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Models and Methods for Network Selection and Balancing in Heterogeneous Scenarios.

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To my Family, my Friends and MCLab Team

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Acronyms

3GPP 3rd Generation Partnership Project

5G Fifth Generation

ADAS Advanced Driver Assistance System

ADR Aggregate Data Rate

AHP Analytic Heirarchy Process

ALoW Additive Logatithm Weighted

AMQP Advanced Message Queiuing Protocol

AP Access Point

ARERA Italian Regulatory Authority for Energy Networks and Environment

ATSC American Television Standard Committee

BER Bit Error Rate

BR Browsing

CDF Cumulative Distribution Function

CMS Conventional Multicast Scheme

CNM Centralized Network Management

CQI Channel Quality Indicator

D2D Device to Device

DG Distributed Generation

DMS/EMS Distribution / Energy Management System

DNM Distributed Network Management

DR Demand Response

DSO Distribution System Operator

e2McH Energy Efficient Multi-Hop Communication Solution

eMBMS evolved Multimedia Broadcast and Multicast Services

eNodeB evolved Node B

ESS Energy Storage System

FDD Frequency Division Duplexing

FDPS	Frequency Domain Packet Scheduler
GM	Gaming
GSM	Global System for Mobile
GUI	Graphical User Interface
HetNet	Heterogeneous Network
HLS	HTTP Live Streaming
HQ	High Quality
HTH	High Throughput
HV	High Voltage
ICT	Information and Communication Technology
IED	Intelligent Electronic Devices
IoT	Internet of Things
IP	Internet Protocol
ISM	Industrial Scientific Medical
ITU	International Telecommunication Union
JFI	Jain's Fairness Index
LCID	LTE cell ID
LDM	Layer Division Multiplexing
LGW	LoRa Gateway
LN	LoRa Node
LoRa	Long Range
LPWAN	Low-Power Wide Area Network
LTE	Long Term Evolution
LTH	Low Throughput
M2M	Machine-to-Machine
MAC	Media Access Control
MCDA	Multi Criteria Decision Analysis
MCH	Mobile Call Handoff
MCS	Modulation Coding Scheme

MDI	Minimun Dissatifaction Index
MEW	Multiple Exponential Weighting
MIH	Media Independet Handoff
MNO	Mobile Network Operator
MPEG DASH	Dynamic Adaptive Streaming over HTTP
MQTT	Message Queuing Telemetry Transport
MS	Multicast Subgrouping
MTC	Machine Type Communications
MU	Measurement Units
MV	Medium Voltage
n6	node 6
n7	node 7
NB-IoT	Narrow Band IoT
NOM	Non-Orthogonal Multiplexing
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
ns-3	Network Simulation for Internet system
OFDM	Orthogonal Frequency Division Multiplexing
OGP	Open Gaming Protocol
OMA	Orthogonal Multiple Access
OMS	Opportunistic Multicast Scheme
PF	Proportional Fairness
PLC	Powerline Communication
PLS	Packet Loss Ratio
PQ	Power Quality
PSNR	Peak Signal to Noise Ratio
PtMP	Point to Multipoint
PV-ESS	Photovoltaic Energy Storage System
QoE	Quality of Experience

QoS	Quality of Service
RAN	Radio Access Network
RB	Resource Block
RES	Renewable Energy Sources
RRM	Radio Resource Management
RTSP	Real Time Streaming Protocol
S3	Sardinia's Smart Specialization Strategy
SC	Short Circuit
SCADA	Supervised Control and Data Acquisition
SC-PTM	Single Cell - Point to multipoint
SF	Score Function
SIC	Successive Interference Cancellation
SINR	Signal Interference plus Noise Ratio
SS	Signal Strenght
STOMP	Streaming Text Oriented Messaging Protocol
SubOptADR	Subgrouping Optimal Aggregate Data Rate
SVC	Scalable Video Coding
TCP	Transport Control Protocol
TSO	Transmission System Operator
TTI	Transmission Time Interval
TU	Throughput per User
TVWS	TV White Space
TYDER	Traffic Type-Based Differentiaded Reputation Algorithm
UDP	User Datagram Protocol
UE	User Equipment
UF	Utility Function
UHF	Ultra High Frequency
UVA	Unità Virtuale Abilitata
UVAC	Unità Virtuale Abilitate di Consumo

UVAM	Unità Virtuale Abilitate Miste
UVAN	Unità Vituale Abilitate Nodali
UVAP	Unità Virtuale Abilitate di Produzione
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2X	Vehicle to Everything
VANET	Vehicular ad-hoc Network
VDU	Virtual Dispatchable Unit
VI	Video
VPP	Virtual Power Plant
WSN	Wireless Sensor Network

Chapter 1

Introduction

1.1 Motivations

The outburst of 5G technologies for wireless communications can be considered a response to the need for a widespread coverage, in terms of connectivity and bandwidth, to guarantee broadband services, such as streaming or on demand programs offered by the major television networks or new generation services based on augmented and virtual reality (AR/VR). The use of video tends to occur during the evening hours and has a "prime time", unlike the general use of the Web that occurs during the day. As a result, more video usage means more traffic during peak hours of the day. Social media applications together with devices as smartphones, laptops, or tablets are leading to replace traditional unicast connection (i.e., point-to-point (P2P)) with new delivery schemes for allowing users to share self-produced live video content or to receive live video streaming or video-on-demand contents.

In this context, a big number of users needing to be connected anytime and anywhere are going to request more and more resources to satisfy growing expectation in terms of Quality of Service (QoS). For example, multimedia applications (e.g., Gaming, streaming, AR/VR) ask for data transmission with high-reliability and extended coverage to guarantee adequate QoS also to devices in disadvantaged positions.

Moreover, the massive use of IoT device services is exponentially increasing the number of devices connected to the infrastructure networks (i.e., wired and wireless). To meet these requirements, a series of new generation standards and technologies have been developed, such as New Radio (NR), 802.11ax, Narrow Band IoT, and LoRa.

The increasing diversification of the network and the standards available to the devices raises problems relating to the management of networks so that the best possible connection is always offered based on the type of device used and on the type of service requested.

Another problem that arises is how to differentiate traffic in such a way as not to waste radio resources, this can happen for example using multicast. In fact, multicast allows to serve many users who request the same services simultaneously with relatively low latency and high levels of QoS. However, the management of multicast-type services presents problems related to multi-user diversity and to the different channel quality encountered by users within the same multicast group.

For this reason, the 3rd generation partnership project (3GPP) introduced the evolved multimedia broadcast/multicast services (eMBMS) to provide long term evolution LTE transmissions from a single source to multiple devices, using a common channel to share the same content in order to improve the management of available radio resource. Nevertheless, nowadays mobile users are able to access the Internet also via other wireless technologies, such as wireless fidelity (WiFi) standard 802.11n/ac/ax constraining to implement other mixed schemes.

Furthermore, it is necessary to prevent the networks from congesting. For this reason, several schemes have been proposed that offer a dynamic handover to allows maximizing the QoS, guaranteeing a minimization of the costs that users have to bear for the service offered.

One of the possible solutions is to carry out a traffic balancing on heterogeneous networks, ensuring that none of the networks available for a given user goes into saturation and therefore has a decrease in performance. Currently, most of the traffic balancing algorithms perform a selective procedure to assign the best network to each device by combining the received signal strength, throughput, delay, economic cost to the user and energy consumption. Such as systems have shown an improvement in network performance, but they also have limitations in terms of efficiency and computational complexity.

1.2 Objectives

The study I'm going to present aims to solve two of the main problems that will occur with the outburst of 5G:

- the search for the best possible connectivity, in order to offer users the resources needed to enjoy new generation services;
- multicast as requested by the eMBMS.

The aim of the thesis is the research of innovative algorithms that will allow to obtain the best connectivity to offer users the necessary resources to take advantage of 5G services in a heterogeneous scenario. Studying UF that allows to improve the search for the best candidate network and to carry out a balancing that allows to avoid the congestion of the chosen networks. To carry out these two important focuses I carried out a study on the main mathematical methods that allowed to select the network based on the QoS parameters based on the type of traffic carried out by the users. A further goal was to improve the performances in terms of computational computation that they present.

Furthermore, I carried out a study, in collaboration with important research studies (Università degli Studi Mediterranea di Reggio Calabria and University of the Basque Country - UPV / EHU), in order to obtain an innovative algorithm that would allow the management of multicast. The algorithm that has been implemented addresses the needs present in the eMBMS, in realistic scenarios.

1.3 Contributions

The contributions made by the thesis work follow the two macro areas of research presented in the paragraph 1.2.

To obtain the best available network, a new method has been studied which would allow me to optimize the network selection. Regarding this objective, the first objective was to calculate the network's reputation so that the devices can always connect to the best available network. This led to the balancing of the networks to prevent saturation and performance degradation. With the use of Utility Functions (UF) I have taken into consideration the diversification of the devices, the services required and the user profiling, with the definition of a priority condition for certain users. This was achieved using Game Theory (GT). From this study the additive logarithmic weighting game theory-based algorithm was born (ALOWGATH). It is a new algorithm that combines the selection of networks with their balancing.

Later an algorithm was designed to improve network selection. So a raking network was created with the best performance in real time, differentiating the type of traffic used by the device at a specific time. This led to the creation of the traffic type-based differentiated reputation algorithm (TYDER). The novelty presented by this work is the possibility to select the best network based on the type of traffic made at that moment.

Furthermore, I proposed an algorithm for multicast of 5G services through the creation of subgroups of users, to efficiently manage radio resources and, consequently, to guarantee to different groups of users the simultaneous access to the same multimedia content with a differentiated QoS. In particular, I proposed the use of eMBMS with the aim of addressing services from point to multipoint and non-orthogonal multiple access techniques (NOMA) that allow to increase the efficient use of the spectrum in environments multi-user with asymmetric data delivery.

Subsequently some cases of use of 5G were presented in real applications. Their purpose was to show the potential of the standard in applications other than telecommunications and how they can be improved in terms of QoS.

1.4 Overview of the Thesis

The structure of the thesis follows the progress of the study conducted over these three years.

In the chapter 2, an excursus is made on how the problems presented in this chapter have been dealt with in the literature.

Starting from the balancing of networks, chapter 3 offers an overview of the network balance and the tools I used to make it. Entering the ALOWGATH algorithm in detail. Then the network reputation problem will be introduced in chapter 4. The ranking of networks and the algorithm used to carry it out in 5G network scenarios are presented.The TYDER algorithm will be introduced and explained in detail.

After this first part, which focuses on the application level of the ISO/OSI stack, in chapitol 5 the multicast problem and the solutions designed to solve the critical issues present in it are introduced.

In the chapter 6, use cases are presented in which 5G technology is applied. In the first use case, a scenario of application of LoRa technology is addressed, in particular the use of multihop to limit the energy consumption of IoT devices. In the following two scenarios, 5G technology is applied in smart grid environments for communication to monitor the devices used.

Finally, the conclusions of the work carried out will be presented in the chapter 7.

Chapter 2

Related Works

This section presents a survey on the state of the art of research relating to heterogeneous networks and on multicast management mechanisms.

The paragraphs 2.1 and 2.2 concern heterogeneous networks, particular attention was given to solutions involving the selection of the access network, the reputation of the network, the certification of skills with emphasis on their main limits. The main problem in the network selection algorithms is to identify the selection parameters and define the mechanism to combine them.

In the paragraph 2.3, an overview of the systems adopted to perform an additional resource allocation mechanism in the radio resource management entity (RRM) is proposed.

2.1 Balancing Heterogeneous Networks

The main challenge for users equipped with a multi-mode device is to exploit the "best" radio access network (RAN), intended as the RAN offering the highest QoS. Network selection is complex, depending on the capacity to rely on a large number of parameters, such as service class type, user preferences, mobile devices, battery level, network load, time of the day, service price, etc. Moreover, the procedure is further complicated by the combination of static and dynamic information involved in decision-making, the data accuracy, and the effort to collect it with available resources (e.g., battery, memory, and device processor), that may lead to limitation in performance due to devices characteristics.

The selection decision needs to be performed a first time to start the connection, and then repeated as part of the handover procedures, so whenever the situation of the network or device undergoes a change. In the last few years, different approaches have been proposed to select the candidate networks and to achieve a network load balancing, thus preventing the networks from saturating with consequent performance decline and QoS degradation.

In [1], the selection of candidate networks is based on the received signal strength. Using the repeated prisoner's dilemma game, the solution models the interaction user-network as a cooperative game showing that defining the incentives and disincentives for cooperation against defection allows achieving high QoS. This solution, based on the multiplicative exponential weighted (MEW) algorithm, was developed to perform a selection procedure over 3rd-generation (3G) networks not allowing to migrate the method for its use in a 4/5G perspective.

Also in [2], the MEW algorithm was performed to determine the score of each network that the user can access, through multiplicative mathematical operations. This method was applied to the selection of the candidate network. This document combined various inputs such as received signal strength, throughput, packet delay, cost per user, type of traffic required, and type of device.

In [3], the authors focused on the realization of a heterogeneous network environment with a combination of macro and small cells to spread the traffic load, increase the bitrates, and maintain high QoS.

In [4], a self-organizing network (SON) was proposed to simplify network management, performing evaluation and decision actions based on a set of rules and metrics. SON coordination becomes very complicated with a varied control structures. To overcome this limitation, cognition is addressed for enabling devices to independently learn the required optimal configurations.

Several approaches have been presented in [5], where three different directions based on current key challenges were followed:

- adaptive multimedia solutions aim to maintain high levels of quality perceived by the user by efficiently using the resources of the wireless network, either automatically through the services offered by the device, or through techniques for the adaptation of video delivery on the Internet;

- energy efficient solutions take into account the energy consumption of the mobile device to prevent mobile users from running out of battery during a video session. Mechanisms were classified into five macro categories: surveys and studies on energy consumption, selection of the energy efficient network, energy efficiency based on operating modes, cross-layer solutions for energy saving, and energy efficient multimedia processing and delivery. Their purpose is to identify the energy source and to manage its consumption allowing energy savings and increasing battery life;

- multipath content delivery solutions aim to address a problem caused by the increase in the use of video-type multimedia applications, requiring a continuously expanding network able to offer a large amount of bandwidth. Currently, no single-access network technology would be able to meet these new traffic requests. One solution for integrating these bandwidth-rich multimedia applications would be to split traffic across multiple routes.

Another challenging topic is the management of network saturation, also considering the upcoming 5G networks growing and the massive use of Internet of Things (IoT) devices.

In [6], a virtual network embedding (VNE) algorithm is proposed to flexibly select the appropriate functional split for each small cell to jointly minimize the inter-cell interference and the fronthaul bandwidth utilization by dynamically selecting the appropriate functional split.

In [7], the authors proposed an algorithm that balances the small-cells networks avoiding the collapse of one or more of them which would create a significant worsening of the throughput. The algorithm is based on the progress of the overloaded and adjacent cells, adapting the state of the network load and considering the load estimate.

The use of resources depends on the quality of the signal and the traffic requests of the user equipment (UE) connected in. The proposed solution does not fit heterogeneous networks and can only be used on networks that rely on the resource blocks (RBs), which are the basic resources of LTE.

In [8], the ORCHESTRA framework was proposed to manage the different devices based on a fully transparent virtual medium access control layer and an software-defined networking-like controller with global intelligence, introducing capabilities such as packet-level dynamic and intelligent handovers, scheduling, load balancing, and replication.

Another good strategy for balancing networks is to use the GATH [9]. GATH is widely used in the management of HetNet to make choices that require the presence of different types of network selection criteria that have a competitive behavior between them (i.e., for networks and users). In literature, there are many examples of how GATH can be used to solve problems related to HetNet.

In [10], game theory is used to solve the problem of cooperative communication between the relays and the base station. They focus in particular on the selection of relays, with the aim of guaranteeing the required performance in terms of capacity. They model the transmission scheme as a non-transferable coalition formation game, with a characteristic function based on an approximate capacity expression. Introduced the theory of the coalitional type of game in order to provide a concept of a reliable solution to the game.

In [11], an algorithm based on GATH together with a self-optimizing power control scheme was proposed to solve a priority access problem applying the separation between primary and secondary users. For channel assigning strategy, they consider the allocation to be done dynamically on the basis of cell selection game. Their proposed scheme outcomes better system throughput, capacity as well as increased revenue of operators considering optimal price for consumers. The NE was used to study spectrum sharing within a heterogeneous network, in order to offer the maximum QoS to the users while reducing the co-channel interference.

In [12], the authors proposed a solution based on an analytical hierarchy process (AHP) to establish a hierarchy between the network evaluation criteria for different types of service requests. The hierarchy of the network obtained from the AHP analysis is then combined with the non-cooperative GATH to find the optimal network for specific assistance requests. The strategic game is formed on the network scores of different service requests for different RANs. Users willing to pay network providers for service requests are used to model a network game against a user. The NE of this game represent the RANs selected by each user with the highest result.

All these methods showed good performance but none of them solved the problem of the presence of zeros in the score function and the absence of a balance between the networks. Moreover, all these works do not take into account the required type of traffic, the device being used, and the user priority defined as the capability to satisfy user requests compared to others.

To overcome these issues, in [13] an adaptive real-time multi-user access network selection algorithm is presented for load-balancing over heterogeneous wireless networks (ARMANS) through the definition and use of four different QoS classes, as defined by the WiFi standard. However, this work has a limited number of connection points to the network, a limited number of users with different priorities. Moreover, the balancing takes place in a global manner without the presence of specific users priorities. Furthermore, ARMANS uses a MEW score function which presents the limit of the presence of zeros, forcing the algorithm not to take into account networks with an utility function (UF) (i.e., a measure of the parameters of the candidate network) equal to zero even in the presence of UFs that show very high values.

Another novel method was proposed in [14], where the authors developed a network selection algorithm based on hybrid unicast-multicast utility, called HUMANS, which offers the option to select multicast transmissions in the network selection process during video delivery. The solution aims to serve users with good channel conditions through the use of unicast transmissions, while delivering content to users with poor channel quality via multicast. This allows offering high performance solutions in terms of percentage of interruption and average quality of transmission, both in low and high density scenarios, also ensuring operators more efficient use of the resources made available. Although HUMANS shows high performance in ultra dense networks scenarios, it uniquely performs a network selection procedure without any balance of the traffic load.

2.2 Reputation Networks

In [9] the authors have studied and compared systematically the most important mathematical theories used for modeling the network selection problem in the literature. Multiple Attribute Decision Making (MADM) is proposed to enable making a preference-based decision over the available alternatives that are characterized by multiple (usually conflicting) attributes.

In [15], the researchers have introduced a novel MADM based on critical parameters, such as the speed of the mobile device, network load and cost of the service, weighted through a fuzzy logic scheme, to obtain a candidate network suitable for the user. A QoS factor is attributed to each network. This factor is calculated for each network by processing the weighted decisional matrix using the analysis of data rate, delay, jitter and packet loss ratio. The focus of the proposed solution is on getting a candidate network with a low computational burden.

Desogus et al. [2] have proposed a MEW approach to MADM for network selection in a LTE-A/WLAN heterogeneous scenario. MEW combines several inputs such as power of the received signal, throughput, packet delay, cost-per-user, the requested type of traffic, and type of device in order to improve the real-time balance of available radio resources.

In paper [16], the authors have proposed a MADM solution for network selection in ultra dense scenarios, such as the 5G system, with the aim of eliminating unnecessary handovers. To minimize handovers, authors take into account different classes of traffic related to different user requirements. The proposed scheme is designed to minimize the handover only and not to improve QoS.

Trestian et al. [1] have proposed an algorithm for network selection which increases the energy efficiency of content delivery and prolongs the mobile device battery lifetime. This is achieved by selecting the network that offers the best energy-quality trade off. Much importance is given to battery power saving of the device, which becomes the central element of network selection. The selected network is the one that allows for the highest energy savings.

In [17], the authors have proposed and implemented an algorithm for network selection based on a newly defined network reputation metric which emphasizes the mobility of users within the network. The focus of the paper is to keep the level of QoS high while managing the user's mobility. Network reputation is calculated based on device profiles, user reputation reports, and network conditions. It is used in the selection decision of the network in order to allow the user to connect to the most appropriate one.

In [18], the authors have proposed a technique to order preferences by similarity to an ideal solution, called Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), when solving the problem of offering the final user the highest QoS. TOPSIS combines utility function, reputation theory and MADM for selecting the best network alternative. The basic concept behind this method is that the selected alternative must have the shortest distance from the ideal solution and is furthest from the ideal negative solution. The Euclidean distance has been proposed to evaluate the relative proximity of the alternatives to the ideal solution. The reputation of the network is based on utility functions and is used to give greater and lesser advantage to a given utility within the method TOPSIS. In TOPSIS, the network's reputation is a static value that is not updated over time.

In these works, the reputation is attributed to the network without considering the type of traffic that is requested by users. In particular, in most cases video is the only type of traffic focused on. Moreover, none of the above methods have been tested on new generation networks, such as NB-IoT.

In paper [19], the authors try to remedy the problem of latency management in communication between user and cloud. The rapid growth of online games and especially the Massively Multiplayer Online Games (MMOG) leads to the growth of problems related to cloud management. This is because graphical rendering is downloaded to the cloud, so data transmission between end users and the cloud increases significantly response latency and limits user coverage, thus preventing cloud games from achieving high QoS levels. The proposal is to create a Fog-Assisted Cloud Gaming Infrastructure (CloudFog). CloudFog consists of supernodes that are responsible for rendering gaming videos and streaming them to nearby players. Fog allows the cloud to be responsible only for the intense calculation of the state of the game and for sending of supernode update information. This significantly reduces traffic and use of resources, therefore decreasing latency and bandwidth utilization. Each super-node is assigned a reputation, in order to assign to each player the suitable supernode able to provide a satisfying video streaming service. This type of strategy is specific to gaming.

In paper [20], the authors have proposed a solution to tackle the problem of Quality of Computing (QoC), in IoT systems. They introduced a dynamic network selection mechanism based on Software Defined Networks (SDN) designed to provide QoC in urban IoT scenarios in which heterogeneous network resources are shared. The proposed mechanism dynamically assigns portions of data from IoT flows on licensed and unlicensed bands to ensure QoC while minimizing operating costs and occupation of the licensed band. Proposing a solution that works on band portions instead of at the application level makes this method less flexible.

In paper [21], the authors have taken into consideration the problem of energy consumption in applications and devices that deal with transmission and reception of video content. This is because video content requires high-energy consumption. The algorithm is proposed to provide high Quality of Experience (QoE) levels to the user during multimedia delivery while maintaining a balanced trade-off between quality and energy. Among the various factors that are taken into consideration are the average loads and geographical positions. The algorithm, then selects future segments in two steps, in the first step considers the previous throughput and energy consumption of the user device to choose an appropriate quality level, and in the second step identifies the most suitable host peer based on their previously shared load and location. It foresees the storage of the situation that has verified the neighbor, so as to be able to predict with better approximation the consumption of the i_{th} device. In this case, the algorithm does not have a real reputation of the network but an evaluation of the same based on what has occurred or is occurring close to the user. Moreover, the focus is exclusively on video type traffic.

In paper [22], the authors proposed a solution for a smart vertical handover framework to simplify network selection and reduce latency and handover frequency. By integrating the Media-Independent Handover (MIH) and Software-defined Network (SDN) technologies, it is possible to ensure that the handover takes place between only two potential networks regardless of the types of available technologies. The purpose is to avoid multiple handovers. The network selection takes place through a selective algorithm, and is based on the maximum possible QoS value. The developed model makes the most of the computational capacity on the network side, which increases the efficiency of calculation and at the same time reduces the energy consumption of the mobile terminal. It also improves the accuracy of the handover decision, as decisions are made at the three-level pre-selection. The amount of information exchanged during the decision-making process of handover and in the global network has considerably decreased. The final effects produce the optimization of the signaling load between the networks and the back-haul requirements. Although based on 5G technology, the proposed solution does not differentiate the various available networks and neither considers various types of traffic.

In [23], the authors focused on network selection that allows the best connectivity based on the characteristics of the network, considering their variation over time, and based on the user's position within each network. They proposed a network selection solution that can detect the user's location that aims to improve the distribution of content in a heterogeneous wireless network environment by selecting the best network. Based on the network performance information and the mobile user's location and speed, the algorithm selects the best available network to ensure the delivery of high quality data into the heterogeneous wireless network environment. Even in this case, the network does not have a reputation, but the selection is based on distance and user mobility. Moreover, traffic differentiation is not considered, either.

In [24], the authors have addressed the problem created by the heterogeneity of mobile devices (e.g., screen resolution, battery life and hardware performance) that create a serious impact on the end user's QoE. They proposed Evolved QoE-aware Energy-saving Device-Oriented Adaptive Scheme (E^3DOAS) for mobile multimedia delivery over future wireless networks. E^3DOAS uses a strategy of allocation of rates based on coalition play within the heterogeneous multi-device environment and optimizes the trade-off between the quality perceived by the end user of multimedia delivery and the energy saving of the mobile device. The focus of the algorithm is the balancing of networks based on the energy saving of the device. In this case, the networks do not have a reputation and a ranking that takes into account the progress of the QoE over time. Finally, the algorithm does not take into account the type of service used by the user.

In paper [7], the authors have introduced an algorithm that balances the LTE small-cells networks. The purpose of the algorithm is to perform balancing between the networks avoiding the collapse of one or more of them which would create a significant worsening of the throughput. To carry out this balancing, they are based on the progress of the overloaded cells and adjacent cells, adapting the state of the network load and considering the load estimate. The use of resources depends on the quality of the signal and the traffic requests of the User (UE) connected in LTE. The proposed solution does not fit heterogeneous networks and can only be used on networks that rely on the resource blocks (which are the basis of LTE). Furthermore, the reputation of the network is not calculated. The main purpose is in fact to have a set of balanced LTE networks.

In paper [14], the authors have looked for a solution to the problems due to Dense heterogeneous Networks (DenseNets), in which mobile users make the choice in terms of the network to connect to, in order to balance energy savings and delivery performance. The proposed solution is a Hybrid Unicast-Multicast utility-based Network Selection algorithm (HUMANS), which offers the additional option of selecting multicast transmissions in the network selection process during video delivery. This allows to outperform other solutions in terms of percentage of interruption and average quality of transmission, both in low and high density scenarios. Neither reputation or traffic differentiation is considered.

2.3 Subgrouping and Non-Orthogonal Multiple Access Techniques

It is expected that the first fifth generation (5G)-network-based solutions will be commercially launched by 2020. The requested minimum requirements are noted into the technical performance report defined by International Telecommunication Union (ITU) IMT-2020. Following those terms and the expectations from both users and operators, one of the main challenges of future 5G wireless networks is to include the efficient provision of mass mobile multimedia services through one or several broadcast transmission modes [25].

The demand for video services in mobile networks (streaming, downloading, conferences, live social broadcasting, etc.) is rapidly increasing, and it is expected that video will account for more than 80 percent of mobile data traffic by 2019. Consequently, in order to satisfy the increasing media and entertainment (M&E) content distribution, the 5G ecosystem will seamlessly integrate different network technologies [26],including unicast, multicast, and broadcast. In 5G systems, conventional application scenarios such as mobile pedestrian, vehicle-to-vehicle (V2V), and vehicle-to-infrastructure (V2I) communications, generally referred as to V2X communications, will gain higher interest with specific focus on dense urban scenarios within the framework of smart cities [27].

Meanwhile, the mobile and broadcast industries have both independently developed several point-to-multipoint (PtMP) technologies to support large-scale consumption of mass multimedia services on mobile devices. Broadcasters have proposed layer-division multiplexing (LDM) to enable mobile TV on top of conventional terrestrial digital TV services [28]. LDM is a non-orthogonal multiplexing (NOM) technique, which has been included in the American Television Standards Committee (ATSC) 3.0 standard [29]. A similar concept was previously presented for cellular environments in [30]. Regarding the broadband industries, 3GPP introduced evolved multimedia broadcast multicast service (eMBMS) within the Long Term Evolution (LTE) systems and beyond to provide data transmissions from a single source to multiple devices [31]. Efficient resource allocation, in case of multimedia delivery, is a key issue for eMBMS, and the implementation of subgrouping techniques is a promising solution [32].

Chapter 3

Balancing Heterogeneous Networks

The main challenge for users equipped with a multi-mode device is to exploit the "best" radio access network (RAN), intended as the RAN offering the highest QoS. Network selection is complex, depending on the capacity to rely on a large number of parameters, such as service class type, user preferences, mobile devices, battery level, network load, time of the day, service price, etc. Moreover, the procedure is further complicated by the combination of static and dynamic information involved in decision-making, the data accuracy, and the effort to collect it with available resources (e.g., battery, memory, and device processor), that may lead to limitation in performance due to devices characteristics.

The basis of the balancing of the networks lies in the combination of the various parameters that make up the decision criterion,and it will be explain in details in paragraph 3.1.

Once the criteria on which to base the selection of the candidate network is decided, it is necessary to decide the mathematical method that combines the identified parameters. In the paragraph 3.2, the first method is presented which uses a Multiplicative Exponent Weight algorithm.

In the paragraph 3.3, an algorithm is presented that combines an Additive Logarithmic Weighting mathematical method for the selection of the network and Game Theory to carry out the balancing of the networks within the system of networks present.

3.1 Decision Criteria

Decision criteria consist of a series of data that are sent as input to the selection algorithm in order to choose the best network. Based on their nature these criteria can be divided into four categories:

- network parameters: characterize the network, such as the technology offered, bandwidth, power, pathloss, latency, security, etc.
- device parameters: they reflect the typical features of the device, such as the resolution and the size of the screen, battery life, etc.
- application parameters: they characterize the applications by offering information on the minimum and maximum thresholds required so that the service can be used, such as delay, jitter, packet loss, required throughput, bit error rate, etc.

- user parameters: express the requests of the end user, such as the cost of the service, the expected QoE, etc.

The various criteria are not in separate compartments, but interact and influence each other leading to a decision that comes from the contribution of each of them. For example, it can think of how the signal strength affects the device's energy consumption, or how bandwidth can lower the thresholds of a given application and how the expected QoE depends, for example, on the resolution of the device.

Moreover, the parameters that contribute to the realization of a selection criterion have different units of measurement that do not allow comparing them with each other. It is therefore necessary to carry out the normalization in order to obtain a dimensionless value, included between [0 and 1], which allows to compare different subsets of parameters between them.

The normalized parameters are called UFs and compose the SF, which aims to provide a value that allows the comparison between the different networks in order to obtain the best candidate network.

An example of SF is shown in 3.1 :

$$U^i = \sum_j (u_j)^{w_j} \tag{3.1}$$

where U^i represent the SF for the i-th network, u_j is the single UF taken into consideration, and w_j indicate the weights they have within the SF.

An important phase in the decision criteria is that relating to the weight of the UF. The varying weights defines the importance that the UFs have for the specific service that they decide to optimize. For their choice there are numerous methods that combine the parameters considered. In the paragraph 3.1.1, the one used in the algorithms used in this work is illustrated.

3.1.1 Weights

Each UF is normalized with their respective weights, attributed considering the importance of a particular weight compared to the other ones. The value of the single weight has to satisfy the constraint in equation (3.2):

$$\sum_j w_j = 1 \tag{3.2}$$

where w_j represents the weight from the j-th UF.

Weight values are determined by means the Saaty scale [33], based on Analytic Hierarchy Process (AHP) method [9].

The multi criteria decision analysis (MCDA) has been performed to evaluate and to assign the weights. The MCDA is oriented to support the decision making in the case of a big amount of requests and conflicting decisions, allowing to achieve a compromise solution in a transparent way. More in detail, the values of each weight are assigned using the Saaty scale, based on the AHP method that is defined by five steps:

1. a hierarchical list among the involved variables is defined;

2. starting from the list, a symmetric matrix of comparisons is obtained by grouping the different variables in couples;
3. the local weights are assigned to each couple;
4. the analysis of the consistency of judgments is made;
5. the global weights according to the principle of hierarchical composition is defined.

During the weight assignment phase, this scale is considered [33], in the equation 3.3 the values that are attributed to the pairs of parameters taken into account are shown.

$$\begin{cases} 1 & \text{if } i \text{ and } j \text{ are equally important} \\ 3 & \text{if } i \text{ is a little more important than } j \\ 5 & \text{if } i \text{ is more important than } j \\ 7 & \text{if } i \text{ is definitely more important than } j \\ 9 & \text{if } i \text{ is absolutely more important than } j \\ \frac{1}{3} & \text{if } i \text{ is a little less important than } j \\ \frac{1}{5} & \text{if } i \text{ is fairly less important than } j \\ \frac{1}{7} & \text{if } i \text{ is definitely less important than } j \\ \frac{1}{9} & \text{if } i \text{ it is absolutely less important than } j \end{cases} \tag{3.3}$$

where i and j are the pairs of variables to which the weights must be attributed.

3.2 Multiplicative Exponent Weight Algorithm

As previously illustrated, one of the possible solutions to prevent a network overcharge from occurring and therefore a decrease in performance is to perform the balancing of traffic on heterogeneous networks, ensuring that the networks available to a specific user at a given time do not are overloaded. Currently, most load balancing algorithms perform network selection by combining throughput, received signal strength, packet delay, monetary cost to the user and power consumption.

The preliminary work aimed to develop a novel algorithm to select the candidate network based on the Multiplicative Exponent Weight method (MEW) that it offers for a better balance in real time of the available radio resources.

Figure 3.1 shows the logic behind the MEW algorithm, which receives as input information on the profile of network users, devices, and applications returning the candidate network.

The MEW algorithm is used to determine the score of each network to which the user can access, through the multiplicative mathematical operations. Alternative criteria are normalized with the relative weights, according to the different relevance that is attributed to them.

The UF applied to this algorithm is given by equation 3.4:

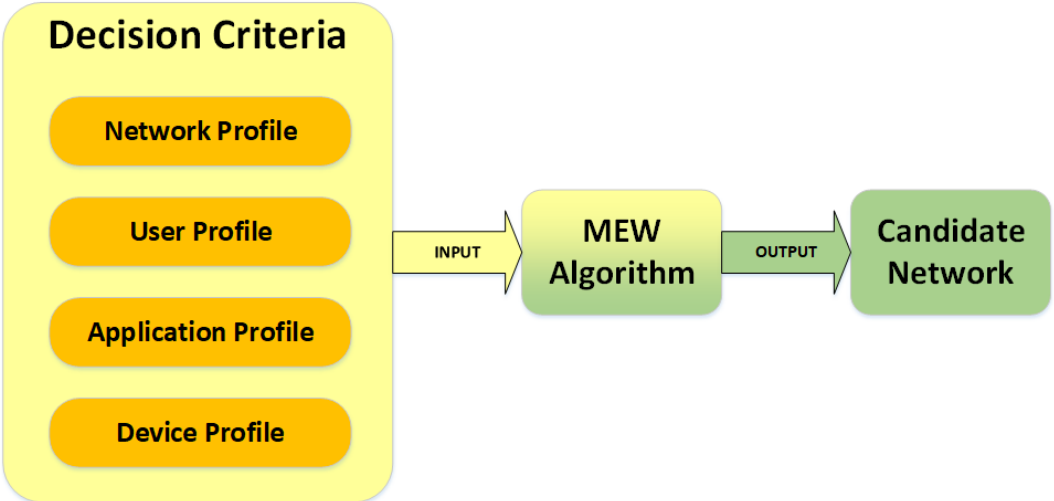

Figure 3.1: Decision Criteria for MEW Algorithm

$$U^i = (u_l^i)^{w_l} + (u_p^i)^{w_p} + (u_s^i)^{w_s} + (u_v^i)^{w_v} + (u_c^i)^{w_c} \tag{3.4}$$

where U^i represents the overall value of the UF that considers five different criteria for the i-th network, u_l^i is the UF for the load, u_p^i is the signal strength, u_s^i is the Signal to Interference Noise Ratio (SINR), u_c^i is the monetary cost of the network, andu_v^i represents the user mobility. The weights w_l ,w_p,w_s, w_c , and w_l represent the normalized incidence (i.e., [0-1]) of load, signal strength, SINR, monetary cost, and user mobility, respectively. The network with the higher score U^i represents the best candidate network.

3.2.1 UFs

The UFs are computed for each of the selected candidate networks and the network with the highest score is selected as target network.

3.2.1.1 Load Utility - u_l

The Load UF is computed using equation 3.5:

$$u_l = c_{available} - \sum_j l_j \tag{3.5}$$

where $c_{available}$ is total available load for the i-th network (kbps), l_j is the load for the j-th user connected to i-th network (kbps).

3.2.1.2 Signal Strength Utility - u_p

The Signal Strength UF is defined as in equation 3.6:

$$u_p = P_t + G_t + G_r - Att_r \tag{3.6}$$

where P_t is the transmitted strength (dBm), G_t is the transmission gain (dBm), G_r is the reception gain (dBm), $Attr_t$ is the attenuation from pathloss and fading (dBm).

3.2.1.3 SINR Utility - u_s

The SINR UF is calculated through equation 3.7:

$$u_s = \frac{P}{I + N} \tag{3.7}$$

where P is the power of the received signal, I is the interference, N is the noise.

3.2.1.4 Cost Utility - u_c

The monetary cost of the network function 3.8 follows the paradigm "lower is better":

$$u_c = \begin{cases} 0 & \text{if the service is free)} \\ 1 & \text{if the service is payment due} \end{cases} \tag{3.8}$$

3.2.1.5 Speed Utility - u_p

In terms of speed, users can be divided into three categories:

- high speed: more than 15 Km/h, the speed of a user on a vehicle;
- low Speed: less than 15 Km/h, the speed of a user on foot or a slow vehicle (e.g., a bicycle or wheelchairs);
- stationary users: the user does not need mobility support

The speed UF 3.9 is defined as:

$$u_v = \begin{cases} 0 & \text{if high speed} \\ \frac{1}{2} & \text{if low speed} \\ 1 & \text{otherwise} \end{cases} \tag{3.9}$$

3.2.2 Use Case and Performance Evaluation

The tests were carried out using the ns-3 [34] network simulator. They are validated by studying a true city of the pedestrian area in front of the Poetto coast (Cagliari, Italy), as shown in Figure 3.2.

The proposed MEW solution considers a scenario in which a wide range of heterogeneous transmitters is employed considering the presence of two eNodeBs and 24 longitudinally evenly spaced access points. A variable number of pedestrian and vehicular users were uniformly distributed (i.e., 0 to 200), with different speeds (i.e, 0 to 60 Km/h). The simulation setup is shown in Table 3.1. WiFi and LTE network parameters are set according to the IEEE 802.11n [3] and (3GPP) LTE [35] standards, respectively. The traffic type is H.264 video streaming [36] for all the performed simulations

Figure 3.2: Poetto Shoreline Scenario

Table 3.1: Simulation Networks Parameters

Attributes	WiFi Network	LTE Network
Technologies	802.11n	LTE cat 6
Number of AP/eNB	24	2
Radius Cell	250 m	500 m
Transmission Power	22 dBm	46 dBm
Bandwidth	40 MHz	20 MHz
Data rate Max	300 Mbps	300 Mbps
Propagation Model	Hybrid model (i/o)	Hybrid model (i/o)

Results have been evaluated in order to compare ARMANS algorithm with the proposed MEW algorithm. The choice of the ARMANS algorithm is due to the fact that it presents a significant improvement in performance compared to other algorithms present in the literature.

The first obtained result is presented in Figure 3.3, where the Peak Signal to Noise Ratio (PSNR) has been quantified according to the increasing number of users. The left part of the Figure 3.3 indicates how the two algorithms performs in a similar manner. When the number of users exceed 90, MEW algorithm performs better showing higher PSNR values.

The second result is shown in Figure 3.4, in which the packet delay parameter has been quantified according to the increasing number of users. Even in this case, in the first part of simulation the two algorithms performs in a similar way. When users exceed 50, MEW algorithm performs better obtaining lower packet delay values compared to the ones with ARMAS algorithm. With MEW algorithm, a linear trend of packet delay has been achieved.

Finally, the third result is presented in Figure 3.5. The aggregate throughput has been quantified according to the increasing number of users. The two algorithms performs in a similar way but MEW algorithm performs better obtaining lower throughput values considering the same number of users.

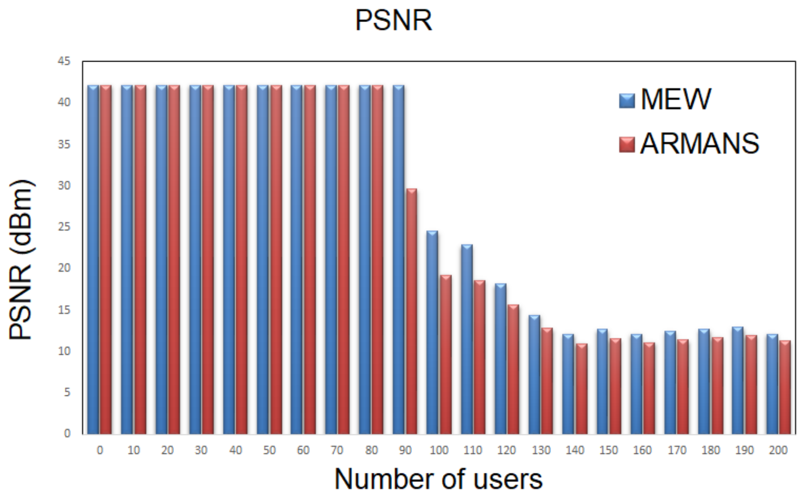

Figure 3.3: PSNR over number of users

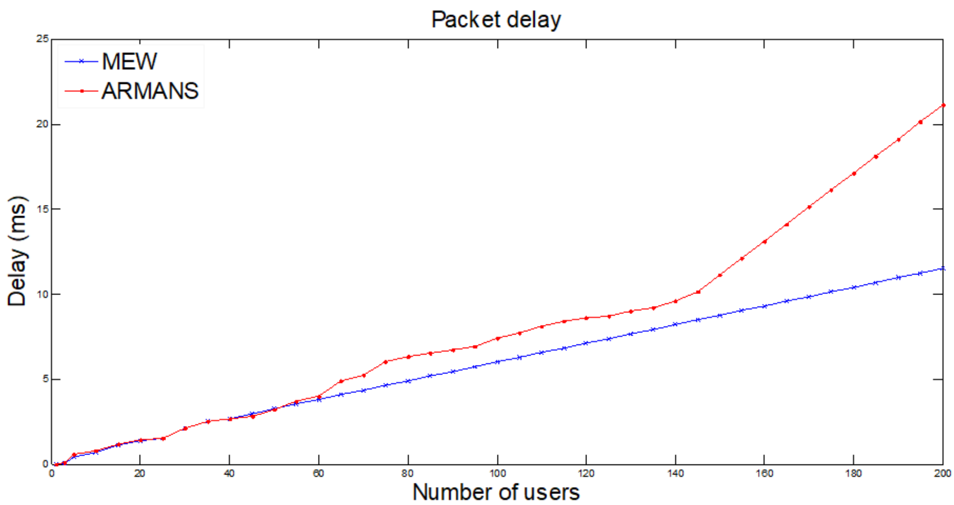

Figure 3.4: Packet Delay over number of users

Thanks to the three graphical results, an average improvement of 15% was estimated in all the metrics considered with respect to the balancing performed with the ARMANS algorithm.

3.3 Additive Logarithmic Weighting Game Theory Algorithm

The previous method had some limitations, such as the use of the exponential multiplicative method. I therefore developed a solution based on an additional logarithmic weighting algorithm (ALOW) optimized through a cooperative GT approach.

The algorithm is ALOWGATH.

The solution presented carries out the selection of a network taking into account several user's heterogeneous parameters:

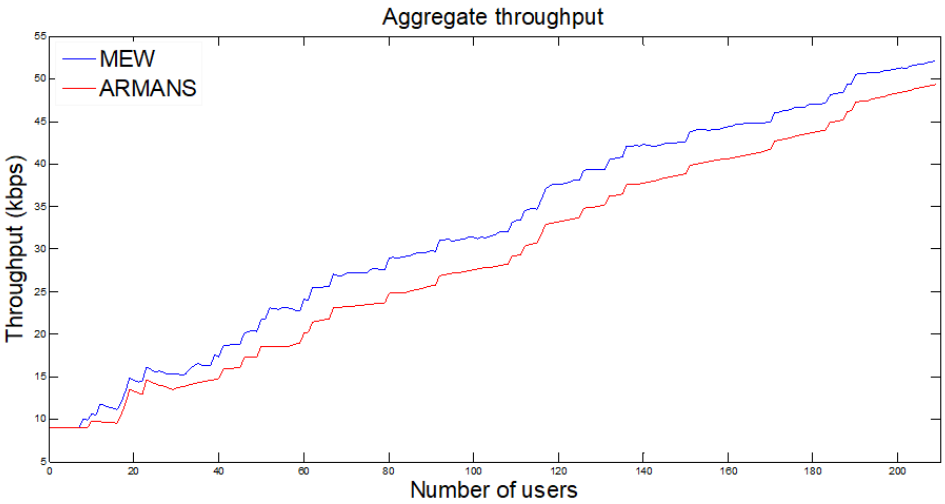

Figure 3.5: Aggregate Throughput over number of users

- available load;
- perceived signal to interference plus noise ratio (SINR) level;
- economical availability (i.e., in terms of type of contract with the service provider);
- mobility.

In parallel, network overloading is avoided thanks to the use of a network balancing method based on GT, allowing the balance of the networks to be associated with user differentiation. In fact, through the use of the GT it is possible to select the best network with the management of resources in search of the optimal solution.

3.3.1 ALOWGATH Architecture

The ALOWGATH algorithm can be located at server side at application layer of the TCP/IP model, as shown in figure 3.6.

The protocols used in the lower layers can be considered as "transparent" for the user: e.g., a video service can use UDP protocol in the transport layer, while a messaging application exploits a TCP protocol. At the same time, it will be able to receive useful information from other layers (e.g., network status). The algorithm, in order to perform network balancing, needs a series of information about user profile and network status.

This information is collected through network monitoring mechanisms, such as the services offered by the 802.21 standard, and special applications that allow user to set its own preferences. In fact, the 802.21 standard has been developed to offer all the useful tools for carrying out the handover.

The data collector stores information about network, user, and device profile and sends them as input to the score generator. The score generator creates a list of available networks that is used by the network filter to evaluate the candidate network. Finally, the handover procedure can start. The server side module is summarized in figure 3.7.

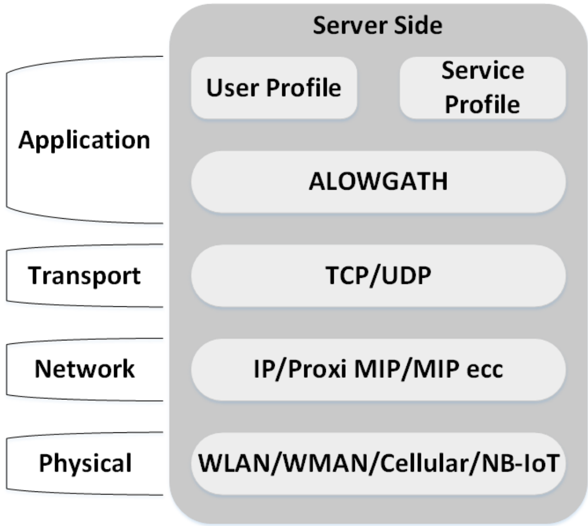

Figure 3.6: Server Side Protocol Stack

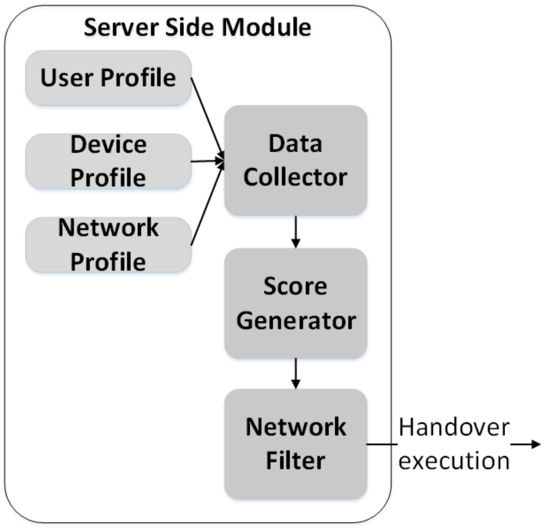

Figure 3.7: Server Side Module

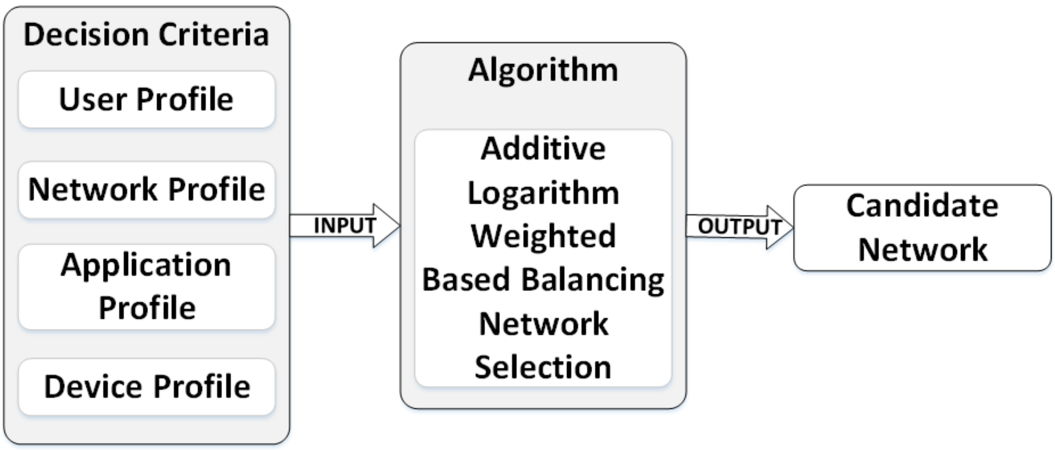

Figure 3.8: ALoWGaTh framework

The client side module has a passive role, receiving the list of the available networks, with their corresponding scores, from the server side module. Once the client receives this list, it select the first available network going through the list.

The ALoWGaTh framework is represented in figure 3.8. Two macro areas can be identified, the first one concerning the decision criteria and the second one dealing with the algorithm.

3.3.2 UFs

In this subsection, the four UFs are shortly described:

- Load UF – u_l is computed to evaluate the available load using the equation (3.10):

$$u_l = \begin{cases} 0, & \text{if } c_{available} < l_j \\ c_{available} - \sum_j l_j, & \text{if } l_j < c_{available} < c_{max} \\ 1, & \text{otherwise} \end{cases} \tag{3.10}$$

  where $c_{available}$ is the total available load for the $i-th$ network (kbps), l_j is the load for the j-th user connected to the $i-th$ network (kbps). The load UF has values within the [0,1) interval.

- SINR UF – u_s, useful to estimate the perceived SINR, follows this equation (3.11):

$$u_s = 1 - \frac{P}{I+N} \tag{3.11}$$

  where P is the power of the received signal, I is the interference between cells, and N is the channel noise.

- User's budget UF – u_c (3.12) quantifies the economical availability, following the paradigm "lower is better":

$$u_c = \begin{cases} 0 & \text{if } 0 \le t \le t_{min} \\ 0.5 & \text{if } t_{min} \le t \le t_{max} \\ 1 & \text{otherwise} \end{cases} \tag{3.12}$$

  where t is the paid traffic threshold that the user has available, t_{min} is the minimum threshold that the user wants to preserve for his own traffic, and t_{max} is the maximum traffic limit available to the user.

- Speed UF – u_v states the mobility. In terms of speed, users can be divided into three categories:
  - high speed: more than 15 Kmph, typically for vehicular users;
  - low Speed: less than 15 Kmph, for pedestrian or slow vehicles (e.g., a bicycle or wheelchairs);
  - stationary users: the user does not need mobility support.

It is defined as (3.13):

$$u_v = \begin{cases} 0 & \text{if high speed} \\ 0.5 & \text{if low speed} \\ 1 & \text{otherwise} \end{cases} \tag{3.13}$$

Through these steps the comparative values indicated in table 3.2 were obtained, where the most important value was given to the load, whereas a lower value was attributed to the SINR, User's budget and speed, respectively.

Table 3.2: UFs Comparison

	Load	SINR	User's Budget	Speed
Load	1	7	7	5
SINR	$\frac{1}{7}$	1	1	$\frac{1}{5}$
User's Budget	$\frac{1}{5}$	5	5	1
Speed	$\frac{1}{7}$	1	1	$\frac{1}{5}$

3.3.3 Decision Criteria

The definition of the weights was attributed through the method presented in the paragraph 3.1.1.

Starting from matrix U [37]:

$$U = \begin{pmatrix} 1 & \frac{1}{7} & \frac{1}{7} & \frac{1}{5} \\ 7 & 1 & 1 & 5 \\ 7 & 1 & 1 & 5 \\ 5 & \frac{1}{5} & \frac{1}{5} & 1 \end{pmatrix} \tag{3.14}$$

by applying the priority assignment method, a priority vector W is calculated:

$$W = (0.6, 0.1, 0.1, 0.2) \tag{3.15}$$

The weight values calculated for the UFs are shown in the table 3.3.

Table 3.3: Example of weight for UF

Utility	Weight
Load	0.6
SINR	0.1
User's Budget	0.2
Speed	0.1

ALOWGATH needs several information to select the candidate network. These data concern user profile, network characteristics, and required service. Decision criteria is the module that collects all these functional information (left block ok figure 3.8).

A graphical user interface (GUI) installed on a device allows to extract the profile of a user, that provides preferences and information as the tariff plan (e.g., budget in terms of available Gbyte) or possible priority. During the creation of the profile, a user can decide how to weight the different parameters on which the ALOW algorithm is based, as described in next subsection. This procedure allows the algorithm to efficiently adapt to the needs of the user.

The profile of the device gives information about its location, to know real-time movement speed, and resolution of display, useful to calibrate a service based on video content.

The profile of an application characterizes a service performing on a device in a precise moment, as different services have different requirements. For example, a video streaming application requires a minimum bandwidth to guarantee a minimum quality level.

Finally, through the IEEE 802.21 media independent handoff (MIH) standard [38], it is possible to collect QoS information related to available wireless networks (i.e., throughput, delay, and transmitted power), combined into the network profile.

3.3.4 Additive Logarithmic Weighting (ALOW) Algorithm

The ALOW algorithm is used to evaluate the scoring of each network the user can access. It receives as input data from network, user, device, and application profiles, returning as output the candidate network. Each score is determined by ALOW method performing a decision making mechanisms [39]. Alternative criteria are normalized with their weights, depending on the different relevance attributed to them.

The UF applied to this algorithm, that is the reputation value that is attributed to the selected network, is given by:

$$\begin{aligned} ln(U^i) = w^l * ln(u_l) + w^s * ln(u_s) + \\ + w^c * ln(u_c) + w^v * ln(u_v) \end{aligned} \tag{3.16}$$

where $ln(u_l), ln(u_s), ln(u_c), ln(u_v)$, are UF for load, SINR, user's budget, and speed, respectively, while w^l, w^s, w^c, w^v are weights of the single UFs.

3.3.5 Game Theory

The GATH is a mathematical tool finalized to the comprehension and modeling of competitive situations involving the interaction of rational decision makers with common and conflicting interests. It has been widely used in telecommunications to solve problems related to resource management or allocation, and, more in general, in the engineering field when there is the need of strategical interaction and modelling between several actors.

The main components of the GATH are outlined as follows:

- the set of players, that is entities able to make the decision;
- the set of actions (i.e., strategy set) that players can accomplish;
- the set of payouts that players can get to have a utility;
- the balance, i.e. the combination of strategies that lead to the best payoff possible;

- the NEbalance is achieved by combining strategies aimed at obtaining the users' payoff finding a solution to the game.

Within a heterogeneous network scenario it is possible to identify different types of games by differentiating the type of players. They can be grouped into games between users, games between networks and games between users and networks. In this study we will focus on the game between users.

The game between users takes into consideration the problem caused by the fact that users, when egoistically choose the network considering to be the best, lead to network congestion and consequently to degradation of performance. This type of game is a non-cooperative type.

At this point, there are limits due to the user's need to obtain the best network and the costs due to congestion of the selected network.

For this reason, cooperative games have been proposed, in which users collaborate to obtain the mutual benefit of satisfying bandwidth requirements while maintaining a good level of QoS. In the case of limited resources, each user has a reduction in bandwidth in order to avoid the cost of performance degradation.

The cost of each user depends on the congestion of the selected network, as shown in 3.17:

$$u_k(i, \sum u_l \in K) \tag{3.17}$$

where u_k is the k^{th} user, $\sum u_l \in K$ indicates the total number of users in the network, i is the boolean value that indicates whether the user has selected the i^{th} network.

To obtain an NE, the situation must be reached where no player can have greater advantages by unilaterally changing his strategy.

In this considered case, the solution to the problem with NE is obtained when all users are able to choose the network that involves the minimum cost in terms of QoS. This can be indicated as:

$$\zeta_{ki} u_k(i, \sum u_l \in K) \leq u_k(i, \sum u_l \in K) \tag{3.18}$$

where $\zeta_{ki} u_k(i, \sum u_l \in K)$ is a binary variable representing whether user k is within the coverage of network i^{th}.

In our case study, the users and the networks each of them can access are considered the players. The set of actions or strategies that can be taken by the users during the game are: bandwidth request, subscription with network operator, network resources release, and user mobility inside network cell increasing or decreasing the QoS. The action to be consider for the network are dynamic resources offered in order to satisfy the largest number of users.

The winning users are given by the profit they can get in terms of bandwidth and QoS, estimated using the UF. On the other hand, the network profit is to offer the service as many users as possible avoiding network saturation.

In this study, we focused on the users behavior, identifying three possible attitudes they can take:

- **Cooperative**: users cooperate to get the mutual benefit of meeting the bandwidth requirement by maintaining a good level of QoS. In case of limited resources, each user has a decrease in bandwidth in order to accommodate new users, as shown in [40].

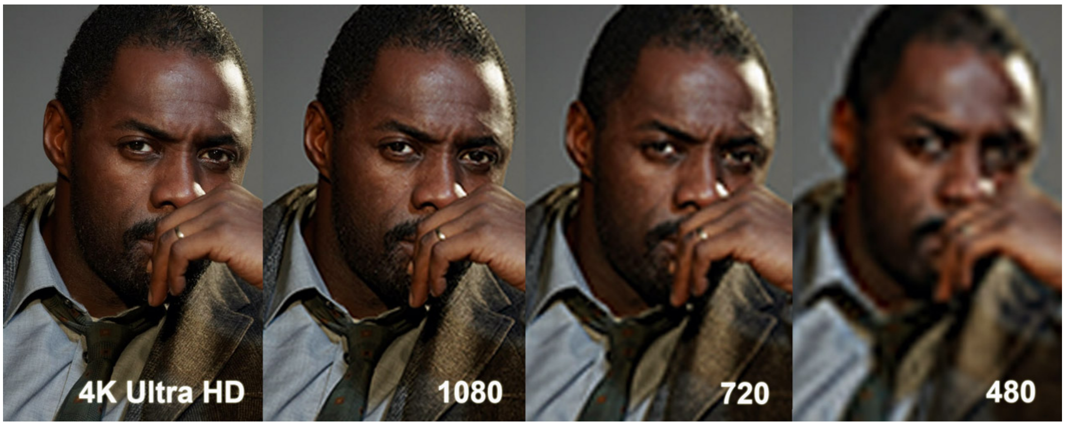

Figure 3.9: Variable Resolution Encoding

Table 3.4: Lowered Encoding Video

Name	Resolution	Bitrate HQ (Mbps)	Bitrate lowered (Mbps)
1080p	1920x1080	9.0	6.0
720p	960x720	4.0	4.0
576p	768x576	2.5	2.3
480p	640x480	2.0	1.5

- **Non-cooperative**: users do not cooperate with each other and try to maximize their QoS level. In case of limited resources, they do not undergo bandwidth and no further users are accepted within the network.
- **Cooperative with priority**: it involves the presence of both users who cooperate with each other and uncooperative users. The latter are users with high priority level. In case of limited resources, the band is lowered to cooperative users but not to users characterized by higher priorities. This last behavior will not be studied in this paper but will be object of future works.

Fig. 3.9 shows what happens when bandwidth reduction occurs: while maintaining the same resolution the bit rate is gradually lowered, affecting the perceived quality.

It can be noted that the variation of the bitrate leads to a deterioration of the image quality until the total loss of the QoS, considerably lowering the quality of experience (QoE) even in the presence of small screens.
Starting from the data summarized in table 3.4, the bitrate will be lowered from the high quality (HQ) to the next level and the video frames will be decreased (e.g., from 30 fps to 25 fps).

For lower values, the risk is to provide bad quality videos involving a drastic lowering of user's satisfaction, even if the audio component does not change during the quality down phase.

3.3.6 ALOWGATH Algorithm

Figure 3.10 shows the ALOWGATH flowchart. The proposed system mainly consists of two main phases:

- the first one allows to evaluate the existence of a network (i.e., its setting) that can meet the traffic user's request. In case of positive feedback, network selection will be carried out using LoW algorithm;

- in case of bandwidth saturation a GT approach is employed to release resources needed to accommodate new user's requests.

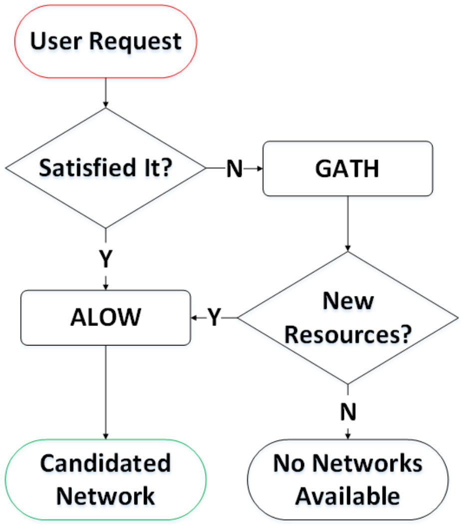

Figure 3.10: ALOWGATH Algorithm flowchart

A pseudo-code of ALOWGATH is presented described in Algorithm 1.

ALOWGATH performs several steps in order to individuate the candidate network (CN), shortly summarized as follows:

1. The purpose of the ALOWGATH algorithm is to obtain the CN between the available networks by each users. Available networks are all those networks that the user can connect to. These networks are collected within a List of Networks (LoN) available for user.

2. To ensure that the CN is calculated, some variables are initialized, such as:

   - CN, that has a null starting value;
   - Score represents the overall value of the UF for each considered network;
   - BestScore identifies the best network at a specific time for a user.

3. For each node n into the LoN available for each user, Score is calculated, through the use of ALoW, shown in equation 3.16.

4. If the obtained Score is better than BestScore, BestScore is replaced with Score value and n becomes the new CN.

5. The CN's searching procedure ends when all n within LoN have been evaluated. However, it must assess whether the CN is able to handle the user's traffic request (UR).

Algorithm 1: ALOWGATH Algorithm

```
Result: This algorithm return the Candidate Network = CN
Input: User = us;
       User Requests = UR;
       List of Network available for user = LoN;
       List of Users in Network = UoL;
       Minimum Threshold = mTS;
       Local Threshold = LT.
begin
    CN = null;
    Score = 0;
    BestScore = 0;
    LT = MaxThreshold
    foreach n in LoN do
        Score = w^l * ln(u_l) + w^s * ln(u_s) + w^c * ln(u_c) + w^u * ln(u_u);
        if Score ≥ BestScore then
            BestScore = Score;
            CN = n;
        end
    end
    while CN.bandwidth() ≤ UR OR LT ≥ mTS do
        Use GameTheory Algorithm;
        foreach u in UoL do
            u.AdaptStreaming();
        end
        LT.lowerThreshold();
    end
    UoL.AddUser(us);
    return (CN);
end
```

6. If the available bandwidth of CN is lower than UR, the GT algorithm is performed.

7. Until the available bandwidth of CN is lower than the threshold or higher than the minimum possible threshold, for all users (u) connected to the CN the streaming threshold is lowered using the values in the table 3.4.

8. Finally, considering the selected CN, if the requested services can be guaranteed by lowering the users threshold, the algorithm can end. Otherwise, the UR will be rejected and the user will not have a CN.

3.3.7 Use Case and Perforance Evaluation

Two scenarios have been designed to evaluate the performance of the proposed algorithm.

The first scenario is an ideal case and represents a simplified and balanced scenario, while the second one is a real scenario representing the seaside area of Cagliari, Italy.

3.3.7.1 Scenario 1 - Ideal Case

This first ideal scenario is characterized by a simple HetNet composed by a LTE eNodeB (eNB) and two access points (APs) for the 802.11ac standard, as shown in figure 3.11.

The distance among APs is equal to 120 m, whereas the eNB is placed to enclose the APs in LTE radio coverage. The HetNet is progressively loaded adding a user each time interval up to 200 users. The idea is to progressively overload the network. Each user has a pseudo random position (i.e., a method used by the simulator to define the position of users) within an area of 1 km^2, uniformly distributed random speed between 0 and 20 kmph, and performs video content traffic at different resolution, to be delivered to devices with different screen resolution according to table 3.5.

Table 3.5: Encoding Video and Audio Data Rate

Name	Resolution	Video [Mbps]	Audio [kbps]
1080p HQ	1920x1080	9.0	128
720p HQ	960x720	4.0	128
576p HQ	768x576	2.5	64
480p HQ	640x480	2.0	64

The simulations were conducted in accordance with data provided by Cisco for the years 2017-2022 [41], showing that most of the traffic was video traffic type. Specifically, as shown in table 3.6, the video traffic mainly involved is from downlink transmissions. As for the APs, in accordance with the specifications of the 802.11n standard different modulation and coding schemes (MCS) have been considered as in the table 3.7. MCSs were chosen to cover the distance between APs as to avoid service interruption.

A user is associated to a MCS related to the AP location. As can be seen in figure 3.12, close to the AP the user will have MCS equal to 31 that corresponds to a maximum data rate of 600 Mbps, while as it moves away from the AP, this value gradually decreases up to a minimum value (i.e., 0 Mbps at 120 m).

For higher distances, there is further signal decay up to total loss for distances greater than 250 m. For this reason, it was chosen to impose the user's position within a 250 m radius from the AP. Considering the cellular network, the maximum MCS supported by a LTE user is obtained evaluating the perceived SINR and its corresponding channel quality indicator (CQI), as shown in figure 3.13. The simulation set-up for this first scenario is characterized by the parameters listed in table 3.8.

Table 3.6: Type of Traffic - CISCO 2020

Traffic Type	Total Traffic 2020	Downlink%	Uplink %
Video	82%	98%	2%
Other traffic	18%	76%	24%

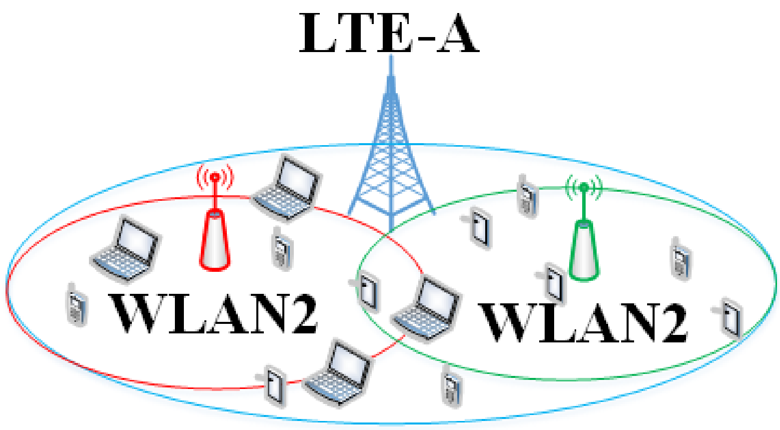

Figure 3.11: Scenario 1

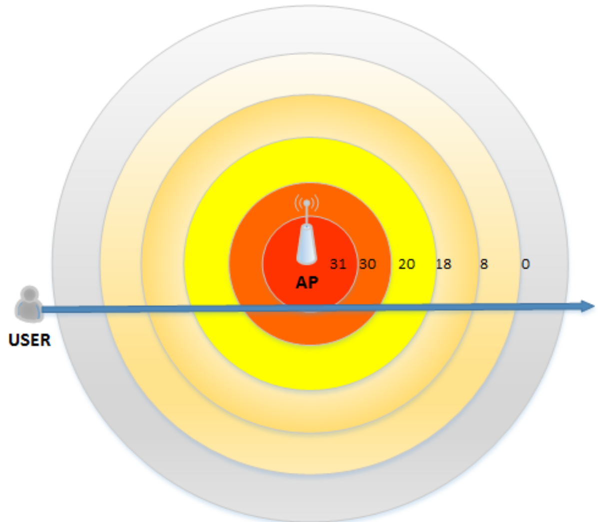

Figure 3.12: Scenario 1 - 802.11 MCSs

Table 3.7: Scenario 1 - MCS and Data Rate

MCS	Data Rate [Mbps]	Distance [m] %
31	600	10
30	540	20
20	270	40
18	135	80
8	30	90
0	15	120

3.3.7.2 Scenario 2 - Real Case

The second scenario represents a urban pedestrian seaside area located in Cagliari, Italy. 24 APs have been installed to serve the area along the seafront, approximately 2 Km long, distant from each other 80 m on public lighting poles at a height of 10 m from the ground. The area is also covered by the LTE service through an eNB. In

Table 3.8: Set-up for Scenario 1

Parameters	WiFi Network	LTE Network
Technologies	802.11n	LTE cat 6
Number of AP/eNB	2	1
Radius Cell	250 m	500 m
Transmission Power	20 dBm	46 dBm
Bandwidth	40 MHz	20 MHz
Data rate Max	600	300
Propagation Model	Hybrid model	Hybrid model

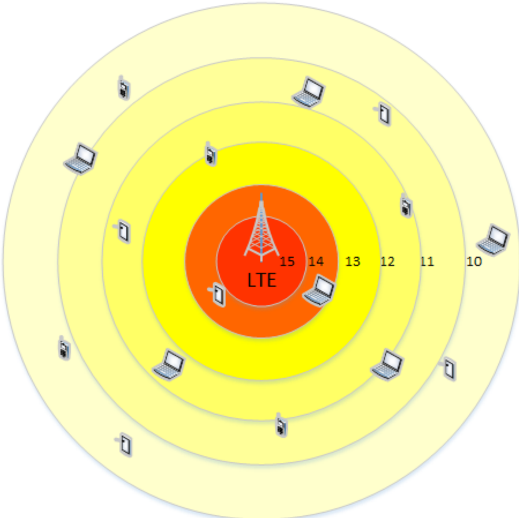

Figure 3.13: Scenario 1 - LTE MCSs

figure 3.14, the real urban scenario is shown. The red points represent the APs whereas in blue the eNB location is represented.

Figure 3.14: Real Urban Scenario - Seaside Area in Cagliari

Measurements were made on the site to evaluate the quality of the signal perceived by users using a third-party application called "Network Cell Info Lite", a tool for monitoring and self testing the cellular network [42]. This can also provide the cell map and signal strength (SS) indicators for several cellular network technologies (e.g., LTE, HSPA, WCDMA, EDGE, GSM, CDMA, or EVDO). The information obtained through the measurement system is summarized in table 3.9, including SS, eNB distance, LTE cell ID (LCID), and available technology.

Table 3.9: Cellular Network Characteristics

Provider	Network type	Distance	SS
Operator 1	LTE-A	450 m	-104 dBm
Operator 2	LTE-A	500 m	-115 dBm
Operator 3	LTE-A	600 m	-123 dBm

A second series of measurements has been carried out to analyze the behavior of the WiFi signal at various points along the seafront through "Analyzer WiFi", an application that allows to scan all the WiFi networks detectable from a smartphone and provides useful information to evaluate performance. The app shows the active networks in a considered area indicating their names, the band (i.e., 2.4 or 5 GHz), the Mac address, the type of protection, and the ones with the most powerful signal. Moreover, a time chart gives the trend of the signal strength in a certain time period.

The received power level for two equidistant APs, located 80 m away from the reference AP, is comparable and equal to -70 dBm. Similarly, a mobile device receives signals as it is under the coverage range of other transmitters within a radius of 250 m from the mobile receiver. The SSs of the N APs, with N indicating the number of APs in the scenario, gradually decreasing as they move away from them.

Table 3.10: Set-up for Scenario 2

Parameters	WiFi Network	LTE Network
Technologies	802.11n	LTE cat 6
Number of AP/eNB	24	2
Radius Cell	250 m	500 m
Transmission Power	Shown in [41]	46 dBm
Bandwidth	40 MHz	20 MHz
Data rate Max	300	300
Propagation Model	Hybrid model (i/o)	Hybrid model (i/o)

As for the ideal case, the scenario was populated until saturation. In this case, users requesting video content services were progressively placed in a random way up to 1000, moving with variable speed uniformly distributed (i.e., between 0 and 20 kmph). During the simulation, the AP characteristics were adjusted based on the APs actually installed along the way. The technical data of the installed APs can be obtained from the CISCO website [41]. Similarly, for LTE the characteristics of the installed devices were obtained by the service providers. The simulation set-up for this second scenario is characterized by the parameters listed in table 3.10.

3.3.7.3 Results

For each scenario, simulations were performed using ns-3, a discrete-event network simulator for Internet systems [43]. A comparative analysis was carried out between ALOWGATH and ARMANS considering the first ideal scenario, characterized by the presence of a single eNB and 2 AP. Due to this, it was not possible to compare the two algorithms with HUMANS because this method was developed for ultra dense HetNets. A second comparative analysis between the three solutions (i.e., ALOWGATH, ARMANS, and HUMANS) was carried out considering the real scenario presented in subsection 3.3.7.2.

The choice of the two algorithms was motivated by their effectiveness with respect to the previous algorithms presented in the literature. Moreover they perform a dynamic balancing of the network, thus making it possible to compare the parameters used for the evaluation of the algorithm.

The results are evaluated in terms of average throughput, aggregated throughput, peak signal-to-noise ratio (PSNR), and average PSNR. The use of the PSNR as evaluation parameter is due to the choice of simulating video content based services.

The results obtained for the first scenario show an improvement in both the average throughput and the average PSNR compared to the use of ARMANS solution, as shown in table 3.11.

Table 3.11: Simulation Results for Scenario 1

	ALOWGATH	ARMANS
Av Thr [Mbps]	8.55	8.11
Av PSNR	28.99	27.99

Average throughput shows a 9% improvement, while PSNR values are comparable for the two considered solutions. Figure 3.15, representing the PSNR variation with the number of users for the ALOWGATH and the ARMANS algorithms, proves this trend. The trends are overlapped up to the saturation point, which occurs with 85 users. Subsequently, ALOWGATH shows an improvement due to the better balancing of the networks.

The trend of the aggregate throughput, that is the sum of all the throughput perceived by all the served users, is presented in figure 3.16, reflecting the results obtained so far, showing how the ALOWGATH configuration leads to better results. Figure 3.17 shows how the average throughput trend is coherent with previous obtained results.

For this second comparative analysis, the real scenario presents a peculiarity dues to the presence of numerous APs against only two eNBs to serve users. Moreover, being a real scenario, the speed of users has directly influenced the trend of the results.

Table 3.12 indicates that the use of the GATH for balancing heterogeneous networks provides benefits in terms of average throughput. On the contrary, the average PSNR is comparable for both the three methods, as previously denoted for the first scenario.

Figure 3.18 shows the average throughput variation for the three algorithms. As can be observed, ALOWGATH presents a stepped trend dues to the GATH method. In fact, the throughput is maintained equal for all the users in the network until all of them can be served, than its value is decreased to accept new users.

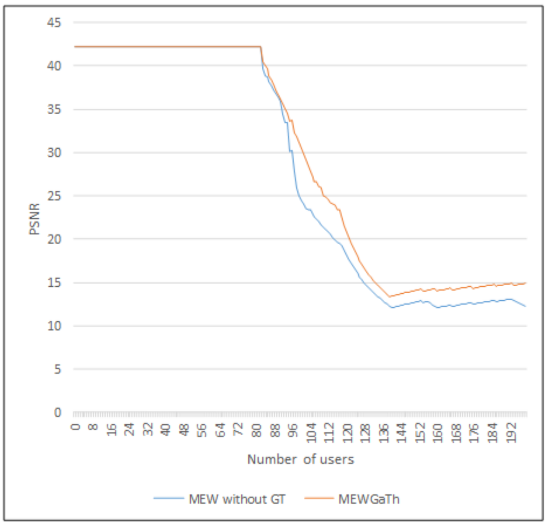

Figure 3.15: PSNR Trend for Scenario 1

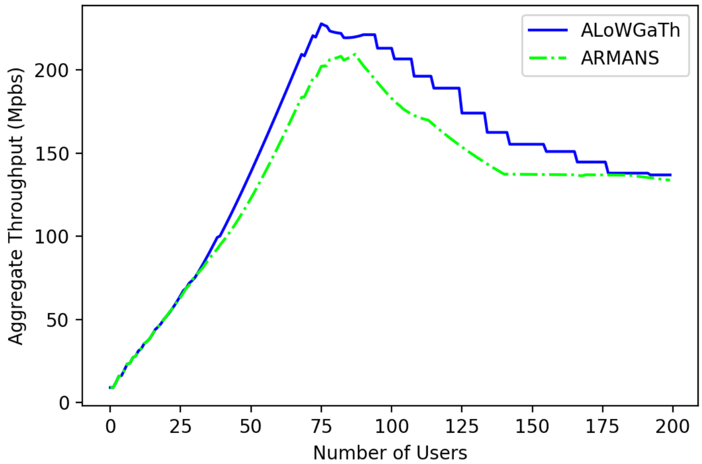

Figure 3.16: Aggregate Throughput Trend for Scenario 1

Table 3.12: Simulation Results for Scenario 2

	ALOWGATH	ARMANS	HUMANS
Av Thr [Mbps]	8.71	8.45	8.27
Av PSNR	28.99	27.99	28.45

This particular characteristic leads to guarantee higher values of average throughput, compared to ARMANS and HUMANS methods. As the number of users increases, the ALOWGATH algorithm starts to performs even better, as shown in figure 3.19, where a focus over the trend considering a network with more than 800 users is presented.

Figure 3.20 shows how the aggregate throughput variation for the three algorithms are practically overlapped till about 800 users. In figure 3.21, where the throughput trend from 800 to 1000 users is presented, it is possible to notice that:

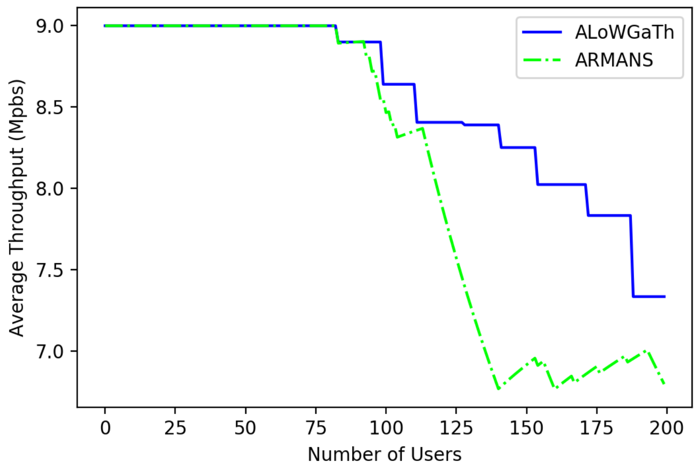

Figure 3.17: Average Throughput Trend for Scenario 1

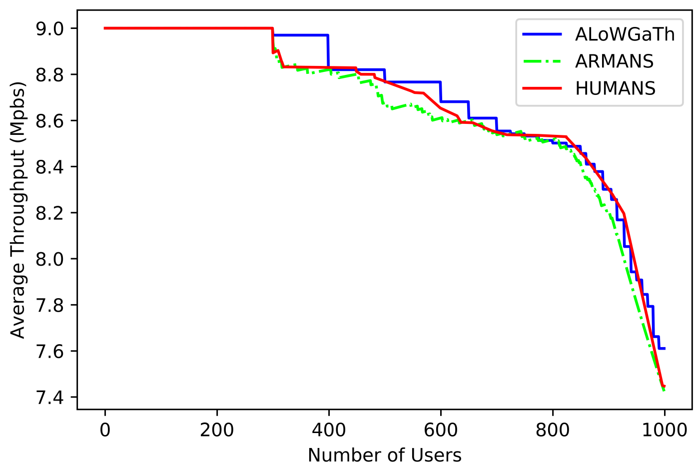

Figure 3.18: Average Throughput Trend for Scenario 2

- between 800 and 900 users interval, ALOWGATH performs in a better way compared to the other methods;
- HUMANS presents a pick at 900 users, than starts to decrease;
- for more than 970 users, ALOWGATH restarts to ensure higher values than the other algorithms.

It means that the network saturates later. This result is due to the particular characteristics of the real scenario that shows an overestimated number of APs considering the size of the area to cover; this coverage solution depends on the fact that this area is often designated to host big live music events (i.e., to serve overcrouded areas).

Finally, the satisfaction index, that indicates the value of appreciation perceived by users in terms of the ratio between the data rate received and the data requested by each user, has been evaluated and the results are summarized in figure 3.22. The

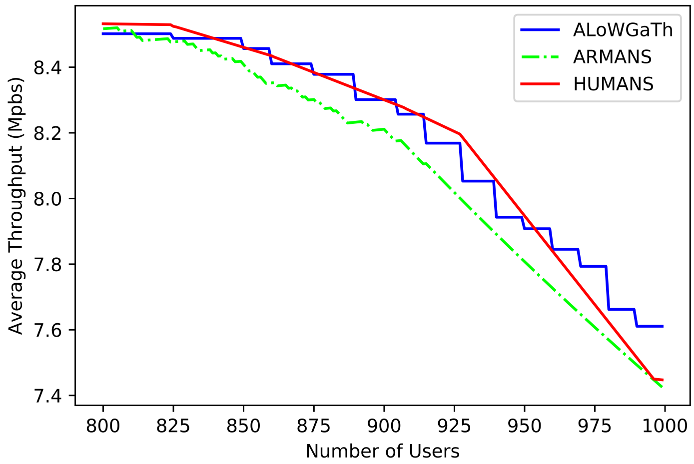

Figure 3.19: Average Throughput Trend for Scenario 2 considering 800 to 1000 users

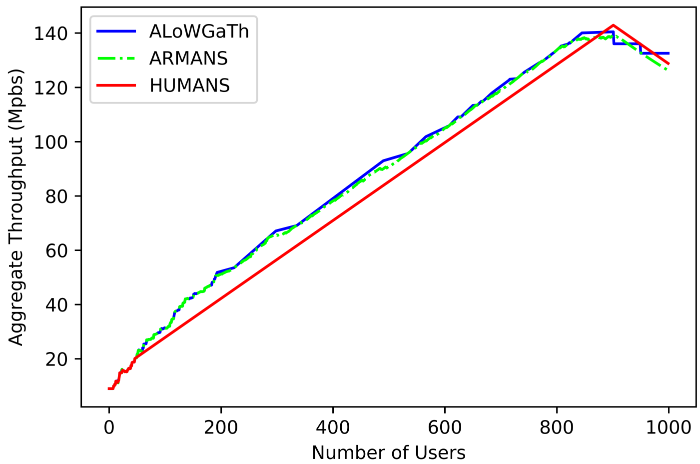

Figure 3.20: Aggregate Throughput Trend for Scenario 2

satisfaction of users is comparable considering ALOWGATH and HUMANS solutions, while ARMANS shows a satisfaction decreasing as the number of users overcome approximately 150.

As for the balanced video delivery in heterogeneous networks scenario, this paper has presented ALOWGATH, a new HetNet selection algorithm based on additive logarithmic weighting that combines information related to the class of device, the requested service, priorities, data related to received signal power, network load, and packet delay. Resource allocation is performed using a balancing algorithm based on Game Theory (GATH) and Nash equilibrium (NE).

To evaluate the effectiveness of the solution, ALOWGATH was compared with ARMANS and HUMANS algorithms in two different scenarios. The results showed improved performance in terms of average throughput, aggregate throughput, and satisfaction of users. Moreover, the computational complexity of ALOWGATH is lower than the computational complexity of ARMANS and HUMANS that carry out a mul-

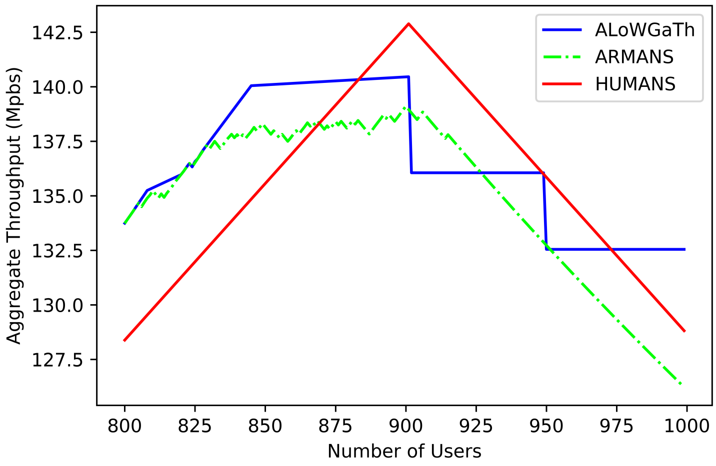

Figure 3.21: Aggregate Throughput Trend for Scenario 2 for 800 to 1000 users

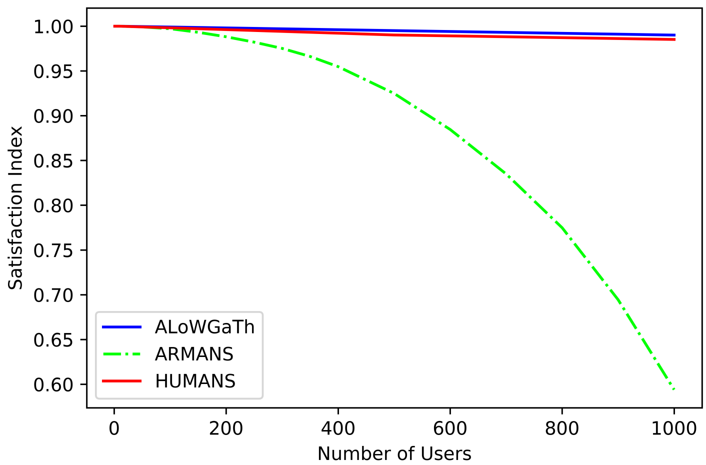

Figure 3.22: Satisfaction Index Trend for Scenario 2

tiplicative exponential weighted (MEW) method.

In the future, the algorithm can be improved by allowing the user to choose the type of traffic he intends to use in order to be able to customize the performance on the type of traffic required, allowing the use of multiple types of services simultaneously.

Chapter 4

Ranking Heterogeneous Networks

Radio resource allocation and scheduling algorithms are proposed in order to increase users' satisfaction levels when served with diverse services via heterogeneous wireless networks. These algorithms are employed in several areas of concern, including cognitive radio networks, satellite-terrestrial coexistence-communications based on radio maps, and radio sensor networks [44]. In particular the fast growth of Machine-to-Machine (M2M) communications introduces additional challenges when satisfying diverse Quality of Service (QoS) requirements of massive number of Machine Type Communications (MTC) with limited radio resources [45]. In this context, Device-to-Device (D2D) communications refer to technologies that enable devices to communicate directly with each other, avoiding data-path routing through a network infrastructure. D2D communications technologies are the most common solutions employed for M2M communications in 5G network environments [46]. The devices considered in D2D scenarios are pieces of User Equipment (UE) able to transfer data using the IP protocol and perform networking according to 3GPP specifications.

Current scenarios have a great variety, both regarding the type of networks and services users require. As far as the networks are concerned, in addition to today's classic new generation broadband wireless networks, such as 802.11ac/ad/af [47] and cellular networks such as LTE-A [48], it is possible beginning to see the emergence of new 5G standards and networks such as the NarrowBand IoT (NB - IoT) [49].

This network environment is supposed to address the new demands of mobile users, which are highly diverse and increasingly rich. The trend that is expected in next years includes a growth in demand for services that once attracted small groups of users. In particular, there will be a remarkable growth in gaming services and high resolution video requests will reach very high demand levels. These services will be accompanied by mobile IoT traffic, such as that generated for example by mobile health applications. This is as the number of mobile phones are expected to be surpassed by that of IoT devices at end of 2018 [41].

The presence of so many types of available services and a range of heterogeneous and constantly expanding networks, leads to the need to understand what is the best network for any particular service. In the literature, the concept of network reputation has come a long way. Reputation allows us to determine which network is able to offer a better QoS. The limit of reputation, as currently employed, is that for each type of service, the same evaluation parameter is used. This approach does not take into account that different services have different needs and issues and may require different types of protocols and different solutions to meet their requirements. Differentiated traffic delivery [50] and network reputation [23] have already been considered independently in the literature, but differentiated traffic-based reputation in the network selection process has never been considered.

In this thesis work, four different types of traffic were considered:

- Video, such as videos on demand and streaming, 360 videos, video calls, etc.;
- Games, such as cloud gaming, massively multiplayer online, real-time strategy, ect;
- Document access and navigation;
- IoT, such as smart buildings, smart transport, smart healthcare, ect.

A different type of communication protocol is associated to each type of traffic, mostly used for its delivery and affected by certain network parameters. These will be specified more in details in section 4.1.

In a scenario, such as the one described, characterized by heterogeneous networks and diverse rich services, the problem of choosing the best network that meets the user's QoS needs becomes extremely important and is increasingly more complex than in the past.

This work introduces a network TYDER, which differentiates the treatment of data delivery in heterogeneous multi-network environments according to its type. This work extends the research on reputation-based network selection by diversifying the reputation concept to consider different types of services.

The proposed TYDER solution evaluates reputation based on feedback received automatically during data delivery. The feedback is assessed using different score functions, appropriate for each type of service considered. In order to perform evaluation, QoS parameters such as delay, packet loss ratio, and throughput are used. TYDER has been compared with a classic Multiplicative Exponential Weighting (MEW) approach [2]. MEW combines several inputs such as power of the received signal, throughput, packet delay, cost-per-user, the requested type of traffic, and type of device without considering network reputation concept. Furthermore, TYDER has also been compared to E-PoFANS [1] which proposed a reputation-based network selection scheme, but only for video traffic in 3.5G (i.e., UMTS/HSDPA) and WLAN heterogeneous access networks.

4.1 Protocols

The differentiation of service type is performed based on the protocols employed. The protocol list includes (and is not limited to) the following major ones:

- For the Video service type (VI), one of the following protocols is likely to be employed:
  - Dynamic Adaptive Streaming over HTTP (MPEG DASH) [51]; it is based on dynamic adaptive streaming media technology. It allows the customer to choose the bitrate based on download speed, network status, and buffer

change [52]. This is very useful because if the network is particularly slow, smaller blocks are required to be transmitted in order to maintain satisfactory QoS levels.

  - HTTP Live Streaming (HLS) [53]; like MPEG DASH, HLS is an adaptive protocol. At the start of the streaming session an extended M3U (M3U8) playlist is downloaded. This contains the metadata for the various sub-streams that are provided. According to network conditions one or another of these sub-streams are played.
  - Real Time Streaming Protocol (RTSP) [54] defines control sequences useful in controlling multimedia playback. While HTTP is stateless, RTSP has state; an identifier is used when needed to track concurrent sessions. Like HTTP, RTSP uses TCP to maintain an end-to-end connection and, while most RTSP control messages are sent by the client to the server, some commands travel in the other direction (i.e., from server to client). RTSP is not an adaptive protocol and controls data delivery only. The transmission is performed using other protocols such as Realtime Transport protocol (RTP) [55].

  The first two protocols are proprietary protocols, present respectively in Microsoft Windows and Apple products, whereas RTP and RTSP are not. Video content transmissions performed using these protocols are sensitive to jitter, throughput, and delay.

- Gaming service type (GM) uses protocols such as:

  - Open Game Protocol (OGP) [56]. OGP was developed and designed to provide specific real-time information about games running at any given server. Most effort was made to meet all the needs of a flexible game protocol which is supposed to support every kind of game;
  - Transport Control Protocol (TCP) [57] and User Datagram Protocol (UDP) [58]. TCP and UDP are transport layer protocols and perform data delivery using reliable or unreliable solutions, respectively. Depending on the type of online game, one, the other or both transport protocols are preferred.

  This type of service is particularly sensitive to delay, packet loss rate, jitter, and throughput.

- The IoT service type (IoT) uses a number of new generation protocols such as:

  - Message Queuing Telemetry Transport (MQTT) [59], it has been designed as an extremely light publication/subscription message transport. It is useful for connections with remote locations where a small code is required and/or network bandwidth is a priority. The version currently in use is MQTT-SN [60], acronym of MQTT for Sensor Networks. It is aimed at embedded devices on non-TCP/IP networks, whereas MQTT itself explicitly expects a TCP/IP stack.
  - Simple/Streaming Text Oriented Messaging Protocol (STOMP) [61] is a text-based protocol, making it more analogous to HTTP in terms of how it

looks under the covers. It is a very simple and easy to implement protocol, coming from the HTTP school of design; the server side may be hard to implement well, but it is very easy to write a client to get yourself connected. For example you can use Telnet to login to any STOMP broker and interact with it.

  – Advanced Message Queuing Protocol (AMQP) [62], this protocol was designed as an open replacement for existing proprietary messaging middleware. Its greatest strengths are reliability and interoperability. It also provides a wide range of features related to messaging, including reliable queuing, topic-based publish-and-subscribe messaging, flexible routing, transactions, and security. AMQP exchanges route messages directly in fan-out form, by topic, and also based on headers.

  In general, these protocols are designed to manage a large number of very small size packets. The performance of IoT services is influenced by:

  – Energy consumption;
  – System lifetime: a measure of the longevity of the nodes;
  – Latency: the time delay experienced in a system;
  – Delay and delay variation: refer to delay and delay variation in data collection from nodes;
  – Bandwidth, capacity and throughput: indicate the capacity of a sensor network to send data over a link within a given time.

- Document Access and Navigation service type is associated mostly with web browsing and file access. Therefore this service type is also referred to as *browsing* (BR). It is associated with protocols like HTTP/TCP and is more sensitive to:

  – Packet Loss Rate, as loss causes retransmissions, which are then translated in jitter and delays;
  – Delay;
  – Jitter;
  – Throughput.

4.2 TYDER

TYDER associates a reputation to each network available to the user and within each network for each of the four types of service considered. The reputation is based on feedback from users who use the network and considers in its calculation feedback variation during the day and week, respectively. The feedback the users send to the sever is numeric and is calculated through a multi-criteria method, differentiated according to the service used. This approach puts particular emphasis on the fundamental factors for the QoS of each particular service type. The risk or sensitivity factors of each service are converted into UFs that are used in conjunction to determine a score associated with the network that is being used at that very moment in time. This score is sent to

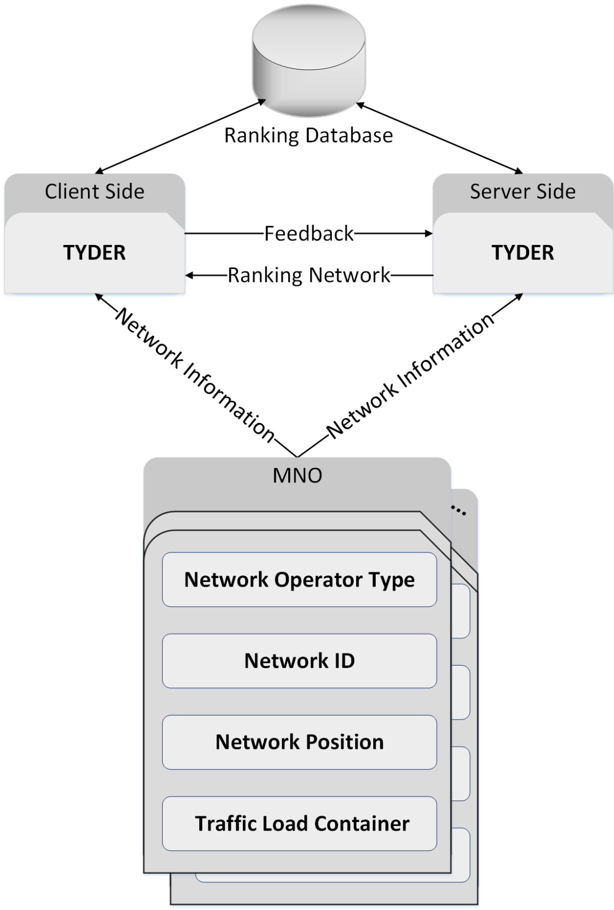

Figure 4.1: TYDER Architecture

the server that stores it in its own database of networks and can be processed alongside other such scores. This database is queried every time a user enters the network, moves within it or changes its service.

4.2.1 Architecture

TYDER architecture mainly relies on two macro modules, the Client Side and the Server Side, both connected to MNOs from which they receive information regarding wireless networks, such as Network Operator Type, Network ID, Network Position and Traffic Load Container. The two modules are connected to each other and exchange information. The client module sends feedback to the server side and the server module sends the list of networks with their respective reputations to the Client Side. This architectural solution is illustrated in Figure 4.1.

A possible software implementation and deployment of TYDER can involve two major apps. The Client Side consists of a special app installed in the user's device. The Server Side requires an app in the cloud connected to a database, so that all users can at any time query the application and get the information necessary for the operation of the proposed system. The two apps would work at the application layer and are able to communicate with the lower layers regardless of what communication protocol is employed. This is to be able to identify the various types of services employed.

Fig. 4.2 shows the stack of the two modules taken into consideration. As one

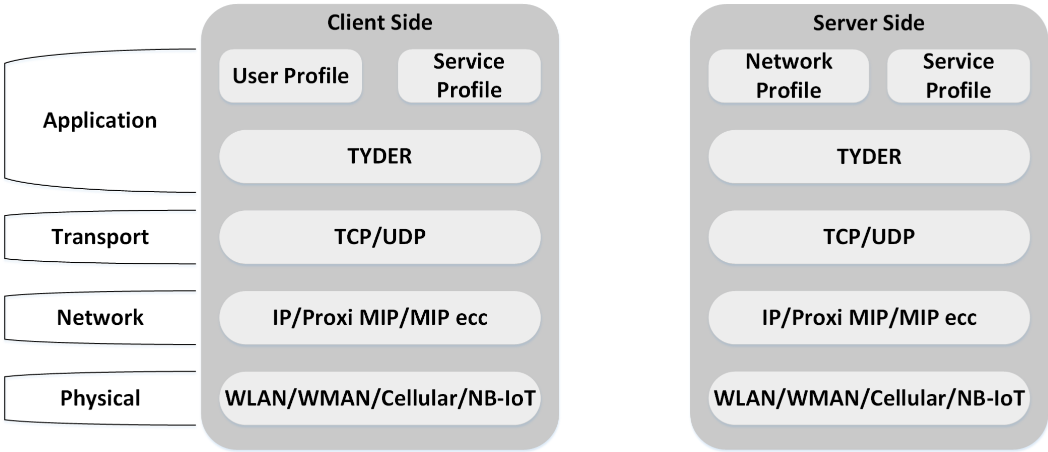

Figure 4.2: Client/Server Side Protocol Stack

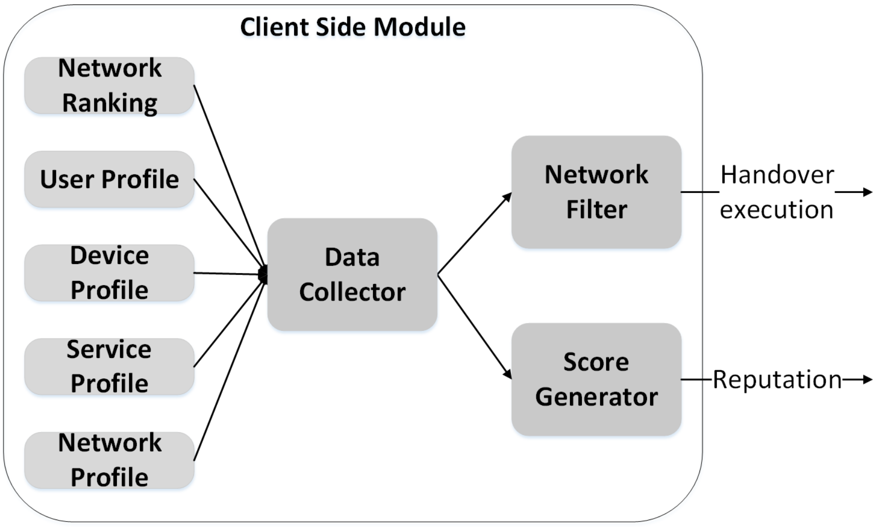

Figure 4.3: Client Module

can see, both client and server solutions work at the application layer of the TCP/IP network stack. This allows for total independence of the transport level protocols used by the services and the physical layer on which the information will travel (eg LTE, NB-IoT or WiFi).

4.2.2 Client Side Module

The Client Side takes care of managing two very important parts of the system:

- Ranking received from the server side in order to decide which is the best candidate network for its interest;
- Creation and delivery of feedback to the server-side.

Fig. 4.3 shows how these two parts are integrated into the client-side module.

4.2.2.1 Candidate Network Selection

The first function of the client is to select the candidate network. When the user accesses the system of heterogeneous networks for the first time, when they move within it or when they switch from one application to another, they must query the server to obtain the ranking of the network. During the query, the client side will send information about the user profile and service type to the server. The server side will send the ranking of the network containing the reputation of the available networks, associated to the specific service requested.

The Data Collector block will collect this information together with the information contained in the User Profile and the Service Profile and pass it to the Network Filter. The Network Filter block eliminates all networks that do not meet the minimum/maximum criteria. For example, if the device speed exceeds the maximum quota supported by the network standard, it will be eliminated from the possible choices. It will then get the network that has the best reputation for the service requested at that time. In this way the device can connect to the network able to offer the best QoS.

The User Profile block will contain all user preferences and will also be useful for managing information on the position of the device in order to store the user's mobility models. The Device Profile block contains the specific properties of the device, among them very important is the location service that allows us to identify the position of the device and its speed of movement. In terms of speed, it is possible to have three different types of speeds:

- high speed (more than 15 Km/h), the speed of a user on a vehicle;
- low speed (less than 15 Km/h), the speed of a user on foot or a slow vehicle;
- stationary users when the user does not need mobility support.

The Service Profile contains all the information regarding the type of service that the user is currently using. The services are grouped into four macro areas that correspond to the most used services and with greater scope for development: VI, GM, BR, and IoT, respectively. Each of them will be associated with an identifier that will enable the use of a specific function, most appropriate to that service type.

The Network Profile contains all the information concerning the network, such as the ID, and type of network. The Network Ranking contains the ranking network scores that are received from the server database.

The diagram in Fig. 4.4 shows the steps necessary to perform the candidate network selection, the first function of the client side:

1. The Client Side sends a query (A) containing the type of service used, to the database that contains the network ranking.
2. The database sends to the Client Side the answer to the query (B), the ranking of the networks available to the user at that precise moment. The ranking contains a list of tuples that contains:
   - ID of the network;
   - Type of network;
   - Value of its reputation.

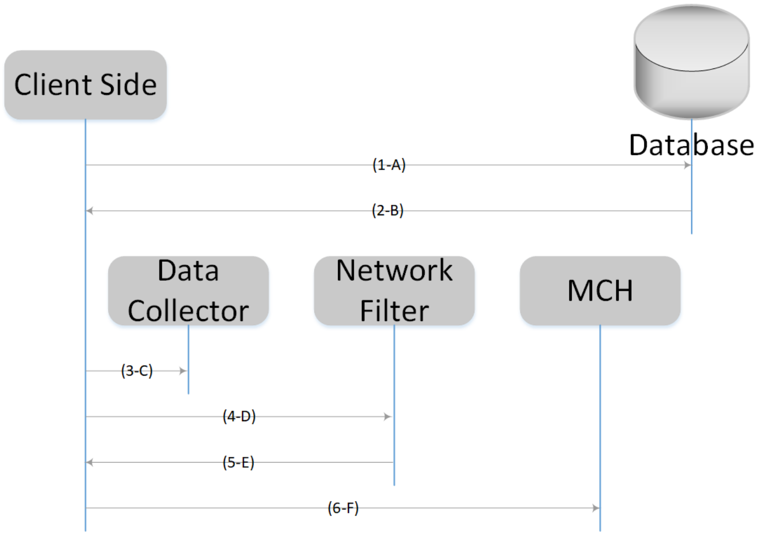

Figure 4.4: (a) Client Procedures

This information is sent to the client via TCP/IP.

3. The Client Side, through the Data Collector module, groups together the necessary informations to select the candidate network. This informations are:
   - Ranking Network;
   - Service Profile;
   - User Profile;
   - Device Profile.
4. The data collector sends this information to the network filter module. The network filter module makes a selection on available networks, eliminating networks that do not be included in the minimum/maximum criteria.
5. The network filter module returns the ID's candidate network (E).
6. The Client Side sends the ID of the candidate network (F) to the Mobile Call Handoff (MCH).

4.2.2.2 Network Evaluation

The second function of the client side is the evaluation of the network. Regularly (e.g. every minute) the device sends network evaluation info regarding its service use to the server side. The Data Collector block will contain relevant information about: Service Profile, Device Profile, and Network Profile. This information will be sent to the Score Generator block. The function of this block is to calculate the value to be assigned to the network and send it to the server side, in form of feedback. Depending on the type of service used, a specific score function will be activated. However, the server will always receive a value between 0 and 1.

Diagram 4.5 shows the sequence of actions of network evaluation, the second function of client side. The client side calculates and sends the reputation of the network to the server side.

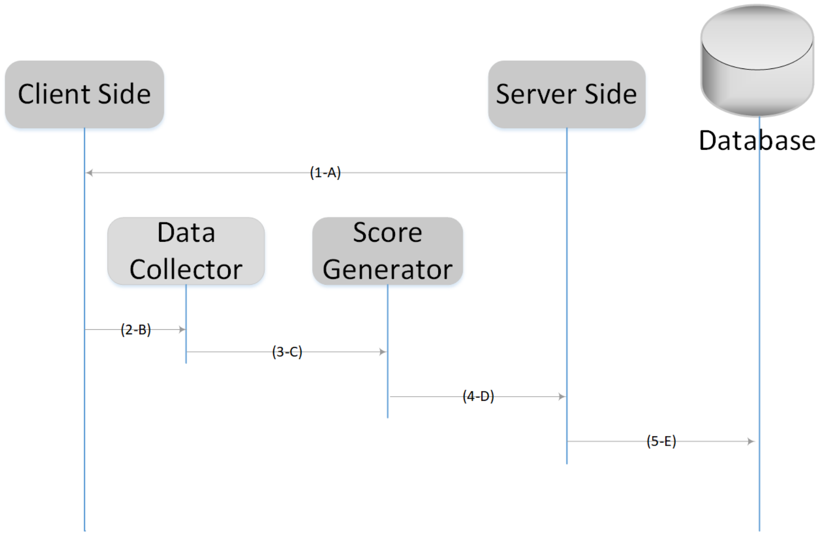

Figure 4.5: (b) Client Procedures

1. The Client Side requires reputation on the Server Side. The Server Side sends the information (A) in the form of a network ranking for that specific type of traffic.

2. The Client Side groups the information necessary for the calculation of the reputation through the data collector module (B).

3. This information are service profile, device profile and network profile (C).

4. Through the use of the UFs, the score generator module calculates the feedback of the used network and sends it to the server side (D).

4.2.3 Client Side Algorithm

The purpose is to provide feedback about the network that user was using or is using. The information sent to the server includes:

- Feedback value;
- Type of service;
- ID network;
- Time stamp.

The first problem is to calculate the feedback and based on which attributes to calculate it. In factit is known that different types of services have different needs. So, the type of service is differentiated. For each service type, there is a Score Function. The evaluation of this Score Function results in a score which is in fact the feedback value.

Contributing to the calculation of feedback will be a very different and often conflicting set of attributes. For this reason, a MADM is adopted, extremely used in literature in situations where there are some conflicting attributes. There are numerous utility functions in the literature, many of which are specific to the video service.

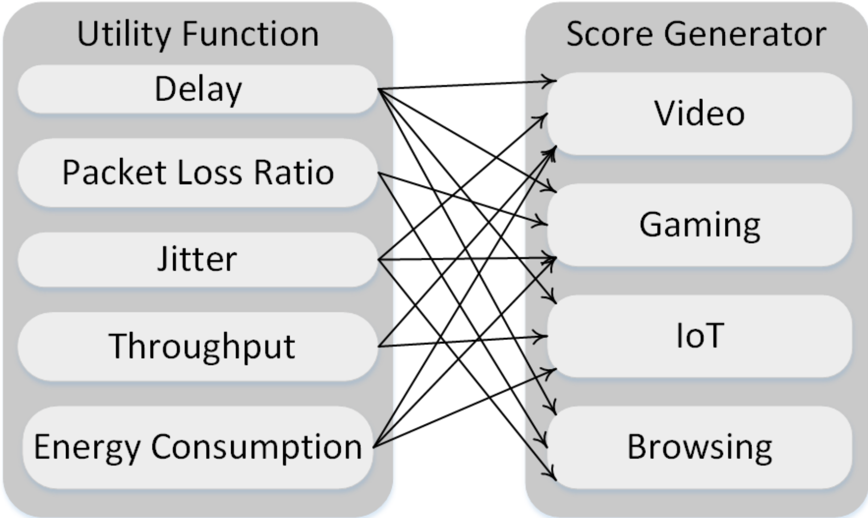

Figure 4.6: Utility Function and Score Generator

It is possible to use of these or modify the single part of this and weights, e.g., multiplicative exponent weighting, additive logarithm weighted, etc. In fig. 4.6 it is shown how utility functions affect the performance of the score for the various types of traffic.

The purpose of TYDER algorithm, described in Alg. 2, is to calculate the network feedback based on the type of service used.

The algorithm receives incoming data on the network and the type of traffic used. As already indicated, the four types of traffic considered are VI, GM, BR, and IoT.

Once the network has been identified by the transmitted ID, check the type of traffic and, depending on it, the corresponding function is applied. Feedback is calculated based on QoS values. These are used to derive the values of the individual UF, which are added together using an additive logarithm weighted model.

In the presented algorithm, the weights of the individual UF are attributed according to their importance within the requested service. In this way the UFs are differentiated within the Score Function (SF). SF, UF and the other aspects are explained in more details in the following paragraph.

4.2.3.1 Utility Functions

Different UFs are used by TYDER. They are described next.

- UF for Delay - see eq. (4.1):

$$u_D = \begin{cases} 1 & \text{if } 0 \leq t \leq T_{min} \\ \frac{-1}{(T_{max}-T_{min})}(t - T_{max}) & \text{if } T_{min} \leq t \leq T_{max} \\ 0 & \text{otherwise} \end{cases} \tag{4.1}$$

  where: u_D is the UF who estimated delay; T_{min} minimum delay of traffic; T_{max} maximum delay of traffic; t real delay of traffic.

- UF for Packet Loss Ratio (PLS) - see eq. (4.2):

Algorithm 2: Feedback Computation

Result: Return the value of feedback for the used network.

input: typeOfService = type of service used by the user;
ID = identifier of the network to which the user is connected;
WoJ = weight of Jitter;
WoT = weight of Throughput;
WoD = weight of Delay;
WoPLR = weight of Packet Loss Ratio;
WoEC = weight of Energy Consumption.

begin
  for $i \leftarrow 0$ **to** $listOFNetwork$ **do**
    if $ID = i$ **then**
      if *typeOfService* $==$ *VI* **then**
        feedback = $WoJ * ln(u_J) + WoT * ln(u_T) + WoD * ln(u_D)$
      end
      if *typeOfService* $==$ *GM* **then**
        feedback = $WoD * ln(u_{D_i}) + WoPLR * ln(u_{PLR_i}) + WoJ * ln(u_{J_i})$
      end
      if *typeOfService* $==$ *BR* **then**
        feedback = $WoPLR * ln(u_{PLR_i}) + WoD * ln(u_{D_i}) + WoJ * ln(u_{J_i})$
      end
      if *typeOfService* $==$ *IoT* **then**
        feedback = $WoEC * ln(u_{EC_i}) + WoD * ln(u_{D_i}) + WoT * ln(u_{T_i})$
      end
    end
  end
end

$$u_{PLR} = 100 * (\frac{MissedPackets}{TotalPackets}) \tag{4.2}$$

where: u_{PLR} is the UF who estimated the packet loss ratio.

- UF for Jitter - see eq. (4.3):

$$u_J = D_{peak-to-peak} + 2 * n * R_{rms} \tag{4.3}$$

where: u_j is the UF who estimated total jitter; $D_{peak-to-peak}$ is deterministic jitter; n is based on the bit error rate (BER) required of the link; R_{rms} is random jitter.

- UF for Throughput - see eq. (4.4):

$$u_T = \begin{cases} 0 & \text{if } Th < Th_{min} \\ 1 - e^{\frac{-\alpha * Th^2}{\beta + Th}} & \text{if } Th_{min} \leq Th \leq Th_{max} \\ 1 & \text{otherwise} \end{cases} \tag{4.4}$$

where u_T is the UF who estimated Throughput, Th is the predicted average throughput for each of the candidate networks (Mbps), Th_{min} is the minimum throughput necessary to obtain the requested service (Mbps), Th_{max} is maximum achievable throughput, α and β are two positive parameters which determine the shape of the UF (no unit).

- UF for Energy Consumption - see eq. (4.5):

$$u_{EC} = (r_t + Th_i * r_d) * t + c \tag{4.5}$$

where: u_{EC} is the UF who estimated energy consumption (Joule); t represents the transaction time (seconds); r_t is the mobile device's energy consumption per unit of time (W); Th_i is the available throughput (kbps) provided by RAN i; r_d is the energy consumption rate for data/received stream (Joule/Kbyte), c is a constant (no unit) [1].

4.2.3.2 Additive Logarithm Weighted method

The UF that have been defined are grouped using the Additive Logarithm Weighted (ALoW) method [9]. The choice was made due to the mathematical properties of logarithms. In fact, the UFs are grouped together with a series of summaries unlike what happens in exponential multiplication methods. In this way, if a UF assumes a value of zero, it will affect in a less decisive way the final choice of the candidate network. Formula from eq. (4.6) shows ALoW method.

$$ln(U^i) = \sum_j w^j * ln(u_j) \tag{4.6}$$

where $ln(U^i)$ is the natural logarithm of U and i indicates the i-th network. Sum of the j-th weight multiplied by the natural logarithm of the UFs, where j indicates the j-th UF. The result obtained is the reputation value that is attributed to the network used.

In the following manner, the SFs for each type of service are computed.

- SF for VI - see eq. (4.7):

$$\begin{aligned} ln(U_i^V) = w_J * ln(u_{J_i}) + w_T * ln(u_{T_i}) + w_D * \\ * ln(u_{D_i}) \end{aligned} \tag{4.7}$$

- SF for GM - see eq. (4.8):

$$\begin{aligned} ln(U_i^G) = w_D * ln(u_{D_i}) + w_{PLR} * ln(u_{PLR_i}) + \\ + w_J * ln(u_{J_i}) \end{aligned} \tag{4.8}$$

- SF for IoT - see eq. (4.9):

$$\begin{aligned} ln(U_i^{IoT}) = w_{EC} * ln(u_{EC_i}) + w_D * ln(u_{D_i}) + \\ + w_T * ln(u_{T_i}) \end{aligned} \tag{4.9}$$

- SF for BR - see eq. (4.10):

$$\begin{aligned} ln(U_i^B) = w_{PLR} * ln(u_{PLR_i}) + w_D * ln(u_{D_i}) + \\ + w_J * ln(u_{J_i}) \end{aligned} \tag{4.10}$$

where U_i is the SF for i^th network, $u_{J_i}^{w_J}$, $u_{T_i}^{w_T}$, $u_{D_i}^{w_D}$, $u_{PLR_i}^{w_{PLR}}$, and $u_{EC_i}^{w_{EC}}$ are the UFs which will be defined for jitter, throughput, delay, packet loss rate, and energy consumption respectively.

w_J, w_T, w_D, w_{PLR}, and w_{EC} are the weights that are attributed to each UF within the specific score. The weight value will be given based on the importance of the single UF within the specific SF. In general, the rule from eq. (4.11) is applied:

$$\sum_j w_j = 1 \tag{4.11}$$

The definition of the weights was attributed through the method presented in the paragraph 3.1.1.

Through the values defined in the Saaty Scale it is possible to obtain the weights of the single UF. Following the steps necessary for AHP, as shown in 3.1.1, a hierarchy is created between the variables used, creating a matrix in which the variables taken into consideration are compared, two at a time, in this way a relative weight is obtained. An example of this process is shown in the table 4.1.

Where the video service case is shown, whereas the video is very sensitive to jitter and throughput and less to delay. Therefore, jitter and throughput must have a greater weight than the delay. Among them, however, have a similar importance, so they can have the same weight.

Once the feedback value is calculated, this is sent to the server to be able to compete in network reputation.

Table 4.1: Example of weight for Video SF

	Jitter	Throughput	Delay	Weight
Jitter	X	1	5	0.4
Throughput	1	X	5	0.4
Delay	$\frac{1}{5}$	$\frac{1}{5}$	X	0.2

4.2.4 Server Side Module

4.2.4.1 Network Ranking Provisioning

The server side is responsible for sending the ranking of available networks on the device that request it, and keeping the ranking updated by obtaining feedback from the devices, as shown in fig. 4.7. Whenever a device requests it, the server side must send the ranking of the networks available to the user. To do this, it must collect information regarding the type of service requested, the networks available to the user and the user's profile, through the Data Collector block. This information is sent to the Network Ranking block that queries the database, based on the type of service requested selects the available networks, and finally sends the user a list of networks with their reputations.

4.2.4.2 Network Reputation Update

The second function of the server side module is to keep the network reputations database updated. To do this, the Ranking Score block collects the various feedback scores that are sent by the devices. As feedback arrives at this block, it stores them in the database and keeps track of the network's reputation. To keep the value updated, a ranking algorithm is used that takes into account the current reputation of the network and its trend during the day and during the week. This value is stored in a tuple $R_i(V, G, B, I)$ where R_i is the reputation tuple for i^th network, V is the reputation for video service, G is the value of reputation for gaming service, B is the reputation for browsing service, and I is the value of reputation for IoT service.

The server side deals with the management of mainly two system functions:

- Send ranking to the client side, which will manage it;
- Process the feedback received from the client side.

The function of sending the Ranking to the Client Side is the simplest of functions performed on the Server side. In fact, when a user enters the system, he makes a request to the server. This request specifies the type of traffic that you decide to use at that time. The Server queries the networks, based on the type of traffic requested and will send to the Client side, the network or networks that have a better Ranking value at that time.

The second function occurs when the user sends feedback on the network used. This happens every time the user leaves the network, because he has moved away or because the conditions of the network have changed and it is necessary to carry out a handover. The Client Side sends the network feedback to Server, calculated according to the QoS parameters that were obtained during use of the network. The Server Side

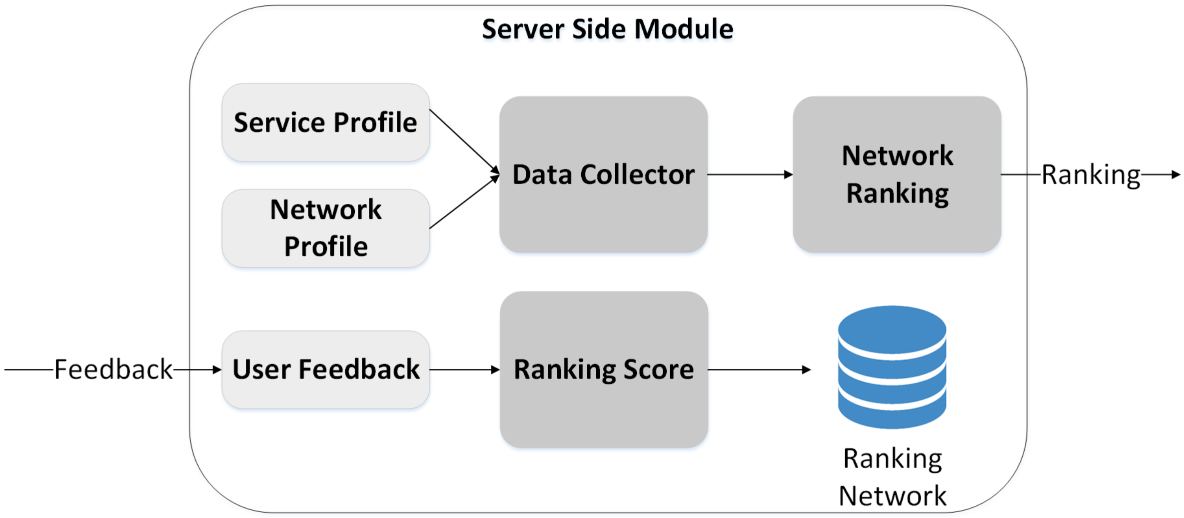

Figure 4.7: Server Module

processes the data sent and updates the database in a way that is consistent with the current situation of the network. In this way the reputation of the network is always updated with the latest info.

The diagram in fig. 4.8 shows the steps necessary to perform these important functions at the server side:

1. (1-A) Client sends a request to the Server for the best ranked network associated with the service indicated and Server replies with the network ID that matches the Client request.

2. (2-B) The Client uses the network and then it sends feedback to the Server regarding the network used.

3. (3-C) The server processes the feedback information according to the Ranking Score algorithm which will be presented later..

4. (4-D) The processed information is sent to the database where it is stored for future use.

4.2.5 Server Side Algorithm

On the server side, the problem of how to use the values sent from the client side was highlighted. There is a 4-tuple including values that will be stored and processed in order to be returned as a reputation when a user wants to connect to the network. The individual feedback values sent by the user are maintained as they are received for a period of time (e.g. one hour), after which they will be aggregated and saved as an average value, whereas the individual values are deleted to give way to new values. The purpose of the algorithm is to rank the available networks, based on their reputation, attributed over time by clients to each individual network. The algorithm is designed to take into account reputation trend in both short and long term. By combining the trend over a day with that over a week, the overall network ranking value is obtained.

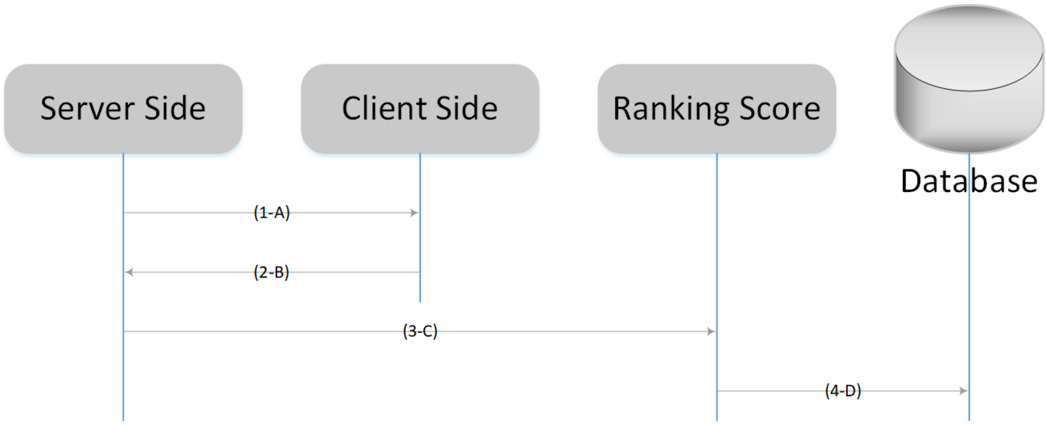

Figure 4.8: Server Procedures

This function is shown in algorithm 3 Called for all available networks, it receives the type of service that the user intends to use, and calculates the ranking for all networks. The ranking takes into account the values stored over time, attributing to them an increasingly smaller value as you move away from the current moment.

Algorithm 3: Computation of network reputation and update of network ranking

---

Result: Return the value of reputation for the network.
input: ToS = type of service required.
RN = Reputation Network
RD = Reputation Day
FN = Feedback Network
for *s in type of service available* **do**
  if *ToS* $= t$ **then**
    foreach *day* $= d$ *in a week* **do**
      $RD_d = FN_{d1} + \sum_{k=2}^{24} FN_{dk} * (1 - \frac{k}{25})$
    end
    $RN = RD_1 + \sum_{i=2}^{7} RD_i * (1 - \frac{i}{8})$
  end
end

The second function, performed according to the algorithm 4, focuses on saving the feedback sent by clients. It is simply attributed to the network used by the user and associated to the type of service requested.

4.2.6 Use Cases and Performance Evaluation

The evaluation of the TYDER algorithm, was carried out by integrating Python code in models built using the OMNeT++ [63] network simulator. The simulations were performed using the parameters presented in table 4.2. They respect the main characteristics of the three access technologies used: Wi-Fi, LTE and NB-IoT.

The simulations use the same network configuration, while considering different traffic situations. The traffic configuration involves the coexistence of three different

Algorithm 4: List of Reputation Networks

Result: Ranking storage.
input: ToS = Type of Service
ID = identification of network
feedback = feedback value attributed by the user to the network
LoN = List of Networks
foreach *network in LoN* **do**
    if *ID = network* **then**
        network[ToS].add(feedback);
    end
end

Table 4.2: Simulation Networks Parameters

Attributes	Wi-Fi Network	LTE Network	NB-IoT
Technologies	8002.11ac	LTE cat 6	NB-IoT
Number of AP/eNB	2	1	4
Radius Cell	250 m	500 m	5000 m
Transmission Power	20 dBm	46 dBm	23 dBm
Bandwidth	40 MHz	20 MHz	180 KHz
Data rate Max	600 Mbps	300 Mbps	250 kbps
Propagation Model	Hybrid model (i/o)	Hybrid model (i/o)	Hybrid model (i/o)

Table 4.3: Data Rates Used

Service	Data Rate
Video	4 Mbps
Gaming	3 Mbps
Browsing	100 kbps
IoT	2 bytes

types of access networks. Specifically, the presence of two Wi-Fi access points, an eNB for LTE and 4 eNBs for NB-IoT, this is because this technology is designed to exploit the existing LTE infrastructure.

The simulations were preceded by a training simulation. The training simulation involved the presence of only one user within the simulation system. For each network, it was positioned in the cell center and on the cell edge. For each position request of the 4 types of traffic was simulated, for a duration of 30 seconds each. This allowed to fill the database with the initial simulation data.

The traffic has been differentiated in such a way that it is possible to simulate the four different types of services offered. The different network data rates used are shown in table 4.3.

4.2.6.1 Scenario 1

In the first scenario, a single user without mobility case was considered, as shown in fig. 4.9. It employs the 4 different types of traffic for the duration of 3 minutes each. This allows for population of the reputation tables of the individual networks and at the same time evaluation of the behavior of the TYDER algorithm in comparison with the situation when the proposed algorithm was not deployed.

The user can use a different type of device (e.g. smartphone, laptop, tablet, smartwatch, mobile device, etc.) and request access to one of the services shown in the Table 4.3.

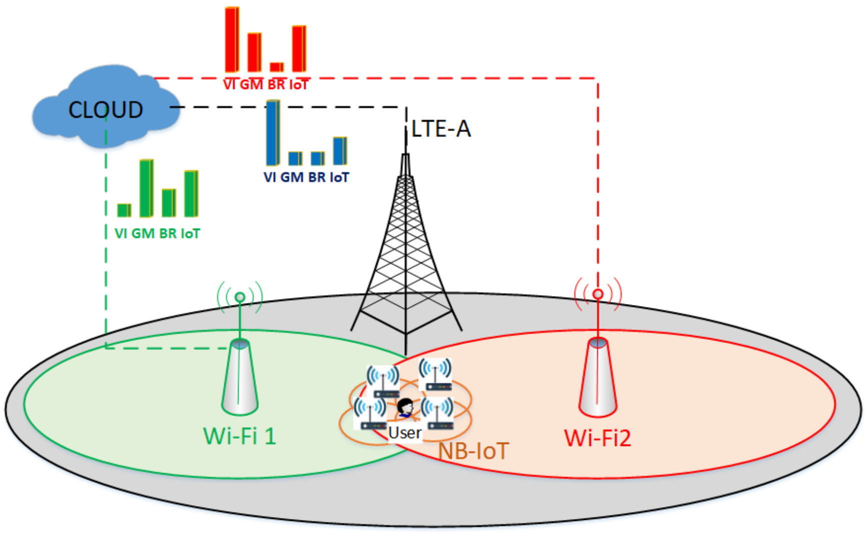

Figure 4.9: Scenario 1 - Static User

4.2.6.2 Scenario 2

In the second scenario, the behavior of a mobile pedestrian user was evaluated, walking at 3 km/h along a linear path of 500 m, as shown in fig. 4.10. The duration of the simulation is 450 seconds, to allow the user to complete the entire route. This scenario simulates realistically the behavior of pedestrians and vehicles in dense urban environments and heavy traffic.

This second simulation tests the dynamic behaviour of the algorithm over time and space. Along the route, the user performs a service change every 10 seconds, supporting a homogeneous distribution of service requests during the simulation. During user movement, multiple handovers are performed.

4.2.6.3 Scenario 3

Finally, in the third scenario, background traffic was considered. In scenario 3, other 200 users were introduced, distributed in a pseudo-random way among the different networks and who request the 4 different types of traffic, as shown in fig. 4.11. The traffic of these users significantly influences the reputation of the various networks.

The simulation has the same duration as in the second simulation and the evaluations are carried out by focusing on a pedestrian user with linear mobility with a speed

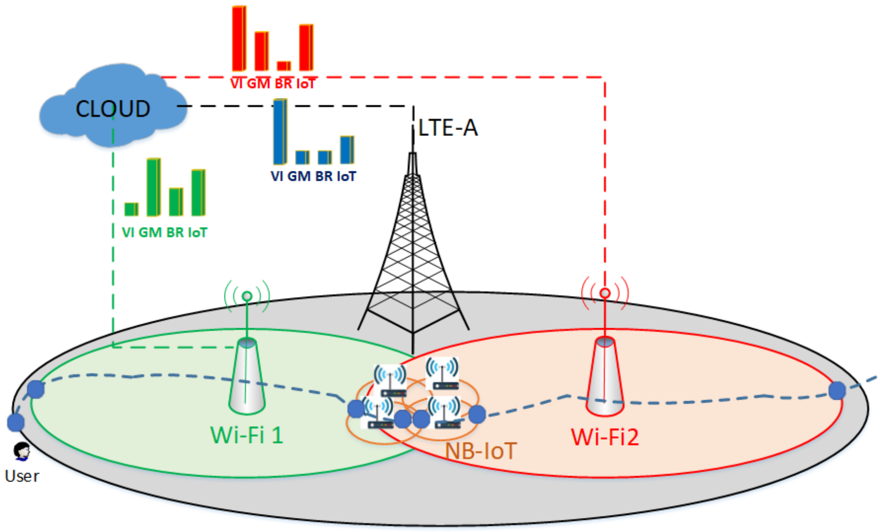

Figure 4.10: Scenario 2 - Mobile User with no Background Traffic

of 3 Km/h. This scenario allows for testing the behavior of the algorithm in a realistic situation with ordinary traffic. The number of users introduced enables validation of the operation of the algorithm in loaded traffic conditions.

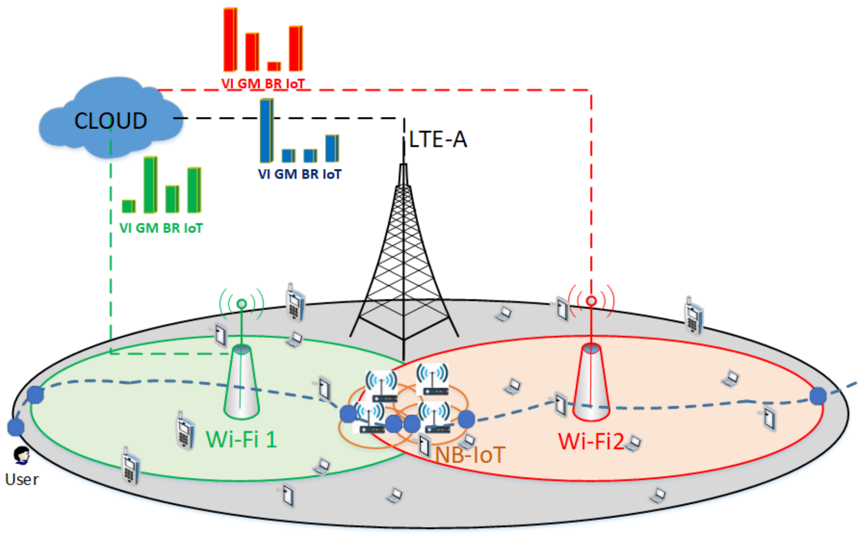

Figure 4.11: Scenario 3 - Mobile User with Background Traffic

4.2.6.4 Results

In this section the proposed TYDER algorithm is evaluated and compared with MEW [2] and E-PoFANS [1] algorithms. Fig. 4.12 shows the type of traffic selected and analyzes the performances between the proposed TYDER and the two algorithms used for comparison. The obtained results are oriented to QoS performance evaluation. In the case of VI, GM, BR, and IoT traffic types, an improvement in terms of maximum throughput that a user could obtain is observed.

Figures 4.15, 4.16, and 4.17 show the throughput, packet delay and packet loss rate, respectively, when the user is moving as explained in scenario 2. The mobility of the user implies the consideration of dynamics aimed at intelligent selection of the access network. The proposed TYDER algorithm is able to select in real time the best candidate based on the QoS parameters examined. In these cases, it is possible to see a significant increase in average throughput and a decrease in packet delay and the loss rate for both types of traffic.

Figures 4.18, 4.19, and 4.20 show the throughput, packet delay and packet loss rate, respectively, when a dense traffic scenario has been proposed. As indicated in scenario 3, the mobility of the user is combined with the traffic contribution of the other users present in the scenario. Mobility and background traffic have significantly influenced the choice of the candidate network. In fact, the reputation obtained the input of users' feedback in the simulated system. As can be seen from the results, which show a better trend than the respect algorithm.

Finally, figures 4.21, 4.22, 4.23, and 4.24, show the average throughput trends during the simulation in scenario 3 for the different types of traffic. The graphs are plotted with a 10-second step, to take into account the change in reputation caused by background traffic. It has been simulated that a user changes his traffic type 30% of the time, randomly. This leads to a trend in average throughput that is not perfectly linear. In general, it is possible to see how the behavior of the reputation algorithm behaves better than MEW and E-PoFANS, in all four services required.

TYDER has an average improvement of 8% against MEW and 5% for E-PoFANS. This improvement is noted above all in the Video and IoT services, where TYDER records the biggest improvements.

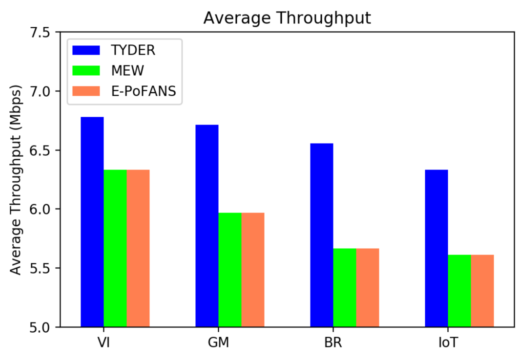

Figure 4.12: Avg Thr Scenario1

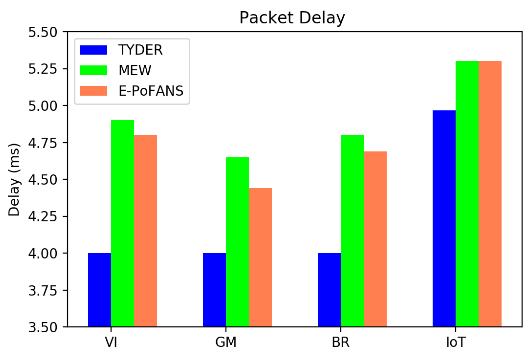

Figure 4.13: Packet Delay Scenario1

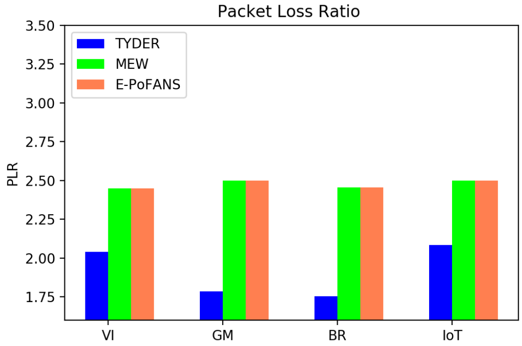

Figure 4.14: Packet Loss Ratio Scenario1

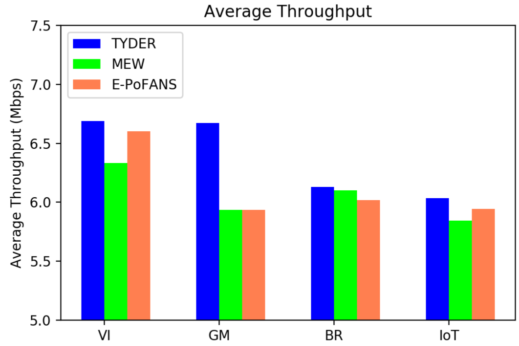

Figure 4.15: Avg Thr Scenario2

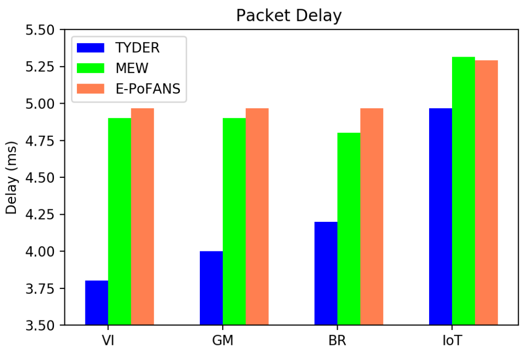

Figure 4.16: Packet Delay Scenario2

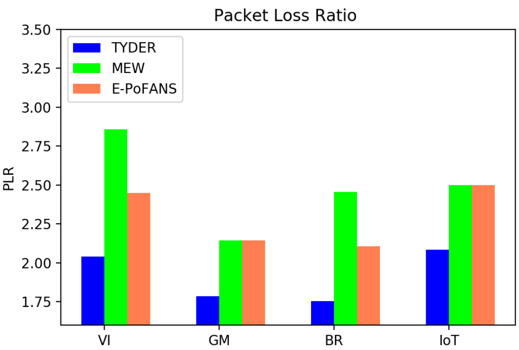

Figure 4.17: Packet Loss Ratio Scenario2

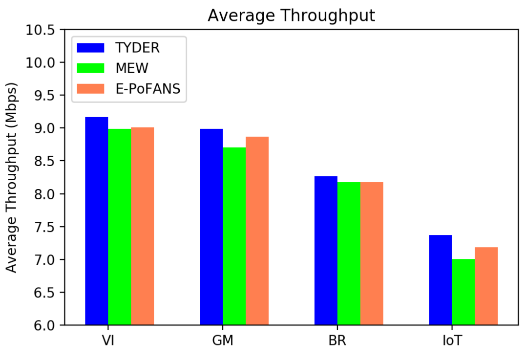

Figure 4.18: Avg Thr Scenario3

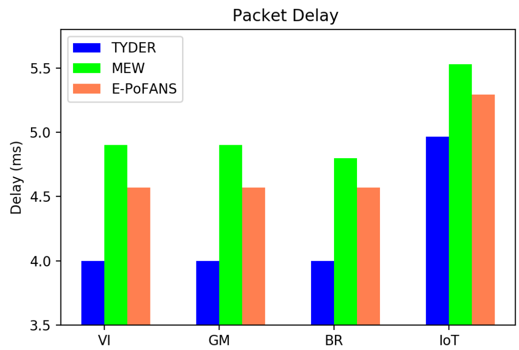

Figure 4.19: Packet Delay Scenario3

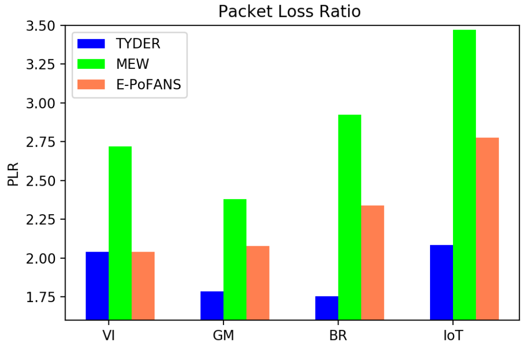

Figure 4.20: Packet Loss Ratio Scenario3

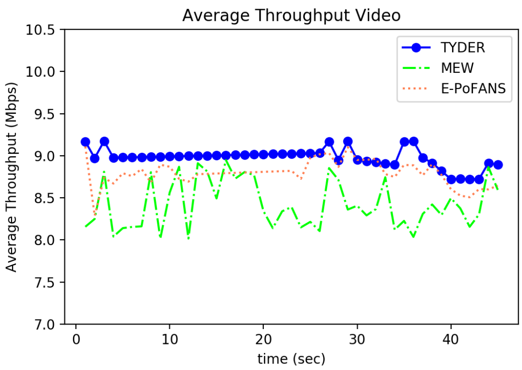

Figure 4.21: Avg Thr Scenario3 VI

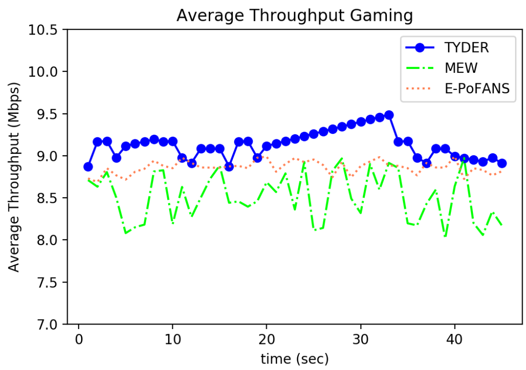

Figure 4.22: Avg Thr Scenario3 GM

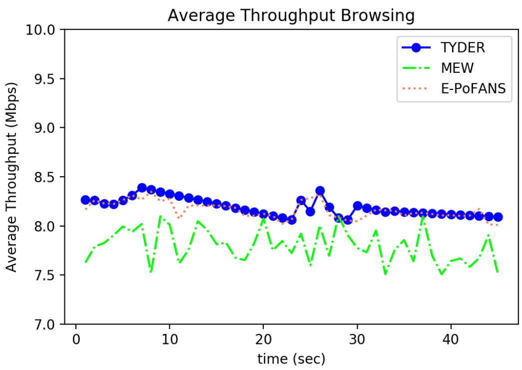

Figure 4.23: Avg Thr Scenario3 BR

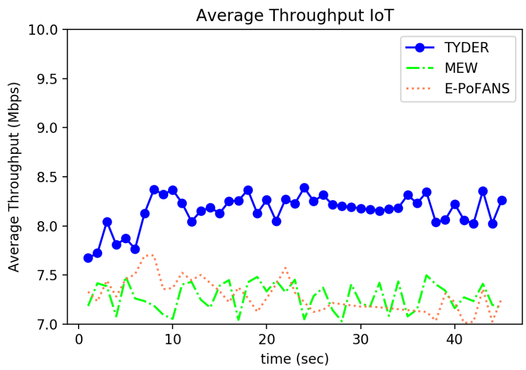

Figure 4.24: Avg Thr Scenario3 IoT

Chapter 5

Multimedia Multicast Services in 5G Networks

The 3rd Generation Partnership Project (3GPP) has introduced the broadcast Multimedia and advanced Multicast (eMBMS) services within Long Term Evolution (LTE) systems (and beyond) to provide data transmissions from a single source on multiple devices [31]. eMBMS uses a common channel to send the same data to multiple receivers, thus serving a greater number of users with, at the same time, efficient management of available radio resources. Multi-vector modulations have become a key technology in communication systems [64]. In this context, an efficient link adaptation and modulation coding scheme (MCS) is a key feature to allow LTE systems to react promptly to changes in channel quality.

Of all the multicast RRM options available within LTE, the division of potential receivers into different subgroups with different SNR values available is a well accepted technique to allow more efficient exploitation of spectral resources. This technique is known as the multicast subgroup (MS) [65] . With MS, in fact, each user of a multicast group transmits feedback to the channel quality indicator (CQI) to the eNodeB, which decides on a per-group basis the number of resource blocks (RB) to be allocated and the modulation schemes and coding to choose. Furthermore, the single-point-to-multipoint mechanism (SC-PTM) [66] uses the eMBMS to improve radio efficiency and end-to-end latency. In fact, the goal is to provide efficient radio use and flexible distribution for a range of multimedia applications and services. In this way, the transmission / multicast area can be dynamically regulated by cell-cell based on the user's distribution, interests and movements.

Furthermore, 3GPP has developed a solution for vehicle-to-whole communications (V2X) starting with Rel-14 [66]. For clarification purposes, V2X communications address the connection via the cellular infrastructure (ie, in addition to the 4G and 5G networks) between vehicles (V2V), network vehicle (V2N), infrastructure vehicle (V2I) and Vehicleto-pedestrian (V2P) [67]. The objective of V2X is to improve road safety, increase the efficient flow of traffic, reduce environmental impacts and provide additional information services for travelers.

eMBMS, as mentioned, will probably be exploited in 5G networks, introduces the point-to-multipoint transmission mode in cellular networks and covers various functions related to the management of multicast services [66]. In particular, PtM simultaneously serves all users interested in a given multicast service through a shared channel, with the aim of improving the system's capacity and, theoretically, serving an unlimited number of users. The main challenge for the support of multicast services in the eMBMS environment is linked to the efficiency of the RRM approach in optimizing the allocation of radio resources available in the radio access network.

Multicast transmissions are influenced by multiple users' different receiving conditions, mainly due to the particular channel propagation distortion experienced by UEs. In Fig.5.7 an envisaged scenario is depicted, where the receivers are divided into different subgroups according to the experienced channel conditions. Least channel gain users (i.e., users with the lowest CQI) could affect the performance of the complete multicast group, since they can only support the lowest MCS level. This brings on bad spectral efficiency and very poor throughput. Traditional approaches like the opportunistic multicast scheme (OMS) and conventional multicast scheme (CMS) suffer from low user fairness and weak spectral efficiency, respectively. Indeed, the former serves only the subscribers able to optimize a given objective function, which allow maximizing the system throughput.

Hence, for each time slot OMS aims to efficiently exploit the multiuser diversity by selecting the portion of multicast members to serve with the most suitable MCS. Nevertheless, OMS cannot guarantee short-term fairness among users, because only a portion of them will be served at each time slot. Vice versa, the CMS algorithm guarantees the multicast service delivery to the overall set of multicast receivers. Indeed, CMS selects the MCS parameters according to the worst CQI value collected by the RAN (e.g., eNodeB in LTE) from all the multicast subscribers in a cell. Therefore, the multicast session performance is bounded by the UEs with the worst channel conditions. CMS and OMS belong to the single-rate multicast scheme, according to which all users within the multicast group share the same resources, and a single transmission with a fixed data rate is delivered to each UE. Although single-rate schemes present advantages in terms of simple implementation and low complexity, they suffer from poor spectrum efficiency or low fairness [32].

Effective approaches aiming to overcome the inefficiencies introduced above are multi-rate schemes [68]. Such schemes allow each user device to receive multimedia traffic based on its capabilities. In particular, two techniques have been presented in the literature for multi-rate multicast transmission: stream splitting and group splitting. Stream splitting is based on splitting highrate multimedia contents into multiple substreams of lower data rate. A base substream, receivable by all users, is transmitted in order to accomplish full coverage of the multicast group. Afterward, users with good channel condition receive additional enhancement streams to improve information quality. Scalable video coding (SVC) is typically at the base of this approach.

An effective group splitting approach is subgrouping [69], which is based on splitting the multicast clients into subgroups and applying subgroup-based adaptive MCSs, which enable more efficient exploitation of multi-user diversity.

Subgroup formation may be performed by designing the subgroup formation according to an optimization problem [69] that can be formulated in order to achieve different goals, for instance, maximization of system throughput, spectral efficiency, or energy efficiency. In doing this, the most suitable subgroup configuration (i.e., number of subgroups with the related MCS, portion of users, assigned resources, and data rate for each enabled subgroup) is dynamically selected by the base station based on the minimization (maximization) of a given cost (utility) function. The main issue faced by the subgrouping approach is the computational complexity.

In the session 5.1, a scenario is presented that allows you to compare the three major multicast services in a mobile environment for vehicles.

In the session 5.2, a comparison was made between techniques of subgroups of the OMA and NOMA type.

5.1 Mobility Aware eMBMS Management in Urban 5G-Oriented System

In this context, a new realistic scenario has been introduced in which all users in a given area (for example, vehicles and pedestrians) can contribute to uploading a video content (created by the surrounding environment) to their nearest eNodeB with the goal of creating new 3D video content useful for ADAS systems. From a series of images, the 3D geometric information of an environment can be obtained and used in the localization and virtual reconstruction of the environment for further analysis [70]. Thus, the eNodeB will perform multicast transmission to make the new streaming video available for all vehicles in that area.

Considering this scenario, the study focused on eNodeB multicast transmissions of streaming video for groups of vehicles in a real environment.

The main objective of the work carried out is to compare the advantages and disadvantages of three different approaches proposed for the management of multicast services in a mobile vehicle environment:

- Conventional Multicast Scheme (CMS) [71], where the total throughput is limited by the user with the worst channel conditions, and all the users are served at the same throughput leading to low satisfaction experienced by the users with good channel conditions;
- Opportunistic Multicast Scheme (OMS) [68], that allows to maximize the system throughput according to the channel quality, not serving all users in a given time slot;
- Multicast Subgrouping Optimal Aggregate Data Rate (SubOptADR) overcome the limitations of CMS and OMS algorithms, based on the multicast subgrouping policy [72] [73], whereby multicast destinations are grouped into different subgroups depending on the user equipment (UE) channel quality in order to maximize the Aggregate Data Rate (ADR), that is the sum of data rate values obtained by all the multicast members.

Simulations of real LTE network multicast scenario in mobile environment, focusing on group-oriented video services and different user classes, is presented on order to analyze the capabilities of algorithms in terms of ADR, and the Quality of Experience (QoE) perceived by each user in a SC-PTM scenario.

5.1.1 Multicast LTE simulator

The simulations were performed via OMNeT++. This is because through the SimuLTE library it is possible to perform simulations of LTE/LTE-A in frequency division Duplexing mode (FDD), with heterogeneous eNodeBs (eg Macro, micro, pico, etc.), using omnidirectional and anisotropic antennas.

The great advantage using this simulator is the possibility to model a real scenario characterizing both node objects (i.e., eNodeBs and UEs) and mobility (i.e., pedestrian, vehicular, and urban), fading, or antenna models for each node. Since the last version, it has been decided to modify and implement new modules to simulate grouping and multicast transmissions.

Thanks to these new modules:

- each UE transmits CQI feedbacks to the eNB which can decide the number of RBs to allocate the MCSs for a multicast transmission in a common channel used by the multicast group (MG);
- each eNB can use one of the three different approaches proposed for managing multicast services (i.e., CMS, OMS, and SubOptADR), opportunely developed;
- scheduling strategies and Hybrid automatic repeat request (HARQ) procedure have been modified;
- output parameters have been introduced to evaluate ADR and QoE for each node.

The eNodeB, in order to execute each of the three algorithms implemented for creating MGs, collects the CQI feedbaks perceived by all UE. This operation is executed every time to interval (TTI), that is a parameter set before starting the simulation, as the duration. The CQI feedbacks can be seen as input of the new three modules that implement the proposed algorithms, described in next subsessions.

5.1.1.1 Conventional Multicast Scheme

CMS scheme is a conservative approach that aims to serve the whole set of users. The eNodeB collects all the CQI feedbacks obtaining the corresponding MCS level, transmission parameter used to take into account the channel qualities of each multicast member. All the members are served with the MCS level supported by the member experiencing the worst channel conditions. In this case, resources are evenly distributed and all the users are served with the same data rate. Unfortunately, this technique suffers from poor spectral efficiency

5.1.1.2 Opportunistic Multicast Scheme

OMS scheme allows to serve not all users in a given TTI. The objective is to maximize the system throughput according to the higher MCS levels supported by the users experiencing the best channel conditions. This technique shows a lower fairness level compared to CMS, but higher spectral efficiency.

5.1.1.3 Multicast Subgrouping Optimal Aggregate Data Rate

SubOptADR scheme aims to maximize the ADR, the sum of data rates experienced by multicast members. The objective is to find an optimal configuration, in terms of subgroups, that provides the maximum ADR. The eNodeB enables a different amount of

RBs to several sub-groups, each one grouping a number of members according to similar MCS level. Users with good channel quality are served in sub-group with higher MCS levels. This technique serves all the users efficiently exploiting the multi-user diversity.

5.1.2 Use Cases and Performance Evaluation

Figure 5.1: Real urban scenario in Cagliari for vehicular (red marks) and pedestrian (yellow marks) users

For the simulations, a real urban location of the city of Cagliari in Sardinia and shown in Figure 5.1 has been reproduced. In this particular scenario, two main areas are considered in order to discriminate two type of users:

- a four lane road with only vehicles (i.e., red line in Figure 5.1);
- a pedestrian area (i.e., yellow line in Figure 5.1).

Both the two areas are served by the same eNodeB. The pedestrian area is further than the vehicular area compared to the eNodeB, also showing the presence of buildings. Whereat, CQIs are expected to be higher for vehicular users.

Two different configurations have been investigated: a MG where 30% pedestrian users and 70% vehicular users share the same resources and a MG with only vehicular users to serve. A 20 MHz channel (i.e., 100 RBs), 100 equally distributed users joined in the MG, and a 120 seconds time window is considered for all the simulations. Vehicular users have a speed between 30 and 60 Kmph and pedestrian users have a mean speed of 3 Kmph. The set-up used for the simulations is summarized in table 5.1.

The described different approaches have been compared in terms of the following performance metrics:

- Mean Throughput: average data rate experienced by the multicast group members [74]; the greater the throughput, the higher the service quality, and the "satisfaction" level of the multicast users.
- Jain's Fairness Index (JFI): it indicates the "fairness" in the distribution of throughputs experienced by multicast users [75]. The higher the JFI, the closer the throughput of multicast members.

Table 5.1: Simulation Parameters

	MG1	MG2
Vehicular users	70	100
Pedestrian users	30	0
Vehicular speed	30-60 Kmph	30-60 Kmph
Pedestrian speed	3 Kmph	
CH BW	20 MHz	20 MHz
RBs	100	100
Sim Time	120 s	120 s
Feedback time	6 ms	6 ms

5.1.3 Results

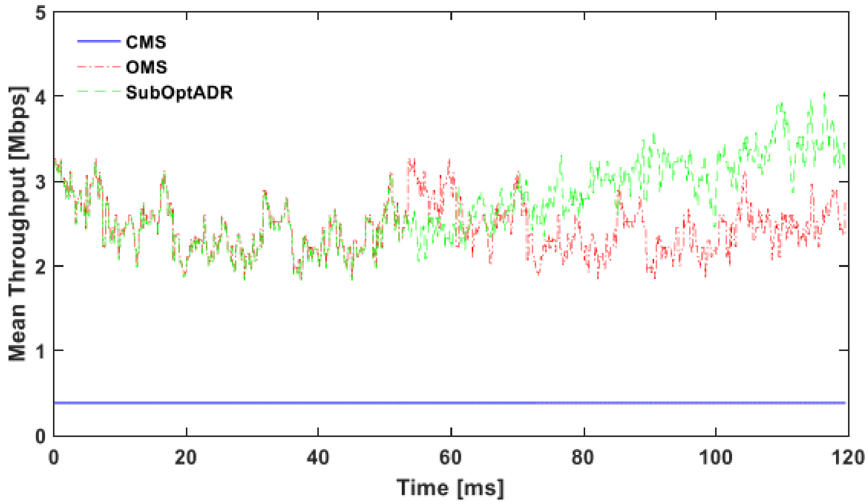

Figure 5.2: Mean Throughput calculated for the three approaches considering 70% vehicular users and 30% pedestrian users

Figures 5.2 and 5.3 represent the Mean Throughput values obtained for the three approaches considering the two simulated configurations presented in previewed session. In both cases, the CSM algorithm shows the lower values being limited by the user with the worst channel conditions (i.e., the lower CQI). Considering the MG with both vehicular and pedestrian users (i.e., figure2), OMS and SubOptADR algorithms show similar results during the first 50 seconds. Then, SubOptADR starts to perform better showing higher mean throughput. In the case with only vehicular users, SubOptADR always performs better than OMS reaching almost a twofold average increase. Comparing the SubOptADR trend, the specific real scenario highlighted its ability to increase the mean throughput in presence of users characterized by on average high CQI.

Figure 5.4 and 5.5 show the JFI values for the three algorithms considering a MG with 70% vehicular and 30% pedestrian users and a MG with only vehicular users, respectively. As expected, CSM algorithm guarantees perfect fairness, since resources are evenly distributed and all multicast members experience the same data rate. OMS

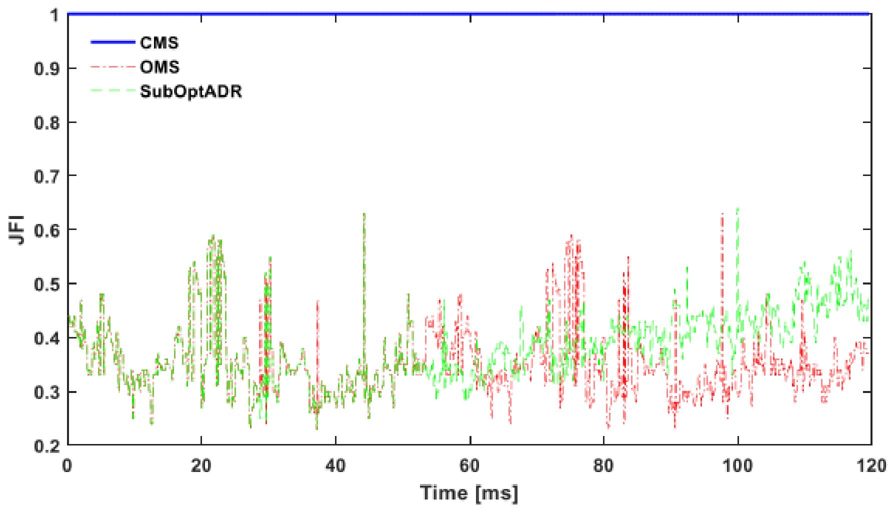

Figure 5.3: Mean Throughput calculated for the three approaches considering only vehicular users

algorithm presents comparable values for both the two considered cases showing its lack of fairness, in line with its features. Finally, SubOptADR algorithm improves its fairness for vehicular users. Even in this case, as it was for the mean throughput, the higher the CQIs, the higher the JFIs.

5.2 Subgrouping and Non-Orthogonal Multiple Access Techniques

The first solutions based on the 5G network will be launched commercially by 2020 and will perfectly integrate different network technologies [26], including unicast, multicast and broadcast. This is why the mobile and broadcast industries have independently developed several point-to-multipoint (PtMP) technologies to support large-scale consumption of mass multimedia services on mobile devices.

Broadcasters have proposed division-level multiplexing (LDM) to enable mobile television in addition to traditional digital terrestrial television services [28]. LDM is a non-orthogonal multiplexing technique (NOM), included in the standard American Television Standards Committee (ATSC) 3.0 [29]. A similar concept was previously presented for cellular environments in [76]. Regarding the broadband sectors, 3GPP has introduced an advanced multicast multimedia transmission service (eMBMS) within LTE systems and beyond to provide data transmissions from a single source to multiple devices [31]. The efficient allocation of resources, in the case of multimedia delivery, is a key issue for the eMBMS and the implementation of subgroup techniques is a promising solution [32].

A scenario was proposed that would allow the joint application of two of the aforementioned techniques, including LDM as an additional resource allocation mechanism in the radio resource management entity (RRM) and considering it in the subgroup decision-making process. To demonstrate their functioning, computer simulations have been carried out that confirm the performance advantages of the subgroup technique

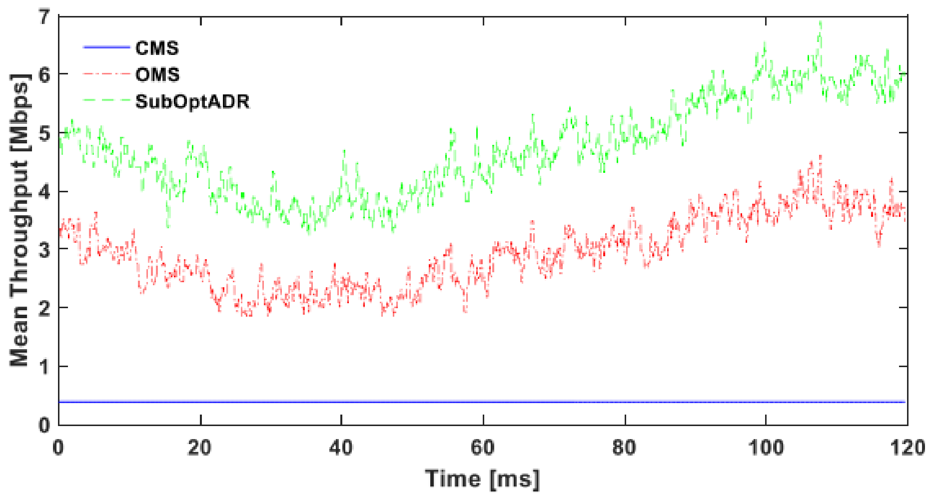

Figure 5.4: Jaie's Fairness Index calculated for the three approaches considering 70% vehicular users and 30% pedestrian users.

based on LDM and conclude with the challenges and future directions of the proposed work.

5.2.1 NOMA/Layer-Division Multiplexing

In a conventional cellular network the devices' physical connection with the network architecture is handled by the radio access network (RAN). This is the entity in charge of providing resources through different channel access multiplexing techniques to the user equipments (UEs) involved in the communication process. The wide range of solutions present in the literature can be gathered in two categories:

- Orthogonal multiple access techniques (OMA). In this technique the available frequency/time resources in the network are orthogonally assigned to the different UEs. Thus, at the receiver side, under perfect conditions, the desired data can be unequivocally separated from the rest of the information.

- Non-orthogonal multiple access techniques (NOMA) [77].In this techniques, the available resources, both frequency and time, are completely shared among different users, and therefore, when decoding the desired content, the rest of the signals are considered an additional source of noise (Fig. 5.6 (a)).

In the literature, the spectral efficiency of both proposals has been widely studied from an information theoretic point of view. In principle, NOMA-based techniques have shown higher efficiency, especially when the throughput rate among different users is asymmetric [77]. Figure 5.6 depicts the different achievable theoretical spectrum efficiencies when two different services are multiplexed, with either NOMA (green solid line) or OMA (blue dotted line). The reception thresholds have been obtained from the set of the signal-to-interference-plus-noise ratio (SINR) values associated with the channel quality indicators (CQI) included in the current LTE release. As shown, NOMA always performs better than OMA, especially for asymmetric scenarios, where the gain can be up to 1.0 b/s/Hz for the high SINR service. When both services' CQI

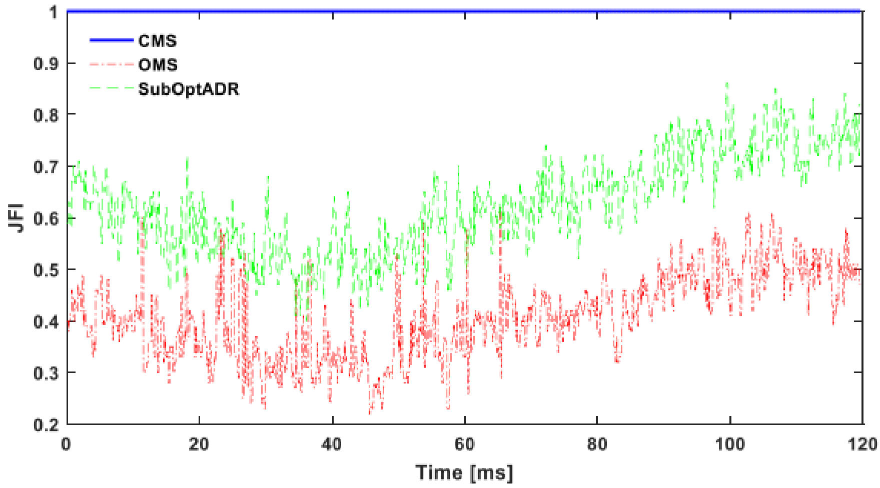

Figure 5.5: Jaie's Fairness Index calculated for the three approaches considering only vehicular users

values are closer (i.e., CQI 1 & 7), the reception threshold difference is smaller, and consequently, the maximum gain is reduced down to 0.25 b/s/Hz.

In NOMA, the content can be multiplexed on either a code-domain basis or a power-domain basis. In this work, the proposal is oriented toward the latter approach, with a particular profile for multicast/broadcast services known as LDM. A simple representation of this particular use case for a NOMA superimposed signal is described by the following equation:

$$X(n) = \sqrt{P_{\alpha_1}} S_1(n) + \sqrt{P_{\alpha_2}} S_2(n) \tag{5.1}$$

where P is the total transmitted power, $S_{1,2}$ the delivered signals, and $\alpha_{1,2}$ the fraction of power assigned to each service, provided $a_1 + a_2 = 1$. In general, from the receiver point of view, the main characteristic of the NOMA techniques is the implementation of a successive interference cancellation (SIC) technique for accessing the overlaid contents. At the transmitter site, the content has previously been arranged according to the assigned portion of the total available power (Eq. 5.1). Therefore, at the UE the services are processed following the same order. First, the strongest signal is decoded, remodulated, and subtracted from the received signal. Consequently, the next user can access the second signal with less interference. This process should be repeated until all the users have accessed their content.

The main disadvantages of this family of multiplexing techniques are related to the latency in accessing the buried contents and the hardware complexity increase. As a matter of fact, the overlaid content cannot be accessed until the stronger signal is successfully decoded and subtracted from the superimposed data. Depending on the SIC strategy, this could lead to a small delay in the decoding process. However, in many use cases associated with broadcast/multicast scenarios, delay requirements are not as tough as in unicast point-to-point communications, and in any case, both complexity and latency can be greatly reduced with a synchronized data delivery approach in the transmitter part [10].

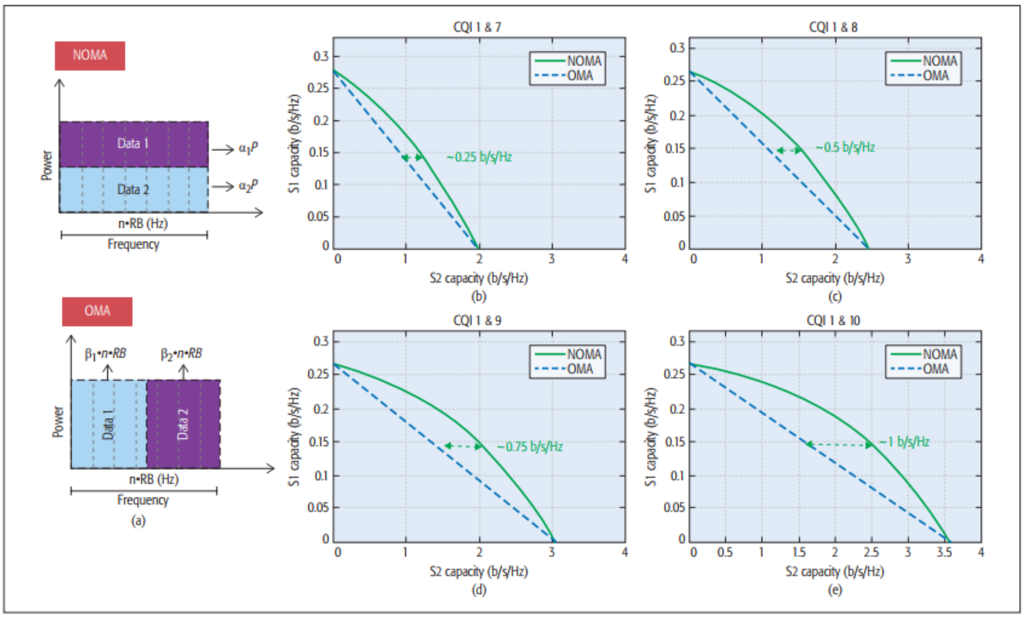

Figure 5.6: (a) The implementation of two different services within the same RF channel following the NOMA and OMA techniques, where a stands for the shared power value and the β for the assigned piece of bandwidth respectively. In (b), (c), (d), and (e), the theoretical capacity for different receiving conditions are depicted.

5.2.2 Subgrouping Technique for Multicasting

eMBMS, which is likely to be exploited in 5G networks, defines the network enhancements to support the transmission of multicast services over LTE. It introduces the point-to-multipoint transmission mode in cellular networks and covers different functionalities related to the management of multicast services [11]. In particular, PtM simultaneously serves all users interested to a given multicast service through a shared channel, with the aim to improve the system capacity, and theoretically, serve an unlimited number of users. The main challenge for supporting multicast services in eMBMS environment is related to the efficiency of the RRM approach in optimizing the allocation of the radio resources available in the radio access network. In particular, according to the channel conditions experienced by the UEs belonging to the multicast group, the RRM is in charge of performing link adaptation procedures, that is, the selection of the most appropriate transmission parameters for multicast content delivery, such as the modulation and coding scheme (MCS).

5.2.3 LDM Applied to subgrouping techniques in 5G

3GPP has divided the 5G normative work into two phases. Phase-1 (Rel-15) will address the more urgent subset for commercial deployments, whereas Phase-2 (Rel-16) will address all the identified use cases and requirements. According to the preliminary technical reports, the 5G RAN will keep the LTE principles, with the same orthogonal frequency-division multiple access (OFDMA) technology for the downlink for both cases, either New Radio (NR) or Release-16 [66]. What is more, this new radio access should cover mainly the enhanced mobile broadband (eMBB) using mmWave frequencies, where the multicast and PtMP services will be key to empowering vertical

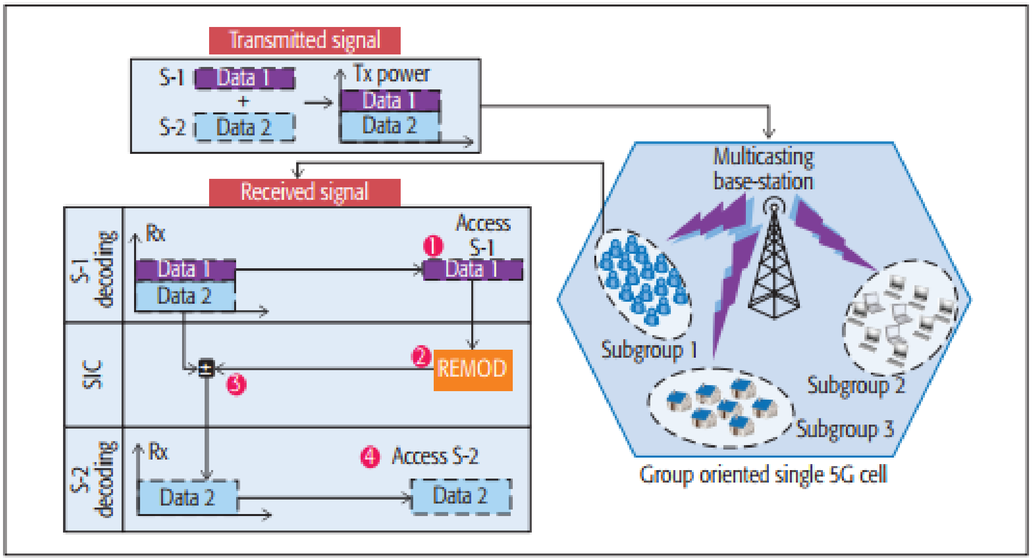

Figure 5.7: Proposed solution application scenario and simplified receiver architecture.

industries. Consequently, the subgrouping and NOMA techniques, which independently proved to be valuable for previous releases and standards, are jointly proposed as a cutting edge joint technology for facing the challenge of satisfying the mass media video consumption in PtMP scenarios.

5.2.4 Subgrouping with NOMA Resource Allocation Strategies

It is expected that in NR-5G, the resource block (RB), which corresponds to 12 consecutive subcarriers, will be also the smallest frequency resource, which can be assigned to a terminal. The set of available RBs is managed by the packet scheduler to efficiently handle resource allocation to mobile users in both the frequency and time domains. Our proposal mainly focuses on the frequency domain packet scheduler (FDPS), which is in charge of executing the fast link adaptation procedures by selecting the most appropriate MCS level and number of RBs for each multicast service. The NR-5G base station carries out such selection every TTI, which lasts 1 ms, by considering the CQI feedback received by all multicast users. According to the CQI value, each user will support a given MCS. In principle, a higher MCS level does not guarantee a better quality transmission for the user, whereas a lower MCS implies inefficient use of the spectral resources.

Therefore, subgrouping techniques in [66] are proposed as a valid solution to increase the efficiency of splitting multicast users in different subgroups according to their capabilities. The main challenge is the formation of the optimal subgroup configuration, which is tackled as an optimization problem, aimed at maximizing (or minimizing) a given objective function. The potential of using subgrouping techniques relies on the independence of the optimization from the objective function considered (e.g., throughput maximization, fairness optimization, minimum dissatisfaction index [78]).

Considering the conventional time and frequency resource allocation techniques, the best subgroup analytical configuration was found in [68], when maximum throughput (MT) was set as cost function. The authors demonstrated that the optimal solution can be found within 1 TTI, that the optimal number of subgroup is no greater than two, and that the number of RBs to assign to the lowest subgroup is 1 or 2, whereas remaining RBs are assigned to the highest-level subgroup. Starting from this result, this proposal aims to exploit the LDM technique as an alternative to optimize the resource allocation in the subgrouping process. In such a way, the FDPS also considers the NOM multiplexation in order to assign the different resources to the groups. In particular, in the case of LDM every subgroup will access the whole frequency band 100 percent of the time. The FDPS will assign a different weighted power to each service, performing layered delivery, which in most cases is more efficient than the classical multiplexing schemes.

Our proposal is to exploit the LDM concept of splitting the total available power for multicast subgrouping. In such an approach, the different layers defined through the LDM technique are matched with the subgroups derived by the multicast subgrouping approach. Furthermore, the performance of the proposed technique has been evaluated according to three different objective functions:

- MT is based on the maximization of a cost function defined as the aggregate data rate (ADR), which is the sum of the data rate obtained by all the multicast members.
- Proportional Fairness (PF) scheduling can be accomplished by maximizing the sum of the logarithm of the data rate.
- Minimum Dissatisfaction Index (MDI) [78] is defined as the weighted difference between the data rate achieved by the UE and the maximum possible value of data rate achieved by a UE when all RBs are assigned to the user.

5.2.5 NOMA Receiver Architecture

In this subsection the main implications regarding the LDM implementation from the receiver perspective are given. In principle, each layer will have its own coverage footprint depending on the targeted subgroup and assigned MCS. Classically, the upper layer will be assigned to the most signal-to-noise ratio (SNR) demanding subgroup (UEs with lower CQI values), whereas the overlaid layer will be assigned to the less demanding SNR with higher CQIs. This way the multicast problem of bandwidth exploitation explained in the previous sections is avoided, and the throughput asymmetry is better exploited.

The transmission approach presented in this solution aims at reducing the complexity at the receiver part. The proposed receiving mechanism is displayed in Fig. 5.7. The architecture assumes that in the transmitter part, in each delivered multicast frame, both layers/services share the majority of the communication blocks:

- OFDM framing;
- interleaving;
- packet scheduling.

This architecture enables use of a simplified SIC approach at the receiver. Provided both layers are fully synchronized, the first modules at the receiever (synchronization, channel estimation, equalization, OFDM de-framing, and de-interleaving) are common for both layers/services. Cancellation is performed at the modulation level, and thus, the memory requirements will not be significantly increased [10].

The upper layer service can be decoded as usual. Afterward, the upper signal is coded and modulated again, and the obtained data is subtracted from the equalized signal. Once the upper service has been removed from the superimposed signal, the second layer content can be accessed. The accuracy of the signal cancellation process is closely related to the channel estimation accuracy.

5.2.6 Identified Multicast/Broadcast Use Cases in 5G

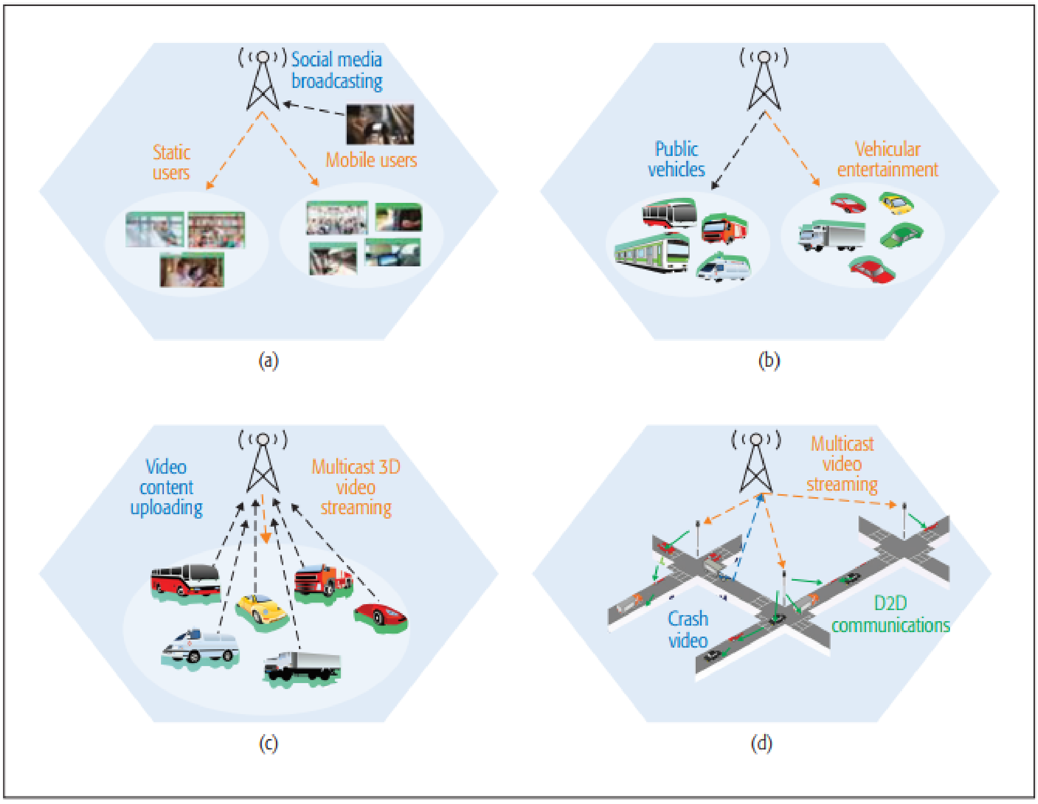

Figure 5.8: Proposed 5G use cases: (a) standard broadcast LDM (dynamic); (b) broadcast for infotainment services; (c) infrastructure-to-vehicle services; (d) IoT multicast message-based services.

Taking into account the evolution of the technology and the expected user media consumption, four potential use cases have been identified within the 5G eMBB scenario framework where the presented technical solution can be considered as a very promising tool (Fig. 5.8).

5.2.6.1 Standard Broadcast LDM (Dynamic)

NOMA techniques, especially LDM, have been identified as a driver technology for multiplexing different contents in classical broadcasting or PtMP applications. They maximize the spectrum efficiency when the different mixed services throughput is not balanced. What is more, its efficiency combined with the dynamic resource allocation will increase the performance shown in classical unidirectional broadcasting scenarios. The eventual number of multicasted services/ layers will strongly depend on the user CQIs and the required number of groups to maximize the throughput. An interesting use case for this group could be the implementation of multiple services with SVC.

5.2.6.2 Broadcast for Infotainment Services

In this case, the transmission station performs multicast LDM transmissions to stream multimedia broadcast contents for infotainment services toward vehicles in a specific area. In a typical urban scenario, different types of vehicles can be identified in terms of their dimensions, speed, constrained routes, and so on. Infotainment services, and subsequently multicast subgroups, can be diversified in terms of class of users and type of contents. In such a heterogeneous scenario, standalone multicast subgrouping (i.e., without LDM) may be inadequate for streaming of different broadcast multimedia contents to different user/vehicle classes. LDM can improve flexibility to create subgroups by adding resources.

5.2.6.3 Infrastructure-to-vehicle Services

A new advanced driver assistance system (ADAS) in which vehicular users in a determined area can cooperate for generating 3D video contents to increase safety is considered. Using 3D video for intelligent safety procedures involves the necessity to guarantee good quality of content in order to avoid failed interpretation by onboard intelligent systems. The base station is in charge of transmitting the new video content to all vehicles through multicast LDM subgrouping transmissions. The main challenge is to guarantee a minimum quality level of the video content to users that belong to a subgroup characterized by low CQIs. In this way, adequate performance of intelligent systems could be reinforced. LDM could be used to improve the quality of the video content experienced by users that perceive worse channel conditions (i.e., lower CQIs), adding extra content to enhance 3D video quality.

5.2.6.4 IoT Multicast Message-based Services

Machine-type communications (MTC) for the Internet of Things (IoT) forecast the involvement of a huge number of devices. Indeed, 5G will have the capability to simultaneously manage multiple MTC devices and to support different multicast machine-oriented applications. The main multicast MTC applications for 5G scenarios are smart environments and software upgrades.

The former gathers all those applications beneficial for smart homes/offices/cities/industries. In such applications, groups of devices simultaneously receive the content in order to take some kind of smart action. Furthermore, smart devices could need either periodic or sparse software upgrades for bug fixes and functionality upgrades. LDM could enhance the device capabilities, enabling them to download data content. The higher the SNR asymmetry, the greater will be the gain provided by the LDM-based approach.

5.2.7 Performance

5.2.7.1 Mobility Models and Performance

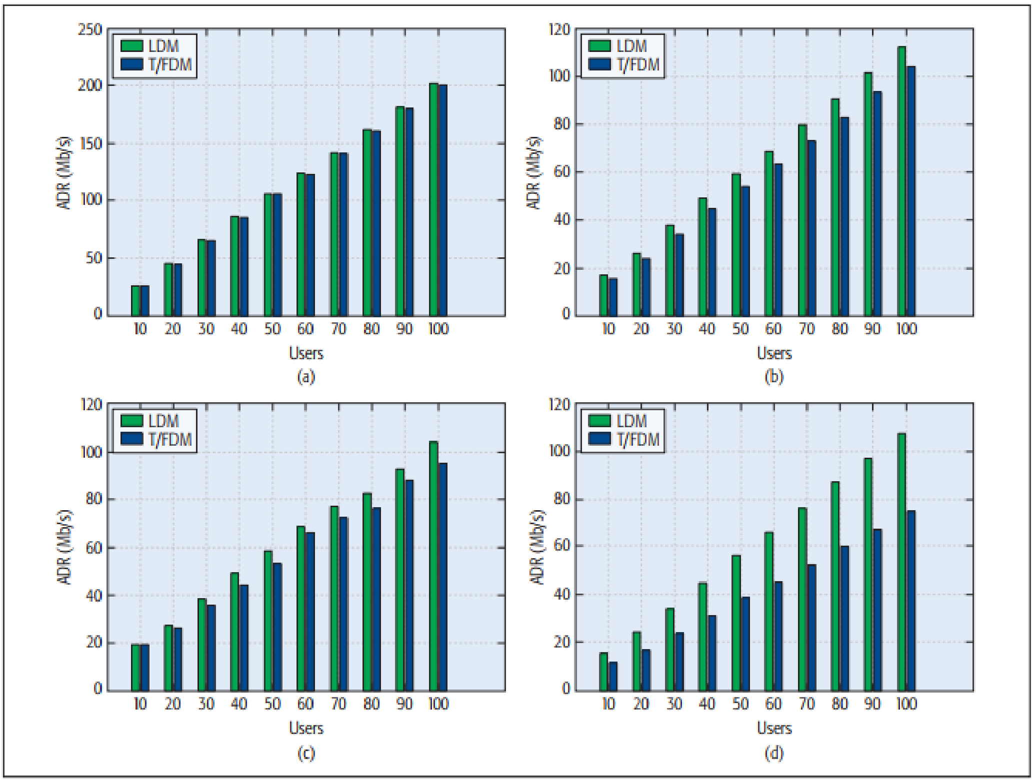

Figure 5.9: Obtained aggregated data rate (ADR) for the random waypoint mobility scenario at 3 km/h with different metrics: (a) MT; (b) PF; (c) MDI; (d) constrained MT.

A dense urban scenario is the typical environment for characterizing 5G communications in a smart city context, with different types of users (i.e., pedestrian, vehicular, mixed, and fixed). Several mobility models can be used to describe the activity pattern of users changing position, speed, and similar location related characteristics. In this work, in order to compare the performance between the classical multicast subgrouping and multicast LDM subgrouping methods, and taking into account the use cases presented in previous section, the Random Waypoint model has been implemented. In this model, the users are uniformly distributed over the environment at the initial stage. At every iteration they move along line segments toward a random destination position at a fixed speed. When the user reaches the target position, he/she waits for a predetermined time interval, and then a new random target position is assigned. In our simulations, users are allowed to change direction every second. This allowed us to realistically reproduce pedestrians' and slow vehicles' moving behavior in dense urban environments, where pedestrians walk in crowded spaces (sidewalks, squares, malls, etc.), whereas vehicles often circulate in severe traffic conditions (e.g., traffic jams, peak hours).

Afterward, the channel conditions for each UE are evaluated in terms of the experienced SINR, which results in an effective CQI level ensuring a block error rate less than 10 percent. Then these results are fed to a simulation model, where the LTE scheduler RRM procedures are simulated, and the resources are shared among the different created subgroups with ideal MCSs. Eventually, the final output parameters for evaluation are the ADR and throughput per user (TU), which are obtained in order to evaluate and compare the proposed methodologies.

5.2.7.2 Efficiency Results and Discussions

The mobility model simulations follow 3GPP standards. The values presented are an average of 50 different realizations covering 180 s. The RandomWaypoint mobility scenario metrics have been obtained for an assumed UE speed of 3 km/h. In this case, among all the use cases explained above, I focused on low-speed mobility scenarios. Nevertheless, the results can be extended to other mobility models and different speed values. Performance analysis has been carried out comparing the proposed solution with the LTE-based multicast subgroup technique [32] (i.e., labeled T/FDM in Figs. 5.9 and 5.10).

The first evaluated parameter is the ADR of the cell, which depends on the assigned optimization cost function of the subgrouping process (Fig.5.9). The first important outcome is that the MT metric does not provide any meaningful difference between the different multiplexing methods (Fig. 5.9(a). That is because, for both approaches, the best solution is obtained offering the maximum number of possible resources to the subgroup with best reception conditions, while the users dealing with more challenging conditions are poorly satisfied. When PF or MDI is used (Figs. 5.9(b) and 5.9 (c), it can be clearly noticed how LDM offers a significant gain ($\sim$10 Mb/s in the best case) with respect to the OMA subgrouping technique (i.e., T/FDM in the figures). This means that LDM achieves higher performance in terms of ADR when exploiting such “fair” metrics.

Finally, the MT metric is modified, adding a minimum bit rate constraint of 0.5 Mb/s (Fig. 5.9 (d), i.e., constrained MT) to one of the services. In this case, it is easily shown that the gain is much higher for NOMA subgrouping, because in OMA subgrouping, according to this constraint, many RBs must be assigned to the low-level subgroups. On the contrary, with LDM both subgroups exploit the whole bandwidth. This assumption represents those use cases, which need to guarantee a minimum data rate to all users.

The reason for this behavior can be found in Fig. 5.10. In this case, each subplot indicates the throughput per user, differentiating the average throughput of each of the two subgroups. In this case, the good SNR condition service is marked HTH (high throughput), and the poor SNR condition group is tagged LTH (low throughput). As expected, according to the theoretical facts explained before, the higher the required bit rate assigned to the most challenging group, the bigger is the gain offered by LDM. It can be noticed that in the MT and MDI cases, the LTH subgroup receives a very poor rate (Figs. 5.10(a), 5.10(c)). In Fig. 5.10(b) with PF and in Fig.5.10(d) when the MT is modified, the gain can be up to 2 Mb/s per user for the high-capacity subgroup. It is expected that this trend will be maintained in the newly designed 5G environments, where the available bandwidths will be bigger and the required minimum bit rates will be higher due to user expectations.

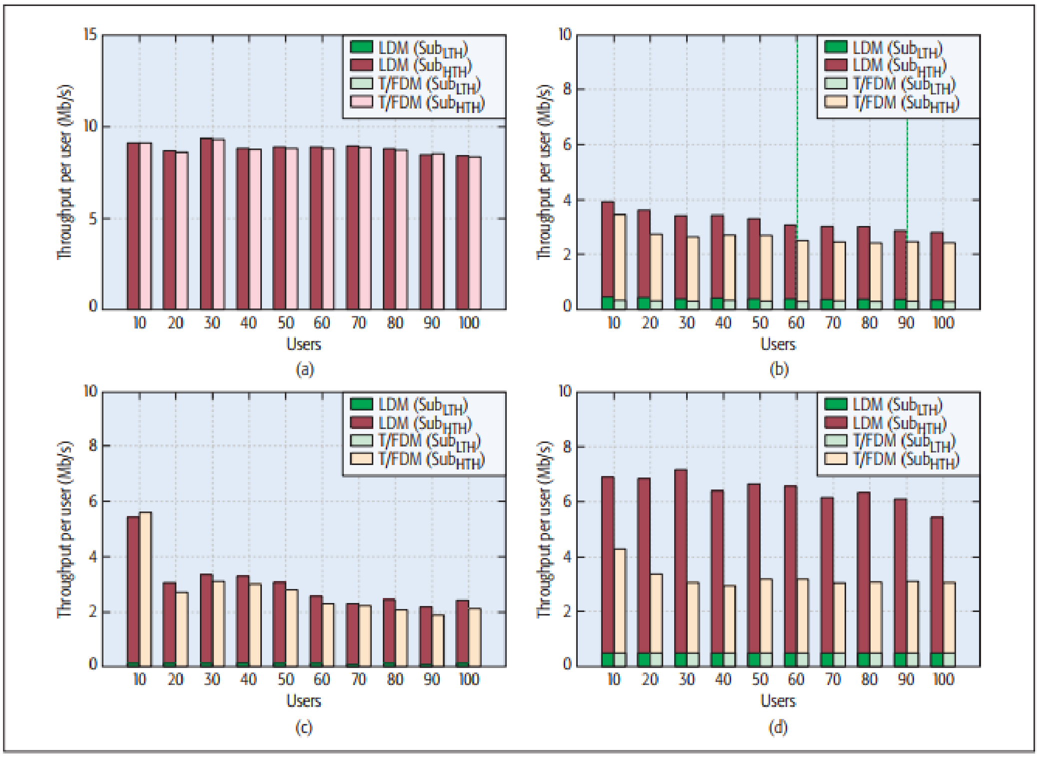

Figure 5.10: Throughput per user for the Random Waypoint mobility scenario at 3 km/h with different metrics: (a) MT; (b) PF; (c) MDI; (d) constrained MT

Chapter 6

5G Use Cases

One of the focus of the thesis was to find fields of application for 5G. Therefore, use cases have been designed in which to develop the main features of new technologies.

One of the emerging technologies is that represented by the Low-Power Wide Area Network (LPWAN). An LPWAN is a solution for the wide area wireless network located at the intersection of research and development in areas covering wide area wireless networks, low power consumption, access to multiple networks, low bitrates over a long range of communication, public networks and private and communications on authorized / unlicensed frequencies. But it has the big limit due to the battery life.

To try to limit the energy consumption of the devices used as much as possible, a scenario was thought in which energy consumption was compared in the case of direct communication and in the case of multi-hop use, section 6.1.

Another very interesting use case concerns the use of 5G technologies in Smart Grid environments.

In the section 6.2, a 5G usage scenario in Smart Grid environments Scenario for Distribution Network Operation and Control.

In the section 6.3.1, new 5G technologies were used in a project for Virtual Energy.

6.1 Solution for Multi-Hop Communications

LPWANs were created for M2M and NB-IoT communications and are able to support large number of connected devices over a wide geographical area [79]. Most LPWANs have a star topology where, similar to Wi-Fi, each endpoint connects directly to common central access points. LPWANs do not rely on a single technology, but rather a group of various low-power wide area network technologies that take many shapes and forms. LPWANs can use licensed or unlicensed frequencies and include proprietary or open standard options.

For instance, the proprietary unlicensed Sigfox network solution [80] is one of the most widely deployed LPWANs today. Running over a public network in the 868 MHz or 902 MHz bands, this ultra-narrowband technology allows a single operator per country only. While it can deliver messages over distances of 30-50 km in rural areas, 3-10 km in urban settings and up to 1,000 km in line-of-site applications, Sigfox's uplink communications are limited to 150 messages of 12 bytes per day. Downlink information exchange is even more limited to four messages of 8 bytes per day. Sending data back to endpoints can also be prone to interferences. The unlicensed LoRa [81], specified and backed by the LoRa Alliance, transmits in several sub-gigahertz frequencies (i.e., 868 MHz and 433 MHz), making it less prone to interferences. While open source, the underlying transceiver chip used to implement LoRa is only available from Semtech Corporation, the company behind the technology. LoRaWAN is the media access control (MAC) layer protocol that manages communications between LPWAN devices and gateways.

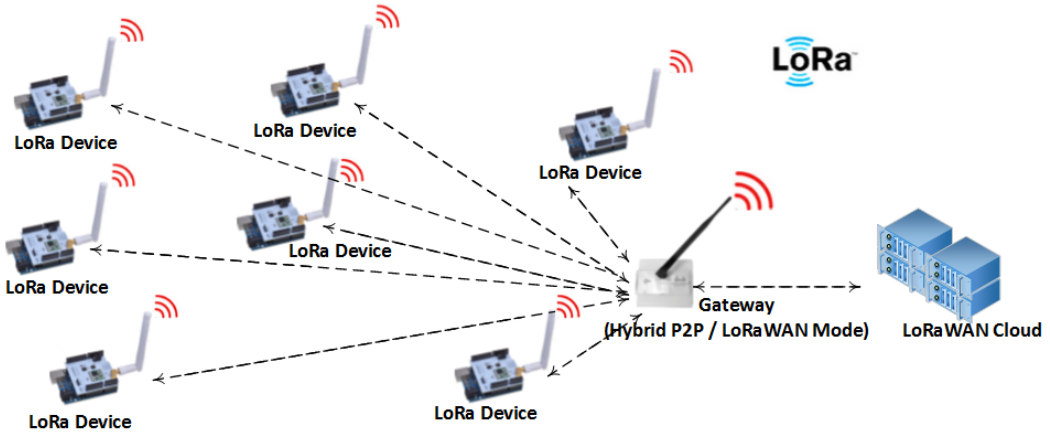

Figure 6.1: LoRaWAN topologies: single hop

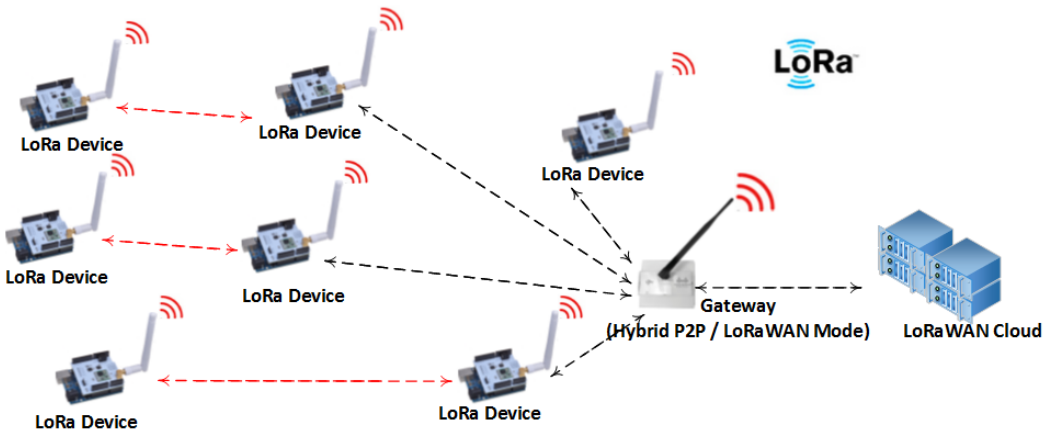

Figure 6.2: LoRaWAN topologies: multi hop

Narrowband-IoT (NB-IoT) and LTE-M are both 3rd Generation Partnership Project (3GPP) standards [82] that operate on the licensed spectrum. While they have similar performance to other standards, they operate on existing cellular infrastructure [83], allowing service providers to quickly add cellular IoT connectivity to their service portfolios. NB-IoT, also known as CAT-NB1, operates on existing LTE and Global System for Mobile (GSM) infrastructure. It offers uplink and downlink rates of around 200 Kbps, using 200 kHz of available bandwidth only.

Unlike other wireless technologies such as Bluetooth, Zigbee and Wi-Fi, LPWAN provides battery-efficient, ubiquitous wide-area connectivity, supporting more M2M and IoT applications.

Yet, a major tradeoff of using LPWAN is the amount of data that can be transmitted, which is very limited. However, according to James Brehm & Associates [84], 86% of all IoT devices use less than 3 MB of data per month, and 3GPP estimates that 99.9% of LPWAN devices will use less than 150 KB of data per month. Cellular networks often suffer from poor battery life [85], may have gaps in coverage and are frequently sunset. As many IoT devices are deployed for 10 years or longer, being affected by sunset is not a feasible option.

This work describes an innovative low-power communication solution to be employed in a real-world scenario in a smart city environment. It introduces the energy-efficient multi-hop communication solution (e2McH) which performs energy-efficient communications in multi-hop manner over LPWAN, employing narrowband technologies. Simulation-based testing employing communications in the European Industrial, Scientific, and Medical (ISM) frequency bands of 868 MHz and 433 MHz in single and multi-hop configurations have shown how energy saving in the range of 15% can be achieved. Future work will involve real life testing using the LoRa protocol in single and multi-hop configurations in urban and suburban environment in the city of Cagliari, Italy. Energy and coverage measurements will be performed when employing both frequency bands of 868 MHz and 433 MHz.

In the past few years, LPWAN communication has picked up interest of both academic and industry representatives, resulting in a more intensive research and development work and outputs. However, the topic is still in progress with numerous open issues to be addressed in areas like power control, interference management, resource allocation, network planning, etc. In the following, some of the relevant research results related to LPWAN will be discussed.

The authors of [86] proposed a LoRa-based LPWAN vehicle diagnostic system for driving safety, called *i-car*. When abnormal vehicle information is detected, the abnormal events will immediately be sent to the LoRa gateway via Arduino and LoRa module. The work described in [87] used the LoRaWAN technology to cover an area with a radius under 2 Km, in an urban environment. The LoRaWAN solution has been used for power grid consumption communications. LoRaWAN technology was also investigated in [87] with the aim of evaluating the orthogonality of virtual channels permitted by the LoRa physical layer. In particular, measurements demonstrated that overlapping transmissions having the same power at the receiver can be correctly decoded if occurring with different spreading factors, whereas co-spread messages require at least 4 ms spacing.

The authors of [88] presented the interference measurements performed in the European 868 MHz ISM band with focus on LoRa and SigFox. The same authors described how they simulated, measured and compared the coverage and loss performance of GPRS, N-IoT, LoRa, and SigFox in a realistic scenario in [89]. Finally, a comparison of the expected lifetime of IoT devices supported by various technologies (e.g., IEEE 802.15.4/e, Bluetooth low energy (BLE), IEEE 802.11 power saving mode, IEEE 802.11ah, and emerging long-range solutions such as LoRa and SigFox) and operating in several wireless networks was performed in [90]. In [91], the authors faced one of the main problems that involves LoRaWAN: energy consumption management. They presented analytical models that allow the characterization of the current consumption of the final LoRaWAN device, duration and energy cost of data delivery. The models used have made possible to quantify how the LoRaWAN physical and Medium Access Control (MAC) parameters and mechanisms, as well as Bit Error Rate (BER) and collisions, affect energy performance.

6.1.1 Proposed Approach

As this study focuses on LPWAN, the following section includes a generic description, which is then instantiated assuming that LoRa is employed as the underlying low power communication technology.

Most LPWANs and encountered related works have a star topology in which each endpoint connects directly to common central access points. Such an access point (for instance a LoRa gateway) is able to gather information from each device (e.g., LoRa sensors) and send data to a LoRaWAN cloud to be processed. The distance between the access point and device (e.g. LoRa gateway and LoRa sensors) can vary by several kilometers in a single hop configuration.

In this study, a reliable variant of the star topology is proposed in which an intelligent node, indicated with LoRa Node (LN), can send its data to another LN closer to the access point, indicated with LoRa gateway (LGW). This enables a multi-hop configuration. Fig. 6.1 and Fig. 6.2 illustrate the two alternative network topologies. Topology 6.1 represents the classic star topology and the starting point of our simulations and real-life environmental tests. LoRa devices were placed in a well defined physical position according to the envisaged scenario which targets environmental monitoring related to smart city air quality stations. Topology 6.2 is the proposed energy-aware multi-hop configuration for deployment of e2McH. e2McH identifies the energy consumption, traffic rate, and residual battery life of each LoRa device and gives instruction to a particular LoRa device to communicate in a multi-hop configuration to a closer LoRa device.

6.1.2 e2McH Architecture and Algorithm

6.1.2.1 Proposed Architecture

The classic LoRa star architecture is based on three different types of devices:

- LoRa end-devices are the final devices, they can be of three different classes to meet different needs [81]:
    1. Bi-directional end-devices (Class A), which allow bidirectional communication in which each transmission by the device is followed by two short reception windows;
    2. Bi-directional end-devices with scheduled receive slots (Class B) that allow bidirectional communication, as in Class A devices, but in addition provide a random receive window;
    3. Bi-directional end-devices with maximal receive slots (Class C), which provide a constantly open reception window, except during transmissions.
- LGW is connected to the network server via standard IP connections, while end-devices use single-hop wireless communication to one or many gateways;
- LoRaWAN Cloud offers a range of services that enable customers or service providers to deploy and connect LGWs.

6.1.2.2 e2McH Algorithm

In this subsection, the proposed e2McH solution is introduced and its pseudo code is presented in Algorithm 5.

The goal of the e2McH algorithm is to optimize the energy consumption of the LNs. This depends on the amount of data to be transmitted and the distance between LN and LGW. For this reason a multi-hop configuration has been proposed reducing the distance between the LN and LGW, and therefore the energy consumption.

The purpose of the e2McH algorithm is to find among the neighbor LNs, the ones with the distance lower than that between the considered LN and LGW. This is done in such a way that by considering a multi-hop data sending alternative solution, energy-saving will be achieved.

The e2McH algorithm can be resumed as follows:

1. For each node LN_i the algorithm evaluates the list of its neighbors, LN_j. Neighbors are determined as nodes within the area with dynamic radius $r <= \frac{d_i}{2}$ centered in LN_i position, where d_i represents the distance between LN_i and LGW;

2. The algorithm calculates distance d_j for each neighbor LN_j, where d_j represents the distance between LN_j and LGW;

3. The algorithm compares the distance d_i with distances d_j. For $d_j < d_i$, the algorithm verifies if the node is in a busy state (i.e., transmission mode) or not;

4. If the LN_j is available, it is the candidate to be *bestNeighbor*. During the iteration the algorithm determines the LN_j with the lowest d_j. Such node becomes the *bestNeighbor*, is used for multi-hop and its state is set to busy;

5. If there is no a free LNs with $d_j < d_i$, the multi-hop procedure is not available and the single-hop procedure will be adopted.

6.1.3 Setup and Scenarios

The proposed solution was assessed using modelling and simulations. Testing was performeed in the simulation environment network simulator OMNeT++ [63]. The behavior of the entire LoRa infrastructure has been reproduced, using modules for LN, LGW and LoRa Cloud. Testing involves a coverage comparison employing LoRa modules working at two different frequencies: 868 MHz and 433 MHz. Two different scenarios are presented to compare the energy consumptions at different frequencies and configurations, single-hop and multi-hop, respectively.

6.1.3.1 Setup

Simulations employ the characteristics of real LNs as described in Table 6.1. It is assumed that the battery capacity is 2000 mAh. Due to the low energy consumption, a dense transmission activity is simulated in order to obtain a rapid discharge of the battery in the simulations. In particular, the sending frequency of 2 packets/second is assumed.

Algorithm 5: e2McH Algorithm

```
Result: The algorithm returns the LoRaNode on which to make the hop, if it
        exists.
Input: LoRaNode = LN;
       List of neighboring LoRaNodes = NLNs
MinDistance = LN.distance;
bestNeighboring = Null;
foreach n in NLNs do
    if n.distance < MinDistance then
        if n.busy != true then
            MinDistance = n.distance;
            bestNeighboring = n;
        end
    end
end
if bestNeighboring != null then
    bestNeighboring.busy = true;
    return bestNeighboring
else
    There are no neighbors with a minimum distance, multi-hop can not be
     done
end
```

Table 6.1: LoRa Devices and Characteristics

Description	Value
Power supply	DC 1.8-3.7V (3.3V)
Chip	SX1278
Frequency	433 MHz – 868 MHz
Operatin temperature	-40 +85°C
Features	
Spread spectrum modulation technology	LoRa™
LoRa device class	C
Super-far-distance communication	15 Km
Voltage constant when the RF power output	+20dBm-100mW
High sensitivity	Low -148 dBm
SPI Communication	Half duplex
Programmable bitrates	Up to 300 kbps
Supports modulation	FSK, GFSK, MSK, GMSK, LoRa™ and OOK
RSSI dynamic range	127dB

6.1.3.2 First Scenario

The first scenario involves the evaluation of the energy consumption of a single node, comparing the energy consumption with single-hop and multi-hop.

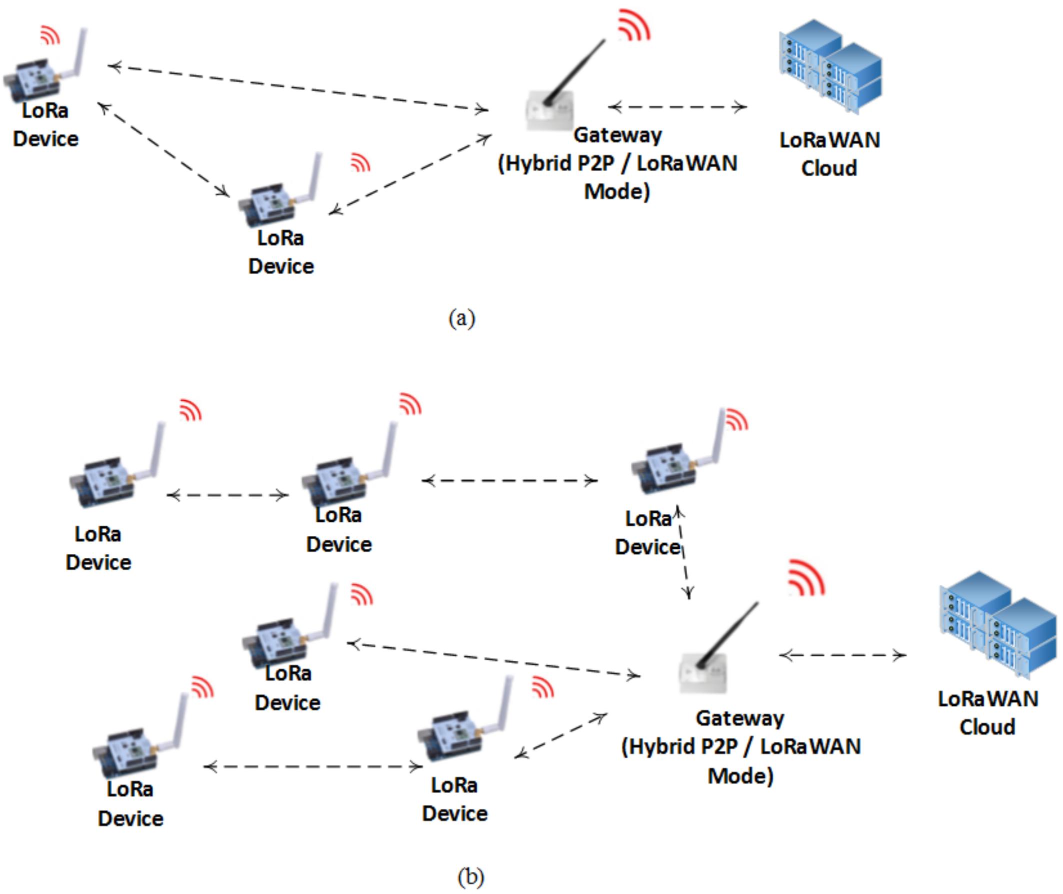

Figure 6.3: LoRaWAN (a) First Scenario (b) Second Scenario

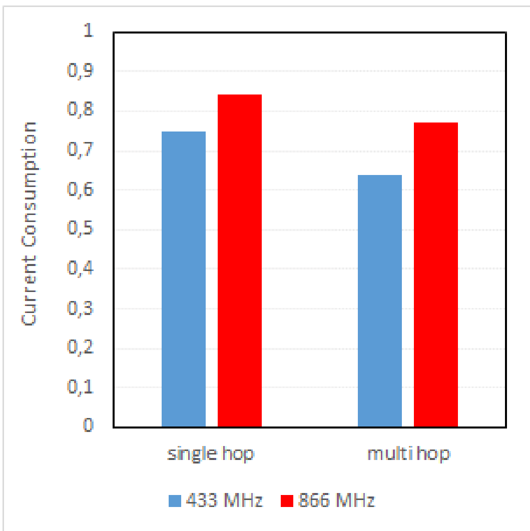

Figure 6.4: LoRaWAN Energy Consumption

In the scenario shown in Figure 6.3(a), there are 2 LNs. The first one is located 12 km far away from LGW, whereas the second is placed in an intermediate position at 5 km away from the first LN and 8 km away from LGW.

6.1.3.3 Second Scenario

The second scenario considers the presence of more LNs. The evaluations carried out in this scenario are related to the calculated average energy consumption and the average battery consumption for all LNs.

In this scenario, there are 7 LNs positioned at different distances to the LGW, as shown in Figure 6.3(b), all nodes are located within a maximum radius of 12 km centered on the LGW.

6.1.4 Simulation Results

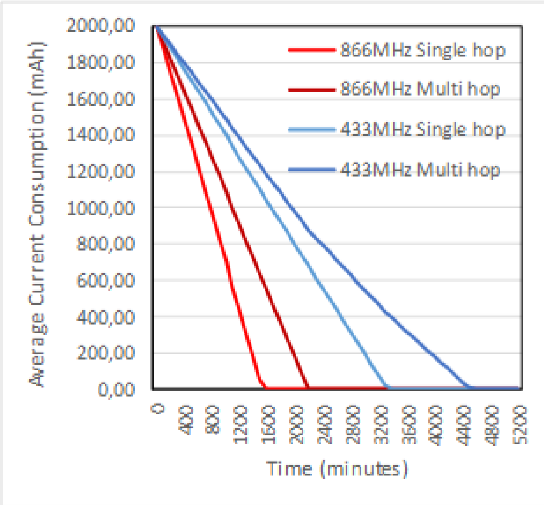

Figure 6.5: Average Battery Consumption

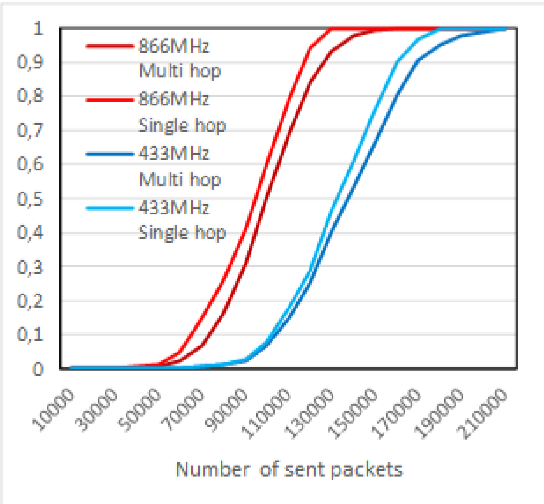

Figure 6.6: CDF Battery Capacity

In this section, the results obtained are evaluated in terms of battery capacity (%) and battery life (minutes) when the number of transmissions and distances between LoRa devices is increased.

Figure 6.4 shows how the energy consumption differs when two frequencies are employed, 868 MHz and 433 MHz, respectively. According to path loss, the higher the frequency, the higher the loss is, when considering LoRa nodes placed at the same positions. The graph shows the comparison between current consumption with single-hop and multi-hop configurations, respectively. It can be observed that the 433 MHz communicating LNs need an amount of current lower compared to that when 866 MHz is employed. Furthermore, according to the proposed approach, the multi-hop configuration saves 15% and 8% of the energy required for data transmission, respectively.

Figure 6.5 shows comparative LNs energy consumption between the single hop and the proposed approach with multi-hop energy saving. It can be seen that the proposed multi-hop method saves 15% of battery energy compared to the classic star topology. All LNs are evaluated in Line of Sight (LoS) propagation link.

Finally, Figure 6.6 shows the cumulative distribution function (CDF) of battery capacity usage based on the number of transmitted packets. It can be seen that the 866 MHz configurations reach the asymptotic tendency with a lower number of packets transmitted than when the 433 MHz frequency was used. The maximum number of packets sent is 210K.

This study introduces a novel single/multi-hop algorithm for energy saving with a LoRaWAN-based technology in a low power WAN context. The proposed method allows increasing LoRa device battery life in a dense urban and suburban environment. The proposed e2McH has the following features:

- considers several amount of traffic in different cyclic sleep scenarios;
- considers different frequency bands (e.g., 868 MHz and 433 MHz) and trades-off between path loss and data rate;
- defines a procedure for energy-saving over LPWAN, in particular LoRaWAN;
- provides results of practical tests wherein LoRa devices send data on environmental conditions in the context of smart city.

The results obtained through simulations show that e2McH offers an improvement of about 15% compared to single-hop scenarios.

6.2 A 5G Cellular Technology for Distributed Monitoring and Control in Smart Grid

The liberalization of the energy market, the commitments under the Kyoto Protocol and the further climate change international agreements, resulted into a strong drive towards a more sustainable production and utilization of the energy [92]. The engagement of governments in the direction of exploiting renewable energy sources (RES) for energy production, along with substantial incentive policies, have fostered the spreading of a large number of distributed generation (DG) systems, frequently of various types and sizes, located on both public and private buildings, in rural and industrial areas. In this context, the Smart Grid is a recent paradigm applied to power systems which presumes the modernization of existing power systems with the addition of information and communication technology (ICT) systems that allows a two-way communication between the power network and all its components and its users. The benefits associated with the Smart Grid include the improvement of the efficiency, reliability and flexibility of the power networks. In fact, with a proper distribution/energy management systems (DMS/EMS), the operation of distribution power systems according to the Smart Grid paradigm allows improving the management of the variability of demand and generation, mainly when related to RES, reducing congestions and network inefficiencies. In addition, the Smart Grid management may reduce the number and duration of interruptions, especially by making it possible to operate in intentional islanding or with network reconfiguration, with smart control of the power line breakers.

The focus of the work carried out in the research phase is on the last feature mentioned, and deals with the performance evaluation of recent communication technologies during fault management in Smart Grids. Protection systems are used to detect power system faults and other abnormal conditions, and the quality of a protection scheme is measured in terms of reliability, speed and selectivity. Protection management with automation schemes are designed to keep power interruptions to a minimum time. The operation of the breakers is highly time critical, since it is necessary to guarantee an instantaneous trigger on the breakers in order to assure an efficient intervention during or after a fault extinction. The implementation of such systems requires a robust Smart Grid infrastructure that allows interrupting the power flow when faults occur, in order to define the area of a fault, while minimizing the disconnection of loads and avoiding that the fault may be fed by RESs.

In this context, the ICT is a fundamental requirement for supporting the distribution network operation, monitoring and control. Communication systems are crucial for the correct implementation of Smart Grid in power distribution systems. Recently, a combination of several cellular technology advances have emerged that will most likely bring the debate to a close and position LTE-A-based Fifth-Generation (5G) mobile wireless technology, supported by internet of things (IoT) technologies, as the global future grid communication networking standard. The common communication requirements such as low latency, reliability, traffic safety and noise immunity have to satisfy electrical-specific expected functionalities, for example network operation with cooperative DER, system protection and/or post fault network reconfiguration [93]. 5G radio access technology (RAT) is designed to meet the requirements of Smart Grid applications. Moreover, 5G is intrinsically built for diverse new applications based on machine-to-machine (M2M) communication [67] and multicast services, and for the operations of critical infrastructures like Smart Grid [94].

In this chapter, in order to compare various types of communications systems during fault management in a Smart Grid scenario, the performances of an LTE-based centralized management approach and a 5G-based distributed management are investigated.

6.2.1 Smart Grid Scenario for Distribution Network Operation and Control

Currently, distribution networks are always operated with a radial arrangement. The low degree of reliability obtainable with radial network is generally improved by adding emergency ties, that provide alternative routes for power supply in case of outages or scheduled interruptions. Meshed networks have well known advantages versus radial schemes:

- a reduction of power losses,
- a better voltage profile,
- a greater flexibility and ability to cope with the load growth,
- an improvement of Power Quality (PQ) due to the fault level increase at each bus.

Obviously, if compared to radial arrangement, a meshed network presents also some drawbacks: a more complex planning and operation, that consequently involves a higher cost, and a rising of short circuit current in each node [95].

With the spreading of ICT in power systems, and with the recent enhancements in wireless solutions that guarantee a performing and reliable communication at low cost, a strong interest is upon the possibility of exploiting the last generation communication systems for supporting the transition of distribution network towards a Smart Grid scenario.

Currently at the distribution level, due to the number of points to control and budget restrictions, supervised control and data acquisition (SCADA) are typically not cost effective at the substation level and rarely at the feeder level, and the majority of the distribution networks is not extensively monitored or controlled. In the future the Smart Grid applications will need even more pervasive and real-time control of each network component, that will have to be equipped with smart meters and communication devices as well as new sophisticated control and protection devices. The management of the smart network will be done by means of a centralized or distributed network management system, that coordinates the balance between energy generation and consumption and guarantees quality of service and protection when faults occur.

6.2.1.1 Smart Grid monitoring and control approaches

The Smart Grid includes new power delivery components, control and monitoring throughout the power grid that need to be controlled by means of sophisticated centralized or distributed control systems. For instance, in [96] an extensive overview of the state of the art on distribution system control architectures is presented. Conceptually, the frameworks are classified into three main categories: centralized architecture, hierarchical architectures and decentralized architectures. The advantages of hierarchical and decentralized over centralized approaches are highlighted. In particular, it is observed the tremendous increase in both dimension and complexity of the distribution system so that an effective management structure should benefit from the use of a more flexible control and management architecture.

In [97] a comparison between a number of wireless sensor networks (WSN) architectures for load monitoring in the Smart Grid is presented. The authors highlight the potential benefits of having distributed storage and distributed information processing, in comparison to centralized approaches, in terms of network performance. The performance of the network is evaluated considering energy consumption and communication

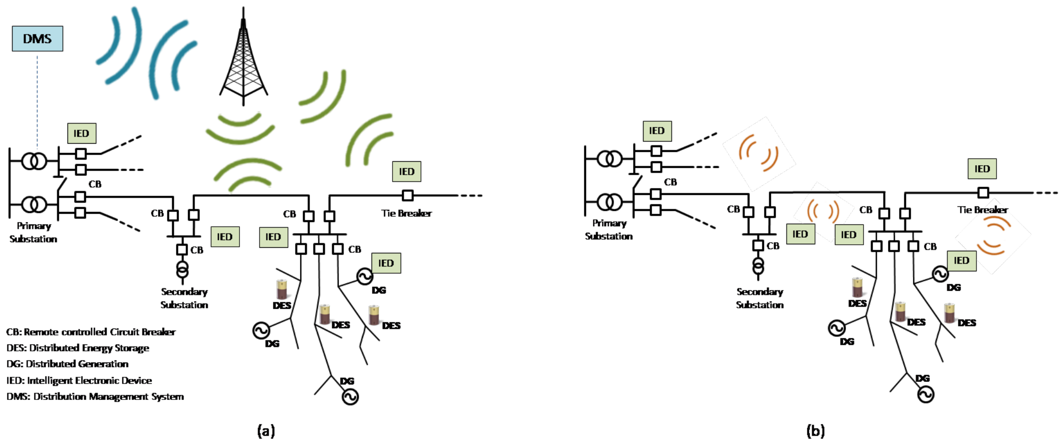

Figure 6.7: Schematic representation of centralized (a) and distributed (b) architectures for modern distribution network

cost, processing requirement, storage requirement, bandwidth requirement, traffic and financial cost of the different architectures.

In [98], Wei et al. proposed a study on delay performance in distributed system versus centralized system, and the impact of asynchronous message delivery based on a micro Smart Grid. The experimental results show that for computationally intensive applications, distributed control system causes a worse delay performance compared to centralized control system. In particular, the centralized control system outperforms the distributed control system by 50% in their case study.

In this work, the following scenario has been assumed for the future smart distribution network.

Two network management approaches have been considered according to the schematic representation shown in Fig. 6.7: centralized network management (CNM) (a) and distributed network management (DNM) (b).

The CNM consists in a central DMS/EMS that checks the data sent from the measurement units (MUs), and performs an operational intervention over the intelligent electronic devices (IEDs) installed on generators, breakers, active loads, storage units, in order to maintain the network in optimal state of operation. The information data flow is vertical, that means that each MU and IED exchange data only with the central controller. In the proposed platform, MUs send voltage and current measures to the DMS with a fixed time step. Therefore, the DMS has the complete knowledge of the network, and is able to localize and manage fault conditions. In case of short circuit, the DMS operates by triggering the breakers that circumscribe the branch with minimum impedance.

On the other hand, on a DNM scheme each IED and MU is associated with an agent, that can communicate with the neighbor devices and assess the network status and perform operational actions. Consequently, it permits to distribute the DMS functionalities, i.e. to keep the optimal conditions and solve any network contingency. The information data flow is horizontal. A local data aggregator may act as interface between the local agents and the Distribution System Operator (DSO) in order to coordinate the network operation. In the proposed platform, each agent, when triggered by an overcurrent measured by the correspondent MU, sends current and phase measures to the neighbor agent. The receiving agent can compare the current and phase locally measured with the information received. The phase comparison allows localizing the fault and intervening by opening the breakers.

6.2.1.2 Communications technologies for CNM and DNM management schemes

A DNM approach brings multiple requirements, among them the most important are:

- a high throughput and reliability, that guarantees a fast and efficient delivery of the information;
- the ability to communicate with particular devices selectively and efficiently;
- the possibility to enable two devices to autonomously exchange data bypassing the central network, in order to save network resources and fasten the information delivery.

The 5G technology, which enhances LTE-A with an IoT perspective and with the advantages of multicast transmission, represents the most promising technology for providing Smart Grids with distributed monitoring and control capability.

The 5G cellular network allows utilities to connect wirelessly to the entire distribution grid assets. Associated with each of these assets, there are one or more low cost stationary LTE-A-enabled M2M modules (embedded chip set) that send and receive data to and from the macro base stations (BSs), small cells, or another M2M module. Among the available routing schemes, the above-mentioned LTE-A and M2M have been combined with the emergent evolved eMBMS [99]. Multicast is a technique for sending data to a group of interested receivers exploiting a single transmission. The main advantages of multicast are a significant lower network bandwidth usage if compared with unicast transmission, along with an easier packet processing of end hosts if compared with broadcast transmission.

Within technologies for M2M, the LTE-A [66], enhanced with NarrowBand IoT (NB-IoT) services, guarantee several advantages compared to other communication standards (i.e., ZigBee, BLE, LP-WiFi, 3GPP Rel. 8) such as low latency (i.e., up to 10 ms), service level agreement, scalability, reliability, low power, and large coverage.

Nowadays, a standard for distribution network control and monitoring is fully or partially missing. According to the advantages above mentioned, the 5G architecture based on LTE-A, M2M and multicast can be considered as a strong candidate for data exchange between Smart Grid devices for monitoring and control.

In this work, a M2M chip set embedded on each IED, in order to ensure a horizontal bidirectional data flow, has been considered. This framework has been applied on a case study where network contingencies are solved in a distributed control architecture. In order to improve the performance, the multicast approach has been used in such a way that a single LTE node may send a single message that is selectively delivered to the interested neighbor controlled nodes.

6.2.2 Comparison of CNM and DNM Management Schemes for Smart Grids

In order to compare the CNM and DNM management schemes for Smart Grids an analysis with a co-simulation platform has been performed. The simulations of the Smart Grid scenario have been carried out by means of a software tool which combines the power system analysis software DIgSILENT PowerFactory and the communication systems analysis software OMNeT++ with the SimuLTE module [100].

PowerFactory [101] is an engineering software for the analysis and design of transmission and distribution power networks. It allows to perform calculations of power flow on stationary and dynamics regime, and to conduct studies on the stability of power network and the transient evolution in fault conditions.

SimuLTE is a system-level simulator for LTE and LTEAdvanced networks based on the OMNeT++ framework [63]. Therefore, SimuLTE exploits the wide range of networking modules that are provided with OMNeT++ based libraries, allowing establishing a flexible and mixed scenario with LTE as a part of a wider communication network [102].

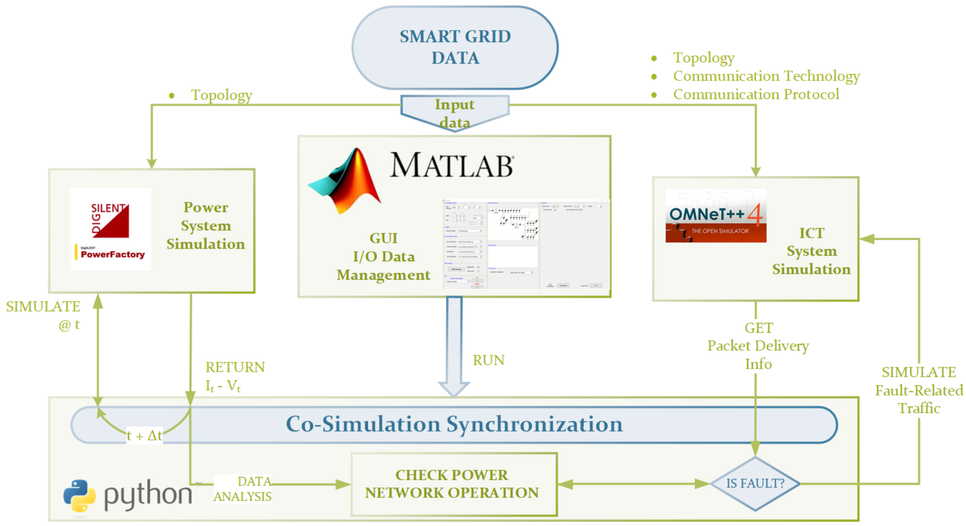

Figure 6.8: Schematic representation of the Co-Simulation tool

The two simulators are integrated in a co-simulation framework. In MATLAB a Graphical User Interface (GUI) has been realized, which allows the user to personalize the input data and to interact with the simulation, meanwhile the synchronization and coordination of the two simulators in a cosimulation approach is delegated to a Python script. The control logic of the DMS/EMS in the centralized scenario, and of IEDs' agents in the distributed scenario, has also been programmed in Python language. In Fig. 6.8 a schematic representation of the co-simulation software is reported.

In PowerFactory, the power network is fully described in terms of electrical component characteristics and load profiles. In OMNeT++, a realistic LTE network is implemented. A M2M multicast functionality has also been implemented by adapting the unicast D2D approach proposed in [103].

The co-simulation framework has been used to study the electric network shown in Fig.6.9(a).

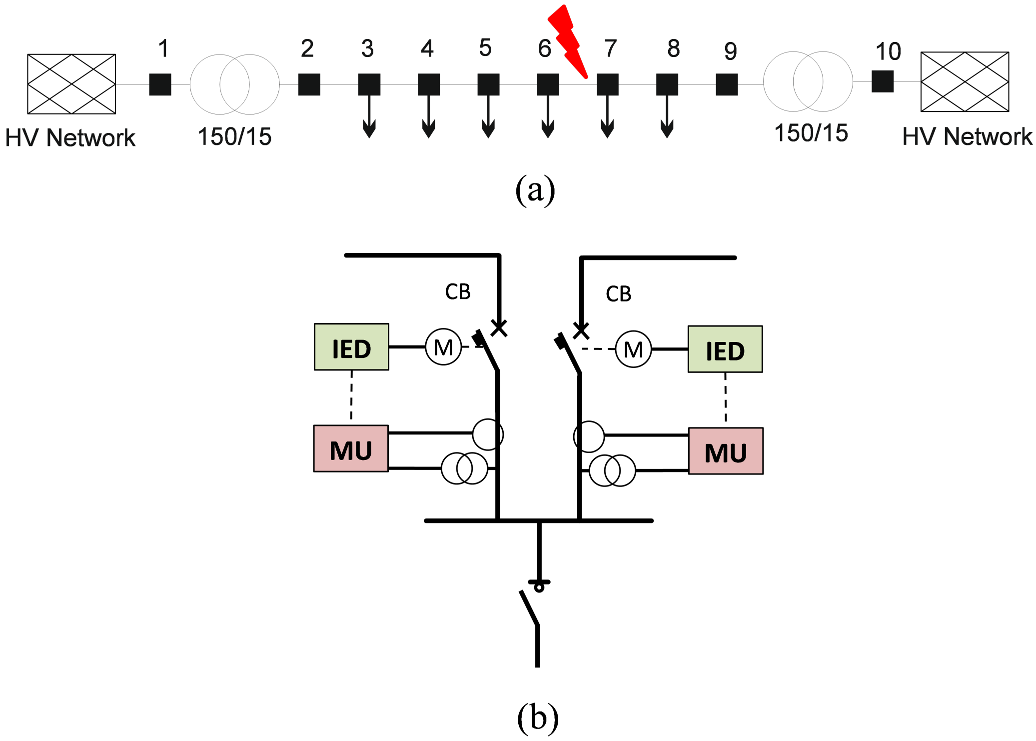

Figure 6.9: Scheme of the electric network studied (a) and schematic representation of secondary substation (b)

The network considered is an urban medium voltage (MV) network fed by two high to medium voltage (HV/MV) primary substations in a ring configuration. The network extends globally for about 1km, and supplies 6 MV nodes, which aggregate mixed urban loads. Each MV node represents a secondary substation, with disconnecting devices (circuit breaker or sectionalizing switch) on the incoming and outgoing feeder as shown in Fig. 6.9(b). A MU and an IED are also installed in the secondary substation, the first is dedicated to measure the electrical parameters, meanwhile the second is programmed to communicate with the DMS or the neighbor agents and operate on the circuit breakers, according to the control management scheme (centralized/distributed).

The two scenarios considered assume a centralized control and a distributed control of the secondary substation IEDs. In both cases, each substation is connected to the LTE network. A LTE user equipment (UE) serves the IED, allowing the substation to communicate, as shown in Fig 6.10.

In the centralized control, the communication is vertical, that is the UE communicates with a central server alongside the DMS. In the distributed control case, the communication is horizontal, that is the UE communicates with the electrical neighbors (the adjacent substations). Therefore, in the distributed scenario the server may be considered as a local aggregator, although in this work the aggregators are not considered, and the communication in the distributed scenario is purely horizontal. Since the global distance covered by the electric network is 1 km, it is possible to provide the LTE service with a single eNodeB. Moreover, the short distance between the neighbors (200 m maximum) allows establishing a M2M connection in the distributed scenario.

In the case study proposed, a short circuit event is considered at 30ms on Line L6-7 (i.e., the branch that interconnects the substations on node6 and node7). Each MU

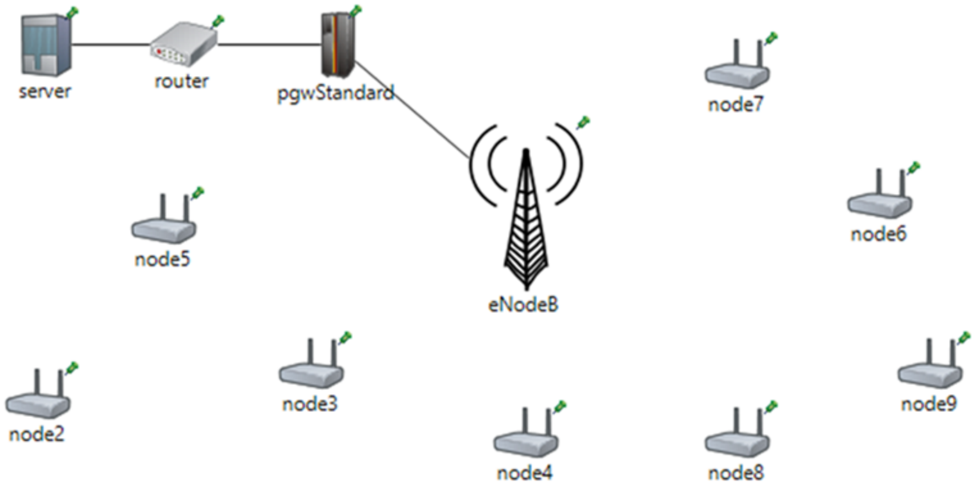

Figure 6.10: Scheme of LTE network

in the secondary substation detects the overcurrent, and triggers the IED to send a packet to the server or to the neighbor agents according to the control scheme. The information is encapsulated in a UDP packet of 32 byte for both scenarios.

The objective of the study is to compare the centralized and distributed protection schemes in terms of speed and selectivity.

6.2.2.1 Case 1: Centralized Network Management

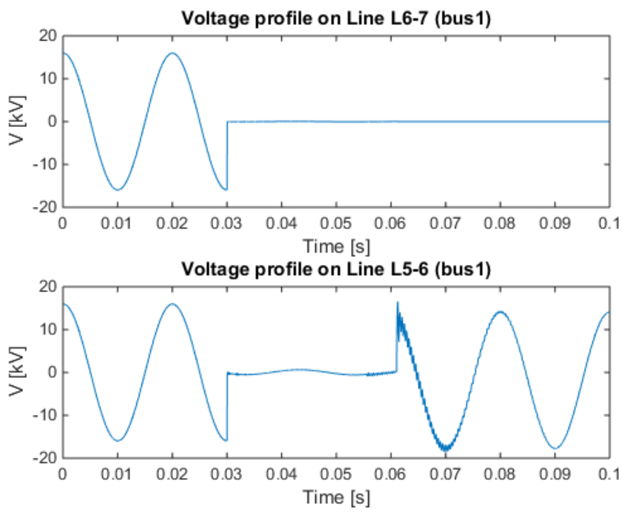

Figure 6.11: Centralized Approach: Voltage profiles

In Fig. 6.11 the voltage Fig. 6.12 and current profiles measured at the first bus of lines L6-7 and L5-6 are reported. It can be noticed that at 30ms, when the short circuit occurs, the voltage drops to zero on L6-7, meanwhile a low voltage is measured on the adjacent line L5-6, because of the cable impedance between the node 5 and 6. The figure shows for the line L5-6 the restoration of the voltage after the fault clearing due to the opening of the switches on the substation 6 and 7.

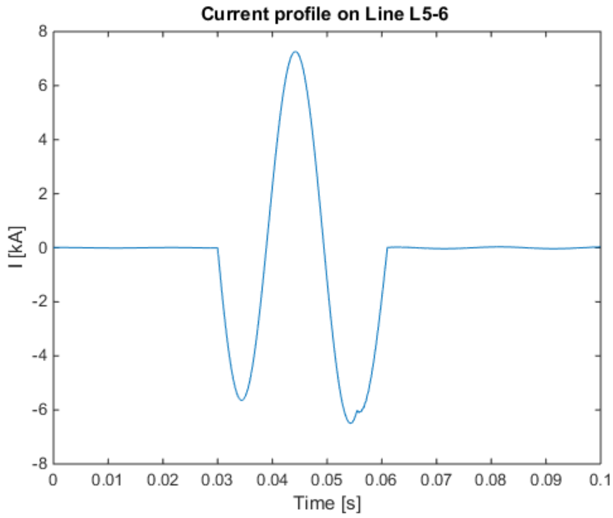

Figure 6.12: Centralized Approach: Current profile

Table 6.2: Latencies on CNM Scenario

	SC [ms]	DMS rx [ms]	Node [ms]	Total Latency [ms]
n 6	30	39	53	23
n 7	30	40	55	25

In Table 6.2 the latencies are reported. The maximum latency measured on the nodes closer to the short circuit (SC), node6 (n6) and node7 (n7), is 25ms. This latency includes the delays in downlink and uplink, in addition to an offset latency that takes into account the DMS packet elaboration (impedance evaluation and fault localization). As shown in Fig. 6.11, 6.12, since the breakers open the circuit when the current crosses the zero, the effective opening of the circuit occurs at 60ms.

6.2.2.2 Case 2: Distributed Network Management

Table 6.3: Latencies on DNM Scenario

	SC [ms]	RXPK1 [ms]	RXPK2 [ms]	RXPK3 [ms]	Tot. Latency [ms]
n 6 - n 7	30	44	46	48	18
n 7 - n 6	30	44	45	48	18

In the DNM scenario, the voltages and currents on lines L6-7 and L5-6 follow the profiles shown on Fig. 6.13 and on Fig. 6.14, meanwhile the latencies are reported on Table 6.3, reporting a total latency of 18ms. This latency includes the arrival of three consecutive packets (RXPK1, RXPK2, RXPK3) that confirm the localization of the short circuit between the two neighbor agents considered (in this case, at n6 and n7), which happens by comparing the measured current phase with the information received.

Even though the difference in terms of latencies between the two scenarios is 7ms,

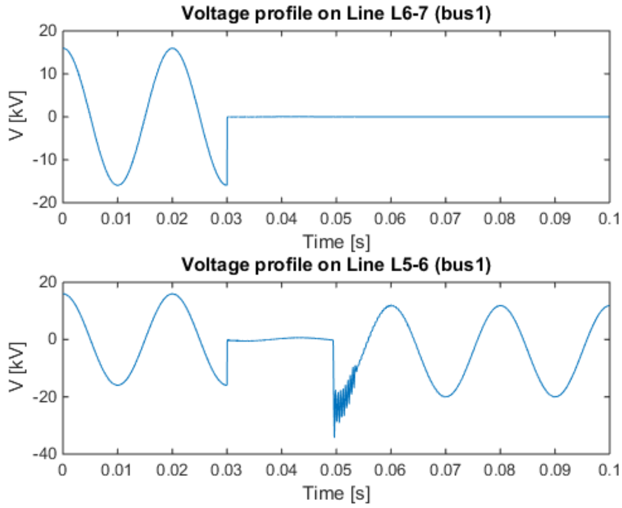

Figure 6.13: Distributed Approach: Voltage profiles

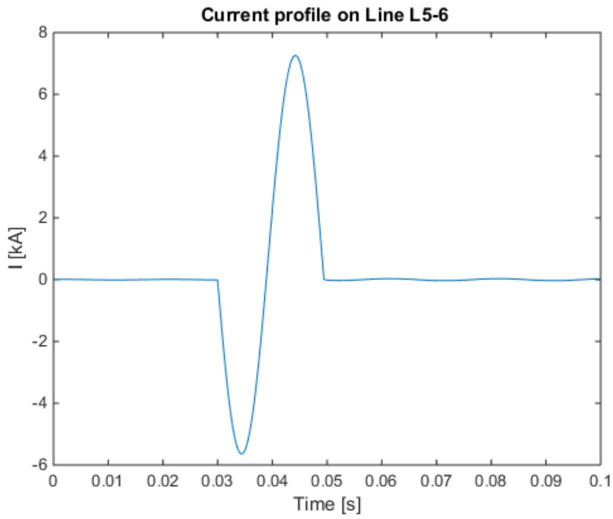

Figure 6.14: Distributed Approach: Current profile

the effective opening of the circuit in DNM is operated 10ms faster than in CNM, since the current zero crossing occurs in the previous half-period.

In the analyzed case studies the DNM approach shows better performances in terms of speed of intervention of the circuit breakers, since the fault condition is interrupted in just two half-periods, compared with three half-period measured in the CNM approach. With a 33% time saving shown in the case study analyzed, the distributed approach candidates as promising solution for network management for strictly time critical intervention operations like fault interruption and circuit restoration.

It is worth noticing that in this comparison the packet size has been considered constant. A further investigation will consider the variable quantity of information exchange necessary in the different approaches. It implies the association of each approach with a specific protocol, characterized by packet size, information details and transmission behavior, which will affect the loading of the LTE network and,consequently, the global performances of network management.

A further issue that needs to be investigated is the influence of computational time by the quantity of handled information. The CNM approach, which gathers in a single processing unit all data transmitted by the network MUs, will require a larger time for elaborating data and taking the proper operational solution. In this sense, network size also represents a significant variable that can influence the performances of centralized approach in terms of total latencies. In conclusion, additional investigation with more complex scenarios, where larger networks and variable packet size permit to represent a more detailed test bed, will allow giving a deeper insight into the comparison of different strategies for the monitoring and control of Smart Grids.

6.3 VIRTUAL ENERGY: A project for testing ICT for virtual energy management

VIRTUAL ENERGY is one of 35 collaborative projects promoted by Sardegna Ricerche through the "Cluster top-down actions" program and is financed thanks to the European Regional Development Fund POR FESR Sardegna 2014-2020. The cluster projects are technological transfer activities conducted by public research organizations with the active collaboration of groups of small and medium-sized companies, to solve shared problems and bring innovations developed in the university laboratories to the market. In particular, the present project falls on the priority 2 of Sardinia's smart specialization strategy (S3).

The S3 identifies the regional excellences in terms of research and innovation and their growth potential. It is the result of a consultation process starting from the identification of the needs of the territory obtained from the analysis of the strengths and weaknesses of the regional system of research and innovation, and as a result of business experiences. S3 strategy defines the priority for Sardinian future public investments in the following areas:

- ICT (P1),
- Smart Grids for the efficient management of electricity (P2),
- Agro-industry (P3),
- Aerospace (P4),
- Biomedicine (P5),
- Tourism, culture and environment (P6).

The increasingly widespread availability of renewable energy systems, the possibility of remote management of domestic and industrial electrical loads, the diffusion of the internet of things (IoT) and the new future legislative scenario to create business opportunities in the development of technologies for the management of Virtual Power Plant (VPP) and/or the aggregation and coordination of consumption and production of electricity on a large scale. In fact, a probable evolution of the distribution system is represented by the definition of clusters of many different geographically dispersed energy sources, controlled by aggregators or ESCOs as VPPs and smartly coordinated by the DSO [104] Fig.6.15. VPP may be considered such as a form of "Internet of

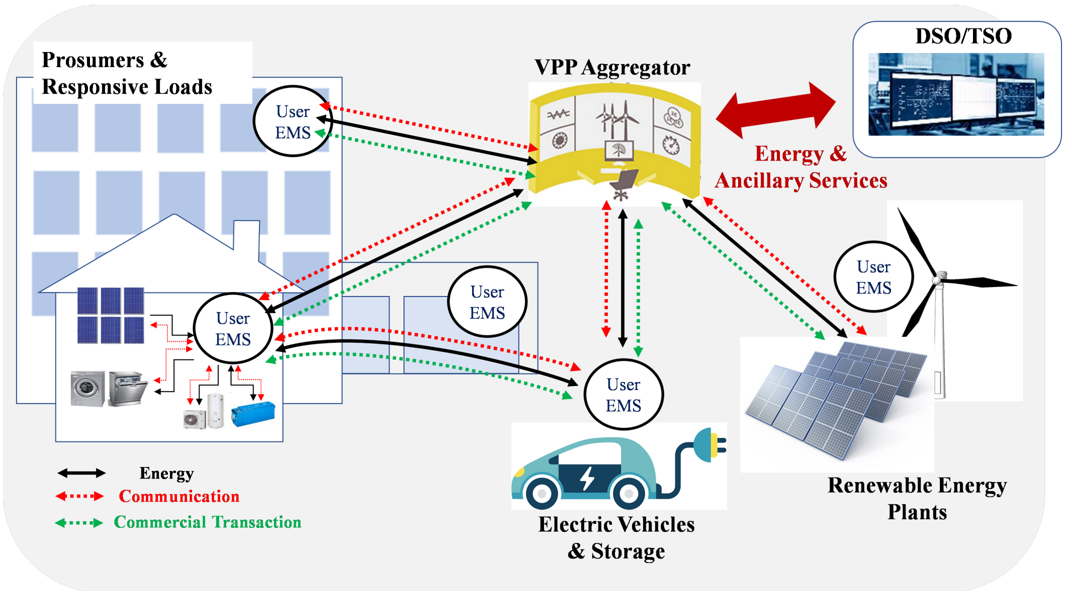

Figure 6.15: Schematization of Virtual Power Plant

Energy", able to integrate diverse smaller energy sources like Nanogrids, electric vehicles, distributed generation (DG) and energy storage systems (ESSs). The increasingly employing of smart devices, and the need for an intelligent management of the power grid in presence of a distributed generation from renewable sources are creating the tight interdependent system which inspires VPPs development.

In order to exploit completely the potentialities of the VPP, a fundamental role is taken by the ICT and its energy management system, together with the availability of good data models of the energy resources and the existence of a defined energy market environment [105].

VPPs can deliver energy demanded at peak usage times under request from DSO, and can store any surplus power, giving the energy aggregator more options, for instance by balancing the variability of renewable energy sources [106].

Other advantages include improved power network efficiency and security, and cost savings in distribution systems by increasing the use of existing assets.

In this future scenario, the DSO will act similarly to a transmission system operator (TSO), with the role of satisfying active and reactive power needs along the distribution feeders.

The DSO will have to manage the network maintaining acceptable voltage levels and avoiding congestions, which may arise, for instance, by unpredictable variations of load demands and DG productions.

The VPP obtained by clustering distributed energy resources will be able to monitor and control the power absorbed by electrical users and provide dispatching/flexibility services to the electricity distributor. First steps towards this opportunity are also given by the recent resolution 300/2017/R/eel of the Italian Regulatory Authority for Energy, Networks and Environment (ARERA), titled "First opening of the market for the ancillary (dispatching) service (MSD) to the electricity demand and to the production units also from renewable sources not already enabled as well as to the storage systems. Such regulatory framework introduced the concept of Unità Virtuale Abilitata (UVA), that is Virtual Dispatchable Unit, defined as a collection of different small producers and consumers, which must satisfy a specific set of constraints. Resolution has been the starting point for different experimental projects referring also to relevant units.

By means of such preliminary activities, Terna aims to evaluate the feasibility of several topics and concepts, i.e.:

- UVAC (Unità Virtuali Abilitate di Consumo), that is virtual consumption units, defined as consumers that may consist also of local production part, when considering industrial processes or self-production systems;
- UVAP (Unità Virtuali Abilitate di Produzione), that is virtual production entities involving not relevant producers, either programmable or not; relevant units powered by renewables sources;
- UVAM (Unità Virtuali Abilitate Miste), representing the natural evolution of UVAC and UVAP concepts, since being defined as mixed virtual units involving small producers and consumers;
- UVAN (Unità Virtuali Abilitate Nodali), that is virtual units as collections of entities connected to the same node of the transmission network.

Another project proposed by Terna, and approved by the Regulator through the resolution 402/2018/R/eel, refers to evaluating the performance of combined systems, i.e. traditional plants and storage devices, when working as primary reserve. Establishment of pilot projects in view of the constitution of the integrated dispatching text (TIDE) consistent with the European balancing code". The document is finalized to develop a market framework for the dispatching service with the intent, among others, of removing discrimination regarding potential suppliers of dispatching resources, including consumers and producers with nonrenewable generation plants programmable widespread in the territory.

6.3.1 The VIRTUAL ENERGY Project

6.3.1.1 Objectives of the project

The VIRTUAL ENERGY project concerns the research and development of systems for aggregation, coordination and optimization of a Virtual Power Plant consisting of energy resources (DER - Distributed Energy resources) through Internet of Things (IOT) and Cloud systems.

The project has the following general objectives:

- GO1. definition of a VPP model in the electricity distribution network adopting an innovative approach based on the integration between the electrical system, control system and communication system;
- GO2. implementation and validation of the systems for the management and control of the VPP, which are innovative with particular reference both the architectures of the VPP and the communication systems, and the functions oriented to the management and control of DERs;
- GO3. identification of the communication system architecture (using innovative wired / wireless technologies) and the system of necessary control;

- GO4. identification of management and control algorithms for the optimization of resources in VPPs;
- GO5. acquisition of experimental data and results on the performance of the solutions proposed for the definition of appropriate business cases in collaboration with the partner companies;
- GO6. training of technical personnel specialized in conducting and designing and developing VPP systems;
- GO7. increasing the quality of fundamental and applied research in the field of smart grids, ICT systems and automatic controls.

The project has also the following specific objectives:

- SO1. Develop methods and algorithms through IOT and Cloud systems that allow the management, control and monitoring of electricity grids intelligent consumers and producers through the proposal of distributed control architectures and methods of aggregating demand energy to allow a measurable and positive impact on the energy market.
- SO2. Develop methods and algorithms for the large-scale management of aggregates of production plants and domestic loads (e.g. domestic smart appliances, heat pumps, etc.) of the new generation for the management of demand and of distributed energy production;
- SO3. Study of the most appropriate solutions related to systems of acquisition, coding and transmission of monitoring and control data characterize the VPP paradigm through appropriate telecommunication systems, which can also make use of a heterogeneous set of technologies, including: 4G, LTE, and 802.11p for vehicle transmissions as well as Powerline communications (PLC) and telephone cable and optical fiber (OF). The harmonization of the IEC 61850 protocols and their extension for the management of distributed resources will also be evaluated.
- SO4. Create preferential channels between a network of companies in the Sardinian territory and the University of Cagliari that provides companies with a partner with whom develop algorithms, architectures and systems for efficient energy management and the development of applications for smart grids / smart cities.

The project is strongly interdisciplinary and for this reason researchers from the research units of the ICT sector, Power Systems and Automatic Controls of the University of Cagliari. The skills of the three units are complementary and allow maximum coverage level those required in the research and technology transfer project.

6.3.1.2 Work Pakages and Milestones

The project is structured into four technical work packages:

- WP1. State of the art and Requirement analysis;

Table 6.4: Companies Involved in VIRTUALENERGY

Name of the company	Business area
ITA Consulenza e Progetti s.r.l.	Renewable energy plants design and permitting
Tholos s.r.l.	Energy services provider (ESCO)
Sinerg s.r.l.	Renewable energy plants design
Bulding Technologies Facilities s.r.l.s.	Building automation and energy efficiency
Enermed s.r.l.	Smart metering and energy services
Soltea s.r.l.	Renewable energy plants maintenance
Proxienergy s.r.l.	Renewable energy electric and thermal sys com.
Essei s.r.l.	Renewable energy plants and microgrids design
Franchini Service snc	Final user interested in energy cost optimization
Mobilificio Orrù snc	Final user interested in energy cost optimization
Alea Energia Spa	Installation and Management of RES plants

- WP2. Design of the communication system architecture of the VPP for controlling the DERs;
- WP3. Design and implementation of a software platform for the management of VPPs;
- WP4. VPP prototyping and testing;
- WP5. Dissemination of results and technology transfer.

6.3.1.3 Tecnology transfer and Companies involved

The project will allow the technological transfer of university knowledge for the creation of a prototype of the intelligent management of the electricity grid by means of a VPP, for exploiting the advantages deriving from the use of renewable sources together active demand management and storage systems. Eleven private companies located in Sardinia are involved in the project as summarized in Table 6.4.

The companies will provide specific contribute on all phases of the project, especially in the analysis of requirements and testing of the VPP prototype.

The development of VPP will provide the opportunity to create new energy management models that will offer new opportunities to companies entering in the market as energy traders, or as simple installers of ICT systems and / or sellers of components for the operation of VPP as well as simple final users interested in participation to new energy market options for cost saving and optimization.

6.3.2 ICT Systems for VIRTUAL POWER PLANT Management

The ICT is a fundamental requirement for supporting the distribution network operation, monitoring and control. Recently, a combination of several cellular technology advances has emerged that will most likely bring the debate to a close and position LTE-A-based Fifth-Generation (5G) mobile wireless technology, supported by Internet of Things (IoT) technologies, as the global future grid communication networking standard. The common communication requirements such as low latency, reliability, traffic safety and noise immunity have to satisfy electrical-specific expected functionalities, for example network operation with cooperative DER, system protection and/or post fault network reconfiguration [93]. 5G Radio Access Technology (RAT) is designed to meet the requirements of Smart Grid applications. Moreover, 5G is intrinsically built for diverse new applications based on machine-to-machine (M2M) communication and multicast services, and for the operations of critical infrastructures like Smart Grid [94].

Within the M2M technologies, LTE-A [66] presents significant advantages in IoT perspective with regard to multicast transmission. In fact, LTE-A, enhanced and supported by the NarrowBand IoT (NB-IoT) [66] services, guarantees numerous advantages compared to other communication standards usable in the IoT environment (e.g., ZigBee, BLE, LP-WiFi, 3GPP Rel. 8, LoRa, Sigfox) as low latency (i.e., up to 10 ms), service level agreement, scalability, reliability, low power and wide coverage [107].

The 5G cellular network allows the utilities to connect wirelessly to all the resources of the distribution network. Associated with each of these resources, there are one or more low-cost stationary LTE-A fixed M2M modules (embedded chip set) that send and receive data to and from macro base stations (BS), small cells or another module M2M. Among the available routing schemes, the aforementioned LTE-A and M2M have been combined with the evolved eMBMS [99] [83]. Multicast is a technique for sending data to a group of affected receivers that exploit a single transmission. The main advantages of multicast are the use of lower network bandwidth compared to unicast transmission, together with simpler processing of final host packets compared to broadcast transmission [108]. Furthermore, a solid potential enabler for the pervasive wireless communications is the paradigm of opportunistic communications in the TV white space [109]. Several studies have been carried out to evaluate the feasibility of such a kind of systems. In particular, in [110] field measurements have been performed in urban, sub urban and rural scenarios to evaluate the power thresholds to avoid interference with licensed communications operating in the same territorial area. Within this framework, the IEEE 802.22 WRAN standard has been developed as to this purpose [111] based on cooperative multiband sensing procedure [112] together with geolocation databases aimed at ensuring protection for existing communication systems. Multi-carrier modulation are used for transmission allowing for increased robustness [113] and power optimization [64] in case of fading channels.

6.3.3 Synergy Among Research Projects

The "Cluster top-down actions" program had some specific rewarding points for projects able to generate synergies with further projects financed by other European Community funds. Due this reason, the authors in the VIRTUALENERGY project planned several collaborations with existing and ongoing research projects. In particular, an important synergy is developed with the project StoRES "Promotion of higher penetration of distributed PV through storage for all" [[114]- [115]], funded by the European Regional Development Fund through the InterregMED Programme (2016-2019), addressing the development of an optimal policy for the effective integration of RES and Energy Storage Systems (ESS). The motivation behind StoRES project is the promotion of photovoltaic (PV) installations in the MED region using smart, optimised and innovative solutions that lift the concerns of all the involved stakeholders of the energy sector. In fact, testing coupled PVESS solutions in different pilot sites and considering local particularities for optimization, current barriers concerning grid reliability with higher RES deployment will be eliminated. Sardinia is a good region for testing PV-ESS solutions, and ESS have been installed in different pilot sites in the Municipality of Ussaramanna (Sardinia, Italy). These pilot resources will be included in the implementation of the VPP proposed in VIRTUAL ENERGY.

The consortium of StoRES consists of members from 7 European countries in the MED region:

- Cyprus,
- Greece,
- Portugal,
- Spain,
- Slovenia,
- France,
- Italy.

Italy is involved through the participation of the Municipality of Ussaramanna (Sardinia), the University of Cagliari and the Autonomous Region of Sardinia – Regional Planning Center.

In addition the project VIRTUAL ENERGY benefits also from a synergy with project CoNetDomeSys, funded by MIUR under call SIR 2014, which developed formal methods to coordinate a large population of domestic thermostatically controlled loads such as electric water heaters and electric radiators with novel multi-agent distributed control techniques. In particular, a plug-and-play distributed control architecture and algorithms have been developed with a focus on domestic thermostatically controlled loads retrofitted with smart power sockets. Some of the methods developed in CoNetDomeSys [116] will be refined and extended to be integrated into the VPP system.

6.3.4 VPP Distributed Resources Coordination

The coordination problem of distributed energy resources will be addressed by exploiting distributed optimization approaches to ensure performance and scalability of the VPP real time control actions.

In the scenario envisioned by VIRTUAL ENERGY, each electric load and power source will be modeled as a discrete time hybrid dynamical system, i.e., a dynamical system which evolves according to some different dynamics depending on which discrete state is active, to enable numerical optimization of its behavior. To experiment with domestic appliances the test-bed developed in project CoNetDomeSys will be included in VPP. In particular, 100 smart power sockets, i.e., electric adapters with ability to monitor the power consumption of the appliance plugged into them, switch power ON/OFF and connected to the domestic WIFI, will be used to monitor the power consumption of uninterruptible domestic appliances such as TVs or microwaves and actively control thermostatically controlled loads such as electric water heaters, electric radiators, air conditioners and, eventually, refrigerators. Raspberries PI-0-W are currently used in CoNetDomeSys to control the smart sockets (see Fig. 6.16 and Fig. 6.17).

Figure 6.16: A Raspberry Pi-0-W and a smart socket

Figure 6.17: An electric water header connected to a smart socket integrated in the CoNetDomeSys testbed which will be part of VIRTUAL ENERGY VPP

The objective of the VPP will be that of optimizing online a global objective function which maximizes the profit for the participants in the VPP. To achieve a scalable system, the online optimization will be carried out through distributed model predictive control. In such a way, a linear in the number of devices will be easily addressed by a linear increase in computational power demanded by the cloud system. The possible assignment of priorities among the electric loads and users will be considered.

The VIRTUAL ENERGY VPP will also control some ESS of the eleven pilots, which have been selected by StoRES project in the municipality of Ussaramanna (Italy).

The systems are typical residential users/prosumers with an existing rooftop PV system, with rated power of 3-12.5 kW, and ESS with rated power of 4-8 kWh (modular systems of 2kWh) suitably coupled with the PV systems (Fig. 6.18).

Figure 6.18: A energy storage systems that will be controlled by the VIRTUAL ENERGY VPP

The city map location of each prosumer equipped with ESS is shown in Fig. 6.19.

6.3.5 VPP Performances Analysys

The project will be focused on the design and realization of a prototype of VPP for the experimental verification of the developed techniques.

There will be defined use case scenarios and will be performed a campaign of testing and validating the solution adopted. The results will be analyzed in order to highlight their strengths and weaknesses, evaluate their effectiveness and usability both from a technical point of view and from the point of view of the end user.

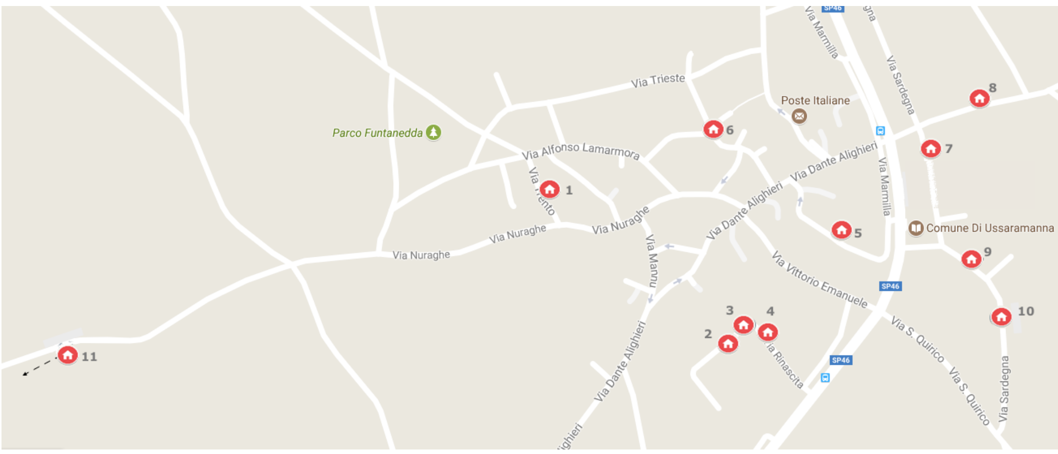

Figure 6.19: Selected Pilot Locations in Municipality of Ussaramanna - Italy

A special emphasis will be dedicated to communication system, because it is crucial for VPP performance. In fact, the VPP is geographically distributed system that requires transfer of measurement and control messages with cloud system (see fig. 6.20).

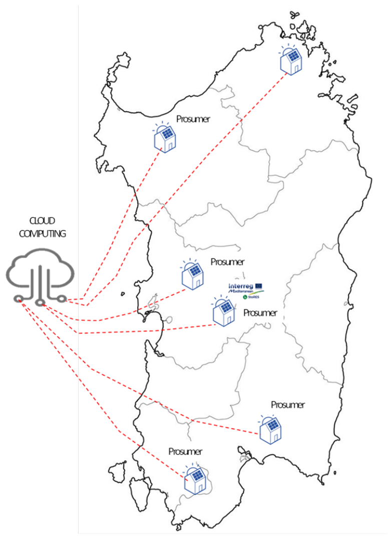

Figure 6.20: Prosumers and DERs controlled by the VPP are distributed in all the territory of Sardinia

In addition, the efficient VPP operation is closely connected with the electricity market; thus, it is necessary to exchange price and market-related data between the VPP and different market actors, ensuring fast and accurate exchange of information.

Some VPP performance analysis are available in literature, for instance in [117] the authors present a case study of an operational VPP communication system providing manual frequency restoration reserve service to the transmission system operator, aggregating two DER: a refinery facility with steam turbines and diesel generator sets, and a papermill plant with an available flexible capacity of 30 MW in total. The study captured the communication traffic data during the VPP live operation over a one-month period with fourteen fully automatic activations. The study analyzed selected communication quality of service parameters, in particular, latency, packet loss, retransmissions, bandwidth, amount of traffic, and message patterns of the IEC 60870-5-104 protocol. In this application, the protocol used is a TCP/IP-based Supervisory Control And Data Acquisition (SCADA) system protocol providing basic functionalities such as polling, cyclic data transmission, and acquisition of events. The profits that this approach brings are the reliability and implementation. The major disadvantage is the lack of functionality for DER aggregation, planning within VPP and product prediction.

Another widely used protocol is OpenADR 2.0b / Open Automated Demand Response (DR), a Non-proprietary, open standardized DR interface that allows electricity providers to communicate DR signals directly to existing customers using a common language and existing communications such as the Internet. It supports hierarchical architecture, dynamic setting of message exchange intervals, and transmission of historic and future flexibility data (e.g. timetables, forecasting, baselines). In general, there is large potential of VPP usage for DERs aggregation and providing benefits to consumers, utilities, system operators, and society at large. The merits of this type of protocols are many, variety of communication protocols is available, both proprietary and open, exchange of large number of small-size messages. However, it is possible only if effective and reliable communication system is utilized. The most timecritical interval for VPP operation is during activation, but requirements on latency and bandwidth are not so rigorous for current communication technologies.

Chapter 7

Conclusions

As mentioned above, the telecommunications sector is constantly evolving. The evolution of 5G technologies accompanied by the presence of increasingly powerful mobile devices at ever lower costs has led to a widespread diffusion of mobile technologies. This is leading to a significant growth in the number of devices that need mobile connection and their bandwidth demands are becoming more and more pressing.

An important challenge in such a heterogeneous wireless environment is to allow network selection mechanisms to keep mobile users "Always Best Connected" (ABC) [118]. However, the presence of such a large number of available technologies makes the selection of the best candidate network crucial. in order to guarantee users the best possible QoS.

During the study that led to the realization of this thesis, various problems were faced due to the differentiation of the type of traffic, the differentiation of the technologies to be used and the exploitation of the resources made available by them.

For this purpose, different types of algorithms have been developed in order to avoid overloading the networks, with a consequent lowering of QoS, the search for the best candidate network and the best use of the resources offered by the network system.

Initially, the work done on the algorithm that performed a load balancing in real time on heterogeneous wireless networks using a dynamic MEW function based on the user's characteristics, obtained good results. The results obtained by the algorithm used showed an improvement in performance in terms of QoS, such as PSNR, average PSNR, throughput, aggregate throughput and packet delay. The estimated average improvement was 15% in all the metrics considered with respect to the balancing performed with the ARMANS algorithm.

However, it presented problems due to the presence of zeros, which limited the selection of the network. This is because the presence of a zero in one of the used UFs, automatically eliminated the network from the algorithm, even if the other parameters taken into consideration had high performances. To overcome this problem, it was decided to use an ALOW type algorithm.

ALOWGATH is based on ALOW which combines information relating to the class of the device, the requested service, the priorities and data relating to the power of the signal received, the load on the network and the delay of packages. The allocation of resources is finally performed using a balancing algorithm based on game theory (GATH) and Nash equilibrium (NE). To evaluate its effectiveness it has been compared with the ARMANS and HUMANS algorithms. The results showed better performance in terms of average throughput, aggregate throughput and user satisfaction. Moreover, the computational complexity of ALOWGATH is $O(nlogn)$, indeed, lower than the computational complexity of ARMANS and HUMANS that, using a MEW method, have a computational burden of $O(2^n)$.

The problem that occurred at this point in the research was to develop an algorithm that would allow managing different types of traffic, in order to obtain the best candidate network for that specific type of traffic.

To obtain the best candidate network for a specific type of traffic, an algorithm based on network ranking was developed. It is based on creating a network ranking based on the reputation of the network for each type of traffic taken into consideration.

TYDER calculates the reputation of the network considering the different types of traffic. Selecting the most appropriate network results in a significant improvement in system performance, as regards the QoS parameters considered for each type of traffic.To evaluate the effectiveness of the algorithm, it was compared with candidate network selection algorithms previously implemented and known in the literature MEW, E-PoFANS. TYDER showed an average improvement on all the QoS values taken into consideration respectively on (8%) and (5%). This makes it an ideal candidate for optimizing 5G networks. The next job will be to make network selection based on different types of services simultaneously. In this way it will be possible to balance the traffic in the most realistic way possible.

For the best exploitation of resources, a study was carried out on the use of the subgroup applied to multicast-type scenarios.

A comparative analysis was carried out between three different approaches for the management of radio resources in multicast services in LTE networks, such as CMS, OMS and SubOptADR.

Simulations were performed in a real urban scenario that represents a position of the city of Cagliari in Sardinia to compare the three algorithms in terms of Mean Throughput and Jain's Fairness Index.

Two different configurations have been studied: a MG with 30% of pedestrian users and 70% of vehicular users and a MG with only vehicle users. The results obtained demonstrate how SubOptADR exceeds the performance of OMS and CMS both in terms of throughput and of JFI.

Finally, a study was proposed on the joint use of subgroup multicast techniques and NOMA in a scenario similar to eMBMS. Performance is assessed in the 5G environments provided, where different quality video services are delivered to a group of users interested in the same content.

NOMA is considered a strong candidate to be included in the 5G ecosystem. Consequently, the challenges associated with its efficient integration in the RAN architecture have drawn a lot of attention. Some of them will also be useful for the technical solution proposed in this work. For instance, there are studies analyzing the impact of the path loss in the NOMA performance or the feasibility of combining non-orthogonal multiplexing techniques with cooperative communications. In addition, NOMA is also considered a very powerful tool for massive MIMO technologies. What is more, recently there has also been proposed in one of the most promising communication paradigms: the visible light communications (VLC) [110]. Finally, regarding the LDM implementation, the error cancellation impact on the overlaid layers and the low-complexity implementations should also be studied.

In the case of the subgrouping techniques, the main challenge is to adapt the current metrics to the requirements expected on the 5G ecosystem for supporting not only bandwidth-hungry services but also machine/IoT group oriented applications. That is to say, new architectures, protocols, and metrics will be needed in order to guarantee high-quality services to the different groups of receivers.

Chapter 8

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  C. Desogus, M. Anedda, M. Murroni, and G. Muntean.

  Published in: IEEE Access (Volume: 7)

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