UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

FUNCTIONAL MODELS AND PROCEDURES FOR THE AUTOMATED MANAGEMENT OF RAN SLICING

A Degree Thesis

Submitted to the Faculty of the

Escola Tècnica d'Enginyeria de Telecomunicació de Barcelona

Universitat Politècnica de Catalunya

by

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In partial fulfilment

of the requirements for the degree in

TELECOMMUNICATION SYSTEMS ENGINEERING

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Barcelona, February 2019

Abstract

The jump from 4G to 5G connections may sound like a small change that does not involve much innovation, but it is not. Since apart from improving the achievements of the 4G, it will be provided new advances, applications and services never seen before (throughout the document it can be seen). But the most revolutionary of 5G networks will be the automation of network management.

It will be carried out using networks that organize by themselves, called Self-Organizing Networks (SON)s. Like this, from its use, important advantages will be achieved, such as improvements in network performance, in costs and in user experience.

In this way, this thesis provides a vision of the SON functions, from the creation of models and functional procedures of two specific application examples.

In the present project, the characteristics of the 5G will be detailed and the manual and automated functions will be described. Next, the diagrams and functional procedures of the application examples will be developed, and the necessary parameters will be provided to implement each algorithm of each function. And finally, the conclusions and future developments of thesis will be included.

Resum

El salt de les connexions 4G a 5G pot semblar un petit canvi que no implica molta innovació, però no ho és. Atès que a més de millorar els èxits del 4G, es proporcionaran nous avenços, aplicacions i serveis mai abans vists (al llarg del document es podran veure). Però lo més revolucionari de les xarxes 5G serà l'automatització de la gestió de la xarxa.

Es durà a terme utilitzant xarxes que s'organitzen per si mateixes, denominades Self-Organizing Networks (SON)s. Així, a partir del seu ús, s'aconseguiran importants avantatges, com ara millores en el rendiment de la xarxa, en els costos i en l'experiència de l'usuari.

D'aquesta manera, amb aquesta tesi, es proporciona una visió de les funcions SON, a partir de la creació de models i procediments funcionals de dos exemples aplicatius en concret.

En el present projecte, es detallarà les característiques del 5G i es descriurà les funcions manuals i automatitzades. Seguidament, es desenvoluparà els diagrames i procediments funcionals dels exemples aplicatius i es proporcionarà els paràmetres necessaris per a implementar cada algoritme de cada funció. I finalment, s'inclourà les conclusions i futurs desenvolupaments de la tesi.

Resumen

El salto de las conexiones 4G a 5G puede parecer un pequeño cambio que no implica mucha innovación, pero no lo es. Dado que además de mejorar los logros del 4G, se proporcionarán nuevos avances, aplicaciones y servicios nunca antes vistos (a lo largo del documento se podrán ver). Pero lo más revolucionario de las redes 5G será la automatización de la gestión de la red.

Se llevará a cabo utilizando redes que se organizan por sí mismas, denominadas Self-Organizing Networks (SON)s. Así, a partir de su uso, se lograrán importantes ventajas, tales como mejoras en el rendimiento de la red, en los costes y en la experiencia del usuario.

De esta manera, con esta tesis, se proporciona una visión de las funciones SON, a partir de la creación de modelos y procedimientos funcionales de dos ejemplos aplicativos en concreto.

En el presente proyecto, se detallará las características del 5G y se describirá las funciones manuales y automatizadas. Seguidamente, se desarrollará los diagramas y procedimientos funcionales de los ejemplos aplicativos y se proporcionará los parámetros necesarios para implementar cada algoritmo de cada función. Y finalmente, se incluirá las conclusiones y futuros desarrollos de la tesis.

Acknowledgements

Undoubtedly, this project would not have gone ahead without the support and contribution to its production by several people.

First of all, I want to thank for my mentor of this final degree project and supervisor Oriol Sallent for having offered me such an enriching project that has allowed me to enter the world of 5G and discover a small part of the research work that is done in the Signal Theory and Communications department. Also, thank you for accompanying me throughout the project process, for your proportionate tenacity, your contribution, your dedication, your orientation and for the help provided. As well as when the time came to solve doubts and when it was time to write the thesis.

Furthermore, I want to express my deep gratitude to my family. In particular my father, my mother, my brother, my grandmother and my partner who have always supported me, have believed in me, have had patience and have given me all the means to get where I am today. Also, thanks to all the people with whom I have worked during this time for their deep understanding, and to my friends and classmates who helped me in my final effort despite the difficulties we faced together.

I share this project with you.

Nerea Centeno García

Revision history and approval record

Revision	Date	Purpose
0	22/11/2018	Document creation
1	20/12/2018	Document modification
2	15/01/2019	Document revision
3	18/01/2019	Document correction
4	24/01/2019	Final document revision
5	25/01/2019	Document delivery

DOCUMENT DISTRIBUTION LIST

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Written by:		Reviewed and approved by:	
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1. Introduction

Today, many of the actions around us were previously done manually, but throughout the years, they have been automated. And in the world of 5G the same thing happens. Since in the development of the 5G, it has considered several technologies of management of networks and services. As it is the case of Software Defined Networking (SDN), Network Functions Virtualization (NFV) or Network slicing.

Going in deep, the slicing management is in the 5G radio access network, called NG-RAN (Next Generation - Radio Access Network). Where for certain functions, interfaces, information models and elements of the NG-RAN infrastructure, a network segmentation management can be presented in an NG-RAN infrastructure, thus allowing the automation of the management processes and provision of RAN segmentation, such as virtualized network functions [1] [2].

But it must take into account the feasibility and complexity of automation in different processes. Since the viability of automation depends to a large extent on the support of the SON functionalities. That it is an automation technology designed to reduce or eliminate the configurations of manual activities in the lifecycle of the execution of a mobile network. Simplifying and accelerating the classic activities of planning, deployment, configuration, management, optimization, maintenance, troubleshooting and recovery of mobile radio access networks. And so, in this way, operating costs can be reduced, and human errors minimized.

1.1. Statement of purpose

The project has been carried out in the department of Signal Theory and Communications. Its objective has been to perform functional models and procedures in two application examples, for the automated management of RAN Slicing, using the SON functions. Taking into account, to a large extent, the management of its lifecycle. In addition, it has been complemented by an analysis of the possible parameters that will be used when implementing the algorithms of each function. In this way, it illustrates the functionalization and a global and more compact view of the automated functions.

• The project main goals are:

1. - Do research and acquire the necessary knowledge of 5G.

2. - Understand deeply everything that encompasses the term automation.

3. - Be aware of the feasibility and complexity of automation in the different processes.

4. - Be able to build different functional models and procedures for the automated management of RAN slicing.

5. - Be able to define the parameters for each algorithm of the SON functions.

6. - Be able to reflect the conclusions obtained of the developed thesis.

1.2. Requirements and specifications

- Project requirements:

On the one hand, it has been necessary to consider the objectives of the 5G that entail a series of requirements. These goals mainly include high data rates, reduced latency, energy savings, cost reduction, increased system capacity and massive device connectivity. Considering this, I must have known how to find the most optimal functional models and procedures possible taking into account the feasibility and complexity of automation in different processes. And therefore, the specific functions of Machine Learning (ML), and tools based on artificial intelligence.

- Project specifications:

At the specification level, it is necessary to keep in mind the regulatory specifications regarding the requirements and architecture of the system to support the segmentation of the network, which 3rd Generation Partnership Project (3GPP: telecommunications association groups) has recently completed. And for my specific function, I must bear in mind that I had a limited time of four months to reach a good result.

1.3. Project background

The origin of the main ideas of this final degree project comes from my interest for the Radio Telecommunications subject that I made the last four-month period. Therefore, in this way, I was curious to see what projects worked in the department of Signal Theory and Communications and see if it was possible to carry out the final degree project with them.

The feedback was satisfactory, and they proposed to me to do it for the 5G world, where they gave me three cases to develop. The first was conceptually theoretical, the second was functional models / procedures and the third was algorithmic to do simulations. In front of these three cases, I opted for the second, because although it was the most complex, it will open more doors for me in this world of 5G and I also found it quite interesting.

Therefore, the initial ideas of the main project are provided by the supervisor and the project is performed in the framework of the development of the department.

The project started from scratch for me, since the contents I have worked with were not taken during the degree. But, on the other hand, I can say that has been the continuation of the investigation of the SON subfunctions that is being done worldwide.

1.4. Work plan

In this section, it will see the workload of this thesis that has been divided into three Work Packages (WP)s, the milestones and the final Gantt diagram.

- Work Packages:

<table>
<tr><td>Project: Functional Models and Procedures for the Automated Management of RAN Slicing</td><td colspan="2">WP ref: WP1</td></tr>
<tr><td>Major constituent: State of the art</td><td colspan="2">Sheet 1 of 3</td></tr>
<tr><td rowspan="2">Short description:
Research on the state of the art in 5G. I acquired the necessary knowledge for the execution of the project guided by my tutor of the project.</td><td colspan="2">Planned start date: 13/09/2018
Planned end date: 01/10/2018</td></tr>
<tr><td colspan="2">Start event: 13/09/2018
End event: 08/10/2018</td></tr>
<tr><td>- Internal task T1:
I found information about the world of 5G. And I read whitepapers about the concepts needed to develop my goal.

- Internal task T2:
I developed the Self-Organizing Network concept. Making different block diagrams according to their types of architecture (Centralized SON, Distributed SON and Hybrid SON) and their subfunctions (Self-Configuration, Self-Optimization, Self-Coordination, Self-Protection and Self-Healing).</td><td>Deliverables:
a) Task T1

b) Task T2</td><td>Dates:
a) 13/09/2018

b) 19/09/2018</td></tr>
</table>

- Internal **task T3**: Writing of the Project Proposal and Work Plan. - Internal **task T4**: I got used to the RAN Slicing concept. Where on the one hand, Network Slicing was developed and its three categories (eMBB, mMTC and URLLC) and on the other hand, Radio Access Network. And a flow scheme of the implementation of RAN Slicing via virtualization was made.	c) Task T3 d) Task T4	c) 01/10/2018 d) 04/10/2018

Table 1.1: *WP1: State of the art*

Project: **Functional Models and Procedures for the Automated Management of RAN Slicing**	WP ref: **WP2**	
Major constituent: **Functional analysis**	Sheet **2** of **3**	
Short description: Functional analysis of RRM and SON functions.	Planned start date: 09/10/2018 Planned end date: 16/10/2019 Start event: 09/10/2018 End event: 16/10/2019	
- Internal **task T1**: Functional analysis of RRM functions. - Internal **task T2**: Functional analysis of SON functions.	Deliverables: a) Task T1 b) Task T2	Dates: a) 09/10/2018 b) 12/10/2018

Table 1.2: *WP2: Functional analysis*

Project: **Functional Models and Procedures for the Automated Management of RAN Slicing**	WP ref: **WP3**	
Major constituent: **Project development**	Sheet **3** of **3**	
Short description: Realization of the functional models and procedures for the automated management of RAN Slicing. And I will focus in future advances.	Planned start date: 01/10/2018 Planned end date: 23/12/2018 Start event: 17/10/2018 End event: 07/01/2019	
	Deliverables:	Dates:
- Internal **task T1**: Realization of a procedure first version of a specific operative example (Capacity expansion of a RAN slice).	a) Task T1	a) 17/10/2018
- Internal **task T2**: Update of the procedures version with a new approach and functional diagrams development.	b) Task T2	b) 09/11/2018
- Internal **task T3**: Writing of the Project Critical Review.	c) Task T3	c) 23/11/2018
- Internal **task T4**: Focus in more detail on the service requested by the client. And reorganize the procedure and the functional models to add a new operative example (New RAN slice activation).	d) Task T4	d) 27/11/2018
- Internal **task T5**: Go deeper into the theme of SLA monitoring.	e) Task T5	e) 04/12/2018
- Internal **task T6**: Search of the SON functions algorithms and writing of the involved parameters.	f) Task T6	f) 11/12/2018
- Internal **task T7**: Functional diagrams creation of the algorithms parameters.	g) Task T7	g) 27/12/2018

- Internal **task T8**: Budget development. - Internal **task T9**: Writing of the final memory.	h) Task T9 i) Task T10	h) 05/01/2019 i) 07/01/2019

Table 1.3: *WP3: Project development*

- Milestones:

WP#	Task#	Short title	Milestone / deliverable	Date (week)
1	T1	Read whitepapers	Investig. of the charcs of 5G	18/09/2018
1	T2	SON subfunctions	SON concept development	30/09/2018
1	T3	Proposal and Work Plan	Writing of the Prop. Work Plan	03/10/2018
1	T4	RAN Slicing	Get used to the RAN Slicing	08/10/2018
2	T1	RRM analysis	Funct. analysis of RRM func.	11/10/2018
2	T2	SON analysis	Funct. analysis of SON func.	16/10/2018
3	T1	Procedures	Proced. of an operative e.g.	08/11/2018
3	T2	Update + func. diagrams	Update of proced. + func. diag.	22/11/2018
3	T3	Critical Review	Writing of the Critical Review	26/11/2018
3	T4	New operative example	Admission of a new example	03/12/2018
3	T5	SLA monitoring	Go deeper into SLA monit.	10/12/2018
3	T6	Algorithms of the func.	Search of algorithms	26/12/2018
3	T7	Funct. diag. of param.	Creation of diag. of param.	04/01/2019
3	T8	Budget development	Budget development	06/01/2019
3	T9	Final memory	Writing of the final memory	25/01/2019

Table 1.4: *Milestones*

- Gantt diagram:

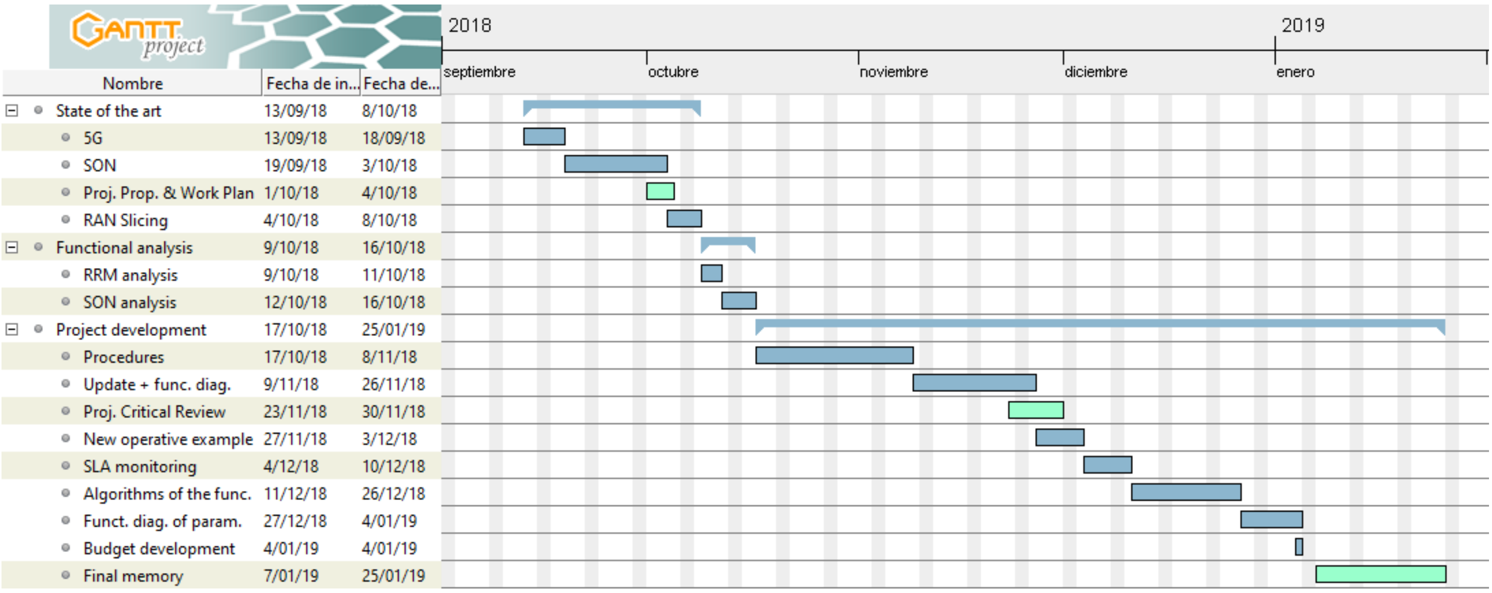

Figure 1.1: *Gantt diagram*

1.5. <u>Deviations</u>

Throughout this project, there have been no critical deviations that conditioned the project process. But when the planning was done, it was proposed to investigate the NFV world, which was discarded because the algorithms parameters of the SON functions were prioritized, that were not contemplated initially. Which has entailed, lengthen the project development two weeks more than expected. On the other hand, it can be said that there have been small deviations by the procedural approaches and functional models, since they have been changing over the weeks.

2. Fifth generation

Nowadays, everyone likes that the internet goes faster and faster. But every time, there are more devices connected to the internet and more people have access to the 4G network, which causes the network is starting to become saturated.

So that the bandwidth does not collapse, it is needed a new type of wireless connection. Here is where the 5G comes in.

The terminology of the word 5G comes from the fact that the "G" means "Generation", to refer to the fifth generation of mobile phone technologies. It is the successor of 4G technology and the other generations. Hence, before explaining in detail the characteristics of 5G, it is going to be done a briefly explanation of the main achievements of each generation:

1G: People could make calls.

2G: People could make calls, send text messages between two devices and it had the international roaming service.

3G: People could make video calls, send text messages, had the international roaming service and surf the internet.

4G: Improved the achievements that 3G reached at higher speeds. And it obtained the ability to watch streaming video, among other things.

5G: It will improve the achievements of 4G at higher speeds, the devices will use Ultra HD and 3D, and the concepts of the smartness of things based on sustainability will come into play, among other things.

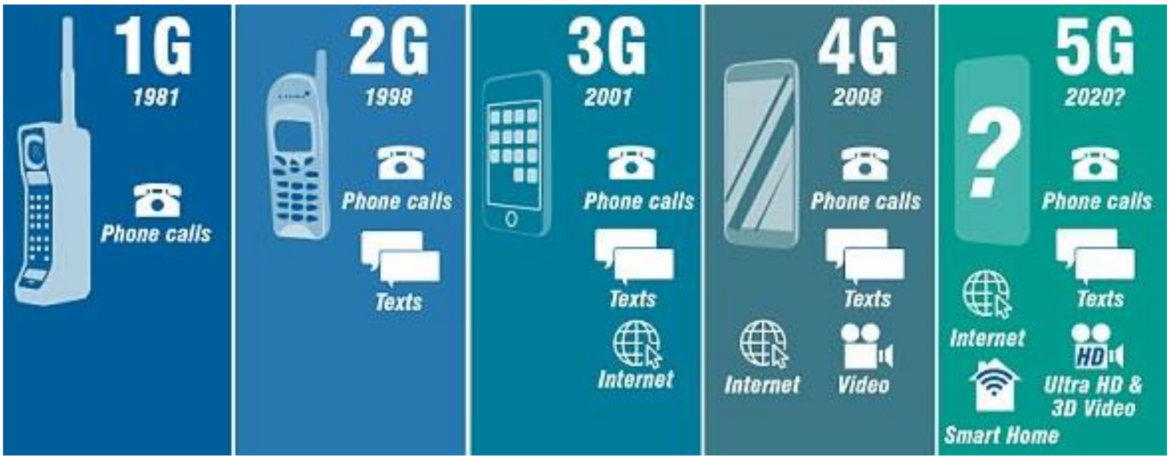

Figure 2.1: *Achievements of the five generations [3]*

Besides, it must take into account that each generation has also been marked by encoding methods. Since for 1G was analogue cellular, for 2G was Code Division Multiple Access (CDMA), Global System for Mobile communications (GSM), and Time Division Multiple Access (TDMA), for 3G was Evolution-Data Optimized (EV-DO), High-Speed Packet Access (HSPA), and Universal Mobile Telecommunications System (UMTS), for 4G was Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE), and for 5G will use a type of encoding called Orthogonal Frequency-Division Multiple Access (OFDMA) [4].

2.1. <u>5G characteristics</u>

The 5G technology is characterized for a series of specifications [5]:

- Up to 10Gbps data rate.

- 1 millisecond latency.

- A bandwidth 1000 times faster per unit area.

- Up to 100 times more connected devices per unit area.

- 99.999% network availability.

- 100% coverage.

- Reduction of 90% in the energy consumption of the network.

- 10 years battery.

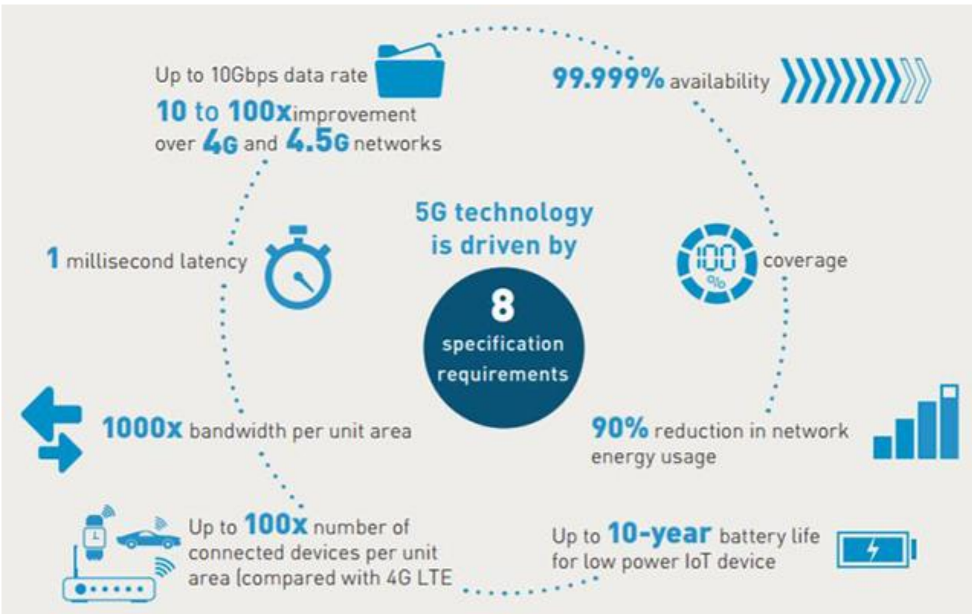

Figure 2.2: *Specification requirements [6]*

From these specifications, it is concluded that thanks to 5G can be satisfied the communication needs of billions of connected devices, with a fair balance between speed, latency and cost. Allowing in this way, to have high data rate transfer, latency reduction, cost reduction, maximum reliability and efficient in communications, flexibility, scalability, security and higher capacity of the system that allowing more users and more devices to be connected at the same time. Also, a massive device connectivity from more places, more intelligence and a low power consumption that will allow connected objects to work for years without the need for human intervention.

And thus obtain these performance goals: make calls, send texts, surf the Internet too much faster and record, upload and download content in Ultra HD and 3D video. Also, thanks to this new technology appears new technologies and applications that until now with the 4G were unthinkable. As for example, enjoy virtual reality on the street and even project holograms from our devices. In addition, it will facilitate the dissemination services, the speed for users in mobility, the Communications Lifeline (exceptional services in case of catastrophes or extreme situations), the connections of wearables, the Smart Home, the Smart Office and other cloud-based services, the new surgical procedures, the safest means of transport and the Internet of Things (IoT) scalability. That with the devices of the Internet of Things, it will unlock highly demanded features such as voice commands, facial recognition, make live interactive broadcasts and interfaces based on gestures. And in this way, it gives rise to the growth of a type of urban development based on sustainability, Smart Cities.

2.2. Necessary technologies

The cellular 5G networks send encoded data through radio waves that unfold a system of cell sites divided into sectors. For this to work, it is needed a series of technologies [7]:

- High frequency millimetre wavelengths: First keep in mind that the data is transmitted by radio frequencies, which are divided into different frequency bands. So, with this first technology, what it want is to use higher frequency spectra. Where it will run in two types of airwaves: below and above 6 GHz. Since having more spectrum available, more devices can connect to the network without being saturated and there will be more bandwidth for everyone and likewise more speed and much capacity. The consequence of a higher frequency, however, is a shorter range. They cover shorter distances and cannot travel through walls, windows or rooftops and tend to be absorbed by trees and rain. Therefore, they become considerably weaker over long distances. This would surely lead to the change of use of these bands from one place to another, always being regulated by the International Telecommunications Union (ITU).

So, this generation will be mainly for an urban service for densely populated areas. For this reason, it is said that the 5G will complement the 4G, instead of replacing it completely. Since for example, when we are driving on the highway or walking on the mountain, 4G technology could be your only option, at least for a while.

To solve this problem, it must resort to the second technology.

- Smart antenna: It will need intelligent antennas, which are nothing more than repeaters. These smaller antennas than normal telephony antennas will need to install on top of each lamp post, on buildings, inside every home, and potentially in every room. So that they bounce the signal and reach the places they would otherwise not reach, thus solving the problem that it mentioned before.

- Massive Multiple Input Multiple Output (MIMO): It is the idea of putting more antennas in our phones and cell towers. The new Massive MIMO antennas will have hundreds of small ports, which are responsible for managing the connection of all mobile traffic to boost signals and capacity. This allows managing up to 22 times more mobile connections. But these antennas have their own complications, and that is that they generate huge interference, so the fourth technology comes into play.

- Beam configuration or beamforming: It is like a traffic light for mobile networks. Instead of the antennas emitting in all directions at the same time, this technology allows them to emit directly to your mobile. This would prevent interference and also allow that a single antenna manages many more data inputs and outputs. But the antennas can bounce the data packages in buildings and objects in such a way that they never interfere until they reach to the recipient. This brings us to technology number five.

- Full Duplex: When the incoming data go on the one hand, and the outgoing on the other. Since using silicon transistors can make high-speed alternators that can momentarily reorient a signal.

Last but not least, 5G will use Network Slicing to deploy multiple virtual 5G networks on common infrastructure and it will try to automate many of the network behaviours. That it will see this in the next point.

But this era could trigger some objections, as a possible audiovisual pollution or in view of concerns about health risks for the cell radios around ours.

3. Network Slicing

Apart from all the services that the 5G will offer us, it must not forget the new factor Network slicing, as mentioned in the previous point.

This technology allows Mobile Network Operators (MNOs) divide the physical network to create subnets (multiple virtual networks) on a common physical infrastructure in a transparent, flexible and dynamic way. With different properties or same characteristics, in order to provide a more adjusted connectivity to the specific needs of applications, services, devices, customers or operators. Unlike now that the network has the same characteristics and offers the same to all types of devices, when the demands of each type of device are not the same, hence those in a category are harmed by those in another category.

Therefore, with Network Slicing, each slice will have a specific bandwidth, speed and latency. Since the slices are isolated from each other in the control and user planes (the technology of now not). And so, it can be optimized by a myriad characteristics and be much more effective than with traditional traffic management techniques. Because the intention is to take infra-structure resources from the spectrum, antennas and all of the backend network and equipment.

Network slicing is a type of virtual network architecture that uses the same principles behind software defined networking, network functions virtualization and network orchestration tools in fixed network, allowing in this way, to be able to automate certain functions of the network [8].

This segmentation of network that the 5G will use, is composed of the following technologies: virtualization, Radio Access Network (RAN) architecture, the network programmability, the central network components of Evolved Packet Core (EPC), the network of switching and aggregation to the data centres, the control of the lifecycle of the network in the cloud, a fully automated management and coordination mechanism, an interface that allows multiple different uses of the network and an agile transport system, among others.

On the other hand, Network Slicing can be classified into three types, according to the needs of the scenarios that can be found [9] [10]:

- Enhanced Mobile BroadBand (eMBB): Scenario requires high data rates across a wide coverage area. And high bandwidth Internet access suitable for web browsing, video streaming, and virtual reality.

- Massive Machine Type Communications (MMTC)s: Scenario with a high requirement in density connections. And narrowband Internet access for sensing, metering, and monitoring devices.

- Ultra-Reliable and Low Latency Communications (URLLC)s: Scenario requires ultra-low latency and ultra-reliability. And services for latency sensitive devices for applications like factory automation, autonomous driving and remote surgery.

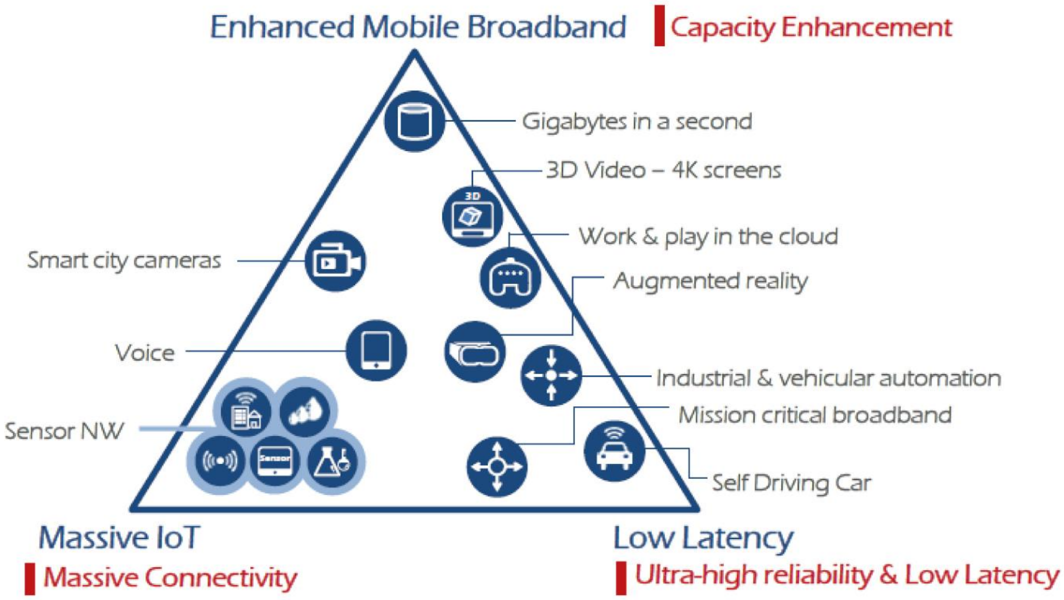

Figure 3.1: *Three dimensions for improvements scenarios [9]*

3.1. Radio Access Network

RAN is one of the key components for this generation. Since the most recent evolution of the RAN architecture divides the user plane of the control plane into separate elements. Which allows the RAN to be more flexible and to adapt to the virtualization techniques of the network functions, which are necessary for 5G. In this way, the 5G technology will divide a physical network into multiple virtual networks capable of supporting several RANs or services that run on an individual RAN. And thus, be able to provide access, coordination and management of radio resources, mobility and data encryption, in an automated way.

RAN is the part of a mobile telecommunications system that implements a radio technology to access the Core Network (CN). This unique wireless network connects individual devices to other parts of a network through radio frequencies and resides conceptually between the user's equipment (i.e. mobile phones, computers or any remotely controlled device) and its Core Network. As of the base stations and antennas that cover a specific region based on its capacity.

In this way, the concept of RAN Slicing is achieved, which is nothing more than a technology based on software defined networks and network function virtualization. That allows to deploy and operate multiple logical networks through a common physical network infrastructure. Where each of the virtual RANs are customizable and scalable according to the type of scenario of the application [10]. Therefore, each of them contains the necessary functions and the corresponding network services, to achieve the requirements of an end-to-end service.

Since a logical network is used, with qualities similar to those of a dedicated autonomous network, but in this case, being able to share resources, such as spectrum, access coverage, signal processors, sites and transport.

Thus, the objective is to guarantee the independence of the segments and to share in a flexible and adaptive way the RAN resources among different owners. To provide a more efficient use of the network resources available so far, a reduction in operating costs, a shortening of the segment creation time and a performance optimization. Obtaining in this way, new use cases of management applications, such as network planning, provisioning and SON functions, through tools based on Artificial Intelligence (AI) and automation.

Many aspects of this functional architecture have already been approved by 3GPP (international organization that governs mobile communication standards). As also, recently, the standard and the final specifications for the 5G in its New Radio (NR) version have been approved. Where it is mentioned, that the 5G will be independent and it will not depend on the existing networks. But all 5G devices, initially, will need 4G before changing to 5G.

In addition, the implementation of slicing in radio access networks has been studied from multiple angles, including aspects of Radio Resource Management (RRM) to the exploitation of virtualization techniques. But the slicing management that allows a dynamic and automatic provisioning of slices, is in a much more incipient state, especially as regards the 5G radio access network, called NG-RAN (Next Generation - Radio Access Network) [11].

With this context, the following two points will explain in detail the RRM functions and the automated SON functions, which are key to the objective of this communication.

4. Radio Resource Management

Radio Resource Management (RRM) aim is to ensure and control efficient usage of the co-channel interference management, radio resources, and other radio transmission characteristics available in wireless communication systems. In particular, RRM is an application level function that manages the assignment, re-assignment and release of radio resources in single and multi-cell environments [12].

In this way, it is possible to maximize the spectral efficiency of the system to satisfy the service requirements at the smallest possible cost for the system. Accomplishing the Quality of Service (QoS) requirements.

RRM has a series of functions that are the following [13] [14]:

- Spectrum Planning: This function arranges the spectrum resources in carriers and how these carriers are assigned to the different cells. And it controls parameters such as transmission power, user allocation, beamforming, data rates, handover criteria, modulation scheme, error coding scheme...

- Radio Bearer Control (RBC): RBC function involves the establishment, maintenance and release of radio bearers. And it is responsible for the configuration of radio resources depending upon the current resource situation as well as QoS requirements of in-progress and new sessions due to mobility or other reasons.

- Radio Admission Control (RAC): RAC function admits or rejects the establishment requests for new radio bearers. It is performed according to the type of required QoS, current system load, and required service. RAC interacts with RBC module to perform its functions. Therefore, it guarantees high radio resource utilization and the QoS for in-progress sessions.

- Connection Mobility Control (CMC): CMC function manages radio resources in connection with idle or active mode mobility. In idle mode, this module defines criteria and algorithms for cell selection, reselection, and location registration by setting of parameters. In active mode, the module manages the mobility of radio connections without disruption of services. Inter-RAT RRM can be one of the sub-modules of this module responsible for managing the resources of the handovers.

- Dynamic Resource Allocation (DRA) or Packet Scheduling (PS): DRA or PS function allocates and de-allocates resources including buffer and processing resources and resource blocks to user and control plane packets. It involves several sub-tasks and considers the QoS requirements and restrictions or preferences on some of the resource blocks.

- Inter-Cell Interference Coordination (ICIC): ICIC function manages radio resource blocks to keep inter-cell interference under control. ICIC mechanism includes a frequency domain component that manages the radio resource and a time domain component. ICIC is inherently a multi-cell RRM function that considers resource usage status and the traffic load situation from multiple cells.

- Load Balancing (LB): LB function handles uneven distribution of the traffic load over multiple cells. The purpose of LB is to influence the load distribution and maintain the QoS of sessions in progress.

- Inter-Radio Access Technology (RAT) Radio Resource Management (IRRRM): It manages of radio resources in connection with inter-RAT mobility. And it also includes functionality for inter-RAT load balancing for idle and active mode User Equipments (UE)s.

5. Self-Organizing Networks

Increasingly, the cellular or mobile communications are growing, the cellular networks continue to become more complex and the performance requirements are more stricter. In addition, the fact of introducing a new advanced technology causes the number of configuration parameters to increase exponentially and thus makes it difficult to manually adjust all these parameters. So, it produces the use of the automated techniques of network management such as Self-Organizing Networks (SON).

SON minimizes the lifecycle cost of running a mobile network by freeing up radio engineers from manual configuration of network elements at the time of simplify and speed up the planning, configuration, optimization, coordination, healing and protection of mobile communications networks to bring improvements. Where this process involves Network Elements (NEs) in Radio Access Networks and Core Networks to enable automatic configuration using a determination software.

Benefits of SON are the automation and improvement of the configuration and optimization of wireless networks to help operators maximize deployed Radio Frequency (RF) and spectrum capacity, reduction of the operating time and to optimize the performance. It also simplifies Radio Access Network management, improves customer experience, reduces dropped calls, lessens congestion as well as energy saving and reduces network Operational Expenditure (OPEX) in manual efforts. And, on the other hand, it reduces Capital Expenditure (CAPEX) due to a more optimized use of network elements and spectrum deployment requirements. In addition, it has the potential to rapidly and simultaneously transform network economics, reducing capital expenditure and protecting revenue by reducing the number of human errors. Always keeping in mind, the quality service [15].

And it must emphasise that SON implementations should be built to allow extensions that offer a platform that can incorporate new optimization ideas and advanced use cases.

SON has three types of architectures and five subfunctions that will be seen in the next two sections.

5.1. SON architectures

According to the location of the SON algorithm, SON is categorized into centralized SON, distributed SON and hybrid SON. But these three architectures are beginning to be defined and elaborated for the 5G in *3GPP draft-TR 28.861* specification. Therefore, this section has been decided to define it for LTE:

The self-organization functionality can be located entirely or even divided and located in different nodes. So, the self-configuration functions are located in enhanced Node Base station (eNB), and the self-optimization functions in OAM (Operations, Administration, and Maintenance) systems or in eNB or in both. Besides, when it is implemented at a high level in the network (OAM), it is called Network Management System (NMS). While the implementation at lower levels (network elements) such as eNBs is called Element Management System (EMS).

Based on this, the architectures are described:

- Centralized SON (C-SON):

This is an example of the network management system (NMS) where the optimization algorithms are created, stored and executed from the OAM system [16]. In this type of SON architecture, algorithms are present in a few locations, which makes it simple and easy to implement, but it does not support simple and fast optimization cases.

C-SON can take into account data from all the nodes in the network to identify, manage, coordinate and address network problems. However, centralized systems can respond very slowly, and their solutions can be more robust against network instabilities.

The centralized SON is now being implemented in the following SON functions (which in the next chapter will be seen): Automatic Neighbour Recognition, Automated Configuration of Physical Cell Identity, Coverage and Capacity Optimization, Energy Saving, Random Access Channel, Cell Outage Compensation, power control, load management in the network operations centre, etc [17].

On the other hand, C-SON operates from a large view of the entire network to execute SON algorithms in all equipments, layer and technology providers over time.

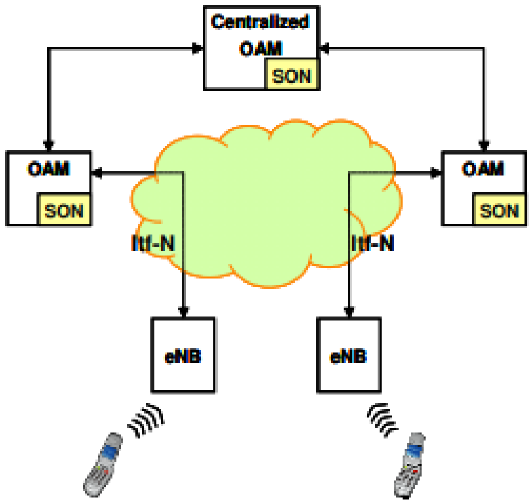

Figure 5.1: *Centralized SON example [16]*

• Distributed SON (D-SON):

Example of the EMS in which the optimization algorithms are implemented and executed in the eNBs [16]. Where automated SON processes are present in many locations at the lowest level of architecture. But this implies, that the distributed SON cannot support complex optimization algorithms. However, it offers a fast optimization / implementation when it comes to one / two eNBs.

Therefore, this functionality is designed to respond almost in real time in seconds or milliseconds, which makes it more dynamic and supports more frequent and localized changes than C-SON. And so, in this way, it can quickly configure the Automated Configuration of Physical Cell Identity, the transmission frequency and the power. In addition, it uses a lower-level micro view of the local regions of network performance to run low-latency SON algorithms, such as Automated Neighbour Relations, Mobility Load Balancing, Mobility Robustness Optimization, some use cases of Energy Saving, Inter-Cell Interference Coordination and Cell Outage Detection [17].

In contrast, D-SON is more vulnerable than C-SON against network instabilities caused by the concurrent operation of SON functions.

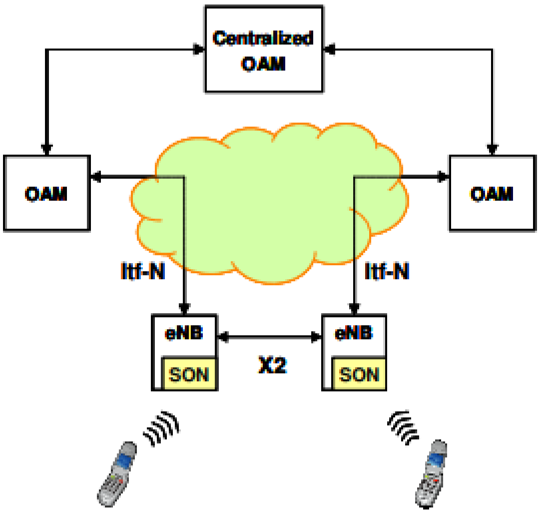

Figure 5.2: *Distributed SON example [16]*

• Hybrid SON (H-SON):

An architecture in which the optimization algorithms are executed as much in OAM system as in eNB. The simplest and fastest optimization processes are executed in the eNBs, while the complexes are managed in the OAM system. Therefore, it provides flexibility to support different types of optimization cases and admits optimization between different providers [16]. In this way, the hybrid SON solves some of the problems posed by the other architectural alternatives. However, it is expensive to implement, and it requires several interface extensions.

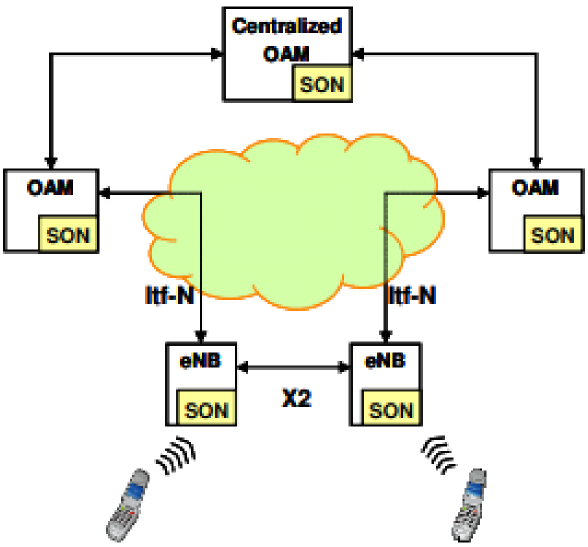

Figure 5.3: *Hybrid SON example [16]*

5.2. SON functions

SON is subdivided into different functional categories. It can be considered that there are five subfunctional groups:

5.2.1. Self-Configuration

As cellular networks become more complex, hardware and software changes become more complicated. Therefore, the autoconfiguration functions intervene, which are the dynamic plug-and-play process of automatic configuration and integration of RAN elements, as the base stations or cells [18]. Hence, with a minimum intervention by the human operator and a reduction costs while ensuring that the cell is correctly integrated into the general network. This process covers the phase of the lifecycle of the cellular system related with the operations of planning, deployment, configuration, authentication and radio configuration. The functions to be highlighted are [19]:

- Automatic configuration of initial radio transmission parameter: Dynamic Radio Configuration (DRC) of a variety of initial elements, such as the emission power, transmission frequency or the inclination of the antenna to provide the required coverage and capacity. So that the base station adapts to the current radio network topology as quickly as possible.

- Automatic Neighbour Relation (ANR): Automatic configuration of neighbour relations to measure, detect, inform, manage, add, delete, optimize and update cells. To achieve an increase in the number of successful transfers, a minimization of the number of dropped calls and from the time required, an improvement in performance and efficiency, a reduction of network workload and OPEX, and an acceleration of the delivery process. And so, in this way it gets a better service for users and avoids using traditional configuration methods for this next generation that is becoming increasingly complex.

- Automated Configuration of Physical Cell Identity (PCI): It has a purpose to configure automatically the physical identity for each cell, which needs to create the list of neighbour cells. Since each cell has a unique ID and it needs to be updated every time that a new cell is deployed or is temporarily out of service in the network. But sometimes there are conflicts, collisions and confusions among cells when they are assigned, so it must be guaranteed that the PCI of a cell should not be the same than its neighbour cells.

- Automatic connectivity management: When the new base station, automatically connects to its domain management system.

- Self-test: Performance of a self-test to guarantee the correct operation of the equipment before activating the final service.

- Automatic inventory: Since the base stations will have several adjustment options depending on the required capacities, it is necessary that an inventory verification be done before continuing. This activity includes aspects such as the identification of the installed hardware boards, the software level, the antennas...

5.2.2. Self-Optimization

Self-Configuration is not enough to guarantee effective network management and optimal performance at all times, since constant monitoring of such configurations, processes and automated algorithms is needed. To be able to regularly compare the parameters of the current system state with the destination parameters and execute corrective actions so that it adapts better to the needs of the operator and the users. This process is known as Self-Optimization.

It consists of a set of mechanisms that optimize the parameters during the operation for possible modifications, in order to automatically adjust the operation of the network [18]. And so, it makes sure that once a cell is installed, it works with its best level of efficiency.

A case of use would be the automatic shutdown of x base stations during the night hours. To obtain energy savings for operators.

There are several use cases [19] [20]:

- Coverage and Capacity Optimization (CCO): Self-optimization technique for the coverage and capacity of the network system that it uses in the administration of wireless networks, which enables scheduled correction of bottlenecks in dynamic environments both daily and seasonally. Through measurements in the network, tests of management and the use of theoretical propagation models in the planning tools.

To be exact, coverage optimization involves identifying a "hole" in the network and then adjusting the parameters of the neighbour cells to cover the hole. But the increase in cellular coverage negatively affects the spectral efficiency due to the decrease in signal strength, resulting a lower capacity. Therefore, it is not possible to optimize coverage and capacity at the same time. But with management, it can optimize perfectly.

Call drop rates give a first indication of areas with insufficient coverage and traffic counters identify capacity problems.

To resolve these aspects:

- Optimization of the coverage holes inter-RAT.
- Settings of the antenna parameters, the power level of the transmitter and the parameters related to the radio.

In order to update the parameters, which are used to implement and operate the system. By minimizing time and human intervention in network management and optimization tasks, reducing feedback delay and interference levels between cells and improving the signal level and quality.

- Mobility Load Balancing (MLB): Function where the cells that suffer congestion transfer their load to the neighbour cells that have spare resources, through the optimization of cell reselection / transfer parameters. Adjusting the control parameters of the network and performing a load balancing to alleviate and even avoid certain problems, trying to level the data access points as much as possible.

Therefore, the load balance seeks to achieve a load balance between neighbour cells, a greater capacity of the system, efficient and effective management of the network for optimal performance, minimal human intervention and an improvement of the user experience.

Avoiding in this way, cell overload, the resulting performance degradation and Ping-Pong transfers when trying to balance the load.

- Mobility Robustness Optimization (MRO): This function adjusts the parameters when a transfer failure occurs and attempts to minimize the risk of loss of the radio connection due to mobility. In some cases, RRM can detect problems and adjust mobility parameters, but sometimes it cannot solve certain problems. However, MRO can automatically adjust the mobility parameters in those cases that RRM cannot do so.

Configuring the handover (HO) and cell reselection parameters to dynamically improve handover operations within the network, providing a better experience to the end user and improving the capacity of the network. Also, reducing the number of transfers between activated round trip, that is Ping-Pong, and unnecessary transfers. Minimizing call drops, radio link failures, idle mode problems, manual task, time consumption and complexity.

- Energy saving (ES): Mechanisms to save on operating expenses through energy savings, to minimize energy consumption in telecommunications networks. From cuts, as long as the capacity offered by the network matches the necessary traffic demand.

There are several options that can be implemented to provide a network of automatic energy optimization:

a) Turn off the cells during periods of low traffic and thus increase the coverage.

b) Adjust the transmission parameters of the neighbour cells to ensure coverage in the areas where the cells were off.

c) Adapt the schemes of multiple antennas (single antenna, Single Input Multiple Output (SIMO), MIMO, beam formation).

d) Design low-power network elements.

e) Put base stations in suspension mode and increase the coverage of others. From the use of modems that consume a reduced amount of energy.

f) Use the local generation as a source of energy, avoiding the use of the electricity grid.

g) Reduce the number of carriers that are active for the hours of least activity.

This will cause a reduction of OPEX and allow sustainable development in the long term. In order to achieve this, the user experience will not be affected, carbon dioxide emissions will be reduced, energy savings will not result in service degradation or incompetence of the network and solutions will not impact the physical layer.

These energy savings are achieved in user equipments, in telephones and in the network, but with different strategies for each case.

- Inter-Cell Interference Coordination (ICIC): Function to reduce or avoid interferences between the cells, from a coordinated use of Physical Resource Blocks (PRB)s. Through the integration of multi-user programming in the operation of the network, the allocation of channels based on geographical location using neural networks and through restrictions and preferences for the use of resources in the different cells and RRM mechanisms related to ICIC.

It could improve the capacity, deactivating the cells that are not necessary for the traffic at some time. Achieving greater quality and performance, a minimization of human intervention in time and frequency dimensions and high satisfaction for users.

- Random Access Channel (RACH) optimization: This function optimizes the RACH parameters to minimize the number of access attempts on the RACH channel. Always keep in mind that when the RACH is heavily loaded, the probability of collision and interference increases. And it affects network configurations and performance, such as antenna tilt, transmission power and handover threshold.

The RACH optimization can be done by adjusting the Power Control (PC) parameter or changing the preamble format. In this way, a positive impact on the capacity and coverage of the system is generated, access delays are reduced in different cells and interference is minimized. Providing a reduced connection time and greater performance with little or no human intervention.

5.2.3. Self-Coordination

To ensure stable network operation, preventing and resolving parametric potential conflicts that arise when multiple individual SON functions intervened in the same network [21]. But keep in mind that the possible complexity of the 5G network could hinder the analysis of potential conflicts and the design of a self-coordination framework. Therefore, it is essential that 5G automatic coordination be organized from the beginning in the design of SON functions.

5.2.4. Self-Protection

Use case related to automated security. System to defend itself against active or passive attack and countermeasures (e.g. creation fake networks), and so avoid any unauthorised user detection [22]. Getting in this way, that security of the system is unbreakable, and the data is confidential and secure. From the monitoring of network communications to the analysis, detection, and mitigation of potential cyberattacks conducted by a botnet and countermeasures. Therefore, it protects the network resources in a flexible and autonomous way, providing at all times, information in real time.

5.2.5. Self-Healing

Features that are used to overcome temporary bottlenecks during the network operation [18]. When the network detects and localises anomalies in itself and applies automatic healing mechanisms to mitigates or solves them by different algorithms or adjusting parameters. And in this way, it ensures insignificant degradation of service performance for the users and reduces maintenance costs without impacting network reliability. Although this can result in a loss of income for the operator, many of these problems can be solved, but a quick response is required once the fault is diagnosed to ensure that the network can return to its pre-fault condition. Therefore, with this fast implementation, these automated means are required, since it is not feasible to adjust it manually.

This subfunction has a series of specifications [19]:

- Self recovery of software: When due to a defective software failure, it is necessary to return to the previous software version in order to restore the configuration again.

- Self-healing of board faults: To recover failures of the circuit board, in case it is necessary to change it.

- Cell Outage Management. This use case is divided in three main functions:

a) Cell Outage Detection: Remote detection of interruptions of cells or sleeping cell effects, through the monitor performance indicators, in order to be able to take countermeasures.

b) Cell Outage Recovery: Routines to help with cell recovery. Including the detection, the diagnosis, the solution and a report of the affected action.

c) Cell Outage Compensation: Methods to maintain the best service to users while repairs are effected. Adjusting the appropriate transmission parameters so that the fault is immediately detected, and the impact quantified by entering the compensation.

- Return from cell outage compensation: Action to return to the state before the failure, removing any compensation action that has been initiated.

- Cell degradation: For the detection and management of cell degradation. With the help of different alarm indicators for hardware and software failures.

6. Methodology / project development

This section mainly describes the procedures of the two selected application examples (New RAN slice activation and Capacity expansion of a RAN slice), in which the use of SON functions will be exposed. In addition, it will also see the SON functions that can be used in other situations and which state it resumes once the specific service provided has been completed. And finally, it will find the parameters involved in the algorithms of each SON function. All this will be accompanied by functional diagrams.

6.1. Reference deployment

At this point, the functional operation of an NG-RAN infrastructure with RAN slicing support is exposed, where it is started to use automated functions.

6.1.1. Deployed hardware infrastructure

First of all, it should be noted that a reference configuration of a RAN infrastructure deployment with RAN slicing support has been considered. To build on it, for the different changes that are going to be produced.

• **Considerations:** It rely on the participation of the Network Slicing concept, which allows mobile virtual network operators, suppliers and vertical market players in the industry, to request and lease resources from infrastructure providers dynamically through of portals. This concept comes from the increase in the use of Software as a Service (SaaS), since it has the characteristic of allowing a single instance of software to serve the same application to many clients (multi-tenant) and to many users, in order to distribute the cost of infrastructure and maintenance among all. Allowing for each tenant, that you can customize your particular services. And thanks also, to the intervention of the sharing of networks, from virtualization mechanisms and capabilities based on software.

It is considered hypothetically that the city of Barcelona wants to give access to different services (later specified) at a specific point in the city, where every day, many IoT are connected to the internet. Therefore, a customer technician, through a web page that provides an operator, configures the desired needs for that particular point.

If they are approved (in this case yes), this client establishes a written agreement (Service Level Agreement (SLA)) with the neutral operator, who offers RAN Slicing services to different external service providers that have 5G backbone networks, such as traditional Mobile Network Operators, private network operators and Service Providers

(SP)s specialized in different sectors. In the agreement, a point of common understanding is defined on the levels of characteristics of the service and the set of associated indicators, which guarantees specific levels of performance and reliability at a determined cost. Specifically, the document establishes the parties involved, the terms of the agreement, the fees, the arbitration policies, the modification terms, the reports, the responsibility of both parties, the workloads, the use of resources, etc.

The service features that the technician has requested are:

- A network segment of the geographic scope, that is, the area where the service is provided, with some associated coverage metrics in terms of km^2 and dBm.

- A network segment of the temporal scope, that is, definition of the moment in which the service must be provided (start time, end time, periodicities ...).

- A network segment of the capacity, in terms of global aggregated values (which, in this case, is the total aggregate bit rate in Mb/s). However, more detailed conditions can also be established at a temporal level (maximum Mb/s that can be offered within a certain time window), at a spatial level (maximum Mb/s in a certain area), or at the user level (aggregated UEs and the maximum bit rate). And they can be more specific in terms of the number and characteristics of the radio access bearers [23].

- A network segment that adapts to mobile broadband services, in terms of MHz.

- A network segment of peak transmission velocities (Mbps).

- An automotive network segment in which the latency is less than 1ms with reliability levels at a small bit error rate, in order to allow for shorter transmission times.

- A network segment of the service availability, in terms of percentage of time that the service should be available for the tenant.

- A massive Internet of Things network segment where scalability is essential to efficiently handle huge amounts of small data [24].

- A maintenance network segment of the network equipment, for service interruptions.

- And agreement on other attributes of the service, such as billing, resources, behaviour and security.

The procedure of the demand and the guarantees that it offers is as follows:

Once the client has requested the services, the portal receives the information of the service orders, it collects the information of the installations for the client of the facilities management system, it creates the information of the SLA subscriber, it breaks down the information on the opening quality and it creates the registration information. The provider then receives the subscription information about the customer from the service order system, supervises it and, if possible, accepts it. Later, with the intervention of the functions monitored again, the process of opening the service begins, warning of the violation danger of the opening quality and calculating the amount of fee to compensate if it is necessary, for not offering of all agreed quality [25]. Always bearing in mind that each of the services has the specific processing functions of the service regarding the opening of the service.

On one side, customer assistance and the problem of assistance is guaranteed, and therefore the time of resolution when it comes to a failure or interruption of services (in general, incidents will be classified according to a certain level of priority). From the automated supervision function of the fault resolution process, where the procedure is as follows: First, it supervises the threshold level and the service quality measure. If it is incorrect, it receives the fault information from the service failure management system. Next, the monitored process repairs it, and it warns about the violation of the quality of time problem resolution. Once finished, it communicates the information on the completion of problems recovery and creates the information of registry, storing it in the history. But also, if there is a possibility of a violation, it inserts a warning message to the operator.

On the other hand, in front of unforeseen scenarios, the quality of the communication is guaranteed, from a threshold that specifies the performance of the service network. Where the function receives the information over the quality of the client's communication from the performance management system. The monitored process manages the quality of the communication, it warns about the violation of the quality of the communication, it determines the information, it modifies the parameters involved and creates the registration information [26].

The parameters automatically modified are: the capacity, the bandwidth, the velocity, the latency, the transfer delay, etc.

In this way, under unexpected scenarios, the tenant buys shares of resources that it consumes instead of paying for the number of requests it sends. At the same time, it gives the provider the opportunity to increase its economic benefit.

In addition, it also intervenes, the service level data analysis process, which collects the QoS data from the network management system, NMS and the network performance data stored in the database, generating statistical data for the operator or user, to process SLA functions.

In this way it is possible to define the needs of the client while controlling their service expectations, in order to simplify complicated matters, reduce conflict areas and favour dialogue in a dispute. Constituting a point of reference for the process of continuous improvement, increasing the level of quality for that service, the determined scope, the level of the performance of a process (KPI)... And thus, get the client satisfied.

But if the level of service provided is below the contract, the client will demand compensation to the service provider. Since the client will be able to evaluate if the provided services are the suitable ones, from different metrics, that will be able to find in the web portal.

In the web portal, you will find service quality factors to evaluate the guaranteed service and methods, to compare the value contracted with the data collected from the network, and evaluate the defined service level objectives. And also, when a breach occurs at the service level, in order to manage the activity of the operator and adjust the billing, calculating the payment method agreed with the customer. In addition, service level improvements will also be reflected, if when analysing the service level data and the list of devices, there are devices or processes to be improved.

And in this way, through the web page, to be able to check with the service level reports according to the client, the administration region and the user's concerns, if what is communicated, is the correct thing, or has to claim the agreed and contracted QoS. Also, it can be said that the client can request changes to its SLA, but it is under the approval of the provider.

Finally, it is important to note that the agreements refer to the services that the user receives, but not to the way in which the provider offers that service.

Given the service requested, it chooses to deploy the following NG-RAN infrastructure with RAN Slicing support:

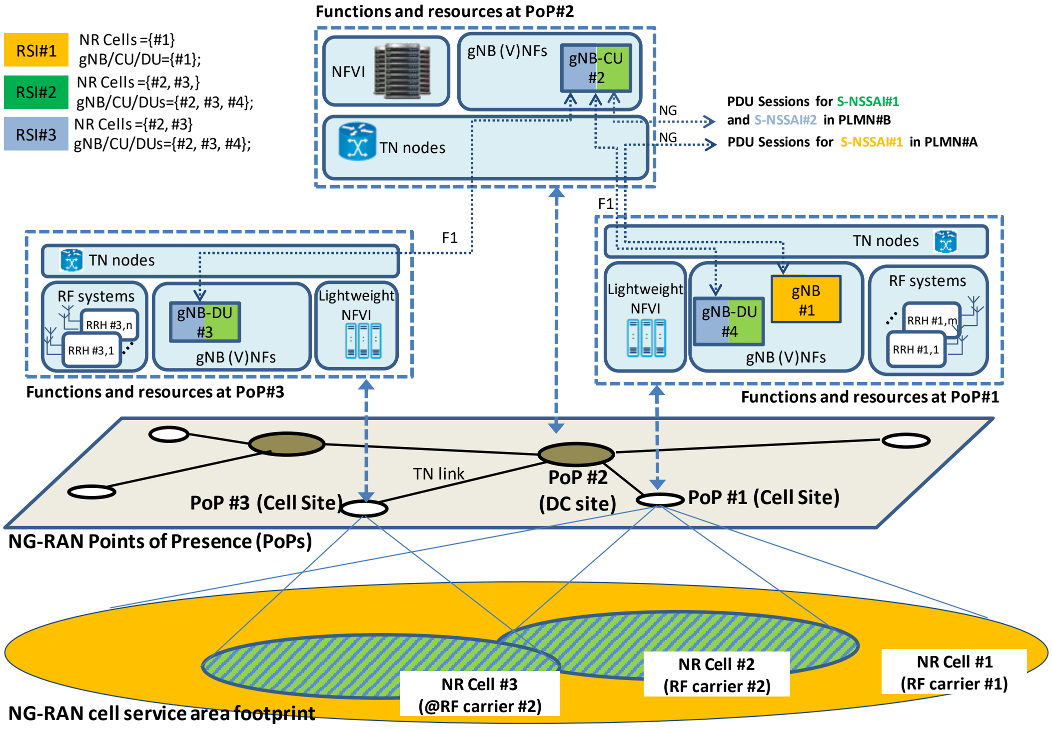

Figure 6.1: *Reference deployment with RAN Slicing management [11]*

As it can see, it is based on three points of presence (PoP)s, where in each of them are located antennas and Radio Frequency (RF) systems, radio equipment, Transport Network (TN) equipment, platforms computation and different functions that will been see throughout this procedure. In addition, each one of them has assigned Network Functions Virtualization Infrastructure (NFVI) and its Network Functions Virtualization, standardized interfaces: Interface-North (Itf-N) and different network functions of the new NG-RAN for the interaction with the UE named Next generation NodeBs (gNB)s. Where gNB-CU is functionally decomposed into a gNB Central Unit and gNB-DU into a gNB Distributed Unit.

• **Functions involved:** Before obtaining the previous illustrative scenario, a series of functions have intervened:

First, the written agreement between the tenant and the service provider about the service that will be offered. Next, the deployment of all the agreed systems, activating the points of presence with all the elements involved and the assignments of the frequency channels. Including computing platforms with general purpose hardware (NVFI), Network Services (NS)s, Physical Network Functions (PNF)s and Virtualized Network Functions (VNF)s.

And finally, the start-up of the computer program Graphical User Interface (GUI) and the Application Programming Interface (API) of the infrastructure deployed.

• **Result:** The scenario with which it will work to solve the applicatives examples has been obtained.

• **Lifecycle:**

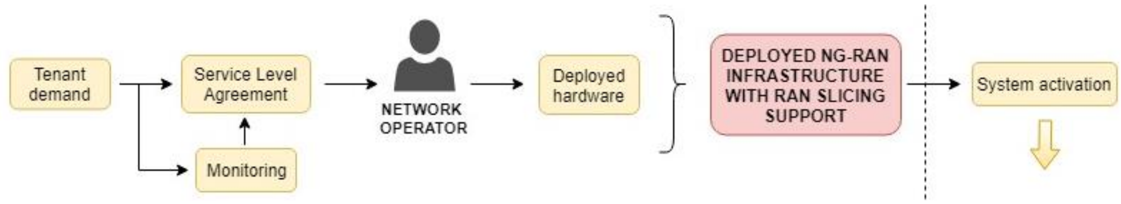

Figure 6.2: *Functional model of the infrastructure*

6.1.2. Pre-operative phase

In this section, it will describe all the functions involved just after activating all the hardware systems required when deploying an infrastructure.

• **Considerations:** On the basis of the previous reference infrastructure. With the intervention of the NOP, three different RSIs are created, in accordance with the established requirements. It is considered that RSI#1 is configured for mMTC services through a 5GC private network. However, RSI#2 and RSI#3 offer the same 5GC public network. But RSI#2 is used for the provision of Enhanced Mobile Broadband services to individuals and companies and RSI#3 for Mission Critical (MC) services for agencies in the Public Protection and Disaster Relief (PPDR). In addition, RSI#1 is appropriate for IoT SP requirements to connect multiple and diverse IoT devices, with a very low traffic demand. On the other hand, RSI#2 and RSI#3 have a configuration based on requirements of transfer velocities and a higher traffic demand [11]. As it can see in figure 1, with the deployment of multiple micro cells (NR Cell#2 and #3).

• **Involved functions:** Manual and automated functions come into play.

It begins by configuring the descriptors (RAN Slice Template) and, in turn, each RAN Slice Instance (RSI) with their respective cells, through the intervention of traditional network management functions:

First, network planning is done, modelling and dimensioning the cells. Secondly, it has the provisioning management application, which is when the operational parameters are configured. From the intervention of the functions of Radio Resource Management:

- Spectrum Planning: It organizes the spectrum resources in the carriers and assigns these carriers to the different cells. And it controls parameters such as transmission power, user assignment, beamforming, data rates, handover criteria, modulation scheme, error coding scheme...

- Radio Bearer Control (RBC): It involves radio resources associated with the establishment, maintenance and release of radio carriers.

- Connection Mobility Control (CMC): It manages radio resources in connection with in idle or active mode mobility. In this case, in inactive mode, where the module defines criteria and algorithms for cell selection, reselection and location registration by setting parameters.

- Dynamic Resource Allocation (DRA) or Packet Scheduling (PS): It allocates buffering and processing resources to user and control plane packages.

- Inter-Cell Interference Coordination (ICIC): It manages radio resource blocks to keep inter-cell interference under control.

And also, the different subfunctions of Self-Organizing Network:

- Self-Configuration:

- Automatic configuration of initial radio transmission parameter: It configures the dynamic radio (DRC) of certain elements such as cell identification, emission power, transmission frequency and antenna tilt configuration to provide the necessary capacity and coverage.

- Automatic Neighbour Relation (ANR): It automatically configures neighbour relationships to measure, detect, inform, manage, add, delete, optimize and update cells.

- Automated Configuration of Physical Cell Identity (PCI): It automatically configures the identity ID of each physical cell, which is needed to create the list of neighbouring cells.

- Automatic connectivity management: When the new base station, automatically connects to its domain management system.

- Self-test: It performs a self-test to guarantee the correct functioning of the equipment before activating the final service.

- Automatic inventory: It performs an inventory verification before continuing, as each base station will have a certain adjustment depending on the capacities it requires. This activity includes aspects such as the identification of the installed hardware boards, the software level, the antennas...

- Self-Coordination:

Activation of this mechanism to coordinate the operation of multiple individual SON functions in the same network, to prevent or resolve possible conflicts.

- Self-Protection:

Activation of this function to protect the resources of the network in a flexible and autonomous way, of possible active or passive attacks and countermeasures. Providing at all times, information in real time.

• **Result:** Configuration of all the functions involved in this pre-operational phase, after activating the necessary systems to start up the infrastructure. With the participation of the RRM functions and the automated ones.

• **Lifecycle:**

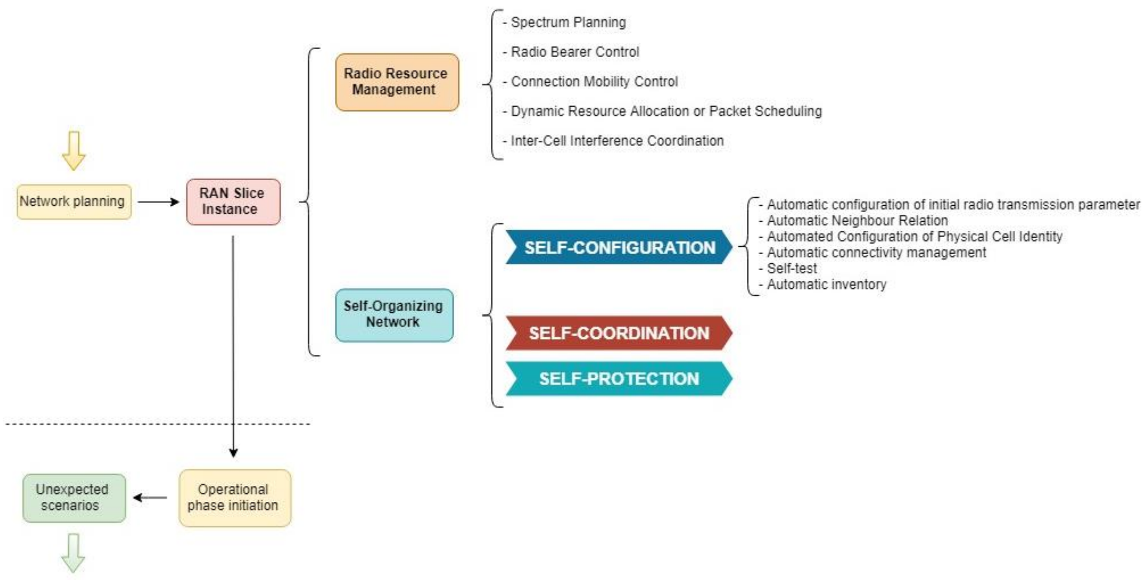

Figure 6.3: *Functional model of the pre-operative phase*

6.2. New RAN slice activation

Once the network is operational, the need arises to cover the first service demanded.

• **Considerations:** At one point, there is a need to provide access to a driver assistance service (new tenant) for road safety, in the sector of all cars that incorporate Car Connect. That requires little added capacity, but a very low latency of message delivery. Therefore, access to another specialized IoT SP must be provided. In addition, it has its own private 5GC network (PLMN#C) to expand the coverage of its services to the area where the

RAN manager has deployed the access infrastructure. Therefore, it is necessary to deploy a new RSI, as can be seen in the illustrative scenario below:

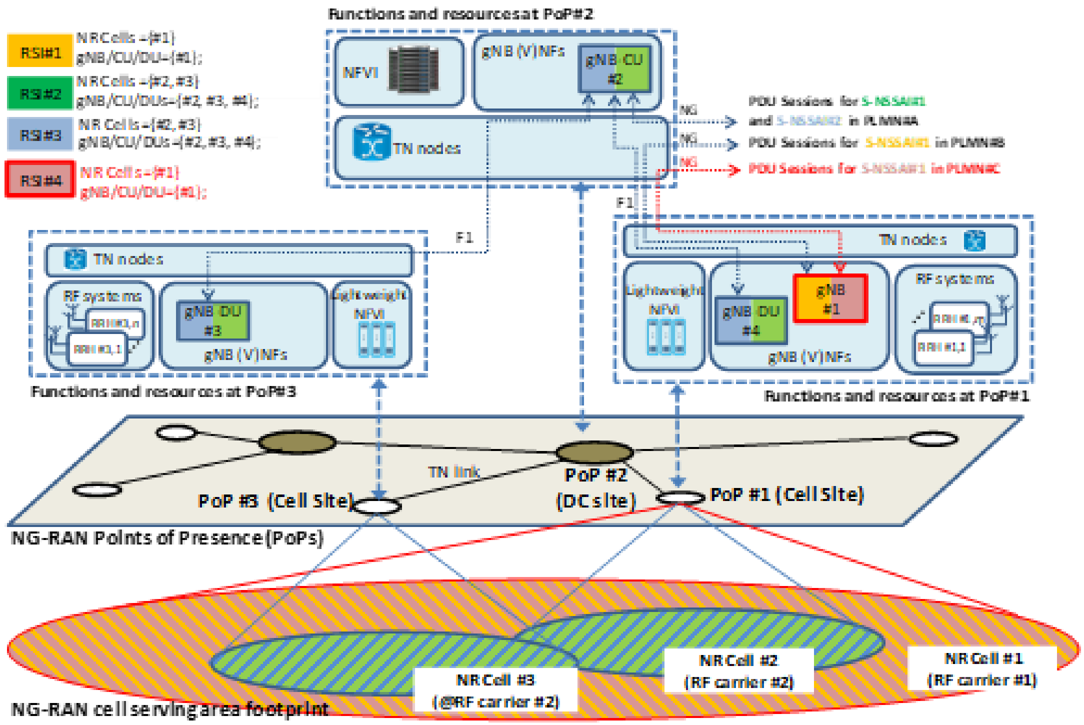

Figure 6.4: *New RAN slice activation [11]*

The changes with respect to the first image are highlighted in red, where it looks the new creation of RSI#4. And consequently, the reconfiguration of the gNB#1 functions that have been involved. In this way, cell NRCell#1 is enabled to provide access to the terminals of both SP IoTs.

• **Functions involved:** Next, all the participant functions will be related when the new RAN Slice is created:

It starts with a prior agreement between the NOP and the traditional mobile operator to formalize the SLA requirements. And it is provided access to another specialized IoT SP.

Then, by the NOP, the descriptors are created (RAN Slice Template). And through the provisioning interface, the new RAN slice (RSI#4) is created. Using the network planning capabilities with support for RAN slices modelling, integrated into the Network Management System (NMS) to determine, for example, the coverage and capacity provided by NR Cell#1 suitables for the provision of the service. Although the latency needs of the new application require that cell NR Cell#1 also operates with numerology (i.e. separation between subcarriers) that allows transmission times lower than those currently supported. The steps to follow are:

- Reconfiguration of gNB#1 functions to support the new numerology of low latency.
- Provisioning of the new network identifiers and slice (PLMN#C and S-NSSAI#1). With the intervention of the Radio Resource Management function:

- Radio Admission Control (RAC): It admits or rejects requests for the establishment of new radio carriers, ensuring high utilization of radio resources.

- Establishment of the relevant resource partitioning between RSI#1 and the new RSI#4 [11].

Next, the subfunctions of Self-Organizing Network intervene again:

- Self-Configuration:

- Automatic Neighbour Relation (ANR): It automatically reconfigures neighbour relationships to measure, detect, inform, manage, add, delete, optimize and update cells.

- Automated Configuration of Physical Cell Identity (PCI): It automatically reconfigures the identity ID of each physical cell, which is needed to create the list of neighbouring cells.

Subsequently, cell NR Cell#1 is enabled, to provide access to the terminals of both SP IoTs and changes are made in the propagation characteristics, in the traffic patterns and in the implementations. And with the intervention of the following subfunction, the performance of the network is managed, monitoring the KPI and the network:

- Self-Optimization:

- Energy saving (ES): Mechanisms to save operating expenses through energy savings, to minimise energy consumption in telecommunications networks.

- Inter-Cell Interference Coordination (ICIC): It minimises interference between cells that use the same spectrum.

- Random Access Channel (RACH) optimization: It optimizes the RACH parameters to minimise the number of access attempts on the RACH channel.

• **Result:** Compliance with the application demanded, mainly through the parameters of the network planning.

6.3. Capacity expansion of a RAN slice

In another moment, the need arises to solve the second scenario.

• **Considerations**: Now, it assumes that in the geographical area where the infrastructure is located, there is a need to expand the capacity of RSI#2 during a given period of time. To cover a specific need for the eMBB service, which requires a high data rate through a wide coverage area. The scenario is as follows:

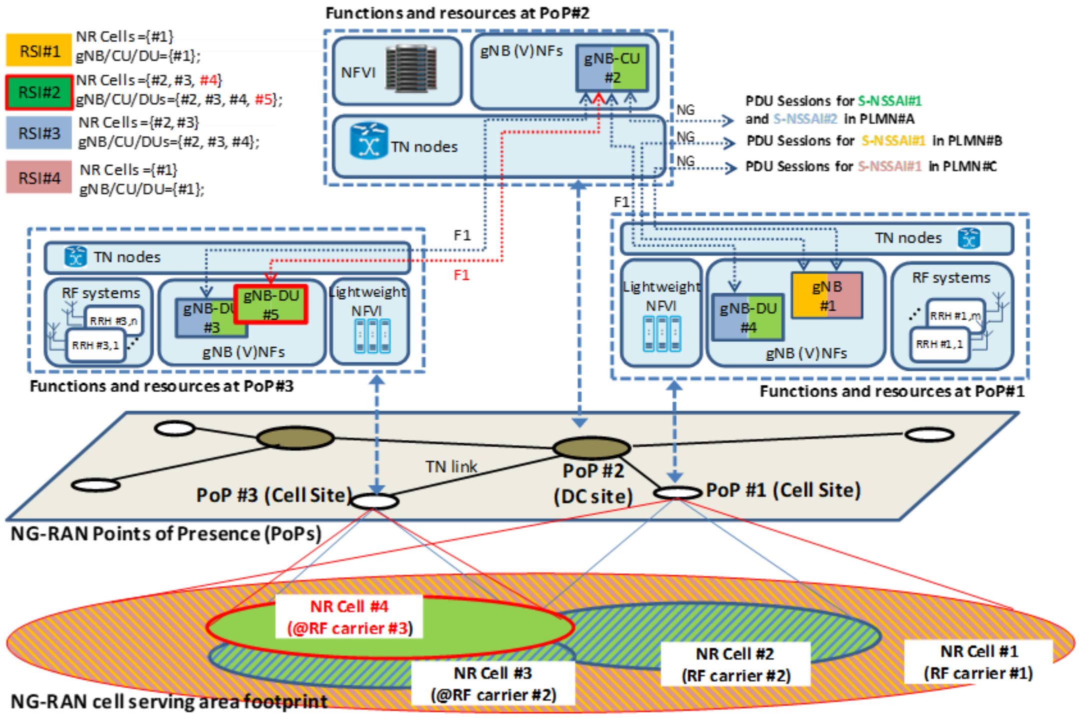

Figure 6.5: *Capacity expansion [11]*

The main changes that entail are: the deployment of a new cell (NR Cell#4) together with a new gNB-DU#5 in PoP#3 and a modification in RSI#2.

• **Functions involved:** Below, all the participant functions will be described when the capacity is expanded:

With the activation of RSI#4, the first step is the network planning process by the NOP to determine the most feasible implementation.

Then, the capacity of RSI#2 is expanded, the new cell is deployed (NR Cell#4) and it creates the new gNB-DU#5 in PoP#3 with the integration of gNB-CU#2 and the new frequency channel.

Later, through the provisioning interface, the RAN Slice Template associated with RSI#2 is modified by the NOP. And immediately, the Management and Orchestration (MANO) functions begin to act for the provisioning procedure that involves [11]:

- The modification of Network Services (NS)s and VNF.
- The interconnection of the new gNB-DU.
- The configuration and activation of the new NR Cell#4.
- The intervention of the subfunction:
    - Self-Optimization:

- Coverage and Capacity Optimization (CCO): It re-adapts parameters such as antenna tilt, transmitter power levels and the like, to maximize coverage while optimizing capacity, ensuring that interference levels between cells are minimized.

- And the possible reconfiguration of some radio parameters in the already existing cells. As it could be the case of:
    - Self-Configuration:

- Automatic Neighbour Relation (ANR): It automatically reconfigures neighbour relationships to measure, detect, inform, manage, add, delete, optimize and update cells.

    - Self-Optimization:

- Mobility Load Balancing (MLB): When cells that suffer from congestion, transfer their load to neighbouring cells that have spare resources, through the optimization of cell reselection / transfer parameters.

- Mobility Robustness Optimization (MRO): It adjusts the parameters when a transfer failure occurs, and it tries to minimize the risk of loss of the radio connection due to mobility.

And on the part of the RRM functions:

- Connection Mobility Control (CMC): It manages radio resources in connection with in idle or active mode mobility. In this case, in active mode, where the module manages the mobility of the radio connections without interrupting the services.

- Load Balancing (LB): It manages the uneven distribution of the traffic load over multiple cells.

- Inter-RAT Radio Resource Management (IRRRM): It manages radio resources in relation to inter-RAT mobility.

• **Result:** Compliance with the application demanded, mainly through the Coverage and Capacity Optimization function of the Self-Optimization subfunction.

• Lifecycle of both examples:

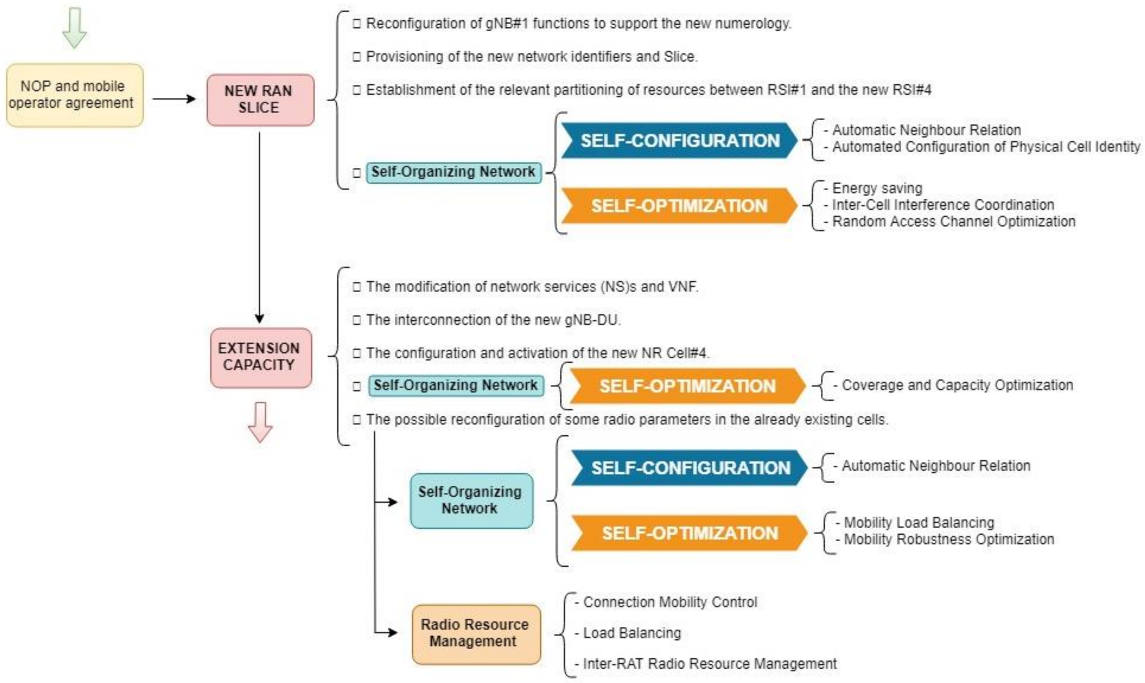

Figure 6.6: *Functional model of the two scenarios*

6.4. <u>Other hypothetical situations</u>

During the services provided, there may be obstacles in the functioning of the infrastructure. Therefore, it will be showing a series of automated functions that allow solving these situations, without the need of the network operator.

• **Considerations:** All the automated functions not mentioned above are shown, which have been approved so far for the 5G network. And so, it allows operators to cope with the diversity of unforeseen 5G scenarios.

• **Functions involved:** Without taking into account the functions already seen in the previous points, it also has the following subfunction of SON, which manages the faults that may occur:

- Self-Healing:

- Self recovery of software: It allows to return to a previous version of the software if problems arise.

- Self-healing of board faults: It recovers the faults of the circuit board, in case it is necessary to change it.

- Cell Outage Management:

  - Cell Outage Detection: It detects remotely when there is a problem with a particular cell.
  - Cell Outage Recovery: It helps with cell recovery, including detection, diagnosis, solution and a report of the affected action.
  - Cell Outage Compensation: It maintains the best service for users while repairs are made.

- Return from cell outage compensation: It returns to the state before the failure, eliminating any compensation action that has been initiated.

- Cell degradation: It detects and manages cell degradation.

And finally, it may be the case that the quality of the link is insufficient, so that the Handover process would be used to transfer the connection of the source base station to the destination base station, in order to avoid interruption of the user's communication service.

• **Result:** Resolution of hypothetical conflicts based mostly on automated functions. Giving a personalized service to diverse applications and service providers.

• **Lifecycle:**

Figure 6.7: *Functional model of other scenarios*

6.5. <u>Return to the operational phase</u>

Once the time period of the claims has elapsed, it returns to the operational phase of the infrastructure, to be prepared in case a new situation arises to resolve.

• **Considerations:** When the specific services have been complied, it comes back at the end of the second phase, which is when the infrastructure has all its systems activated and it is ready to operate.

• **Functions involved:** Series of functions to return to the previous characteristics, before having to solve the demanded applications:

Once the time has elapsed, the new RSI is disabled and network and VNF services are removed. And consequently, the parameters of the RSI#2 and all the parameters involved are reconfigured. With the intervention of the subfunction,

- Self-Configuration with the following functions:

- Automatic configuration of initial radio transmission parameter: It reconfigures the dynamic radio (DRC) of certain elements such as cell identification, emission power, transmission frequency and antenna tilt configuration to provide the necessary capacity and coverage.

- Automatic Neighbour Relation (ANR): It automatically reconfigures neighbour relationships to measure, detect, inform, manage, add, delete, optimize and update cells.

• **Result:** Restoration of the characteristics of the network, just when the infrastructure is deployed with all the systems activated.

• **Lifecycle:**

Figure 6.8: *Functional model of the last phase*

Finally, it can summarize the procedure in four phases, as it can see in the following block diagram:

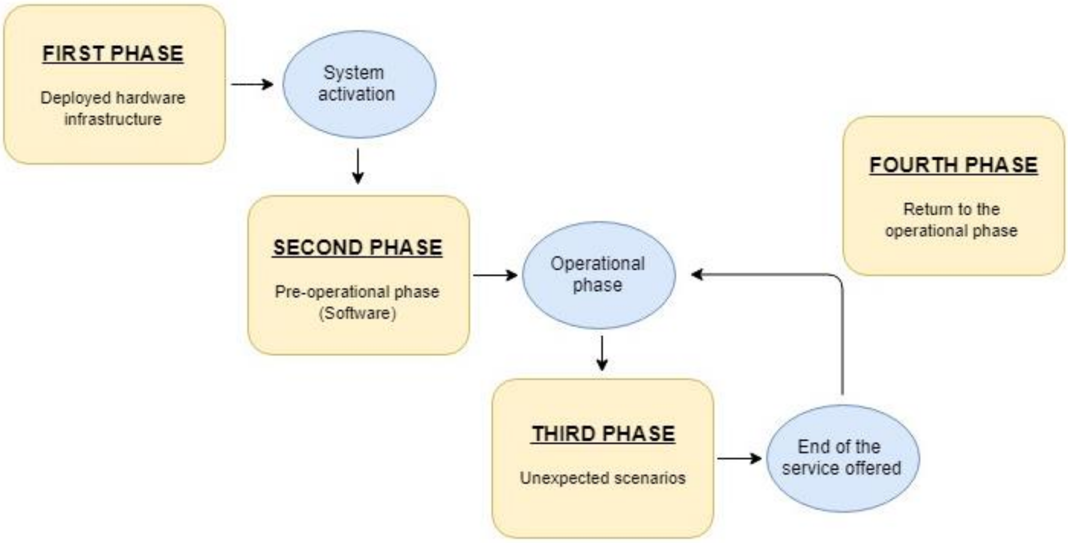

Figure 6.9: *Global functional model*

In this scheme it can be seen the interconnections between each phase, that is, the total lifecycle of a network.

6.6. <u>Parameters involved in the algorithms</u>

In this section, it will see the parameters that will intervene in the algorithms of each SON function, which will be accompanied by a small scheme each one. As also, the parameters that will be shared between the functions, and the main objects of a radio network (the base stations, their cells and cellular relationships) that will participate. But it must bear in mind that it is based on the concept of the parameter, not on the type of measure that each function considers.

- <u>Planning parameters</u>:

Before the SON functions interventions, acts the planning of the radio access network that defines the design criteria between the base stations and the user terminals, in an automated way.

Specifically, it determines the theoretical coverage plans (according to the geographic region demanded) and the capacity of the radio channel (according to the estimate of the number of users that each base station will have) [27]. In addition, it defines the frequency plans and the positions estimation that will be involved. Obtaining the service areas of each base station and the interaction control between adjacent base stations. From propagation calculations, to be able to estimate the power and interference levels, the transmission velocity and other values of the radio parameters [28]. Although possibly later, with the activation of the network, the parameters of radio resources are restored in front of specific scenarios.

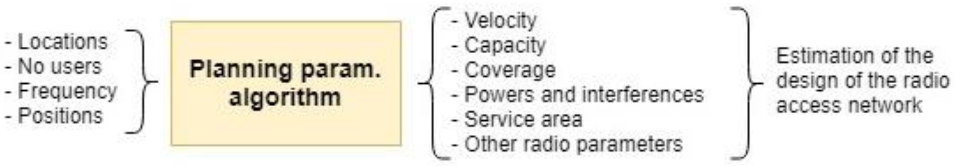

Figure 6.10: *Planning parameters scheme*

- Self-Configuration:

Remember, that the automatic configuration functionality configures the base station and the radio parameters to be compatible with the network configuration.

- Automatic Neighbour Relation:

It is increasingly difficult to organize the neighbour cellular relationships of the network. Therefore, it is necessary to create and automatically update lists of relations of neighbouring cells, according to the measured data of the network, to allow the transfer between cells and the optimization of the performance of the network.

It is obtained from the ANR performance rate, which indicates the tracking of the network evolution and finds problems that occur over time. In addition, it also finds potential problems that may occur in the future, with the help of pattern learning [29].

For the generation of the list of neighbours, a series of parameters are taken into account. Some of the most important are the cells identifiers (CGI and PCI). Cells Global Identity (CGI) are unique and constant over time, but they are more difficult and require more time to detect. In contrast, the Physical Cells Identity (PCI) are easier to detect, but they can vary over time, since they must be unique in a region and may need to be changed. On the other hand, it has the records of the average values of the power and interference of all the signals that are received from all the neighbouring cells, since it is important to detect power shortage in certain cells by factors such as distance, the frequency and the locations between the different neighbouring cells. And so, after grant a priority range to the neighbour relationship between the source cell and the neighbour cell candidate in terms of signal strength. Therefore, it must be taken into account the number of cells, the maximum number of neighbouring cells for the service cell, the service cell, the neighbouring cell, the radius that limits the neighbouring establishment, the coverage marks of the cells and the number of incoming and outgoing pass-through faults [30]. And last but not least, the partial route loss compensation function to mitigate the disadvantage of the destination cells located in the area of lowest cell density.

With all this, the result that is obtained is a list of relations of the neighbouring cells where the benefits are quantified in terms of SINR. To achieve quality, mobility and better service for users, from deliveries of added or deleted cell relationships and PCI changes for detected conflicts, mainly.

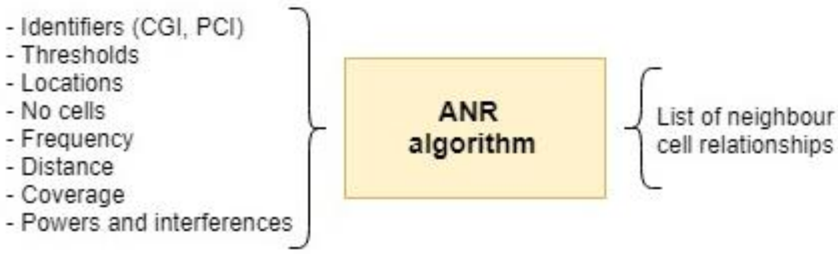

Figure 6.11: *ANR parameters scheme*

❖ Automated Configuration of Physical Cell Identity:

The planning of PCI is one of the most essential parts of the autoconfiguration of a radio cell, due to its significant role in the search of cells and in the creation of synchronization signals.

The parameters to be used to carry out this assignment are: the weight of each cell, the reference of time and frequency, the number of cells in the network, the number of groupings in the network, the number of cells in a group and the number of neighbours in each cell. Which is nothing more than the list of relations of neighbouring cells. On the other hand, it is necessary to consider the transmission power of the cell, the reference signal power received from the cell, the distance and the shortest route between each pair of cells, the path loss and the fading [31].

In order to form groups of cells according to the results of the PCI assignment. Always trying to reduce the interferences due to the reuse of PCI in different cells, and thus save on the consumption of PCI. When you enter or delete a cell in the field for example, since you must select a PCI for each of its compatible cells, avoiding collision with the respective neighbouring cells.

Achieving with this automatic PCI allocation, good performance and a compromise between reducing interference and increasing the reuse of PCI. In addition, operating expenses for PCI allocation can be reduced while increasing optimization and the network stability. And a better user experience is provided.

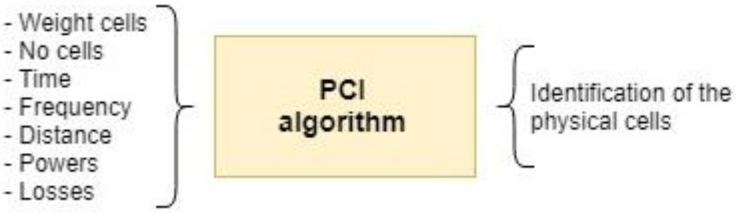

Figure 6.12: *PCI parameters scheme*

➢ Self-Optimization:

Automatic optimization ensures that all operations are fully optimized.

❖ Coverage and Capacity Optimization:

One of the most important and used functions to improve the performance of the network, is the Coverage and Capacity Optimization. In addition, it is one of the biggest challenges faced by mobile network operators (MNO), which is the exponential increase in demand for capacity and better coverage.

Call drop rates give a first indication of areas with insufficient coverage and traffic counters identify capacity problems [32].

To be able to carry out this function SON, a series of parameters are needed:

First, the service traffic differences between the base station (BS) source and other neighbouring BSs are controlled and the cell with the worst performance is detected from a performance metric composed of different KPI elements, such as the performance average normalized cell, the spectral efficiency, the average energy per bit and the occupation of resource blocks [33]. In addition, it is necessary to take into account the average coverage and capacity coefficient, the coverage area (km^2) reached, the type of antenna, the antenna gain pattern, the number of cells, the noise figure, the path loss of the user x which depends on the distance between the user and the base station, the frequency, the total bandwidth, the height of the base station and the power of the received signal to evaluate the performance of the coverage and for the capacity [34]. Also, the user's performance and the resource occupancy index of the cell, the number of users with their velocity and distribution and the normalized data transmitted at time x are used to be able to adequately adjust the parameters. Once the possible adaptations of the power level of the transmitter have been made, the parameters related to the radio and especially the configurations of the antenna parameters (in particular, the adjustment of the inclination of the antenna and the azimuths of the neighbouring cells since the radiation pattern of the antenna and the directivity are directly related to the power of the received signal, and therefore, to the signal-to-noise ratio (SNR)) of the worst performance cell, the optimal parameters are obtained [35]. Based on the optimal performance indicator for all the cells examined.

It must bear in mind that the cellular environment is highly dynamic and constantly changing (such as the density of users, traffic and propagation characteristics), therefore, self-optimization is a significant impact on the quality of service of the users. So, it has to be covered constantly users in neighbouring BSs until all users in each cell can achieve the performance requirement. In order to get increase the capacity of the cells and the performance of the users and improve the area of coverage for the cells.

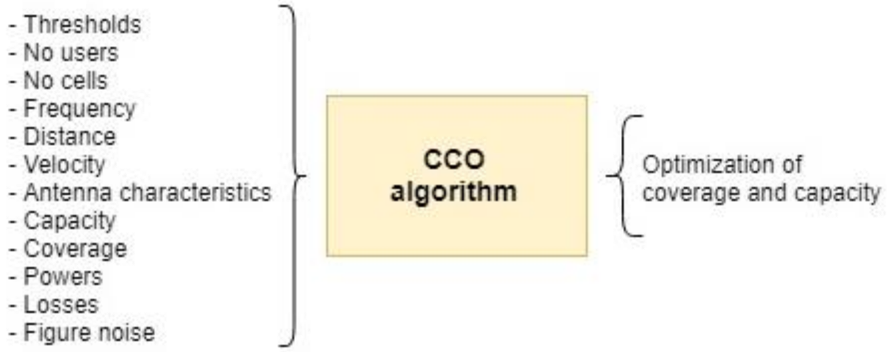

Figure 6.13: *CCO parameters scheme*

❖ Mobility Load Balancing:

Its objective is to solve the problem of the lack of homogeneity in the distribution of traffic over time and space, which results in congestion of the local network and waste of resources. Sharing the traffic demand between the neighbouring cells through the modification of their parameters [36]. But it must bear in mind, that the application of MLB and the Mobility Robustness Optimization (MRO) of the systems (which will be seen in the next point) influence each other.

To solve this problem, the following transfer parameters intervene:

First, a load threshold acts, which detects the unequally distributed loads between the cells by migration of the UEs. Next, the set of specific cells satisfying the restrictions between neighbouring cells is adjusted, according to the load ratio between neighbouring cells, their distance, the transmission velocities, those that have greater power received from the neighbouring cells, the signal to interference plus noise ratio (SINR) within the cell and the total number of UE, since the more UEs, the more load increase in the cells [37]. Later, the load of heavily loaded cells is distributed to cells with less load. Subsequently, in the synchronization process, the target cell accepts an MLB request, and initiates a timer to prevent MLB requests in parallel from the neighbouring cells, without sending its a request to the neighbouring cells. And once the time is over, a new MLB request from the neighbours is taken into consideration, to reapply the procedure.

On the other hand, the antenna pattern, transmission mode, carrier frequency, bandwidth of the system, cellular distribution, path loss and the shadow fading effect have to be considered to optimize the maximum transfers [38] [39].

In this way, it is possible to reduce operating expenses, the total number of transfers and the number of low-performing users. Also, resources efficiency and blocking probability are improved and the probability of high performance is increased, to effectively reduce the proportion of Ping-Pong due to the timer.

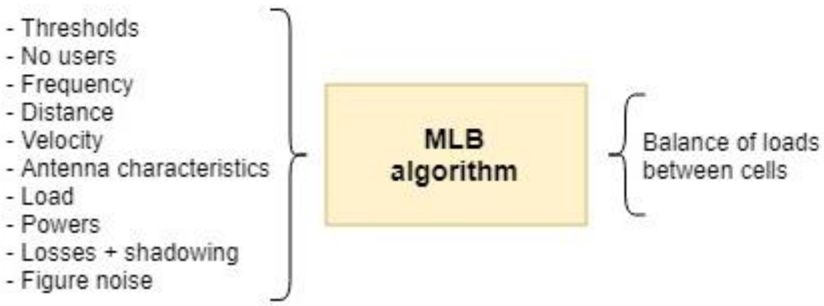

Figure 6.14: *MLB parameters scheme*

❖ Mobility Robustness Optimization:

This function aims to optimize the transfer performance automatically. Detecting and subsequently, preventing connection failures that occur due to deliveries too early or too late, or delivery to incorrect cells.

Mainly from the adjustments of the transfer parameters based on the fault counts and the number of transfers, which are: the handover indicator (which allows locating this situation and solve it as soon as possible), the displacement of handover, the transmission time of the transfer command, derived from both failed and successful transfers (from timers or counters, or some combination of the two) [40]. Also, the transmission power, the power received from the service cell and the neighbouring cells, network topography, system bandwidth, carrier frequency, antenna pattern, antenna height, antenna gain / tilt, channel model, UE velocity, UE number, number of cells, path loss (dB) and coupling losses [41]. And once each of these parameters has been analysed, the UE sends the measurement report to the BS of the service cell and when the service BS receives the UE measurement report, the BS initiates an HO message transaction with the destination BS [42].

Therefore, it can say that there is a trade-off between the reliability of the transfer and the transfer frequency. And so, it avoids that the changes deteriorate the performance of the delivery, such as the network load or the velocity of the UE. In this way, provide a lower failure rate and an improvement in the manual configuration of the handover parameters in the current network systems, since it is a time-consuming task. In addition, a more positive user experience and an advantage of the resources of the network is achieved, since it avoids an incorrect configuration of the transfer or unnecessary.

Figure 6.15: *MRO parameters scheme*

- Energy saving:

Increasingly, ICTs are investigating the reduction of energy dissipation at the network level. At the time to design communication networks more energy efficient, while providing sufficient performance to achieve service level objectives.

The energy consumption to maintain the functioning of the network must be evaluated according to the user requirements and the size of the cell mainly, but also according to the values of the thresholds of all the parameters, the maximum remaining energy and the consumption metrics energy of the nodes, the consumption of node performance and the total energy consumption, so that the transmission can reach the goal. Without forgetting, several input parameters, such as the bandwidth, the maximum number of users, the locations, the distances between nodes, the traffic load, the powers, the temperature / humidity and the time / status [43].

On the other hand, there are parameters that calculate the available energy to meet the needs of the user, fast monitored algorithms to calculate the optimal allocation of resources and monitored algorithms to allow the cells to determine independently, when to deactivate or reactivate, taking into account for its individual traffic, without reducing performance when the transmit and receive nodes are not active. The cell is deactivated if its traffic falls below a certain threshold, which evaluates whether the traffic in a cell has reduced significantly enough so that the cell can be deactivated and then reactivated when the traffic in the active cell increases. So, it can conclude, that each cell has two possible energy states: the active state in which all the functions of the cells are running, and the cell consumes all its required energy and the inactive state where energy is saved [44].

In this way, it is possible to reduce the power consumption of the network system, since the propagation distance between nodes is shortened, and therefore, the required transmission power is reduced. In addition, networks improve in terms of performance, quality of service and costs. Always keeping in mind, the availability of full coverage and the adequate capacity.

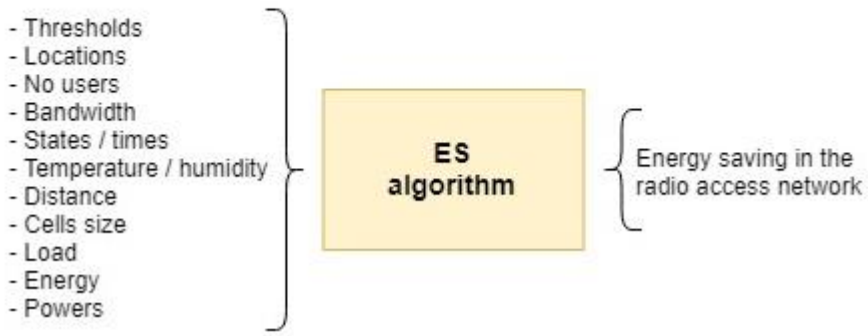

Figure 6.16: *ES parameters scheme*

❖ Inter-Cell Interference Coordination:

Inter-Cell Interference Coordination has become the main factor that influences in the allocation of resources between cells. But it must be limited, to guarantee the impartiality between different users and cells.

For the elaboration of the algorithm for different situations, a series of parameters is required, which are the following:

It has a real time service delay threshold, a system packet loss rate, an average transmission rate, a path loss dependent on distance and a white noise power density, to redefine the movements and obtain coordination [45]. Bearing in mind, the number of users and cells, the number of packets, the cell radius, the transmission time, the average channel capacity, the transmission power, the average transmission velocity and the interference received from the other cells, to guarantee the quality of the service without loss of packages [46]. On the other hand, it is also important, the distribution of the cell and the SINR, and the typical data such as the carrier frequency, the bandwidth and the type of antenna.

In order to achieve a compensation between the interference and the performance of the system, with a limited intercellular coordination. Guaranteeing the quality of traffic for the well assigned resources and a greater performance, avoiding the interference of the neighbouring cells.

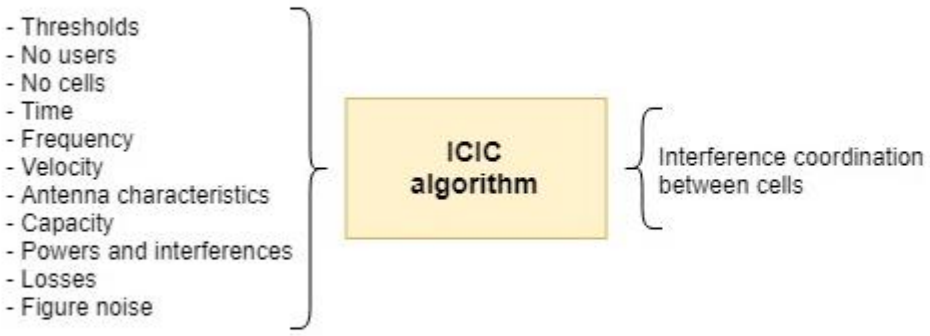

Figure 6.17: *ICIC parameters scheme*

❖ Random Access Channel:

The random access channel is one of the main procedures for enabling channel access for IoT devices and is very suitable for cellular implementation. Since IoTs are inherently a resource constraint and efficient communication is one of the main requirements of these devices.

To be carried out, a series of parameters are needed: the time advance, for the synchronization between the base station (BS) and the mobile station (MS) and the thresholds in the receiver when the UE wishes to access the BS cell, for the detection process and to decide whether the received signal is noise or not. Obtaining, with the thresholds, the detection of preambles in the defined interval where the coverage range of the detection of the random access signal depends on the latency of transmission of the received signal [47].

On the other hand, there is the delay factor for performance measurements in a multipath fading environment, the bandwidth, the carrier frequency, the number of transmitting and receiving antennas, the number of devices competing simultaneously for access to the channel, the velocity of the device, the maximum transmission power for the device, the initial estimate of the transmission power to be provided by the BS and the SNR, which if it is above a threshold, the algorithm allows to reduce extremely the complexity of synchronization.

And finally, during the process of detecting random access signals, the probability of detection is contemplated, which is the conditional probability of correct detection of the preamble when the signal is present. And the false alarm probability, which is the total conditional probability of erroneous detection of the preamble when the input is just noise [48].

In this way, it is obtained beneficial results, such as the reduction of computational complexity and interference between different UEs, a good efficiency that depends on the quality of the random access signal detection and the good performance of random access preamble detection, a probability of detection not less than 99% and a probability of false alarm less than or equal to 0.1%. Avoiding, then, the failures of the RACH, due to the losses for the collision of requests, because of an insufficient transmission power. In addition, the increase in SNR that reduces the probability of detection is avoided. And it can save significant power in the device, which increases the life of the device without causing any adverse effect on the success rate of the RACH.

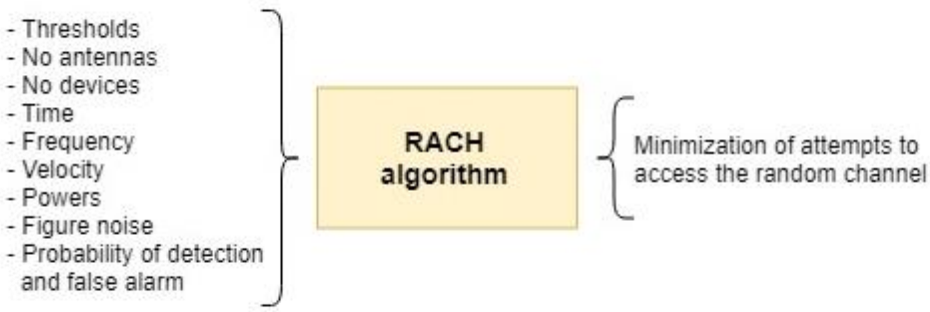

Figure 6.18: *RACH parameters scheme*

➢ Self-Coordination:

The self-coordination function is essential, not only to avoid possible objective or parametric conflicts between the SON functions, but also to guarantee the stable functioning of the wireless networks. Given that there are complex interrelations between the design of the cellular system and the operational parameters, which can induce several types of conflicts between them.

This function is based on the integral identification and classification of potential conflicts that may arise in the main functions expected. Where this classification is achieved by analysing the mutation of the topology of the network, the temporal and spatial environments, the parametric dependencies and the logical relationships that can affect the functioning of the SON functions.

The main conflicts are due to the key performance indicators, of the different parameters, of the direction / magnitude of the output parameters, of the Network Topology Mutation (NTM), of the logical dependency, of the measurements, of the high energy consumption and of the transfer problems. In this way, the principal parameters involved are the performance metrics, the cell interruptions and the threshold measurements of the SON function parameters.

Once the conflict conditions are detected, then the corresponding precautionary measures are executed, and actions are requested, which are allowed / reprogrammed or rejected by the automatic coordination alignment function for the operation without conflicts. Next, the cell reselection method intervenes in such a way that it increases / reduces the cell boundary and modifies the cell priorities to increase / decrease the probability that a cell is selected to camp by UE in idle mode. On the other hand, it also comes into play, the liberation of the Radio Resource Control (RRC) connection with the redirection method, which rejects the connection establishment request during the transition from inactive to connected mode and provides the information of redirection to the UE for load balancing. In addition, with the activation / deactivation method of the suspension mode, it activates / deactivates the base stations according to the load conditions to save energy [49].

One of the methods that could be used, for example, would be a logical decision tree, where it could avoid function conflicts investigating the possible conflict conditions and executing the necessary actions. As well as reducing the shared parameters by pre-defining clear responsibilities for the parameters of the SON functions, combining the objectives of multiple functions in a single optimization function, pre-assigning priority to certain SON functions over others and controlling the execution time of the SON functions behaviour, depending on the operator's policy and the client's demands.

In this way, optimal interactions between self-optimization and self-coordination functions and a network operation without problems are achieved [50]. With a good quality of service and a network stability.

Figure 6.19: *Self-Coordination parameters scheme*

➢ Self-Protection:

It requires preserving a certain level of protection for each node in the network, for the network overall objectives, and thus avoid hackers from the network. Therefore, it is necessary the intervention of a Wireless Sensor Networks (WSN)s with Internet of Thing, which consists of a set of small devices (nodes) that are scattered in the area of the network [51]. These small nodes must be protected against physical attacks from outside the network, since they have many limitations in their resources, such as the battery, the computing, the communications, etc.

Therefore, self-protection focuses on the scenarios in which the nodes must be protected to resist physical attacks and faults directed at them and to preserve the edges between nodes in the network, in a monitored manner.

The metrics involved are: the different parameters of the network in terms of the total number of nodes deployed in the network, the number of active nodes selected, the minimum possible number of nodes to maintain the self-protection restrictions and preserve the connectivity of the same and the energy consumption of the nodes. The thresholds of the parameters of the functions, the size of the network (m^2) and the range of detection are also important [52].

In this way, many benefits are obtained, such as the improvement of security, performance and efficiency, the monitoring of stability and critical resources and the admission of new application scenarios. Avoiding faults and loss of connectivity.

Figure 6.20: *Self-Protection parameters scheme*

➢ Self-Healing:

Self-Healing focuses on overcoming the incidence of a failure by adjusting the adjacent eNodeB parameters.

❖ Cell Outage Management:

Cell Outage Management (COM) is a functionality that aims to automatically detect and mitigate the interruptions that occur in radio networks due to unexpected failures. It is divided into Cell Outage Detection (COD) and in Cell Outage Compensation (COC) [53]. That, through the cooperation of these functionalities, a self-correcting solution is provided. In addition, there are multiple causes for an interruption of the cell, either by hardware or by software, as it has seen in the point *5.2.5. Self-Healing*.

This management is achieved through the following components, the following necessary functionalities and their corresponding interrelations:

On one side, the automated detection function informs if an interruption has occurred and activates the compensation function to perform the appropriate actions, in order to alleviate the degraded performance by properly adjusting the radio parameters in the surrounding sites.

The detection is made through the measurements, the statistics and the analysis of the performance of the system with the KPIs and the radio parameters. From the use of thresholds, counters, timers and pattern recognition. Where the network is continuously monitored, and the measurements are collected each time the catchment samples change. Also, the data information is extracted by accurately notifying if an interruption of the cell occurs, they are collected by different time granularity, they are analysed, and they are processed so that the operator can be informed of the interruption information, through an immediate alarm that indicates the occurrence and the cause of the cut. Also, with the probabilities of cause, the characteristics of the network and the performance in the vicinity of the interruption area are estimated, from the data of prediction of propagation, and thus prevent the unexpected failures.

On the other hand, it has the compensation function, where the reconfigurations and the adjustments of the radio parameters involved in line and in real time intervene to respond opportunely to the interruption. But it must bear in mind that compensations can alter the radio parameters of neighbouring cells, so that some of the user equipment may be affected [54].

The interruption occurs when one cell or several cells stop being operative. Therefore, an attempt is made to switch off the interruption cell to avoid unnecessary interference in the operating cells and to try to solve the problem offline.

The parameters analysed to cover the area of the interruption are: the time, the carrier frequency, the bandwidth of the system, the control parameters, the mobility parameters, all the radio parameters that have an impact on the coverage and the capacity, the antenna parameters (height, tilt, azimuth and gain), the velocity, the number of users, their velocity and their distribution, the sectors, the radius of the cells, the distance between sites, the list of neighbouring cells of the mobile terminals, the ICIC, the number of samples that are detected incorrectly, the transmission power of the cells, of the base stations, of the links and of the users, the power of the receiver of reference signal, the Radio Resource Control (RRC), the Dropped Call Rate (DCR), the success rate of the transfer and the Blocked Call Rate (BCR). On the other hand, it must take into account the factors of the noise figure with the signal to interference plus noise ratio, the loss of trajectory dependent on the distance loss, the shadowing and hence the interferences in the neighbouring cells [55].

In reality, a defective cell begins degradation before entering the state of interruption. Therefore, it can be classified the state of cellular communication in four states. The first is the healthy cell, where the cell is in the normal performance of the communication system. The second is the degraded cell, where the performance of the degraded cells decreases little, but the communication of the clients still has not been seriously affected. The third is the damage cell, where the performance of the communication system decreases seriously, and the quality of the communication has been seriously affected, which is considered a failure in the system. And, finally, it is the interruption cell, where there is an interruption in the communication system, and the clients get a bad service or no service [56].

With all these components, a detection and compensation of the interruptions in the current mobile access networks faster and less expensive for any network parameter is achieved. To satisfy and achieve with the operator's performance requirements based on quality and traffic indicators. On the other hand, there is also minimal operator intervention and a minimization of network performance degradation and revenue losses. It also achieves stability and reliability of the system and less complaints from users. And the total loss of radio services is avoided.

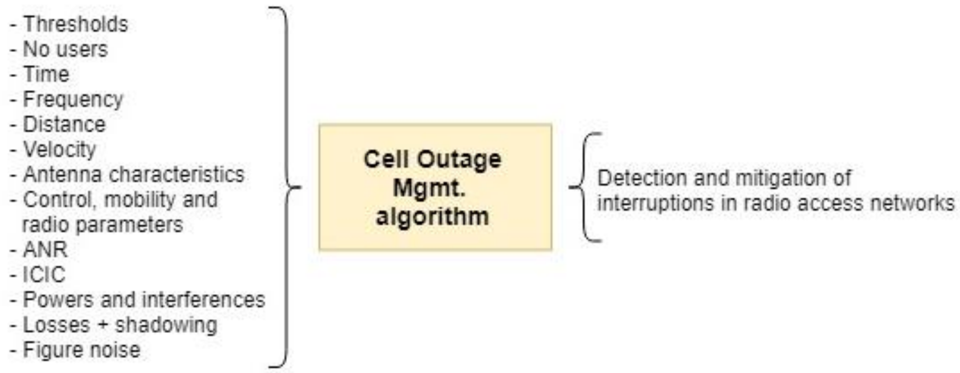

Figure 6.21: *Cell Outage Management parameters scheme*

Finally, in summary mode, a global scheme of all the input parameters that intervene in the algorithms of the SON functions is provided:

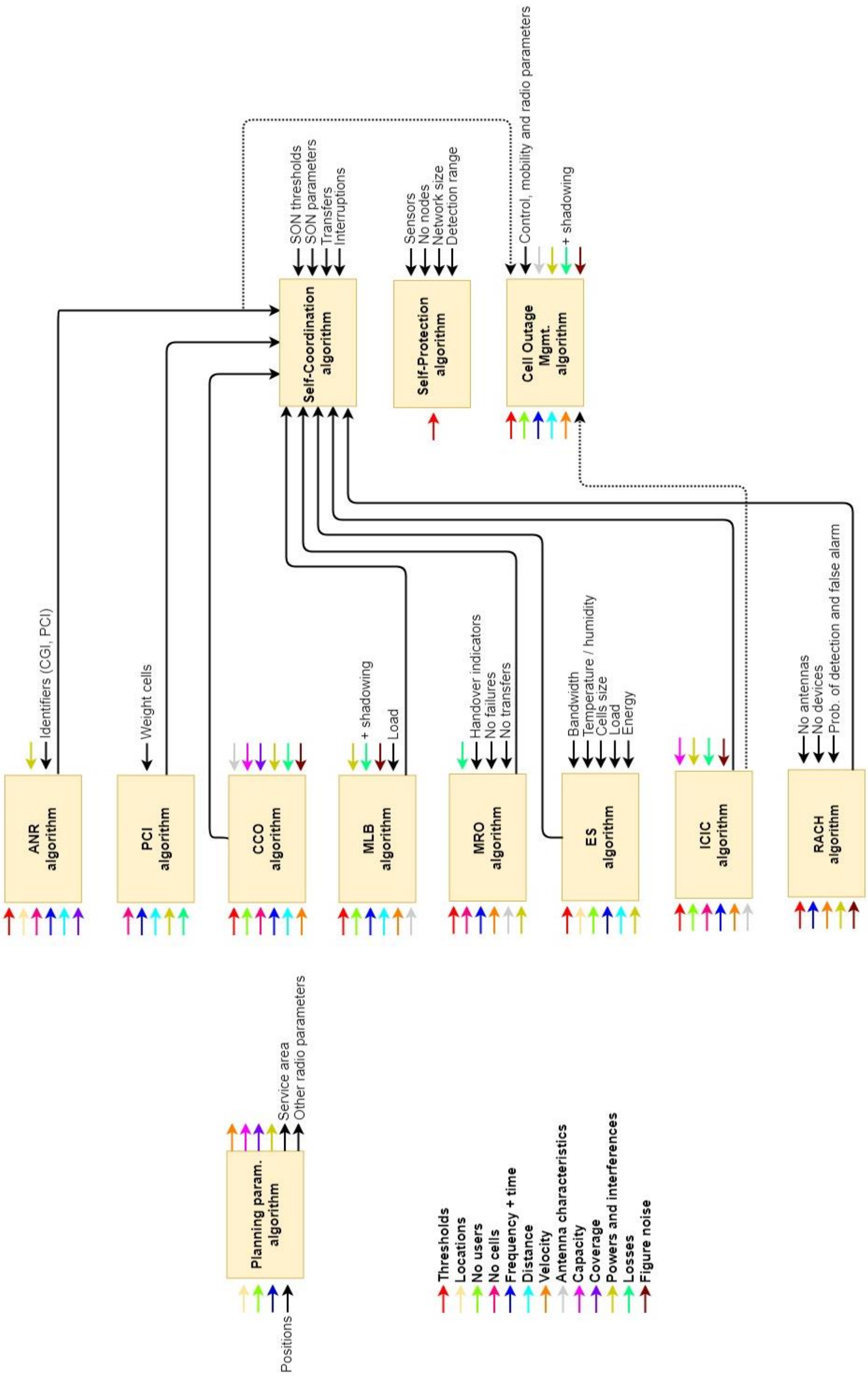

Figure 6.22: *Scheme of all parameters*

As it can see in the image, many functions share parameters between them. These shared parameters are found in the left index that appears, where each one has an assigned colour. In contrast, black arrows are unique parameters of that function.

7. Budget

Remember that the main objective of the project has been the development of functional models and procedures for the automated management of RAN Slicing in the fifth generation of mobile telephony technologies. Where a significant advance has been obtained of the SON concept, which is currently in process.

Nowadays this research is aimed at different market niches. The main recipients are: telephone companies of each country, the multinational communications and technology companies and the International Telecommunication Union. Although it can be said that the stakeholders are mainly the multinational communications and technology companies.

This research project has been developed by a junior engineer (which in this case is me), for just over four months (from September 13, 2018 to January 25, 2019). Where the main material used, has been a computer. And the IEEE Xplore (Institute of Electrical and Electronics Engineers Xplore) service to search whitepapers.

Next, the budget broken down the project is approximated in the following tables:

COMPONENTS			
Materials	**Nº units**	**Cost(€)/unit**	**Final cost**
Computer	1	700 €	700 €
IEEE Xplore licence	1	200 €	200 €
		TOTAL:	**900 €**

Table 7.1: *Used materials*

HUMAN RESOURCES				
Position	**Nº of people**	**Nº hours**	**€/hour**	**Final cost**
Junior engineer	1	510	15 €	7.650 €
			TOTAL:	**7.650 €**

Table 7.2: *Human resources*

In the first table, the total cost of the two components used is considered, where it should be noted that the IEEE Xplore service includes 25 downloads of articles every month for 40€ per month. And in the second table, the hours given by the engineer are shown. That, to be exact, she worked 25 hours per week (the duration of the project was 20 weeks and two days). In this way, a total amount of the realization of this project is obtained of:

TOTAL:	**8.550 €**

8. Conclusions and future development

At the present time, it has already been carried out initial tests of 5G in different cities, which have been launched by both manufacturers and operators. They are incipients demonstrations, but at the same time they represent a great signal of the future bet. Since they are in the process of developing 5G technology and everything that encompasses it.

The dynamic deployment and stringent requirements of future 5G networks have accelerated the introduction of automated and self-organized networks and AI-based techniques. That consequently, different market players are currently developing the algorithms of the different SON functions, taking into account the multiple challenges they address. Therefore, with this project, it wanted to reflect the usefulness of these functions in two practical and specific examples. Where in them, a vision of the intervention of these functions has been obtained, being able to reflect all the benefits commented along the memory that it provides.

On one side, it has been seen that it will be necessary a new functional architecture based on reinforced and self-organized learning. That to achieve the best SON results, the operator must implement H-SON to address complex networks. In addition, this architecture will be focused on the modelling of the SON functionalities. In order to design efficient algorithms to address various challenges, such as the most appropriate location of SON functions and algorithms to adequately solve the problem of conflicts between functions executed in different nodes or networks.

Also note that with the algorithms parameters schemes, it can say that most of the functions share the concept of the parameters, so it will be easier to relate them to each other and optimize them when performing the algorithms. But that will not always happen, since for some cases, the type of measurement of each parameter is different and specific for each function. Preventing in this way, make the most of parameter algorithms in different functions.

On the other hand, these automated functions can always be improved and optimized over the years, and thus it can obtain a greater performance in the operation of the network. And even, new functions may arise to solve specific problems that require a lot of time and are quite complex for an operator.

Finally, all this entail a new technological ecosystem, which will have a decisive impact on artificial intelligence, automation and solutions linked to the Internet of Things.

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Glossary

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
ANR	Automatic Neighbour Relation
API	Application Programming Interface
BCR	Blocked Call Rate
BS	Base Station
CAPEX	Capital Expenditure
CCO	Coverage and Capacity Optimization
CDMA	Code Division Multiple Access
CGI	Cells Global Identity
CMC	Connection Mobility Control
CN	Core Network
COC	Cell Outage Compensation
COD	Cell Outage Detection
COM	Cell Outage Management
C-SON	Centralized-Self-Organizing Network
DRA	Dynamic Resource Allocation
DRC	Dynamic Radio Configuration
D-SON	Distributed-Self-Organizing Network
eMBB	enhanced Mobile BroadBand
EMS	Element Management System
eNB	enhanced Node Base station
EPC	Evolved Packet Core
ES	Energy Saving
E-UTRAN	Evolved-Universal Terrestrial Radio Access Network
EV-DO	Evolution-Data Optimized

gNB	Next generation NodeB
gNB-CU	Next generation NodeB-Central Unit
gNB-DU	Next generation NodeB-Distributed Unit
GSM	Global System for Mobile communications
GUI	Graphical User Interface
HO	Handover
H-SON	Hybrid-Self-Organizing Network
HSPA	High-Speed Packet Access
ICIC	Inter-Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IRRRM	Inter-RAT Radio Resource Management
ISWCS	International Symposium on Wireless Communication Systems
Itf-N	Interface-North
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LB	Load Balancing
LTE	Long Term Evolution
MANO	Management and Orchestration
MC	Mission Critical
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MLB	Mobility Load Balancing
mMTC	massive Machine Type Communication
MNO	Mobile Network Operators
MRO	Mobility Robustness Optimization
MS	Mobile Station

NE	Network Element
NFV	Network Functions Virtualization
NFVI	Network Functions Virtualization Infrastructure
NG-RAN	Next Generation-Radio Access Network
NMS	Network Management System
NR	New Radio
NS	Network Service
NTM	Network Topology Mutation
OAM	Operations, Administration, and Maintenance
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
PC	Power Control
PCI	Physical Cell ID
PNF	Physical Network Function
PoP	Points of Presence
PPDR	Public Protection and Disaster Relief
PRB	Physical Resource Block
PS	Packet Scheduling
QoS	Quality of Service
RAC	Radio Admission Control
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RBC	Radio Bearer Control
RF	Radio Frequency
RRC	Radio Resource Control
RRM	Radio Resource Management

RSI	Radio Access Network Slice Instance
SaaS	Software as a Service
SDN	Software Defined Networking
SIMO	Single Input Multiple Output
SINR	Signal to Interference plus Noise Ratio
SLA	Service Level Agreement
SNR	Signal-to-Noise Ratio
SON	Self-Organizing Network
SP	Service Provider
TDMA	Time Division Multiple Access
TN	Transport Network
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable and Low Latency Communication
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VNF	Virtualized Network Function
WiMAX	Worldwide Interoperability for Microwave Access
WP	Work Package
WSN	Wireless Sensor Network