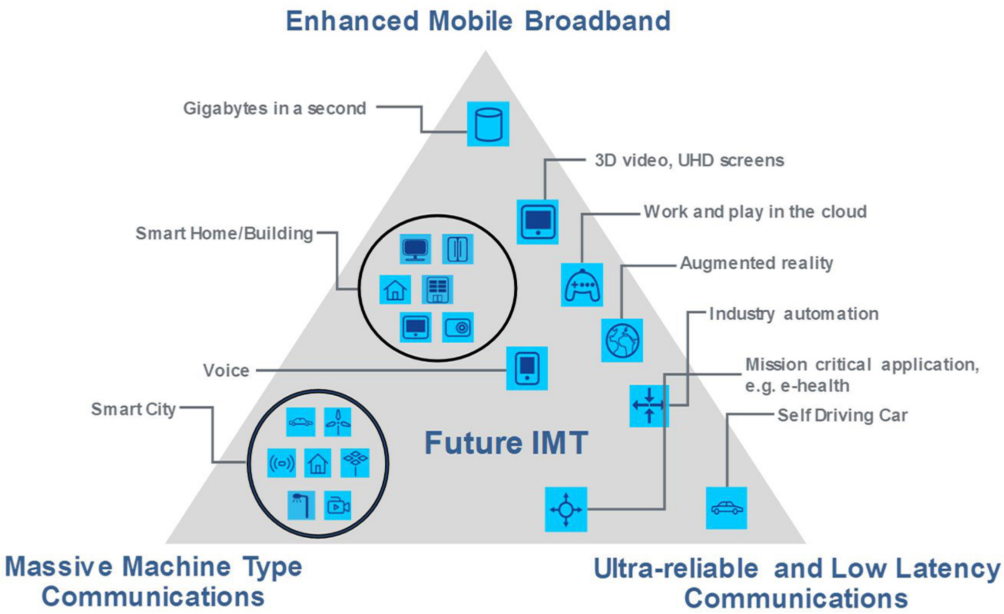

Figure 2.10: 5G Services.

For instance, there would be a better network efficiency as the reliability would increase and the latency decrease drastically, and these two parameters are considered verticals regarding vehicular communications. This can be seen in the Figure 2.10 because they are the basis of the applications shown. As a reliable service composition wants to be achieved, the motivation for developing 5g would be a channel estimation for an efficient use of resources with radio resource management. According to the densities of D2D users, a network management entity i.e. the base station, is going to be the one in charge of generating the schemes for the transmission. These are the main requirements to be supported by forthcoming 5G systems [27]:

- Energy efficiency: Energy handling during harvesting, consevation, and consumption phases.
- Scalability: A huge number of smart devices willing to connect to the IoT world.
- Resiliency: System continuity in harsh conditions, including lack of the network infrastructure connectivity.

- Interoperability: To support the extremely differentiated IoT application scenarios, next generation cellular network need of effective mechanism to handle heterogeneous data handling capabilities, flexibility in managing different radio technologies, integrated mobility management, etc.

- Support to Multimedia IoT: Higher computation capabilities to manage multimedia flows and, above all, communications are more focused on bandwidth, jitter, and loss rate to guarantee acceptable delivery of multimedia contents.

As far as D2D broadcast communications are concerned, there are two main groups: Inband and Outband communication. One of the goals is to reuse the cellular spectrum, so the Inband approach is the desired one as it has been previously explained. Here, another division can be done with Underlay and Overlay resource allocation. In the first one D2D users and cellular users share the whole spectrum, which can lead to interference. But in the second one a part of the cellular uplink spectrum is going to be dedicated for allocating D2D users.

There are potential approaches being analyzed and developed at the moment considering the role that the infrastructure plays in the whole system. Depending on the environment as in 4G the application requirements and channel conditions vary, therefore, the need of finding a relation and balance between both of them and design accurate availability prediction mechanisms. However, the key functions would remain as in 4G including the peer discovery, resource allocation management functions, physical layer procedures, power management and interference checking. Because of that the support of D2D communications becomes crucial in 5G systems.

Chapter 3

Approach

In the previous chapter, the technologies and advancements made for the vehicular networks were explained for our society and how are they currently used. Starting with two main standards as 802.11p and 4G LTE, their advantages and also shortcomings were mentioned, leading to 5G and the relation of D2D communications with the services that it provides. By doing this, many improvements for vehicular communications and its functionality were proposed.

The main goal of the study is to improve the performance of vehicular communication in LTE. In order to achieve that, its verticals are studied. One of them was the resource block allocation as it affects directly the performance of the vehicular communications. Lately several articles were published referring to the fact that the current system is not efficiently developed, and also it has some weaknesses regarding reliability [28]. For example, as there is more than one method to carry out the process of allocating the resources, they can be shaped and selected for different types of scenarios and environmental conditions.

In the Chapter 3.1, an overview of D2D communication is going to be given with the aim of giving more specific ideas of what it is for and how does it work. Moreover, the parameters of interest for the thesis are going to be mentioned. For that, in the next chapter it is shown that there are some assumptions that needed to be defined for achieving more accurate results in terms of time and usage of the vehicular network. It will also help to develop the design of the next chapters, where underlay and overlay methods of resource allocation are described, how the broadcast groups are able to get the resources and interference checking for possible conflict between signals. Finally, some related work is going to be discussed as there are already some different approaches concerning the improvement of vehicular networks.

By doing this, we are going to model Overlay Resource Allocation, and also evaluate its efficiency for vehicular broadcast communication given various D2D metrics:

- Resource Availability Indication

- Control Overhead
- Measurement of system efficiency

3.1 D2D Communications

Currently there are three main communication options regarding vehicular networks, IEEE802.11p, cellular communication and device to device. In the Chapter 2 all the shortcomings of IEEE802.11p were discussed. It was also said that because of its mobility and scalability constraints was not a promising approach for vehicular communications. That is why we are going to focus on the other two.

In the cellular one, the traffic needs to pass through the base station, which makes the link slower because it adds data load and information processing load to the station. D2D is the one we are interested in, as the communication is end to end type, so there is direct traffic between two ends. Relieving the base stations and other network components of an LTE network of some of their traffic-carrying responsibilities, for example carrying rich media content directly between mobile terminals, will reduce the network load and increase its effective capacity. Furthermore incorporating D2D into the LTE standard will provide a common set of tools for proximity-based services, rather than a disparate set of approaches by different application providers. Public safety organisations can benefit from the worldwide economies of scale achieved by the broader LTE system.

D2D communications gains are many, such as the low latency and the hop gain as the information does not need to go through the base station. It also has a lower error rate, which makes the system more efficient and flexible. It also operates in licensed spectrum and the radio resources are carefully managed by the network, to minimise interference and maximise the performance of the system. This is called the inband mode, which carries more advantages that using not licensed bands [29]. D2D could enable even tighter reuse of spectrum than can be achieved by LTE small cells, by confining radio transmissions to the point-to-point connection between two devices.

There are also two ways to do the in-band communication, and here is going to be the focus of the thesis, Overlay or dedicated spectrum and Underlay or shared spectrum. As far as the Overlay method is concerned, there is going to be a pool with some dedicated resources for D2D users. The formation of this pool is managed by the base station by a standardized procedure, and it will determine the duration of the pool, the assignment of time slots, bitmap and other parameters that will be later specified. As for the allocation, in the scheduled or mode 1 the base station is the element in charge using orthogonal or non-orthogonal frequencies, and in the autonomous or mode 2 the nodes themselves make the allocation by random access. In the underlay mode, the base station is the one in charge for managing the allocation, and it can be done orthogonally or non-orthogonally.

3.2 Design

In standard LTE/LTE-A the resource allocation within a cell is orthogonal. The concept of D2D communication underlying cellular network implies using the whole spectrum for both type of users (D2D and Cellular) as follows. It can be done by using only the unused resources of the spectrum, or reusing the ones that are already occupied by other users. Nonetheless, in this study the overlay allocation is developed, so even if both kind of users share the spectrum, there are going to be some dedicated resources to avoid the reuse them.

3.2.1 Scenario

The first step of the design was to create an algorithm for each resource allocation method that would combine all the aspects aforementioned. In this study, we are considering Overlay resource block allocation, and inside the overlay method two different types of assignation of resources: scheduled and autonomous. The scenario proposed has two ENodeBs or cells and each one has a given number of broadcast groups. Each broadcast group has a specific number of receivers within their cover area.

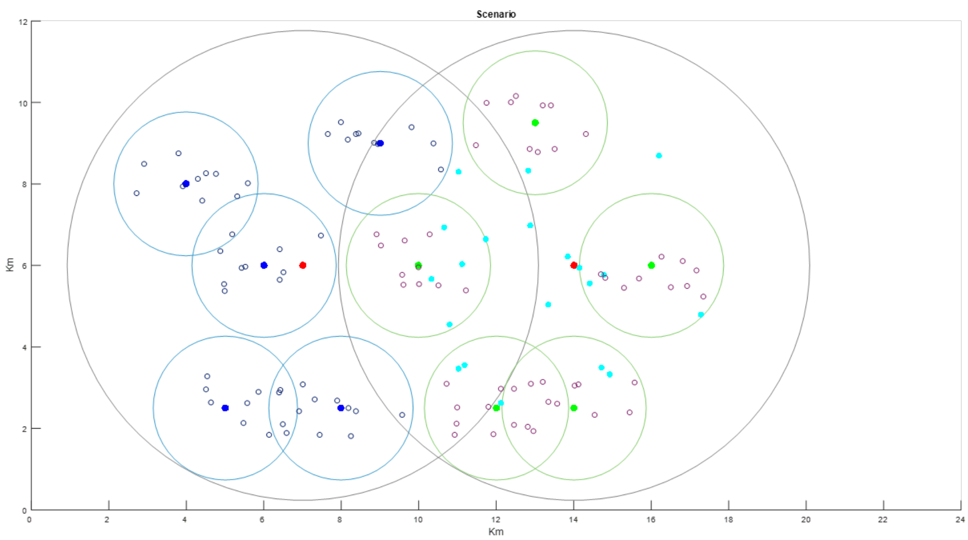

Figure 3.1: System Scenario.

It is only going to be analyzed the behavior of D2D users in the first cell, as we would obtain similar results in the second one. This last one is only going to be used to cause inter-cell interference. The allocation in each cell is going to be independent in order to get more realistic results. Moreover, every position in the space of the broadcast groups and other devices is going to be done by a uniform distribution, creating this way a similar to reality recreation of D2D communication environment.

In contemplation of creating the algorithm, all the elements with their numerical values that are going to be in the scenario, shown in the Figure 3.1, should be distributed and saved. These are going to be kept in different matrixes for posterior calculations. All the simulation parameters that are going to be specified in the Chapter 3.2.2, are going to be variables susceptible of changes. Still, the ones related to the creation of the scenario like the minimum number of broadcast groups is going to be one in each cell for generating the possibility to make some interference, and the maximum would be ten broadcast groups. This maximum number was decided taking into account the coverage area of the cells and the coverage area of the broadcast groups. If more than ten transmitters are settled in each cell the interference would keep growing, but the difference in the performance is already big, so it is pointless to choose a higher amount of nodes to be the maximum.

Once we have created the scenario, the process of the resource allocation starts. In order to proceed with these chapter of the study, the performance metrics and the input parameters for the system are needed to be specified. Moreover, the format of the results is also important. Since we are analyzing device to device communication's system efficiency from the operator point of view, two big matrixes are going to be needed, the transmission resource allocation matrix and the reception resource allocation matrix. When these two are filled with the corresponding information, the aforementioned performance metrics to conclude the study will be determined.

3.2.2 Resource Allocation

It has been already mentioned that in this study Overlay resource allocations is going to be developed. For this reason, in the cellular spectrum there is going to be a dedicated part only for D2D users. This way within a cell, there is not going to be the chance of getting interference for any of both. The part of spectrum that is going to be dedicated is called pool of resources, and the base station is the one in charge of creating them. Nevertheless, there are two ways of managing the pools. This two methods are also going to be developed and tested in the thesis. On the one hand there is the Scheduled mode, and on the other hand the Autonomous. These are the main parameters that are going to be specified and taken as basis for the design of the system. They are going to be common for both methods. The variation of them will have a direct effect on the results, and this is also something that is taken into account to measure the system efficiency.

Simulation parameters	Value
System bandwidth	10MHz
D2D Broadcast transmission power	40dBm
Number of uplink resource blocks	50
Tolerable SINR level at a node	-107dBm
Coverage range of the eNodeB	5km
D2D broadcast transmitter range	1km
D2D broadcast receivers	10
Number of Cellular users	20
Time resource pattern	bitmap pool
Size of the message to be transmitted	1600 Bytes
Number of contiguous RBs per broadcast group	5
Transport block size	782 bits

Table 3.1: Simulation parameters

The main difference between the two modes, is that in the Scheduled mode the base station is the one making the allocation. Whilst in the Autonomous mode the nodes themselves are the ones who need to select the resources on which they are going to send the information. Moreover, there is another big difference, the reuse of the resource blocks. In the scheduled mode, the resource blocks are going to be used only by one broadcast group. Whereas in the autonomous mode, the resources can be reused. This means that, if two or more broadcast groups are far enough one from each other, and they do not cause any interference between them, all of them are capable of using the same resource block during the same time period.

Based on the 3GPP standardization framework, the uplink spectrum is considered for D2D communications, and consequently the physical data channel follows the structure of the Physical Uplink Shared Channel (PUSCH), using Single Carrier-Frequency Division Multiple Access (SC-FDMA) scheme. There are three main reasons for using the uplink channel. The first one is that the spectrum is underutilized when talking about uplink, as mostly all the communications transfer more data in the downlink one, the one we are interested on is not efficiently used. Another reason is that the interference from D2D users may affect the base station in uplink, but usually the eNodeB has interference cancellation capabilities. On the contrary, when using downlink, the cellular users get involved in interference with

D2D users, so their performance would degrade, and also the performance of D2D users. This is the thing we try to avoid by using uplink channel. Finally, the media access control used (SC-FDMA) has a lower peak average ratio, so less energy is consumed for the transmission, compared to Orthogonal Frequency Division Multiple Access (OFDMA).

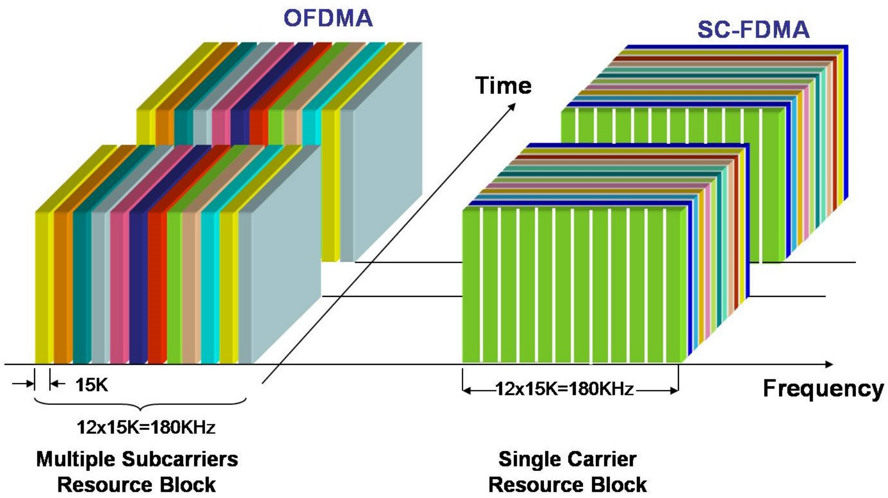

Figure 3.2: Comparison OFDMA/SC-FDMA.

The smallest unit considered for doing the resource allocation is a Resource Block (RB). This is 180kHz (i.e. 12 x 15 subcarriers) in frequency, and if we make the change to the time space, we would have 0.5 ms or 1 slot. Nevertheless, the smallest scheduling time interval considered in LTE is 1subframe or 2 slots in time. For carrying out the transmission a set of subframes is going to be sent, and this subframes are going to be specified by a bitmap. In this bitmap two values are going to be considered, 0 and 1. In the subframes with status 0 only cellular users are going to be allowed to take the resource. While in the subframes with status 1 D2D and cellular users indifferently will be using the resources. Although the D2D users will only be able to use a determined set of resources that were specified in the pool mentioned before. The length of the bitmap is going to be 8 bits because of the use of Frequency Division Duplex. This is specified in the 3GPP Release 12.

0	1	1	0	0	1	1	0

Table 3.2: Bitmap

As for the resource blocks, their allocation is based on the Uplink type 0, determined by a Resource Indication Value (RIV). RIV is a number with which after filling a formula two numbers are obtained, corresponding to a starting RB (RBstart) and a length in terms of contiguously allocated RBs.

$$RIV = \begin{cases} N_{ur}(C_{rb}-1) + RB_{start}, if(C_{rb}-1) \leq \frac{N_{ur}}{2} \\ N_{ur}(N_{ur}-C_{rb}+1) + (N_{ur}-1-RB_{start}), if(C_{rb}-1) > \frac{N_{ur}}{2} \end{cases} \tag{3.1}$$

In LTE the MAC PDU that is transmitted is the transport block. Depending on the application its size can vary. For our transmissions, as we are using 5 contiguous resource blocks and the modulation and coding scheme index 10 (i.e. modulation 16QAM) we will obtain a transport block size of 782 bits. But as mentioned before, if a different number of resource blocks are assigned to each broadcast group or the modulation changes, we could obtain different transport block sizes.

In order to make the communications more effective and reliable, each transport block is transmitted four times (transmission repetition) in four consecutive subframes. This means that in each bitmap or 8 ms one packet is going to be sent four times. In case of interference, there would be a considerable performance improvement because even if one of the resources is wasted, there are still three more to check and more probabilities to be successful. These transport blocks are going to be sent in the subframes that have status one on the bitmap as it has been mentioned.

The bitmap or time repetition pattern is going to be repeated in time until the transmission time interval or SideLink Control Period (SCP) is finished. This is a parameter in UMTS based on the GSM standard that determines a time period where the allocation of the resources remains the same. After this period, 120 ms in our case, is passed, all the allocations of the resource blocks for D2D users is going to be done again. Nevertheless, this period can be changed depending on the allocation mode that we are using, the message size that we want to transmit, or the most important, the number of broadcast groups that we want to allocate for transmission. Later in the results chapter, the effect of these inputs is going to be analyzed.

An example for the allocation is shown in the next figure. The allocation matrix is composed but the 50 resource blocks on its vertical axis, and 120 subframes corresponding to one SCP divided in bitmaps of 8 ms. In this case we want to allocate 4 broadcast groups, and if we are using 5 resource block for each in one subframe, in total 20 resource blocks are going to be allocated in each subframe for all the broadcast groups. These are specified with the green color, and the rest in red are going to be used for cellular users. The allocation of the resource blocks will depend on the mode chosen, but these are the available ones for D2D communications. This way, any interference between cellular users and D2D users is avoided.

Figure 3.3: Resource Allocation Matrix.

Depending on the number of messages that wants to be sent this allocation matrix is going to vary in size. Once that it is filled with all the allocations, the next step of interference check needs to be done on it and see if there are resource blocks that are going to be wasted because of the effect of other transmitters.

3.2.3 Interference Check

Once the resource block allocation is done, we need to check it there is any conflict between the broadcast groups from cell 1 against the broadcast groups and cellular users from cell 2. To carry out this check we need to compare the matrixes filled in the resource block allocation chapter. Nevertheless, in the autonomous mode there is an extra check for the intra-cell interference, so this process would be also done to see if the broadcast groups from the same cell are trying to use the same resources.

All the resource blocks corresponding to the allocation matrix are compared one by one and if two broadcast groups are using the same resource for transmission, the receivers that can be in conflict must be analyzed. We need to see whether the SINR is beyond the established threshold for every receiver, which for D2D communications, as in the design chapter was pointed, is 107dBm. If the signal strength is bigger than the threshold, interference is going to appear in the checked receiver and the transmission is going to be failed, so the resource blocks are going to be wasted not allowing the reception of messages until the reallocation of the resources is done. If the SINR is smaller, it means that there will not be any interference from the other transmitter, so the receiver will be ready for getting the broadcast messages.

Nevertheless, the receivers can still suffer from interference generated by cellular users from the second cell. Because of that, all the checking must be repeated for each receivers of all the broadcast groups. When the checking is done for all the broadcast groups in cell 1, we will get two final matrixes, one for the successfully allocated resources, to see how many resource blocks were allocated without any interference, and one for the message reception part, to see how many messages were received by how many and which receivers.

A possible scenario to see the interference is the one showed in the next figure. Inside the coverage range of a specific cell, there are three broadcast groups a,b,j. Although each node has its own coverage area, they still can influence and create interference on the receivers of the other transmitters. Because not only the distance, but the power with which the brodcast groups are going to deliver the messages is important. In the resource allocation subsection 40dBm were specified for D2D broadcast transmission power. The three of them want to transmit, but in this case we are going to analyze the behavior of j.

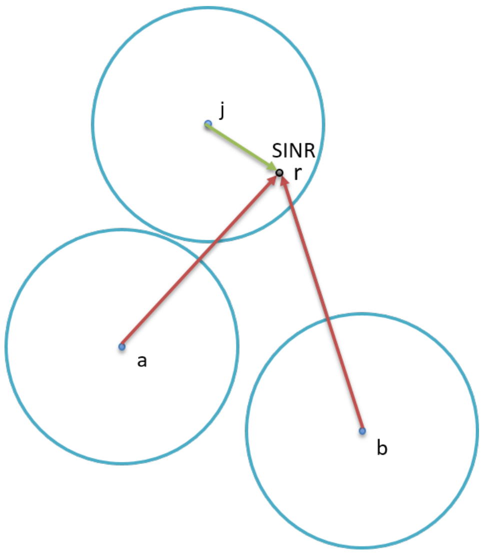

Figure 3.4: Interference Scenario.

To calculate the aforementioned SINR the method used is the next one. In the broadcast group j, the receiver r wants to get the desired signal from its transmitter.

However, there are two more broadcast groups (a and b) close by that also want to use the same resources as j does. In this scenario there is one desired signal and two undersided, so following the Hata model, with the Path Loss formula, the reception power in r from the three broadcast groups is going to be calculated.

$$L_{dB} = 148 + 40log_{10}(d[km]) \tag{3.2}$$

$$L_{dB} = P_{tx}(W) - P_r(W) \tag{3.3}$$

Once that the powers are calculated, the signal to interference noise ratio formula must be filled. This one consists on dividing the received desired power, by the summation of the White Gaussian Noise and all the undesired powers from the other broadcast groups.

$$SINR = \frac{P_{jr}(W)}{WGN + \sum_{\forall i \epsilon IS} P_{ir}(W)} \tag{3.4}$$

3.3 Implementation

In this chapter, the procedure of implementing the whole system is going to be explained. Using Matlab as the only implementation tool, different scripts are developed to simulate the environment in which the simulations for measuring the system performance are going to be done. Firstly the scheduled mode is going to be explained in detail, and afterwards, the autonomous mode focusing on the main differences comparing to the first mode.

3.3.1 Scheduled

The procedure that needs to be followed in this method is the next one. In the first place the scenario is going to be created with all the elements that are going to take part in the system (i.e. cells, eNodeB, transmitters, receivers, cellular users, etc.). In the second place, when all the matrixes are filled with the details of the devices the resource block allocation is going to be done for D2D and cellular users simultaneously and in both cells. Finally, a checking for inter cell interference will be executed and the successful receivers who could get a resource are going to be determined. A test is also going to be run to see how many messages were successfully received in each broadcast group. This procedure will be repeated for different input parameters in order to get significant results.

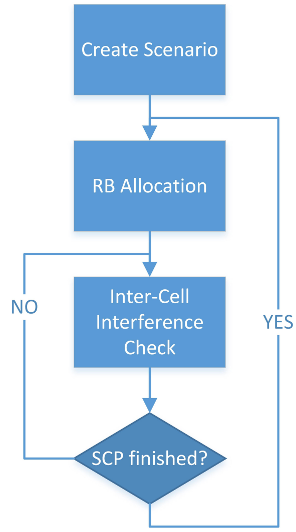

Figure 3.5: Flowchart for the Scheduled mode.

In the design part the structure of the scenario is specified. Hence, the first thing to do is draw all the elements and fill up the matrixes with the details. For the cells with the base stations in the center, the position is going to be specified with their radius or coverage area. Within the specified area the broadcast groups are going to be distributed in a uniform way for creating a realistic environment.

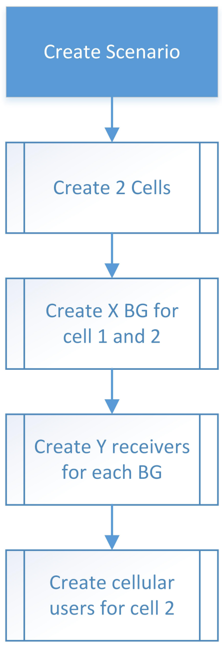

Figure 3.6: Flowchart for the Scheduled Scenario Creation.

Each broadcast group will have in the same time a given number of receivers, ten in this implementation, that will be the ones where the messages need to arrive. They will also follow a uniform distribution inside the coverage area of each transmitter. The cellular users will be only placed in the second cell for the reasons given in the design part, so, again, they will be generated uniformly all along the area of the base station from cell two.

Once the steps for generating the agents of the scenario are finished the resource block allocation starts. First, the whole process for the scheduled mode is going to be explained, and afterwards the process for autonomous mode, pointing the main differences with the other one. As far as the scheduled method is concerned, the most important fact to consider is the no-reuse of the resource blocks. This means that a single resource block can only be used by one broadcast group within a cell.

The base station is the one in charge of doing the allocation. There is a pool where the available resources are specified. The base station takes them and distributes them among the broadcast groups of its area. The same operation will be repeated for the broadcast groups in the second cell. There is not going to be any intra cell interference as it is already solved with the absolute knowledge and distribution of the resources of the base station. For the cellular users of the second cell, the spots that are left for the allocation of them, the ones outside the pool of D2D users, are going to be used.

The allocation of the D2D users is going to be done following the next order. For each cell a bitmap is going to be taken from the bitmap pool. This means that we will have 8 subframes or miliseconds of resources to fill. D2D users are going to be placed in the ones with status one, as it has been mentioned in the design chapter. The base station is going to select a given number of resource blocks for each broadcast group without reusing. In the end, we will have an 8ms bitmap with the D2D allocation done. The configuration of this bitmap is going to be repeated for one SideLink Control Period, and when this time is passed, a new bitmap is going to be taken from the pool and a new configuration for the resource blocks is going to be created by the base station.

Following our current configuration, in each subframe we have 50 resource blocks, and because of the specific RIV that we are using, 20 resource blocks are going to be dedicated for all the broadcast groups from the cell. Taking this into account, in the scheduled mode we will only be able to give service to four broadcast groups in the same time. Nevertheless, after every SCPeriod is finished the configuration will change and those groups which were left without service have a change to get the resources again. As in the next chapter will be shown, different periods of reconfiguration were used in order to test the influence of realocation regarding interference.

Moreover, for the cellular users the allocation is done every 8ms or everytime a bitmap is finished. The cellular users are going to be allocated in the white spaces left for them. This means that in the matrix the spaces or the resources that are not dedicated for D2D users are going to be free for any cellular user that wants to use them. With this shorter periods of allocations we recreate a more realistic scenario and more chances to get interference from cellular users, which are the main users of the spectrum.

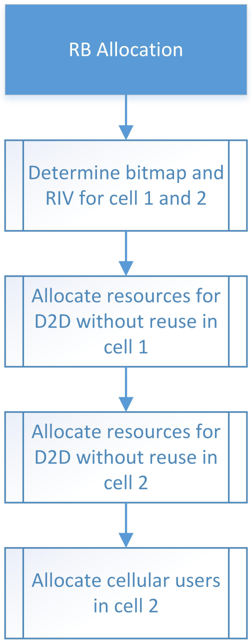

Figure 3.7: Resource Allocation Flowchart.

Once the allocation is finished, the conflict check needs to be done. In the scheduled mode, two different checks are needed to be done. First, the check for interference must be done every 8ms because of the constant change of the allocation of the cellular users require it. This check is going to be between the broadcast groups from cell one with the cellular users from cell two. The check with the broadcast groups from cell two will be only done every SCPeriod as the configuration is maintained all along the established period.

Both checkings are done following the same rules. The elements in conflict must be identified first. For instance, the receivers from the broadcast groups of the first cell, which are the interfered ones, and the transmitters and cellular users from the second cell, which are the ones that create the interference. When the elements are spotted, the SINR in the receivers has to be calculated considering the reception desired power, the white Gaussian noise and the summation of all the undesired powers. The number obtained from this calculation shows the ratio between the signal that we want to receive and all the interference from the other users that use the same resource blocks.

If this number is bigger than the threshold (107 dBm) it means that the interference is too big in the given receiver, so it will not be able to receive the packet from his desired transmitter, and thus, the transmission of the message will be failed. This process will be repeated for all the packets that make up a message, and for the amount of messages that the transmitter wants to send. For the implementation the number of messages chosen is 100, but like all the other parameters, this quantity is variable. Here, the main thing is the periods of checking for cellular users and D2D users, for instance, 8ms and 120ms or length of SCPeriod.

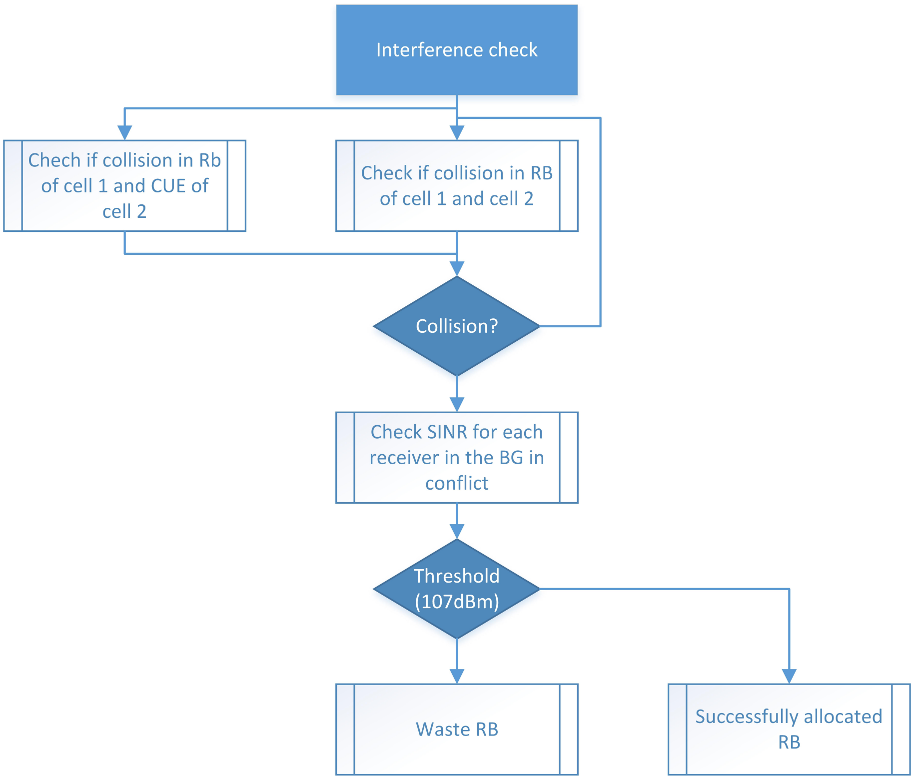

Figure 3.8: Flowchart for the Scheduled Interference Checking.

3.3.2 Autonomous

Once that the first mode is already implemented, we are going to start with the autonomous mode. The main difference with the scheduled mode is that in the autonomous mode the element is charge of doing the resource allocation is the node or transmitter of each broadcast group. From the pool of resources to be assigned each transmitter choses one for each broadcast group, but this resources can be taken more than once, so it can be that more than one broadcast groups is trying to reuse the same resource block. Because of that we have a new type of interference called intra-cell interference. By putting the transmitter in charge of the resource block allocation we minimize the operations made in the eNodeB or base station, but gain a new kind of interference. Later, in the performance evaluation chapter, the comparison between the two modes is going to be done.

The order we are following for this mode is exactly the same as in the scheduled mode. But because of the reuse of the resources, before checking for inter-cell interference, an intra cell check must be done. We have to make sure that all the broadcast groups from the same cell are able to use the allocated resources without creating any interference between them. Nevertheless, this intra cell check is only going to be executed every time a SCPeriod is finished, because we are only considering D2D users, and the configuration remains the same until the reallocation is done. The inter-cell check on the other way needs to be done every 8ms because of the reallocation of cellular users.

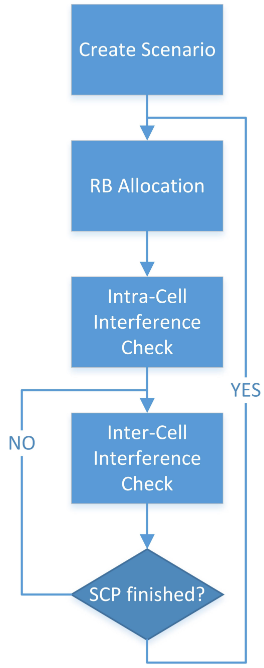

Figure 3.9: Flowchart for the Autonomous mode.

There is also another difference regarding the resource allocation. In the scheduled mode, the higher amount of broadcast groups that we could provide service to using the specified configuration was four. However, in the autonomous mode, the number of broadcast groups that can be served is undefined. The only factors that affects this number would be the coverage area of the eNodeB and the coverage area of the broadcast groups. If its transmission power is bigger, the coverage area is going to be bigger, therefore, more broadcast groups will be fitted inside, and this way, there is less chance for them to interfere one to another. In the same way, if the transmission range of the broadcast groups is smaller, the signal will not be very strong, and the result would be the same as in the other case.

For our coverage range the maximum amount of broadcast groups considered are 10 in each cell. The aim of choosing this number is to compare the performance of the scheduled mode and the autonomous one, as in the second one we will be able to give service up to the 10 broadcast groups, more than twice as much as in the previous one. Furthermore, for the implementation, each resource will have more than one dimension to cover the possible broadcast groups which will use it.

After all the resources are allocated, firstly we need to check if there is any conflict between the broadcast groups within the cell. This process is done for both cell 1 and cell 2. The intra-cell interference check is done exactly in the same way as the inter-cell one mentioned in the scheduled mode. If two broadcast groups are in conflict, the SINR level is checked in the receivers of the broadcast groups and if it is beyond the threshold, the receiver wont be able to get the packet because of the interference caused by the other transmitter. If the interference is too weak instead, both of them are going to use the resource and the receivers will be able to get the packet.

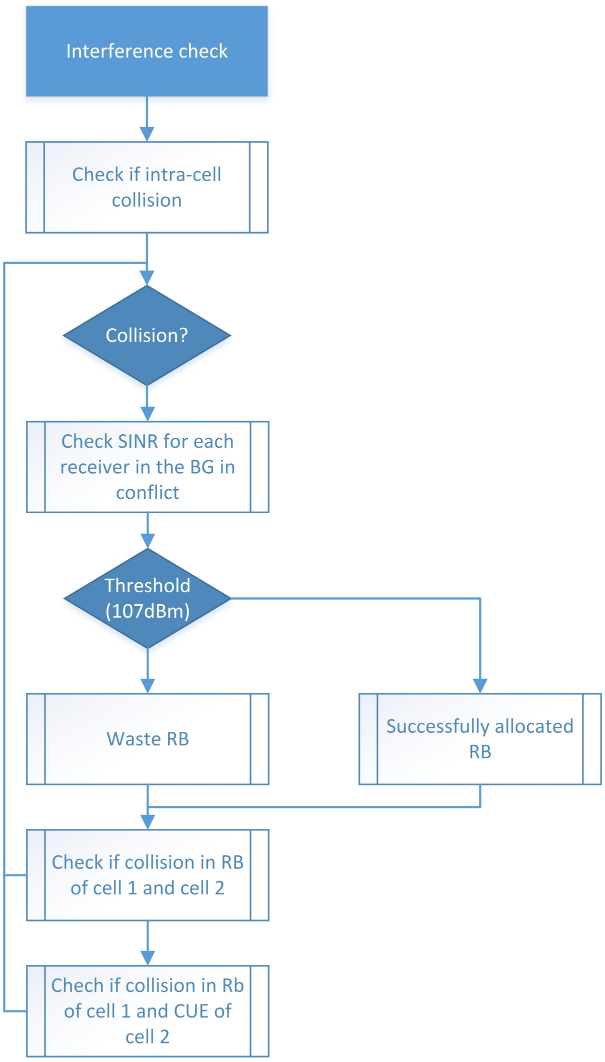

Figure 3.10: Flowchart for the Autonomous Interference Checking.

The process for interference checking in autonomous mode is shown in the Figure 3.10. As a reminder, the intra-cell and inter-cell checks for D2D users will be only done after an SCPeriod is finished, because that is the moment when the reallocation is carried out. While the inter-cell check for D2D groups with cellular users from cell 2 in going to be done every 8ms, but only after the intra-cell one is finished. This way, we already know which receivers cannot get the resource and we avoid the repetitions in the calculations.

The main difference with the scheduled mode is the amount of calculations that needs to be executed for making the intra-cell checking. The added computational load is not very high, but instead of using strong tools as Matlab, simpler ones where used, we would have to take into consideration the benefits that the autonomous mode brings to the system.

3.4 Related Work

With the fast development of communication technologies for vehicular networks, D2D communications promises a big commercial interest and research value, thereby increasing the number of approaches in the scientific world that try to solve the current problems by creating new models and discovering new research challenges on currently existing technologies.

A very common approach can be the one which, focused on the spectral inefficiency [30], chooses the broadcast groups that are going to be provided with service by measuring their channel quality [31]. Consequently, the users with the best conditions (e.g. close to the base station and no interference) will be the ones with preference of obtaining the resources available. Nevertheless, in this approach there is still present the problem of the diminishment of transmission quality when the number of broadcast groups increase.

With the aim of reducing these capacity limitations, there is an alternative scheme called opportunistic multicast scheduling (OMS) [32]. This approach develops the idea of serving during any time slot only the users that not below the threshold of signal to interference plus noise ratio. The idea is similar to the one developed in this study, but the allocation is completely random and the amount of final interference because of the non-dedicated resources is much bigger. The most important point of the design of this system is to make sure that the spectrum is efficiently used, even if this means that a large number of users cannot be served in a given moment or time period. There are also additional issues with the decoding delay, buffer size and computational burden.

This kind of projects are called interference aware resource allocation [33], and there are more than one because it is believed that it is one of the best solutions for improving vehicular networks. Few works addressed that adding the cellular users to the vehicular network would make easier this process because they can act like anchor point to provide extra data to the base station in order to reduce the amount of computational calculation that needs to be done. In the same way the energy consumption of the base station would be considerably less in error recovery as it would be not solved but improved. On the contrary, this approach is not efficient. In order to make the system more effective we are introducing more devices to it, instead of using the minimum amount. The result would have a huge impact on the number of links that would have to be maintained at the end.

The last approach enhances the concept of clustering [34]. Apart from the broadcast groups, all the nearby users create a cluster to share for example packets of the same message with the rest of the members from the cluster. These kinds of networks are called cooperative networks because of the access in groups to the contents. Nevertheless, when sharing extra portions of common interest information, the approach is usually utilized for short-range communications, and generally outband ones. When using in-band communications with a lot of grouped users, the case of not receiving correctly the data can happen. The best scenario for this D2D links would have short ranges between devices, far from the eNodeB not to have interference with cellular users and can support high data rates.

Chapter 4

Performance evaluation

In this chapter the developed system is evaluated in terms of the most influential performance parameters, and the variation of the main inputs with the objective of obtaining illustrative results. During the design of the system these were specified, and now, their relation and effect on the system is going to be analyzed. The scenario is tested for a different number of parameters changed in every run and for different reallocation times to obtain meaningful results. This process is repeated for the scheduled and the autonomous mode to make a clear comparison between them.

4.1 Measurements

Considering the perspective of the work, to evaluate the performance of the system, we are going to focus on the next three variations:

- Introducing a different number of broadcast groups to the system
- Sending messages of different sizes
- Changing the allocation period for each test

The location of the broadcast groups is an important variable in the project because of the interference measurement. Every time a new one is introduces a uniform distribution is done among the cell, and the same things happens with the receivers of each broadcast groups. This data is later used for the SINR formula, that is why all the positions are saved all along the run. The minimum amount of broadcast groups to have in each cell is one because with less we would not have any possible interference, and the maximum number 10, given our 5km coverage of the cell and 1km coverage of D2D transmitters. By distributing them uniformly the space will be covered without an extreme overlap. Undoubtedly, more packets in a message mean that the probabilities of losing it is bigger, because of that, messages from 500 bytes to 1500 bytes are going to be tested. The biggest one will be the one marked by the standard because the future approaches are trying to make the messages as small as possible, so it does not make sense to test bigger ones. Finally, there two changes will be run through different allocation periods. In LTE the durations for reallocation vary from 40ms to 120ms in overlay. Therefore, the periods chosen to study their effect are 40, 60, 80, 100 and 120ms.

4.2 Performance metrics

To measure the system efficiency from the operator part, three are the main performance metrics that have been calculated. By specifying them a big complete picture from the system is taken and the gap between the two modes studied is clearly shown.

4.2.1 Resource Availability

The resource availability indicates how many receivers were able to get all the resources used for the transmission of the packets. This number also describes the effect of the reuse in the two modes.

4.2.2 Control Overhead

Every time the base station needs to contact the nodes for the configuration a certain amount of control information is transmitted. To be precise, the quantity of information that fits in two resource blocks. The most efficient system is the one that obtains the better performance with the less control information possible.

4.2.3 Success Rate

Success rate refers to the percentage of successful messages arrived to the receivers of the broadcast groups from the cell under study. This number will vary in function of the input parameters that are going to be mentioned next. However, the two main ones for this study are going to be the number of broadcast groups within a cell and the size of the messages sent.

4.2.4 Input Parameters

These are the main parameters that can affect the system directly. The modification of them makes a meaningful change in the results. They are based in the specifications of LTE, but in order to evaluate the performance of the systems they are varied. Moreover, many conclusions are obtained by manipulating them as big differences between scheduled mode and autonomous mode are discovered.

System Bandwidth

This is the first basic input to determine. By choosing the system bandwidth we are going to obtain the amount of resource blocks per subframe, and depending on that, the number of dedicate resources are going to be specified. Depending on it the whole design is going to be built, and the change of it may affect the whole study.

Number of Uplink Resource Blocks

As it has been mentioned, this number is directly related to the system bandwidth. For 10MHz, the frequency we will be using, the amount of Uplink Resource Blocks that we are going to have per subframe is going to be 50. With bigger frequencies we would have more resource blocks to allocate for very dense scenarios, and on the contrary, in not crowded scenarios lower frequencies could be used not to waste resources.

Number of Resource Blocks per Broadcast Groups

Taking into account that we are using the cellular spectrum, most of the resources must be dedicated to them. Nevertheless, we are dedicating per subframe with status 1, 20 resource blocks for D2D users. This makes for a full bitmap (8 subframes), 4 with status 1, 80 resource blocks out of 400 dedicated for D2D and 320 for cellular users. This numbers can be varied in function of the amount of users estimated to have in the network.

Number of Receivers per Broadcast Groups

By increasing the number of receivers, the chances to get interference in more of them is bigger due to the lack of space within the coverage area of a broadcast group. If one of the receivers is suffering from interference, the likelihood of having more receivers close that will also be in conflict increases. That is why a reasonable number needs to be determined, in our study case 10.

Number of Cellular Users

The more cellular users we have in the system the bigger interference we will cause to D2D users. As it is explained in the design chapter, CUEs are only introduced in the second cell because with the dedicated resources they do not cause any interference within a cell. The amount must be bigger than the D2D users from a broadcast group, and considering a reasonable number for making a noticeable interference we will use 20 for the simulations. However, this number can be changed in function of the interference level that is wanted to create.

Coverage range of the eNodeB

With the variation of the transmission power from the base station we can either introduce more broadcast groups or less. By making the cells bigger the chance of getting interference from the broadcast groups from the other cell (by keeping the same amount) is lower. Although the energy consumption is bigger, up to a point the sacrifice can be justifiable. For the simulation the value chosen is the one used for standard communications: 5km.

Transmission range of D2D

In order to reduce the interference among the broadcast groups, the ideal case would be to have the smallest range possible for D2D transmitter, but as mentioned before, the smaller the coverage range is, the closer the receivers are. The transmission range used in this approach is 1km.

Message Size

The size of the messages sent is one of the main input parameters to analyze. The usual message size for this type of transmissions is around 1600 bytes. This means that having a transport block size of 782 bits, each message is constructed by 16 packets. If there is any interference and a packet needs to be discarded, messages with less packets have more chances to arrive interference free to the receivers. Therefore, messages with smaller sizes are more probable to be received, because if a packet is lost the whole message is useless. Both allocation modes are tested changing this message size and its effect is studied for D2D communications.

Threshold SINR

The threshold stablished using the formula of the design chapter can be modified in function of the transmission powers of the D2D nodes. Depending on all the parameters aforementioned, this number will let the system to be more or less sharp with the receivers in the boundaries of the broadcast groups and also determine the amount of users that will have interference. If the threshold is increased, it would be more complicated for the receivers to get packets lost.

4.2.5 Other considerations

All the user equipments (UE) acquire the knowledge of their neighbor D2D transmitters and also about their transmission patterns used. In 3GPP the transmission pattern information is included in the preconfigured transmission assignments. This also adds simplicity to the system because there is no need to make a request to the base station to adquire the knowledge.

Moreover, the nodes are able to estimate the path loss from the neighboring broadcast transmitters. This calculation is possible because the information ca be achieved by exploiting reference signals embedded in the packets that are sent from neighboring broadcast. Another functionality of the neighboring broadcast is the knowledge of the transmitter density in the network, so the receivers could be notified in case of congestion.

4.3 Numerical Results

The tests made to measure the performance of the system are bound to the logical variations of the parameters. The system can be tested with any possible value, but the reasons for all the numbers selected have been explained in the previous chapters. All the simulations were done five times (each simulation embeds 100 tests) to prove the system correctness. Moreover, during the process of implementation every single parameter was analyzed as it was created and filled with data with the Matlab debugging tool.

4.3.1 Resource Availability Indication

In the first place, the comparison between the number of served users between the scheduled and the autonomous mode was done, or in other words, how many available resources does each mode have. The main focus of this metric is the reuse gain. It has been previously written that one of the qualities of the autonomous mode is that the same resource block can be used by more than one broadcast group. This means that the amount of nodes that can be served is undefined, the only limit would be the amount of interference created by them, that would increase when more nodes are introduced. On the contrary, in the scheduled mode, for our configuration, at most 4 broadcast groups can be served in a given time period. When it is over, in the next period another 4 would be served.

Because of that, the gain that the reuse provides is show in the following graph. Until the 4th broadcast group the behavior is exactly the same (it could vary with interference). When the 5th broadcast group is introduced, it can be clearly seen that the scheduled mode is stuck with the maximum of 40 users, and the autonomous mode keeps increasing the available resources.

As far as interference is concerned, it is important to mention that the more broadcast groups are in the system, the bigger are the chances to get it. The reflection of that can be easily seen in the irregularities of the graph. If there was no interference in the system we would obtain linear results, and that would be the ideal scenario. But the closer we get to the straight line, we can say that we are approaching to better results. Therefore, it is observed that the results for the autonomous mode are very close to the perfection.

When the number of broadcast groups grows up to four, we can use any of the both modes. In fact, the scheduled mode would be the appropriate one because there is no intra cell interference, so we avoid having it. But once that more than four broadcast groups want to get the resources, undoubtedly, the autonomous one is the best option.

On the one hand, in the X axis of the next graph the number of broadcast groups that were in the scenario the moment the runs were done are specified. On the other hand, in the Y axis the amount of available resources are shown.

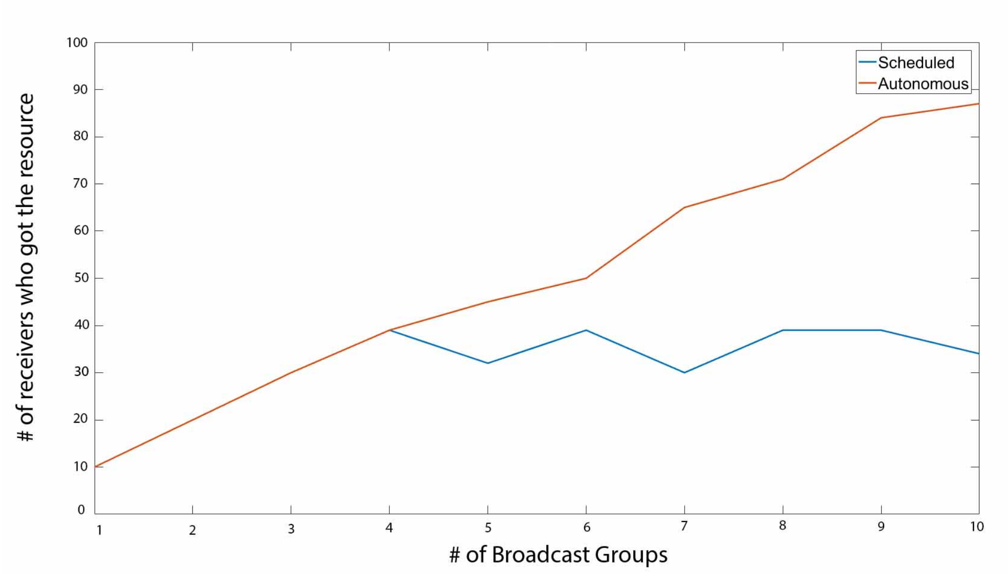

Figure 4.1: Resource Availability Indication.

4.3.2 Control Overhead

One of the main goals of this study was to analyze the control overhead that each one of the modes carries when doing the communication with the base station. It has been mentioned before that every time an allocation period or SCPeriod is finished, the broadcast groups need to communicate with the base station for obtaining the data necessary to carry out the D2D brodcasts. For that reason, with the data the base station sends control information that occupies two resource blocks every time is sent.

Our simulations are done for different allocation periods, and because of that the control overhead is different in each case. The calculation of the overhead is done by dividing the amount of packets that needs to be send to complete a message with the length of the SCPeriod. The result obtained will be the number of reallocation periods used for the transmission of a message. As in each period two resource blocks are used for control signaling, the final result multiplied by two would be the control overhead. In the simulations different message sizes are used, therefore, the control overhead will be calculated for all of them for different reallocation periods.

As it was expected, the bigger the messages are, the more time is needed to send them, so there are going to be more allocation periods used, which means more control information. The same way, the shorter the allocation periods are, the more are going to be used for a given message, because of that more control signaling is going to be send. In the ideal scenario where the interference is not noticeable, in order to achieve the lowest levels of control overhead, very small messages would be used and the reallocation periods would be longer. Nevertheless, in real scenarios, as we suffer from interference, usually the variable that needs to be sacrificed is the allocation period. For some cases it is better to have more control overhead and less interference.

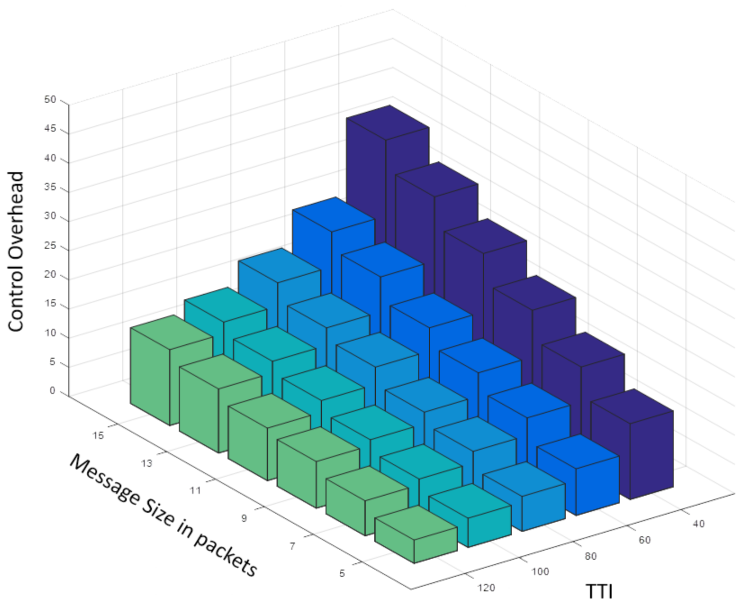

Figure 4.2: Control Overhead.

4.3.3 Message Success Rate per Broadcast Groups

The last performance metric simulated in this study is the message success rate. The aim of D2D communications is to send broadcast messages to the receivers from different broadcast groups, so the only way to test the reliability of the system was to measure for each receiver, how many messages out of 100 were able to receive in each mode.

This one hundred messages were tested starting with one broadcast group in each cell until having 10 broadcast groups. At the same time all the tests were repeated for different SCPeriods, obtaining this way 60 runs for generating each graph. The numbers shown in the graphs are the results of averaging the correctly received messages from all the broadcast groups.

Scheduled mode

In the scheduled mode, what we can clearly see and deduce is that there is a big decrease with the introduction of more broadcast groups. Until the fourth one the behavior is similar, but, for instance, the first and the last colums are compared, or even the fourth with the last, we can see that the percentage of success is very low. The reason for this decrease is the aforementioned no reuse policy. 6 nodes out of 10 are not going to be served in a measured period, and due to this inactivity, the success rate is directly affected.

In addition, as the aim of the system is to give service to all the transmitters of the cell and here six can not obtain a resource, the idea is to have shorter SCPeriods to reallocate the nodes and this way provide with resources the ones that could not get it in the previous interval. If the graph is analyzed, better results are obtained when the reallocation time is shortened.

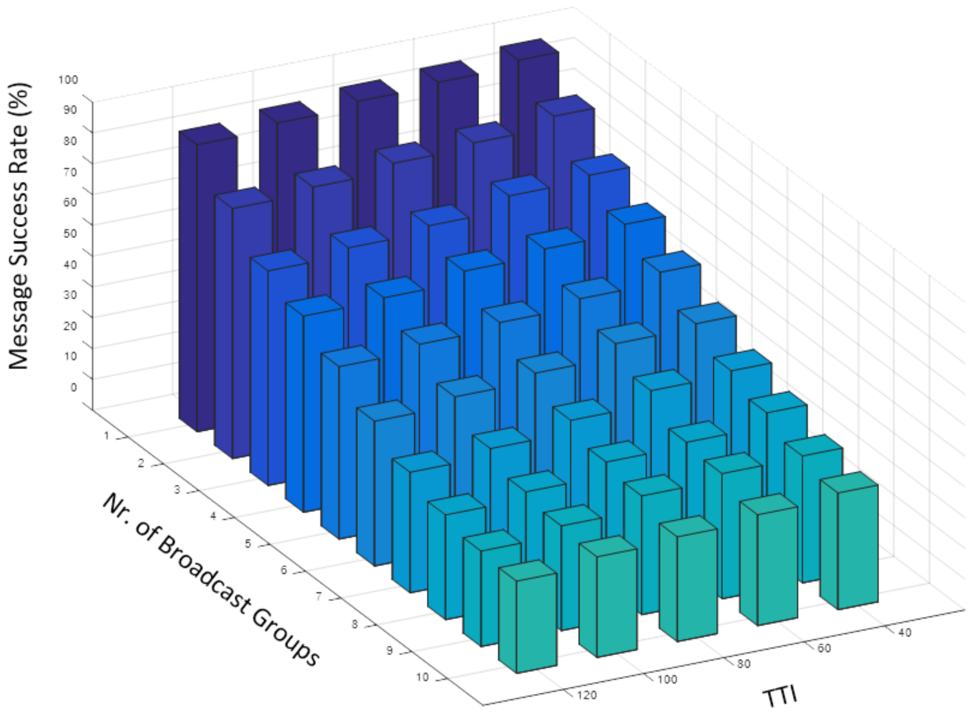

Figure 4.3: Message Success Rate per BG Scheduled.

For the moment the allocation is completely random, but for future releases algorithms where the best connection quality nodes are served can be developed. It can be observed in the Figure 4.3, that the success rate for one broadcast group is almost 85-100% for any SCPeriod (40-120ms). These are very high expected percentages, as introducing a single broadcast group creates a very low probability of having interference. Nevertheless, when more broadcast groups are introduced, for instance, from two to ten, the results will experience a smooth decay until obtaining 30-40% of success rate. In the results with more broadcast groups the difference of using a different SCPeriod can be also easily spotted. When interference is generated, the chance of getting rid of it grows with shorter allocation time intervals (40ms) in the scheduled mode. As a clear example, with 10 broadcast groups in the scenario, the success rate grows from 29% to 39%.

Furthermore, in this mode a maximum amount of 4 broadcast groups can be served, so it is impossible to improve the performance of the system when 5 or more broadcast groups are in the play. The only thing that are going to produce is more interference. Moreover, the ones that didn't get the resource because of the lack of them, will also need to wait until the allocation is done again to get the chance of obtaining a resource for transmission.

Because of the previous reasons the results obtained can not be higher than the 50% of success rate when 8 broadcast groups or more are introduced. The failed messages will increase when more BGs than available resources are trying to transmit. That is why the average successful messages will be less without any chance to get better in the scheduled mode.

Autonomous mode

For the autonomous mode the results are exactly the opposite for the next reasons. First, the chance to get interference is considerably less because of the reuse, so the objective is to maintain the allocation as longer as possible. That is why we obtain betters results with longer SCPeriods. When shorter SCPeriods are used, to send a given message, more allocations needs to be done and the probability of generating allocations with conflict increases. This statement can be proved in the next graph where, for any number of broadcast groups in the scenario, there are always going to obtain a bigger success rate the simulations with 120ms than the ones with 40ms.

Admittedly, the interference keeps growing as more D2D transmitters are introduced in the system, but when comparing both graphs, it can be seen that the results in the autonomous mode is much better than the scheduled one. The decrease is done in a smooth way when the 5th, 6th broadcast groups are introduced, not as in the scheduled mode. Because of that, for dense scenarios like urban areas the autonomous mode is more likely to be used. If we would like to implement the solution in rural areas, because of the low density of users, in that case the scheduled mode could be the appropriate one. By carrying out this last model for rural areas, the allocation configuration is easier to do. Moreover, the computational load for intra-cell interference checking is avoided.

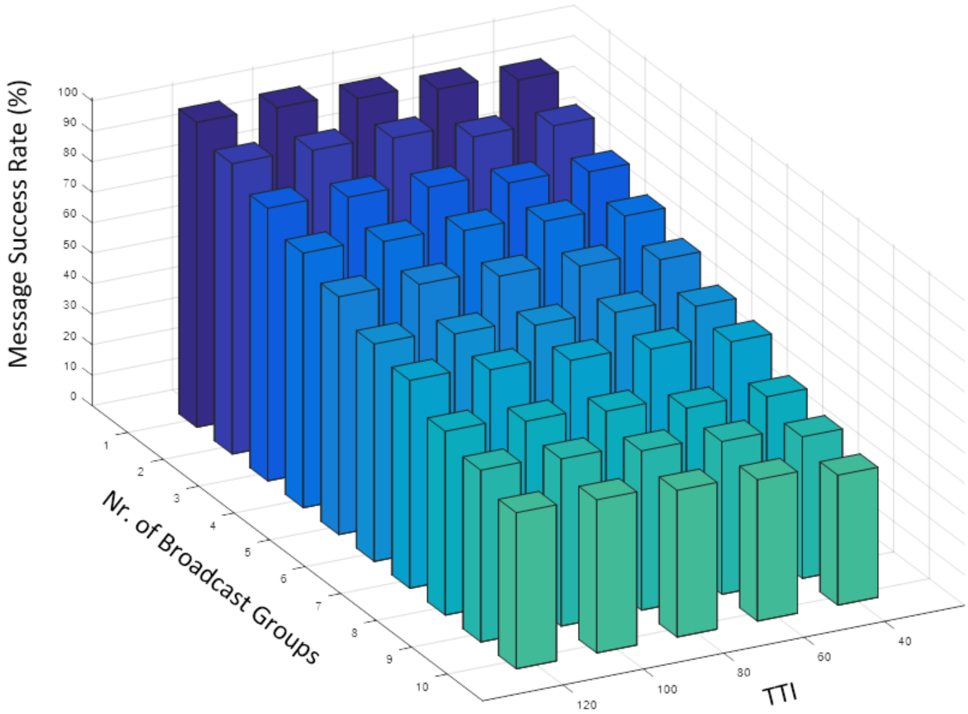

Figure 4.4: Message Success Rate per BG Autonomous.

In the Figure 4.4, comparing to the Figure 4.3, it can be observed that the results until the fourth broadcast group are similar, varying from 100% to 50%. Although the ones from the autonomous mode are slightly better. If the success rate is analyzed for a higher number of nodes, the results clearly benefit the autonomous mode. In the scheduled mode, with 10 broadcast groups, in the best case scenario, using the SCPeriod of 40 ms we could obtain 40% of success rate. While in the autonomous mode, for the same amount of transmitters, we can obtain up to 52%. That means that we have more than 10% of grownth for successful messages.

4.3.4 Message Success Rate per Message Size

Appart from testing the message success rate for a different number of broadcast groups, more simulations were done to study the effect of the message size in the performance of the system. It has been previously said that in several studies is mentioned that D2D communications are trying to send lower amount of data to improve the spectral efficiency, and this implies to reduce the size of the information to the lowest.

1500-1600 bytes is the size of currently send messages, so knowing the fact that bigger messages would only carry worse results, the number of packets in a message have been reduced until sending messages of 500 bytes to see the improvement in the success rate.

This simulation is done for four broadcast groups as that number is the edge for the scheduled mode to overload. In both modes all the nodes can be served. If more or less transmitters were introduced in the cell the results obtained would not be trustworthy. Moreover, the correctness of the system can also be tested here. In the previous simulations, all the TTIs were tested for four broadcast groups for 1500 bytes messages, so consequently, the success rate obtained in these graphs for the same message size should be similar to the ones obtained in the previous ones.

Scheduled mode

In the scheduled mode can be appreciated that the results obtained are improved considerably when the message size is reduced, instead of having 15 packets per message, if we could send 5 packet messages, from the 50-60 percent of success we could reach a success rate of 80%.

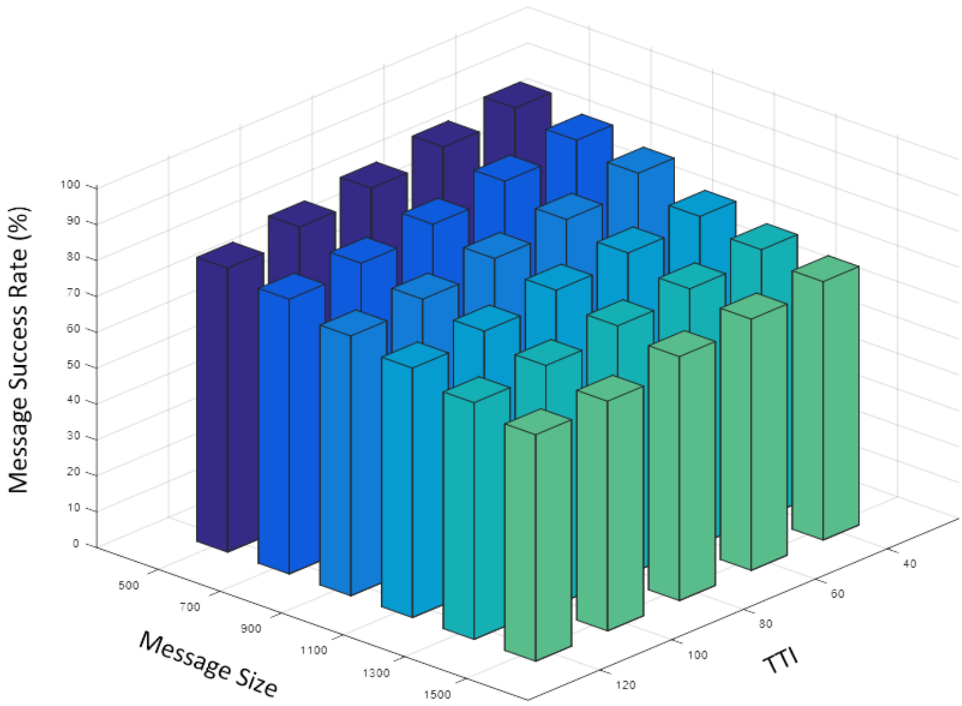

Figure 4.5: Message Success Rate per message size Scheduled.

This change is because the high chances to get interference from the other nodes. If the amount of packets is reduces to its third size (i.e. from 15 to 5), there are 3 times less possibilities to lose a packet. Because of that it would bring great benefits to the scheduled mode if smaller information amounts could be sent. In the Figure 4.3 it can be seen that the values for 4 broadcast groups, for 1500 bytes messages are similar to the ones obtained in the Figure 4.5. For instance, the values go from 53% to 62%. When the packet size is reduced to 500 bytes, the values are increased until 69% and 79% respectively.

However, regarding the higher rates with shorter reallocation intervals the control overhead need to be taken into account. Even if we can send less data by making the messages shorter, we still need to add to the total amount the control signaling information.

Autonomous mode

Finally, the results obtained for the different message sizes in the autonomous mode determine that for the currently used scenario is the best alternative. Even though the success rate is improved when we send messages with less packets, the numbers obtained are still above the scheduled ones.

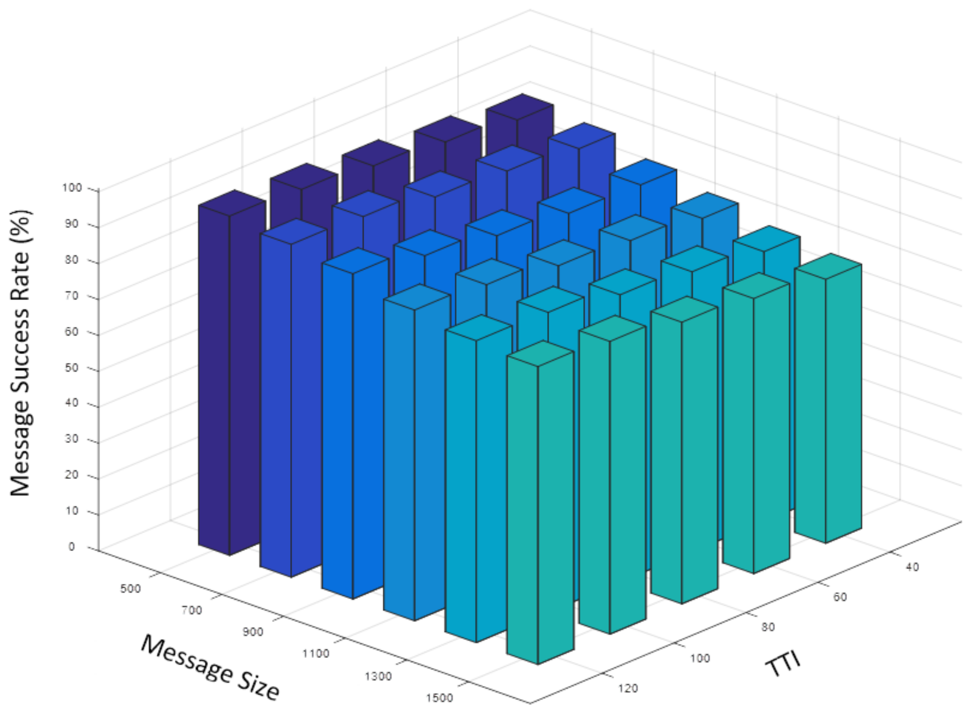

Figure 4.6: Message Success Rate per message size Autonomous.

As the percentage of received messages is already very high, around 70%, for the four broadcast groups studied, it is comprehensible that the increase is smoother than in the scheduled mode. Nevertheless, if both modes were studied again introducing more nodes, regardless of the number of messages tested, we would still obtain significantly better results in the autonomous one.

In the Figure 4.6, even if the changes can not be appreciated at first sight due to the high results, the increase of the success rate varies from 63% for the reallocation interval of 40ms, and 73% for 120ms, to 78% and 87% respectively. This means that, by reducing the amount of packages per message, the results obtained improve considerably.

4.3.5 Performance Comparison

To make easier the visualization of the difference between the two modes 2D graphs have been created for the simulations with a variable number of broadcast groups and for the simulations with multiple message sizes.

Number of Broadcast Groups

Selecting 120ms as the signaling control period this is the gap of the success rate between the autonomous and scheduled mode. Both modes decrease because of the interference but the best performance is clearly done by the autonomous mode. The main difference is spotted starting from introducing a single broadcast group. As the chances of obtaining interference are bigger in the scheduled mode, although it is not big, we do not have 100% of success rate.

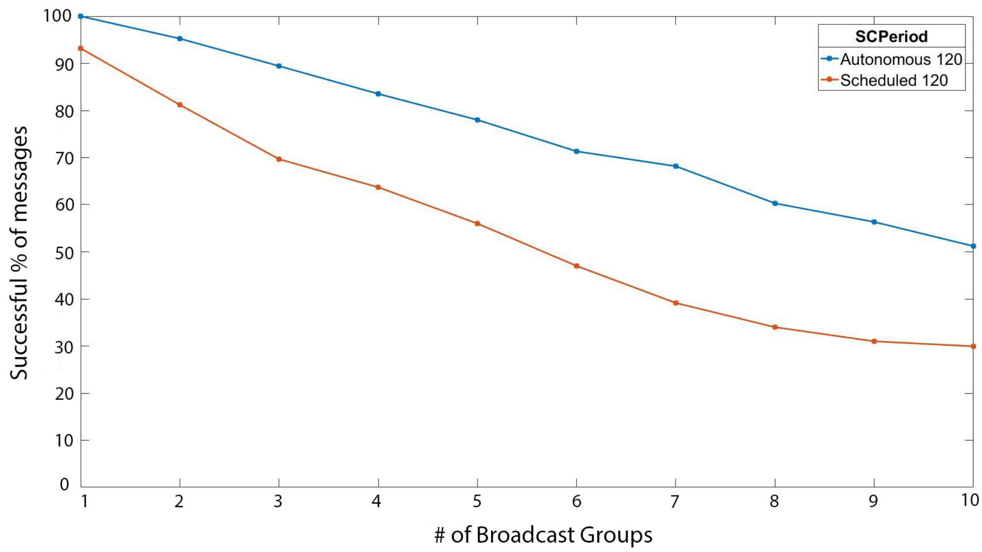

Figure 4.7: Comparison between modes for different BGs.

It can be appreciated in the Figure 4.7 that the interference for the autonomous mode is softer than in the scheduled mode. The gap between the two modes is also figger when more nodes are introduced in the system.

Different Message Sizes

When increasing the number of packets within a message, a bigger change occurs in the behavior of the scheduled mode. Nonetheless, for the most used messages in D2D communications, 1500-1600 bytes, the autonomous mode shows almost 40% more successfully delivered messages. This is because the results in the scheduled mode are worse, as it was mentioned before. So the chance to improve the results is bigger than in the autonomous one. Nevertheless, with the conditions of our scenario, even if this difference is noticeable, it is not as big as it could be given other conditions like introducing more receivers or sending more messages.

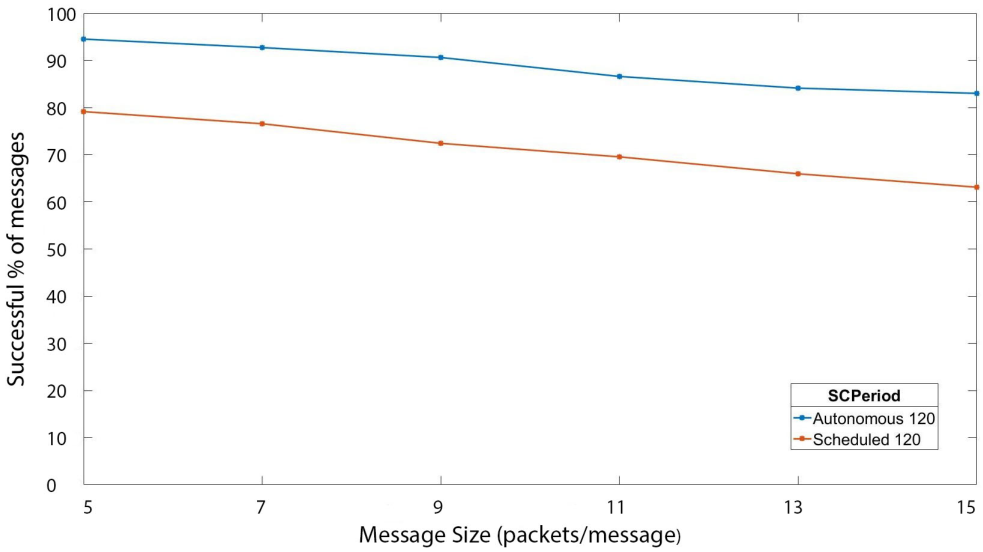

Figure 4.8: Comparison between modes for different MSs.

Chapter 5

Conclusions and future work

This chapter is divided in two parts. On the one hand the conclusions that came out from our work are exposed. On the other hand, the future work or future improvements for the system and D2D communications in general are explained.

5.1 Conclusions

In this study, two resource allocations methods were designed and implemented. The aim was to analyze the performance of D2D broadcast for vehicular communications. To formulate the conclusions of the work, we are going to follow the order on which the research questions were posed, to make sure that all of them were answered.

- Which are the alternatives for 802.11p and 4G? Is there any other technology that can be used to carry out the D2D communication?
- Is the mobile networking system a promising approach for vehicular communication?
- How do we measure the efficiency of the developed resource allocation methods?
- Which are the parameters that have direct or indirect effect in the performance of device to device communication?
- Which are the possible scenarios on which D2D communications can be carried out?
- How can we improve the reliability of the system for the transmission of broadcast information?
- How do we implement the solution to improve the performance of broadcasting in vehicular networks?

In the first part of this study was clearly spotted that iEEE 802.11p and 4G were not the optimal solutions for developing D2D communications. Their many shortcomings show scalability and reliability constrains, which were one of the main basis of the next generation networks. In the background chapter, it has been said that D2D communications lay under the UMTC service of 5G. The most important point here were the increase of cellular network capacity and spectral efficiency, which the current technologies can not meet.

However, we can benefit from the 4G LTE network management to make the baseline of our work. Currently the uplink channel of the cellular spectrum is underutilized. This means that too many resources are wasted, so the channel efficiency is very low. Therefore, the cellular approach may be the correct approach as its conditions are favorable to carry out D2D communications.

To reassure this idea some key performance factors were specified. With them we are able to measure the system efficiency and demonstrate the quality of it. Moreover, they also helped to see the differences between the two implemented modes. In the results chapter the three main performance metrics were explained: resource availability indication, control overhead and message success rate. By calculating these three we proved that the efficiency of the system was good enough for the established conditions.

The input parameters that were make the system susceptible of changing its performance were the next ones. A division between two type of parameters can be done: physical and configuration parameters. Within the physical ones, the most important is the number of broadcast groups. As the main source of interference, the increase of them has a clear effect in the system. The number of receivers also plays an important role on it. The more receivers we have, the closer they will be inside the coverage range of a D2D transmitter, so more of them can be affected by interference. This way the results obtained will be considerably worse. The cellular users are the second influencers on the interference level at the receivers. Because of that we have to take them into account. Regarding the configuration parameters, the system bandwidth is the one that determines the number of resources we will have for carrying out the allocation. Apart from that, the number of messages and their size must be determined in order to calculate the success rate of reception in the receivers. This will also depend directly on the allocation time interval or SCPeriod.

By modifying and variating the input parameters we reached the conclusion that D2D broadcast was a promising approach. The results obtained gave us an insight into resource management aspect of D2D communications. It was also deduced that a certain resource allocation scheme does not fit into all scenarios. For instance, the scheduled mode is more preferable to be used in rural scenarios with not more than four broadcast groups, because the system could not give service eventually to some of the receivers. The autonomous mode otherwise, showed a better performance when more nodes were introduced. So, it would behave better in dense urban scenarios.

Nevertheless, there is still a lot of work to do on the field. There are many ways to improve the reliability of the system, as for example, the modification of the parameters aforementioned. The solution implemented in Matlab can be varied as much as the administrator of the systems wants. But the direction on which the developers and the companies are going, following the resource management path, is to create new approaches focused on Adaptive Resource Allocation.

5.2 Future work

With the fast development of IoV and communication technologies, vehicles and the infrastructure of our cities are gaining computation abilities. D2D communication as IoV is emerging and being an important part of the next generation smart cities. This technology goes beyond what we have known until now, telematics, intelligent transportation systems, sensors, mobile devices to combine all of them and obtain a fully connected heterogeneous network.

The aim of IoV is to incorporate multiple nodes and receivers for providing the best service capable of fulfill their needs. For that and efficient wireless solution must be created. After implementing this work, it was been concluded that several approaches can be done for enhancing the current schemes. However, most of them tend to create solutions focused on Adaptive Resource Allocation as it has been said before.

One of the future solutions could be to create a hybrid mode [35] for alternating the scheduled and autonomous mode depending on the network load. For example, if there are less nodes than resources available, the scheduled mode would be activated. In case that more transmitters are incorporated to the cell, the allocation mode would automatically change to the autonomous one enabling the reuse of the dedicated resources.

Another approach could be the one with power control. In this case, the base station is configured to guarantee the minimum power for each broadcast group. This amount of power is adjusted to a given number of broadcast groups. In case that there is any remaining power because there were less nodes than expected, the first new node entering the cell would get it being able to use it for transmitting instead of waiting for another reallocation.

The last one would be related with interference cancellation. Before making the resource allocation, an algorithm that studies the status of the cell would be executed. By doing this, the best way to deliver the resources would be calculated. Therefore, most of the possible interferences would be avoided. However, this technique requires a high computational load.

Undoubtedly, there are many more ideas for improving broadcast in D2D communications as MIMO based communication, coordinated transmissions, adaptive data rate, adaptive modulation but there are still underdeveloped. In conclusion, there is a high demand for reliable vehicular communications, and for the following years a huge increase is expected for the development of application for Intelligent Transportation Systems.

Chapter 1

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