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5G-RANGE

5G-RANGE: Remote Area Access Network for the 5th Generation

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Executive Summary

Work Package 7 has two main objectives: i) measure the opportunity of connecting the unconnected for Brazil and defining new alternative scalable business models to deploy networks in ultra-low-density areas, and ii) strengthen the impact of the 5G-RANGE project through specific exploitation-oriented activities, communication and dissemination of project information and project results and contributions to standards. This deliverable makes the sizing of the Total Addressable Market (TAM) for the rural unconnected people in Brazil and its translation into financial terms, as well as presents dissemination activities and standardization plans of the 5G-RANGE Project.

The deliverable 7.3 is an extension of the documents previously delivered to this work package 7 and complements the information already presented in order to complete them and meet the objectives of WP7, thus concluding all ongoing activities consolidating all results in exploitation, communication, dissemination and standardization during the project cycle. In attention of review of project carried out in Madrid, the document includes the business model, business plan, roadmap, consolidation of the WP5 and the limitations of the projects.

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Definitions and abbreviations

(Orthogonal Frequency Division Multiplexing)........24
3GPP (3rd Generation Partnership Project)........19
5G-NR (5G New Radio)........25
ACPR (Adjacent Channel Power Ratio)........25
APIs (Application Programming Interfaces)........19
BS (Base Station)........19
CAPM(Capital Asset Pricing Model)........12
CP (Cyclic Prefix)........25
CPE (Consumer Premise Equipment)........22
CPU (Central Processing Unit)........21
CR (Cognitive Radio)........24
EIRP (Effective Isotropic Radiated Power)........25
eRAC (enhanced Remote Area Communications)........23
FAEMG (Minas Gerais State Agribusiness Federation)........24
FPGA (Field Programmable Gate Array)........20
GPP (General Purpose Processors)........21
GWs (Gateways)........19
IoT (Internet of Things)........24
ISM (Industrial Scientific and Medical)........24
ISPs (Internet Service Providers)........24
KPIs (Key Performance Indicators)........20
LOS (Line-of-Sight)........25
LTE (Long Term Evolution)........24
MAC (Medium Access Control)........21
MIMO (Multiple-Input Multiple-Output)........21
MNO (Mobile Network Operator)........16
MOU (Memorandum of Understanding)........29
MTC (Machine-Type Communications)........24
NB-IoT (Narrow Band IoT)........24
NPV(Net Present Value)........12
NR-U (NR for unlicensed spectrum)........25
PCs (Personal Computers)........21
PHY (Physical)........21
PoC (Proof-of-Concept)........19
RF (Radio Frequency)........21
RMIO(Rural Mobile Infrastructure Operator)........12
SAR (Specific Absorption Rate)........27
SDR (Software Defined Radio)........20
SoC (System on Chip)........22
TAM (Total Addressable Market)........14

TRLs (Technology Readiness Levels)....25
TVWS (TV White Space)....24
USRP (Universal Software Radio Peripheral)....20
WACC(Weighted Average Cost of Capital)....12
WBA (whole body average)....27
WiMAX (Worldwide Interoperability for Microwave Access)....24

1 Introduction

Work Package 7 has the goal to measure the opportunity of connecting the unconnected in Brazil and defining new alternative scalable business models applicable in Brazil and potentially in other countries across Latin America and Europe, leveraging local communities and entrepreneurs that would fast and profitably deploy networks in ultra-low density areas whilst having high capillarity for network operations and commercialization. This starts by identifying all the show-stoppers on a systematic way and design the business mechanisms that create the right incentives to foster a massive adoption by local entrepreneurs.

A second objective of the work package is to strengthen the impact of the 5G-RANGE project through specific exploitation-oriented activities, communication and dissemination of project information and project results and contributions to standards.

As such the specific objectives of this Work Package are the following:

- Identify the main show stoppers, including a regulatory analysis, to implement alternative business models in low density unconnected areas
- Define a business model for connecting the unconnected, including a deep study of the processes, activities, investments, costs and expected revenues, using Brazil as an illustrative example
- Create a business case for each of the stakeholders in a scenario of traditional deployment (radio access network owned by incumbent) and in alternative model (Rural Operator owns the RAN);
- Communication of project information including achievements, results, events and other related information via websites, press releases and other media coverage.
- Dissemination of project results via scientific publications, white papers and demonstrations of the 5G-RANGE prototypes;
- Organization of events and workshops to increase the visibility of the project results;
- Promotion of the project results in targeted standardization bodies;
- Foster and promote commercial exploitation of the project output and its assets.

The analysis for all sections is applicable to any unconnected area worldwide (many covered by European operators), although all the detailed analysis has been focused on Brazil due to the relevance in terms of untapped opportunity and the wide casuistic found due to its extension and diverse and challenging geography.

Due to the gradual build-up defined to the deliverables of this Work Package, where each future Milestone looks to add to previous work done on an incremental manner until the final deliverable in Month 36, this deliverable is an extension of the previous documents (deliverable D.7.1 and D.7.2), aiming to expand in various areas, in particular: (1) the alternative business models explored and the outputs of the data analysis to measure the rural unconnected opportunity in Brazil, (2) the roadmap of 5G-Range for Rural areas, (3) regulation aspects for White-Spaces (WSs) unlicensed spectrum usage that are being considered by National Telecommunications Agency of Brazil (ANATEL) and standardisation activities and (4) the dissemination activities developed by the project in its third year

1.1 Deliverable Structure

The deliverable is organized as follows: Section 2 presents the business plan update, attending the request that was made in the Interim Review in Madrid. The focus of this section is in smart farms and the entire process of deploying rural networks. Section 3 presents the 5G-Range Vision for Remote Area networks, presenting the main results obtained with the 5G-RANGE PoC, highlighting the network architecture, the PoC implementation strategy and the efforts towards exploitation and relationship with other technologies.

2 Business Plan

This section presents a business plan update with focus in a risk analysis perspective, an extension of the TAM analysis done in D7.2 with focus in smart farms and a detail explanation of the entire process of deploying rural networks, which explains distribution infrastructure and highlights the social impact of the project.

2.1 WACC sensitivity analysis

WACC(Weighted Average Cost of Capital) is a key financial metric that is used in the context of investment analysis as the discount rate for the cash flows. From a high-level perspective, WACC stands for two main purposes:

- Understand the expected return of a given business for its investors
- Understand the inherent risk of the business

The formula to calculate WACC is shown below, where:

- Ke is the cost of equity
- Kd is the cost of the debt
- E is the equity
- D is the debt
- T is the tax rate

E, D and T are defined by the financial structure of the company and its environment and require no further explanation. However, Ke and Kd do require further explanation

To estimate *Ke,* it is common to use the CAPM(Capital Asset Pricing Model), which helps estimating the price of an asset. Its underlying assumption is a linear relation between risk and financial profitability. The formula is:

$$K_e = R_f + (E[R_m] - Rf) * b$$

where:

- R_f is the risk-free rate, a profitability reference based on bonds emitted by a Central Bank
- $E[R_m]$ is the expected return for the companies in the industry being analyzed
- b is the market risk of an asset, in this case it measures the (leveraged) risk of the business to value

Estimating *Kd i*s easier, since the cost of debt is usually a function of the financial structure and less of capital markets. Therefore, it is usually estimated as *Rf* plus a spread associated to the industry or the type of company.

After studying the formula in depth we see that it measures what was briefly introduced in the first paragraph: expected return and risk. Now, we can study the effect of WACC in the business model associated to the deployment of 5G Range.

First of all, WACC only affects NPV(Net Present Value) analysis. The payback period and the breakeven are not affected by this value, since they depend entirely on the (non-discounted) cash flows.

For this analysis, we will keep constant all factors but the WACC. It is worth mentioning that the terminal growth used in this model is 4% and it will be kept this way. It is also worth mentioning that the lower WACC used in infrastructure projects is 8% because of the inherent risk of the market. Therefore, this analysis will study the effect of WACC varying from the ballpark of this minimal value to the values where the project stops being profitable.

Since the goal of this section is to understand how to make more attractive this investment scheme for RMIO(Rural Mobile Infrastructure Operator), we will be doing the analysis for the NPV only on the

RMIO's side. We will study both main connectivity schemes (direct connectivity and backhaul connectivity) with the realistic scenario. In the figures below we can see the results of this analysis.

Table 1. WACC and NPV

WACC	Total NPV - DirCon	Total NPV - Backhaul
7%	$291.076.182	$1.585.841.788
8%	$196.163.206	$1.082.850.300
9%	$140.100.726	$785.245.572
10%	$103.411.612	$590.104.837
11%	$77.752.325	$453.334.126
12%	$58.954.103	$352.898.989
13%	**$44.703.379**	**$276.568.175**
14%	$33.613.976	$217.011.212
15%	$24.805.401	$169.570.103
16%	$17.692.001	$131.145.240
17%	$11.869.452	$99.595.559
18%	$7.049.901	$73.395.819
19%	$3.023.062	$51.430.999
20%	-$368.089	$32.867.832
21%	-$3.243.038	$17.071.698
22%	-$5.694.208	$3.551.243
23%	-$7.794.123	-$8.079.492
24%	-$9.600.420	-$18.127.571
25%	-$11.159.420	-$26.840.076

Value used (14%)

Low risk (7%–12%)

Mid risk (13%–20%)

High risk (21%–25%)

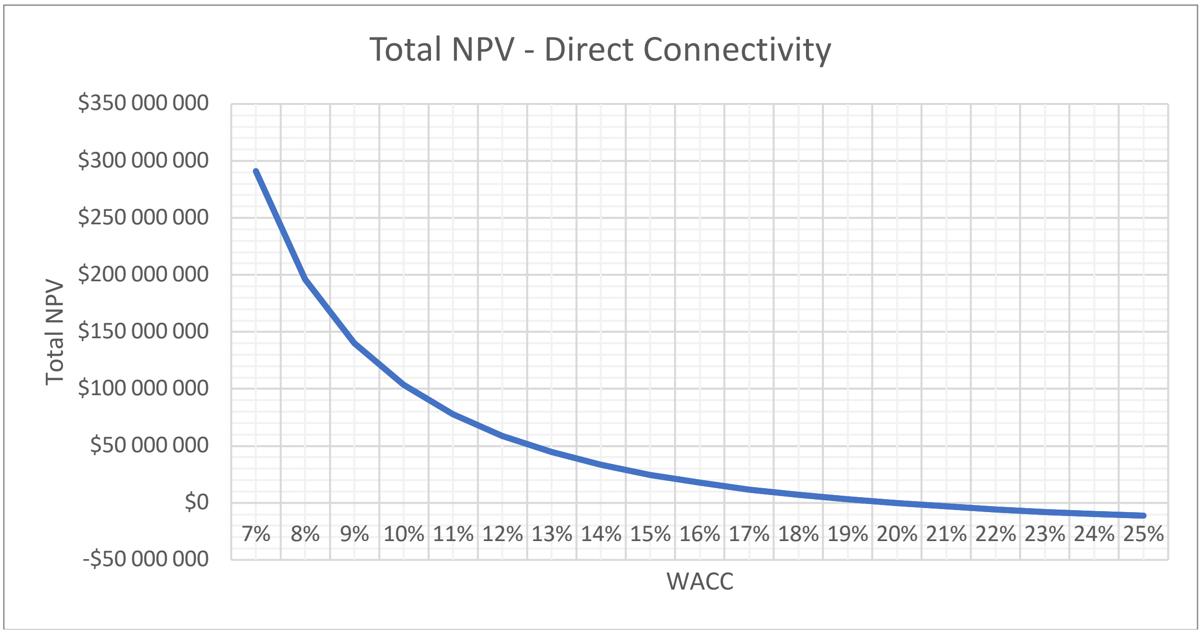

Figure 1. Total NPV Direct Connectivity

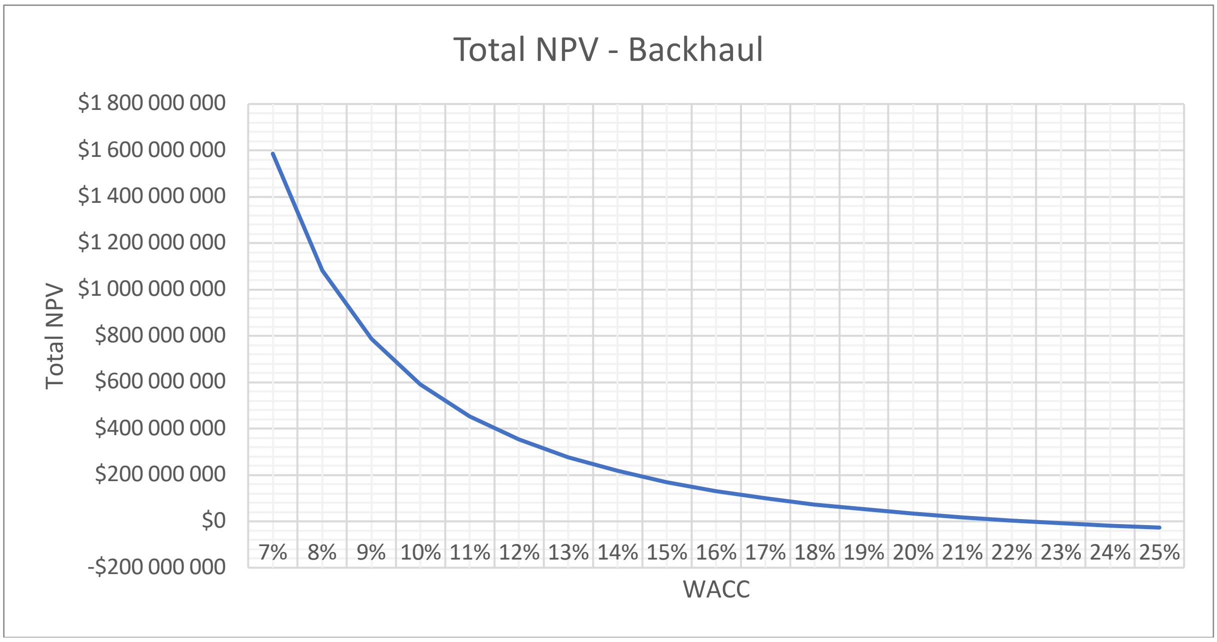

Figure 2. Total NPV Backhaul

As we can see, in both curves, the NPV decreases as WACC increases. For direct connectivity all values of WACC above 19% are non-profitable, while the threshold is 22% for Backhaul connectivity. We can also see that lowering WACC can increase the valuation significantly. However, in the current context where the market (rural connectivity) is very uncertain and the technology is very immature, assuming low WACC values would not make sense from a risk-analysis perspective.

2.2 Farm coverage estimation

This section aims at extending TAM (Total Addressable Market) analysis done in the previous deliverable. As a reminder, the table below shows the summary of the TAM estimations. This TAM is based on the population distribution of Brazil, the existing telecommunications infrastructure and 5G Range's specifications. In short, our algorithm creates an optimal deployment plan and spits out which settlements would be covered by such plan. The specific goal of the section is to estimate the farm coverage that 5G Range could provide, so that farmers could use connectivity to enhance their economic activity.

	Total	Direct Connectivity	Backhaul Connectivity
TAM	14.736.197	11.025.234	6.073.984
# 5G Range sites	-	697	689
# 4G sites	23.121	-	6.029

Figure 3. Direct and Backhaul Connectivity

We will be focusing on the Direct Connectivity use case, since it is the best suited for this purpose and the main connectivity mode of this technology. To estimate farm coverage, we have assumed that any farm will be beside a settlement. They can be arbitrarily big, but at least one point of the farm's perimeter is assumed to be close to an existing settlement. Farms have rectangle shapes mainly. Here we will simplify to squares. However, the analysis would apply to any farm with a rectangle shape with its longest side the size specified in the analysis. Let us explain the methodology used to estimate farm coverage

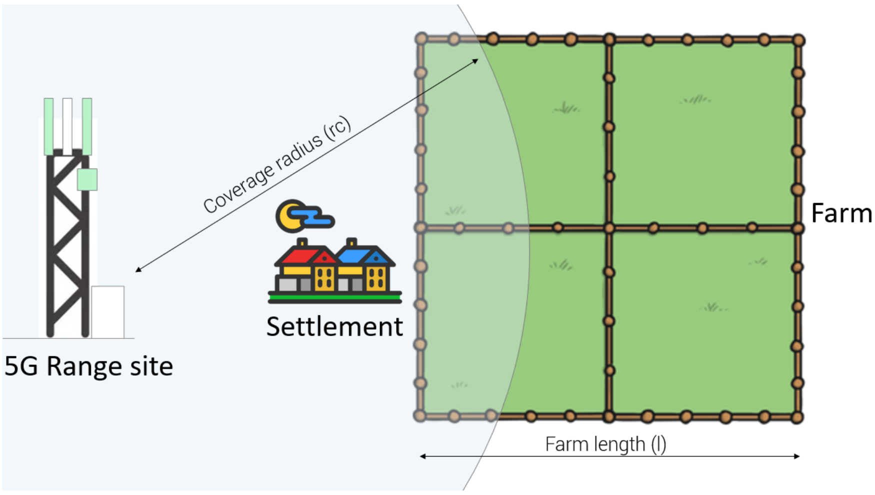

Figure 4. Farm Coverage Estimation

In the figure we can see the 5G Range tower giving service to a settlement that is less than 50 km away (rc = 50km). We can also see the farm next to the settlement, with a squared shape of length l. In a worst-case scenario the farm will be located at the opposite side of the settlement and its lands will be further away from the tower. This is the case displayed in the picture. Let us analyze this case. If the distance between the settlement and the tower is smaller than ($d \leq r_c - l$) then the farm will be fully covered. If the distance is exactly the coverage radius ($d = r_c$) then the settlement is at the edge of the cell and, since the farm is located in the worst possible way, none of the farm is covered. For all other cases where the farm is located differently, the restrictions are smaller.

Let us assume that all the farms are located in this way to analyze the worst case of all worst-case scenarios. We can take all the settlements covered by 5G Range sites in our model and check their distances to the cell edge. Any farm with a side length smaller than this distance would be covered completely. The table below displays the results of this analysis.

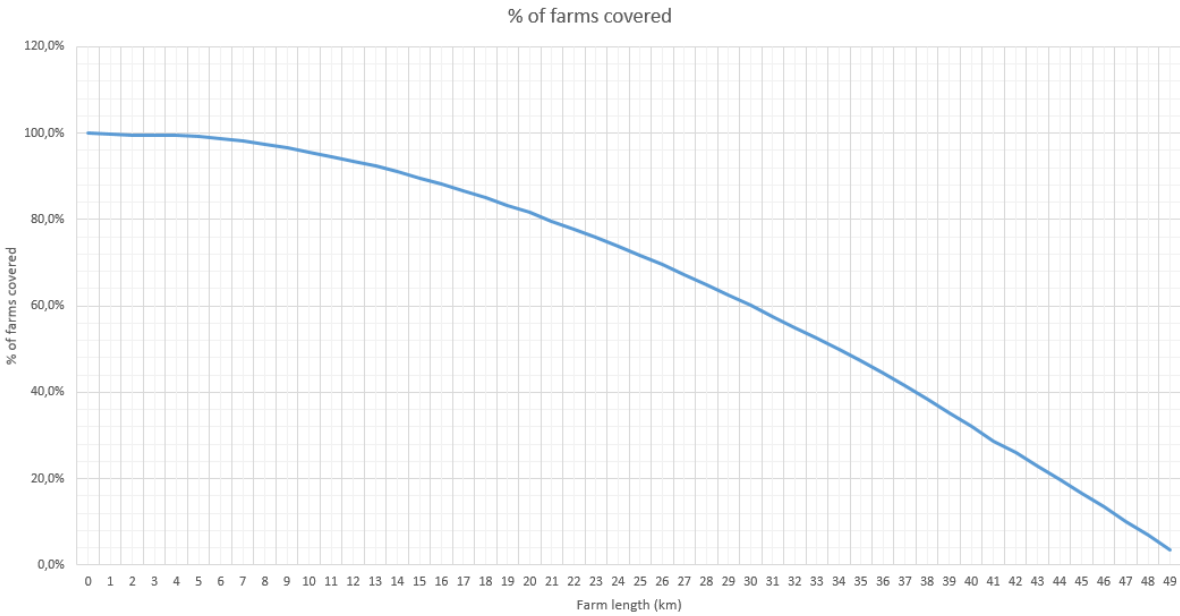

Figure 5. Value Chain

This table shows us the percentage of farms (associated to the covered settlements) that would be covered if they were all the size of the x-axis. We can see that for very large farms of > 20 km, more than 80% would still be covered (bear in mind this is the worst-case scenario).

According to public data (https://www.researchgate.net/figure/Average-farm-size-ha-by-region-Brazil-1970-2006_fig1_311159054) the average size of the farms in Brazil is somewhere around 300 hectares which corresponds to 3 square kilometres. If the farms were a square, this would correspond to a farm size of 1.8 km. To be more conservative, let us assume an average farm side length of 3 km in Brazil. This would mean that, in a worst-case scenario, more than 99% of average farms would be covered.

Doing some more research (https://www.farmprogress.com/story-inside-look-brazils-mega-farms-17-114962), we can see that the largest mega farms in Brazil have an area in the ballpark of 200.000 acres, corresponding to roughly 800 square kilometers. This corresponds to a square size of 28 km. For this case, the chart shows that we would be covering 65% of such farms.

As a conclusion, out of all the population that could be covered with 5G Range, a large proportion of the farms owned by those populations would be also covered. Small, medium and big farms would be entirely covered, while mega farms would be covered in a big proportion but not entirely.

2.3 Explanation of value chain

In this section we will go through the entire process of deploying rural networks with the figure of an RMIO working together with an MNO (Mobile Network Operator). The goal is to clarify the split of responsibilities as well as the flows of value. The following illustration explains this chain, which we further detail below. Bear in mind that black circles indicate actions while yellow circles indicate monetary transactions.

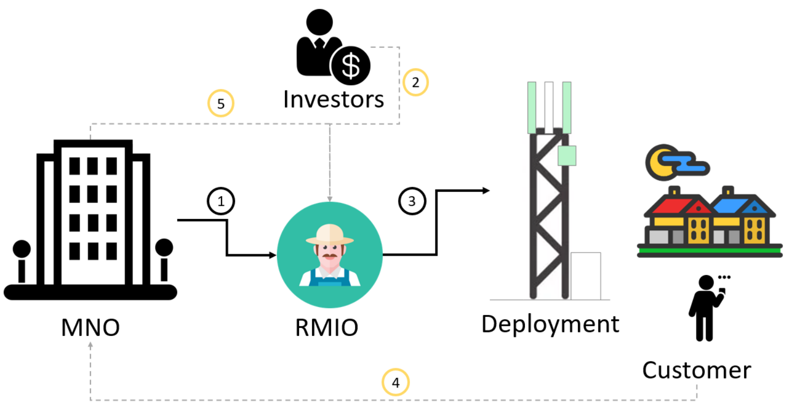

Figure 6. Value Chain

Let us explain the figure step by step. The initial situation is that a given MNO wants to cover a rural settlement. However, because of all the reasons explained in the previous deliverable, it is unable to do so. Then the process starts:

1. The MNO and the RMIO agree to deploy together in the designated area. This requires a lot of contractual work and defining many details, but the idea is pretty simple. Once this is done, we would be ready to start tackling this new deployment.
2. The first thing is to make sure the RMIO has the proper funding to tackle the perimeter that has been agreed. This can be done in a number of ways: the RMIO could fund the whole venture, the MNO could be one investor with either cash or infrastructure as their part of the equity. There could also be external investors such as financial players, governments, development banks, etc. In this phase, the role of governments can be key, not only with direct investment but also with incentives for others to invest in this space.

3. Once the RMIO is properly funded, they are ready to deploy and operate the network. This requires a lot of work and effort (building infra, integrating with the core, monitoring the network, etc.) but is the most essential part of the whole model. This is where the RMIO's scale, local presence and focus allows for the whole model to be sustainable.
4. Once the network is up, customers can start consuming. This includes B2C customer as well as B2B such as farmers. These consumers see the connectivity exactly the same as they would in the city. The spectrum, the brand…everything belongs to the MNO. Therefore, they will be paying their bills to the MNO. All the value initially generated by the new users goes to the MNO.
5. Once the MNO has received this value, it will send a part of that value (defined in the revenue share business model) to the RMIO. This will be the main source of operating income for the RMIO.

Hopefully this explanation clarifies all the processes involved in this business model, at least from a high-level perspective. The table below shows a deep dive of the responsibilities split between the MNO and the RMIO.

Table 2. Responsibilities split between MNO and RMIO

	MNO	RMIO
Settlement selection	X	
Site location		X
Technology selection	X	X
Infra deployment		X
RAN deployment		X
Backhaul deployment		X
Transport provisioning		X
General site deployment		X
O&M		X
Sales channel	X	
Customer management	X	
Spectrum	X	

2.4 Applicability of current work outside of Brazil

5G Range project has a strong focus in Brazil. However, all the work done in WP7 is fully applicable to other countries. Actually, most of the knowledge generated for this project is not theoretical, but rather practical coming from the 'Internet para Todos' project in Telefónica.

Internet para Todos is a company in Peru, created from an innovation project within Telefónica. Its current shareholders are Telefónica, Facebook, IDB and CAF, and it is valued in the hundreds of millions of dollars. The company was created under the RMIO regulatory figure and is currently operating as such. As of today, Internet para Todos has connected more than 8.000 settlements with a population of more than 1.5 million people. They register more than 2.5 million unique monthly users (more than 600.000 recurrent monthly users) that generate more than 1 monthly petabyte of mobile traffic. This success case was built under a very similar model to the one proposed for 5G Range. The great advantage of this is that it is not a purely theoretical exercise, but rather an already proven model. For more information: https://internetparatodos.tid.es/ or browse 'Internet para Todos Peru' on Google. There is abundant information about this initiative.

All across Latin America there are similar figures to RMIO: Co-operatives in Argentina, specialized companies in Colombia with strong local presence, franchise projects for network deployment in almost every country in Latin America, etc.

Besides working in Latin America, there are initiatives similar to the RMIO that have appeared in very different countries. Sometimes they appear to tackle rural deployments, other times they focus on different problematics. For instance, in Spain it is quite common to find small local operators that deploy and operated fixed and mobile networks with a very similar responsibility split as the one presented for the RMIO. They usually serve either small villages or holiday areas that are empty at all times except during summer vacation. In the UK there are also such companies that focus on rural areas underserved for mobile services. Two examples of such companies are Stratto Opencell (https://strattoopencell.com/) and Connectivity Wireless Solutions (https://connectivitywireless.com/)

As a conclusion, the business model proposed in this work package has solid facts that back it. Very similar versions of such a model are being successfully and sustainably implemented across Latin America and other continents like Europe to tackle specific connectivity issues.

3 Roadmap and 5G-Range Vision for Remote Area Networks

The 5G-RANGE project achieved interesting results that can be used to provide reliable and cost-effective mobile coverage in remote and rural areas. The overall system architecture considers different approaches to integrate the proposed network with the 5G Core, allowing a seamless integration of a completely new application scenario to the future mobile network.

The new opportunities that this network can create in remote and rural areas have the potential to chance the reality of a large number of people around the world. A PoC (Proof-of-Concept) has been developed to demonstrate the main features of the 5G-RANGE network, showing that long-range mobile Internet access is feasible. The PoC is also a reference design for products that are attracting interests from vendors, small telecommunications operators, government and farmers in Brazil.

The aim of this report is to present the main results obtained with the 5G-RANGE PoC, highlighting the network architecture, the PoC implementation strategy, efforts towards exploitation and relationship with other technologies.

3.1 5G-RANGE Architecture

The 5G-RANGE network has been conceived to provide mobile connectivity in remote and rural areas, complementing the applications scenarios that are being developed for 5G networks. The 5G-RANGE architecture is composed by a BS (Base Station) that is integrated with the 5G Core using the APIs (Application Programming Interfaces) developed by 3GPP (3rd Generation Partnership Project). There two different approaches for this integration. The first one consists on employing all control channels defined by 3GPP, considering that 5G-RANGE is a standardized air interface for 5G networks, and using the API for non-standardized technologies, which has been developed by 3GPP to allow data offloading with non-3GPP air interfaces.

5G-RANGE can also be integrated with other networks to increase the capillarity of the overall solution. In this case, 5G-RANGE can be seen as the wireless backhaul for LoRA, Sigfox,Wi-Fi and fixed networks. GWs (Gateways) can be used to interconnect of-the-shelf devices with the 5G-RANGE network, reducing the deployment costs. Figure 7 depicts the overall 5G-RANGE architecture. For more details regarding the 5G-RANGE architecture, we invite the reader to access Deliverable 5.3.

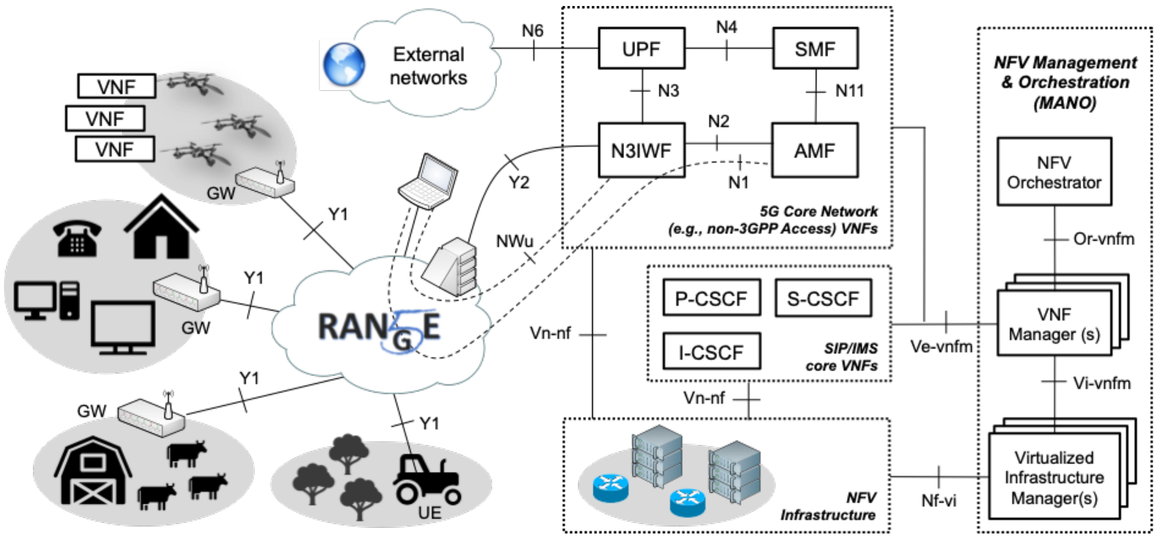

Figure 7. Overall 5G-RANGE architecture.

3.2 Roadmap for the Proof-of-Concept, Demonstration and Product Development

The 5G-RANGE PoC has been designed to present the main characteristics and KPIs (Key Performance Indicators) of the 5G-RANGE network. Due to budget and time constrains, two scenarios have been initially selected for the PoC demonstrations. The first one was the voice and data connectivity and the second one was the backhaul connectivity. Since agrobusiness is an important use case for the Brazilian economy, the 5G-RANGE partners have decided to include this application in the final demonstration as a third scenario. This section will describe the status of the 5G-RANGE PoC development.

3.2.1 Initial Approach for the PoC

The PoC has been initially developed using FPGA (Field Programmable Gate Array) based on LabView platform. This solution achieved full data rate under field test. Up to 50 km links have been established with this version of the PoC. Figure 8 shows a picture of the prototype.

Figure 8. FPGA-based PoC.

Although the FPGA-based PoC could demonstrate the main features and KPIs of the 5G-RANGE network, it presented several drawbacks. The first one was the efforts towards the evolution. FPGA must be programmed using cumbersome hardware description languages, which are not widely disseminated and presents time-consuming learning curves. The second major drawback is regarding technology transfer to the market. Several companies in Brazil have demonstrated interest in developing products based on the 5G-RANGE findings and PoC. However, the LabView environment hinders the solution to be exported to a generic FPGA and only allows the project to run in National Instruments USRP (Universal Software Radio Peripheral). Since the cost of this equipment is prohibitive for the digital radio market, it was necessary to develop a solution that was not based on the LabView environment.

3.2.2 The Evolution Towards SDR Implementation

In order to overcome the restrictions imposed by the FPGA-based PoC, the 5G-RANGE partners have decided to develop a new PoC based on SDR (Software Defined Radio). This PoC is based on an open platform called GNU Radio, where the blocks are written in C language. Highly efficient instructions for modern CPU (Central Processing Unit) allows for conventional GPP (General Purpose Processors) to achieve high throughput in in real-time communication systems. Conventional motherboards with standard CPUs and memories can be used as the main hardware for all PHY (physical) and MAC (Medium Access Control) blocks. Low-cost SDR boards can be used as RF (radio frequency) interfaces for the final product, reducing the overall cost of the implementation.

The new version of the PoC is ready and the current firmware can achieve data rates up to 130 Mbps. Small factor PCs (Personal Computers) are being used for the baseband processing. Although XRTX boards can be integrated to these computers to provide 2x2 MIMO (Multiple-Input Multiple-Output), the new 5G-RANGE PoC is still using the USRPs employed in the previous version. The main reason behind this decision is the fact that this hardware was already available, and the budget restrictions of the project hindered the acquisition of new hardware and the development of a new API. Figure 9 shows a picture of the new version of the PoC.

Figure 9. Picture of the current version of the PoC.

The current version of the PoC is capable of demonstrating all the selected use cases. Up to three devices can connect to the BS and they can be used for different purposes. For instance, one device can provide Internet connectivity to a set of computers using Ethernet or Wi-Fi, the second device can provide connectivity for IoT devices using LoRaWAN and the third device can be used to provide IoT connectivity using Sigfox. For more details regarding the PoC demonstrations, please, refer to Deliverable 6.4.

Although the PoC can be fully employed for the demonstrations, the 5G-RANGE team are looking for opportunities to improve the current implementation. The main desired evolution is to use mini PCI express low-cost SDR interfaces instead of the USRP, which will significantly reduce the cost of the platform. XTRX is the main candidate for the SDR RF interface due to its low cost and MIMO capabilities. Figure 10 shows a picture of the XTRX SDR board.

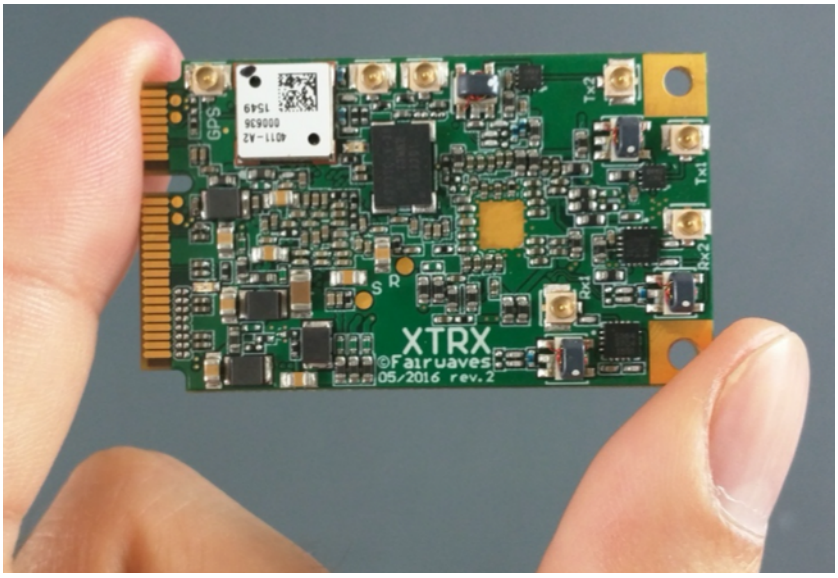

Figure 10. XTRX SDR board.

3.2.3 Our Vision for the Final 5G-RANGE Product

The 5G-RANGE project will provide the complete software stack for the PHY, MAC and Network layers of the 5G-RANGE system. Also, the complete functional prototypes for this equipment will be developed for the PoC. Based on the outcome of the 5G-RANGE project, there are two products that are being considered for the near future. The first one is the 5G-RANGE BS, which will be designed to offer all functionalities of the 5G-RANGE network in a low-cost equipment. This solution will be based on a industrial PC motherboard, with components that are robust to temperature variations. The RF front-end will be designed to fulfil the 5G-RANGE requirements and will be integrated to the base-band processing in a single hermetically closed case. Hence, the 5G-RANGE BS will be composed by a single plug-and-play box that only requires Internet connection (Ethernet or fiber) and power energy (from AC, DC or Solar sources). The equipment will have two RF interfaces for connection with the external antennas and it will be designed to operate outdoors. Figure 11 shows the basic design of the 5G-RANGE BS while Figure 12 depicts the product format of the 5G-RANGE BS.

The second 5G-RANGE product is the CPE (Consumer Premise Equipment), which is a simplified version of the BS. The CPE will be designed to operate indoors or outdoors, and it can also be installed in vehicles for mobile operation. The CPE will be designed to be easily integrated with other technologies, such as Wi-Fi, LoRa and Sigfox, allowing different services over the 5G-RANGE networks. At the time that this report was written, the concept of the 5G-RANGE CPE format was under discussion with potential partners.

The development of 5G-RANGE handheld devices requires a SoC (System on Chip) and the resources for this development are not currently available. Hence, the development of 5G-RANGE handheld devices is not in the roadmap of the project partners.

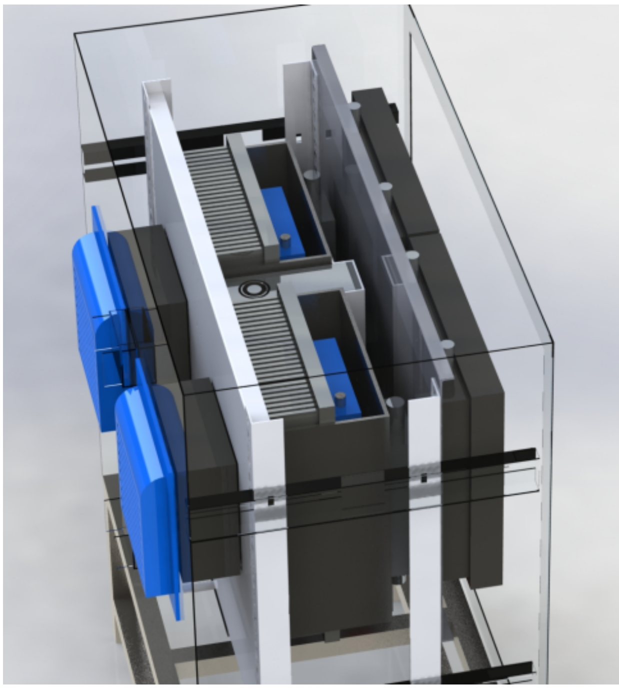

Figure 11. Basic design of the 5G-RANGE BS.

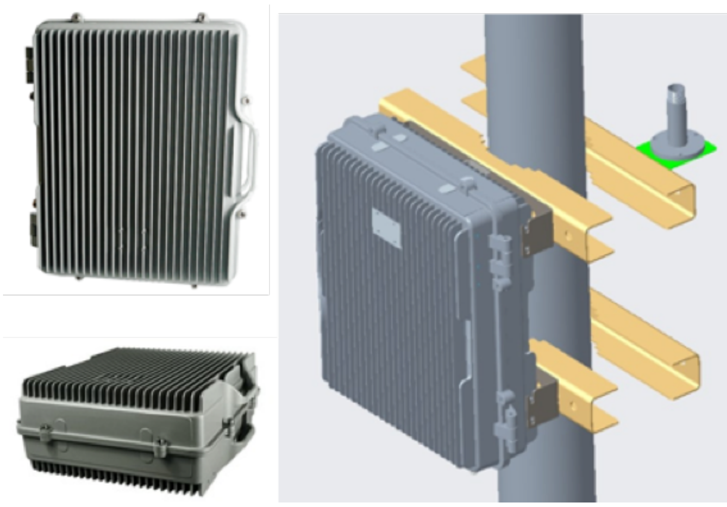

Figure 12. Product format for the 5G-RANGE BS.

3.2.4 Exploitations plans

Mass production of 5G-RANGE products depend on the standardization of the technology, which is a complex process that requires large investments. Although 5G-RANGE project does not have the resources to directly conduct this process, members of the consortium are participating in the discussion and presenting the principles, benefits, challenges and solutions for eRAC (enhanced Remote Area Communications) to a wide set of decision makers in industry, government and operators.

During this discussion, a high demand for connectivity from agribusiness and mining industries has emerged in Brazil and a clear interest in the 5G-RANGE technology has emerged. Inatel is currently developing new partnerships to exploit the outcome of the project for specific applications that does not requires compliancy with the 3GPP standards.

One application is the deployment of a remote area network in the area affected by the Brumadinho disaster. In January 2019, a dam used to store wasting from mining process in the city of Brumadinho, Brazil, has collapsed, affecting 23 cities. The mining company, Vale S.A., was responsible for the disaster and now a recovery plan is being executed to minimize the damage in this area. One of the actions consists on providing connectivity in the entire region in order to provide new tools for the development of the agribusiness, fishing, environment and disaster monitoring and mining. Several technologies are being considered and 5G-RANGE is a strong candidate for the wireless backhaul, allowing other technologies to be deployed in the field. At the date that this report was being written, Inatel was negotiating with the Minas Gerais State and Vale S.A. to develop the 5G-RANGE BSs and CPEs to be deployed in this area.

Besides the initiative with Vale S.A. and the Minas Gerais State, Inatel is also developing a partnership with FAEMG (Minas Gerais State Agribusiness Federation) to provide a 5G-RANGE solution for remote area connectivity. The main goal is to develop BSs and CPEs that can be deployed by farmers and associations of farmers to allow Smartfarms applications. In this case, the 5G-RANGE equipment will have two operational modes. The first mode will operate in frequencies dedicated to private networks (250 MHz and 400 MHz), allowing the users to deploy the network without depending on the regulation of TVWS (TV White Space). The second mode will operate in vacant UHF bands using CR (Cognitive Radio) once the TVWS is allowed in Brazil. This approach allows farmers to deploy the long-range wireless networks without depending on operators and regulators and, once the TVWS is allowed, the 5G-RANGE radios can be configured to exploit vacant TV channels in the area, increasing the overall capacity of the network. At the time that this report was written, Inatel was negotiating with FAEMG and a industrial partner about the production of the 5G-RANGE equipment and the business models for farmers and local ISPs (Internet Service Providers)

3.2.5 5G-RANGE and Other Technologies

5G-RANGE network has been designed to offer Internet connectivity under conditions that no other technology can fully address. Nevertheless, there are wireless technologies that can partially address the demand in remote areas. The main technologies are:

• Wi-Fi: Wi-Fi is designed to be an indoor wire-less network, which has been used by small Internet providers to offer fixed wireless connectivity in remote areas. High power wireless routers with directive antennas use ISM (Industrial Scientific and Medical) bands (typically in the 2.4 GHz band) to cover large distances. However, Wi-Fi cannot handle a large number of connected devices as well as interference with other wireless networks. This leads to a poor performance in terms of coverage and number of simultaneous connections. New standards, such as IEEE 802.11af and IEEE802.11ah aim for the usage of CR engines to exploit TVWS. These new standards focus on low power transmissions (20 dBm) and short ranges and, hence, does not apply for the eRAC scenario.

• IEEE 802.22: This standard is considered the first one to employ CR technology. However, its PHY is heavily based on WiMAX (Worldwide Interoperability for Microwave Access) and it employs OFDM (Orthogonal Frequency Division Multiplexing) as air interface. The high OOBEs from this waveform requires RF filtering, hindering the possibility to change the spectrum when a primary user is detected. Also, the few practical implementations of this standard purely rely on a geolocation database and do not use spectrum sensing. Consequently, unauthorized transmissions cannot be detected, which means that pirate TV signals can interfere with the IEEE 802.22network.

• LoRa: This standard has been designed for low throughput MTC (Machine-Type Communications) applications and it cannot provide broadband Internet access. It can achieve large coverage, but at very low data rates. Furthermore, the round-trip latency is around 1 s to 2 s, which means that this solution cannot be used for mission critical MTC and control applications.

• Sigfox: This is a closed standard designed for MTC applications. It can achieve up to50 km coverage, but the payload is limited to a few bytes and a maximum of 140 uplink transmissions per day.

• LTE Advanced and NB-IoT: 3GPP Release 14 has introduced an evolution of the LTE (Long Term Evolution) line up, which included high throughput and an IoT (Internet of Things) operation mode, called NB-IoT (Narrow Band IoT). The high throughput achieved by LTE advanced is applicable for urban environment and the NB-IoT can be used to deploy MTC services. These features allow new applications to be developed over 4G network. Although the upper MAC layer allows message timing in 100 km links, the limitations imposed by the PHY layer restricts the use of this technology in rural and remote areas. The CP (Cyclic Prefix) length, restricted to 4.7μs in normal mode and16.67μs in extended mode, cannot protect the high data rate stream from doubly dispersive channels with delay spread that can several tenths of μs. Therefore, only low data rates can be achieved by 4G technology in long-rage links. Also, this technology only operates in licensed spectrum.

• 5G-NR: 5G-NR (5G New Radio) was presented by 3GPP in Release 15 as the PHY interface for 5G networks. 5G-NR is more flexible than LTE in terms of subcarrier spacing, which can assume values of $\Delta f = 2^n \cdot 15$ kHz, with n= 1, 2, 3, 4. The CP length is reduced proportionally with the increment of the subcarrier spacing. This approach is an interesting solution for millimeter wave operation in LOS (Line-of-Sight) environment with high antennas gains and beamforming provided by massive MIMO. But it is not suitable for long-range links, where the multipath channel can present long delay profiles with tenths of μs. 5G-NR was also designed for operating in licensed bands, and not in TVWS. Hence 5G-NR requires RF filtering to reduce OOBE and to be compliant with the ACPR (Adjacent Channel Power Ratio) defined by the regulatory agencies.

• NR-U: the unlicensed spectrum access introduced by the 3GPP in 5G networks, named NR-U (NR for unlicensed spectrum), will initially allow 5G networks to exploit the unlicensed spectrum in the 5/6 GHz bands and other frequencies in the millimeter wave bands will also be included. Two operational modes are possible. In the first one, called non stand-alone, an 5G BS operating in licensed spectrum can unload data traffic in the unlicensed spectrum, increasing the overall capacity of the network. For the second one, known as stand-alone, the 5G BS operates only in the unlicensed spectrum, without any connection with a BS operating in the licensed spectrum. This approach is interesting for deploying private 5G networks. NR-U increases the flexibility of the 5G networks, but its operation restrictions reduces its impact in remote and rural areas. The propagation losses in 5/6 GHz frequencies and the restrictions for the EIRP (Effective Isotropic Radiated Power) in unlicensed spectra, considered in the standard, reduces the coverage area of the NR-U BS. In remote areas, the cell size must achieve tenths of kilometers to cover several subscribers and devices and to be economical feasible. Nevertheless, NR-U is an interesting solution that can enhance the opportunities for the last mile connection and distribution of the Internet access provided by a long-range link. Hence, NR-U is a complementary technology that can be combined with the 5G-RANGE solution to integrate new digital services in areas with poor or no connectivity.

3.2.6 TRL Table

The solutions implemented for the 5G-RANGE PoC achieved different TRLs (Technology Readiness Levels), as listed in Table 3.

Table 3. TRL for the 5G-RANGE blocks and PoC.

Block	Description	TRL
5G-MIMORA	MIMO system for remote area operation, covering diversity and multiplexing modes.	6
5G-ACRA	Channel coding scheme, including encoder, decoder and rate adaptation.	6
5G-FlexNOW	Waveform generator and detector for OFDM, GFDM and F-OFDM.	6
5G-IR2A	Algorithms for synchronization, channel estimation and gain control.	6
5G-FRAMER	Flexible frame multiplexer and demultiplexer for different operation modes.	6

5G-COSORA	Cooperative spectrum sensing scheme, including the reporting channel.	5
5G-DARA	Dynamic spectrum access scheme for fragmented spectrum allocation.	5
5G-D2DRC	Device to device communication for the 5G-RANGE uplink.	3
5G-RANGE BS	Base station for the PoC.	5
5G-RANGE UE	User equipment for the PoC.	5
NL-extensions	Cost-effective approach to complement the access network infrastructure resources, using resource-constrained platforms	4

4 Regulation Considerations and Standarisation Activities

This section presents regulation considerations regarding electromagnetic radiation and a description of ANATEL's Public Consultation Regarding a New Regulatory TVWS Framework in Brazil. Regarding the network layer, this section describes the ongoing of rLEDBAT standardisation.

4.1 Electromagnetic Radiation

5G-RANGE operates in the sub 1 GHz bands, exploiting the TV white spaces in VHF and UHF bands. Therefore, 5G-RANGE uses no-ionizing frequencies, which are frequencies unable to break the molecular connection in biological tissues. The only interaction of the 5G-RANGE waves with the human body is thermal.

The main reference for the SAR (Specific Absorption Rate) is the International Commission on Non-Ionizing Radiation Protection Guidelines [1]. This guideline defines the maximum power, in watts, per body mass, in kg, under different situation. Table 6.1 shows the power/body mass limits defined in this guideline.

Table 4. SAR limits.

		SAR (W/kg)	SAR in controlled environment (W/kg)
Whole body exposure	WBA (whole body average)	0.08	0.4
Localized exposure	Localized (peak spatial-average)	2	10
Localized exposure	Extremities	4	20

Table 6.2 presents the power limits for directly exposed people, assuming a 70 kg person and using the limits presented in Table 6.1.

Table 5 Power limits for a 70 kg person.

Condition	Maximum Power (70 kg)
WBA General	5.6 W
WBA Controlled	28 W
Head General	8 W
Head Controlled	40 W

5G-RANGE is aiming for using 6W+6W roof top antennas in the high-power CPE side, which means that the antennas are installed far away from the user. Hence, 5G-RANGE is a safe technology and can be employed without causing any harm to people.

Also, WBA General is assumed to be very conservative by authors that studies the impact of high-power wireless recharge stations for electric vehicles. According to [2], "The maximum accept-power is 55.5 kW to meet the basic restrictions of ICNIRP guidelines and 3.1 kW to meet the reference levels. The reference level is too conservative and can be exceeded provided that the basic restrictions are met, and adverse indirect effects can be excluded".

As can be seen, the power level to which the human body will be exposed in wireless car recharging stations are three orders of magnitudes higher than the 5G-RANGE transmit power. Therefore, it is reasonable to conclude that the 5G-RANGE power levels are not harmful for the users.

It is also important to highlight that the conventional UE terminals with internal antennas will be restricted to the same power levels present in today's smartphones. This means that these UEs will not be able to achieve 100 Mbps in the uplink at the edge of the cell and asymmetric uplink data rates are expected in this situation.

4.2 Transport Layer: rLEDBAT

rLEDBAT was proposed for standardization in the Internet Congestion Research Group at the IRTF (The research branch of the IETF). The document was submitted on July 2019 and accepted as a RG item (the first step towards standardization) in February 2020. The document was presented for the last time to ICCRG in November 2020 and it is progressing as expected. In the last meeting Microsoft reported that they have been working in rLEDBAT implementation.

4.3 ANATEL's Public Consultation Regarding a New Regulatory TVWS Framework in Brazil

The 5G-RANGE project (UFC partner) has participated in the public consultation promoted by the Brazilian regulator ANATEL. This consultation ended in August 2020 and had the objective to receive contributions from the society regarding a new regulatory framework for the TVWS in Brazil.

Our proposal was based on two major and relevant aspects envisioning the massive adoption of TVWS [3] and adapted to the Brazilian reality, as a continental country: 1) new business models, and 2) allow an higher transmitter power at the secondary system without affecting the primary ones, namely TV broadcast.

Particularly, the proposal tries to clarify some normative aspects, increasing the knowledge about the available TVWS channels at specific regions and bringing a more favourable normative framework for the future network operators, so that it is more attractive to invest in the new licensing regime. Moreover, the proposal also brings some technical aspects so that the primary users of TV bands are protected against harmful interference and more TVWS channels are available, especially at wide landscapes and remote regions (Brazil has many of those areas due to its continental dimension).

Only with a more transparent normative framework empowered by the very recent technical advances, it is possible to attract the attention of the society, operators and users, to the TVWS and the new paradigm in spectrum allocation, thus promoting a true digital inclusion.

Up to now there is no public outcome of our participation in the consultation. However, we keep checking ANATEL's official social channels for any possible outcome. Figure X show the identification of the public consultation at Anatel's web site.

CONSULTA PÚBLICA Nº 48	
Item: Regulamento - art. 8º, Parágrafo único	
Parágrafo único. A potência de pico máxima do Dispositivo de Espectro Ocioso (**White Spaces**), medida na saída do transmissor, não pode ser superior a 1 (um) Watt.	
Contribuição N°: 479	
ID da Contribuição:	94136
Autor da Contribuição:	Carlos Filipe Moreira e Silva
Entidade:	Universidade Federal do Ceará (UFC)
Área de atuação:	--
Data da Contribuição:	03/08/2020 23:49:13
Contribuição:	Ou seja 30 dBm. Este valor deve ser ajustado à realidade local. Ele faz sentido em um local com espectro congestionado, como áreas urbanas. Porém em áreas remotas ou rurais, por exemplo, com vegetação densa, esse valor é muito baixo. Uma possibilidade é poder ter faixas de valores, tal como acontece em diversas tecnologias, como no LTE. Por exemplo, no projeto H2020 5G-RANGE, a potência de um CPE pode chegar a 36 dBm, enquanto que um usuário (WSD) pode ter valores de 23 a 26 dBm (ver em deliverable 2.1). Quanto à estação rádio-base, tal como descrito em 3GPP TS 36.104 (versão 14.3.0), a sua potência máxima de transmissão não é limitada quando operando em "wide area mode"; neste caso, é da competência da agência reguladora, limitar a potência de transmissão, o que pode ser até de 48 dBm por antena. Contudo, caso a ANATEL entenda deixar esta normativa mais genérica, os valores de potência devem ser omitidos aqui e especificados no documento que trata da radiação restrita, uma vez que a tecnologia TVWS será assim designada.
Justificativa:	Ver texto acima.

Figure 13. Public Consultation on TVWS : registration at Anatel

5 Communication and Dissemination Activities

5.1 Actual Joint Work between Brazil and EU

During this period, technical activities were focused mainly on WP6, which integrates all solutions developed in the others technical work packages in a PoC (Proof-of-Concept). Firstly, the solutions developed in WP3, WP4 and WP5 (related to the physical, MAC and network layers, respectively) were integrated for a complete simulation of the proposed system. Moreover, the main algorithms necessary to demonstrate the 5G-RANGE key features were implemented in a PoC. Several tests and experiments were conducted with the PoC to validate the proposed solutions and also the performance of the proposed system. Finally, the four use cases defined in D2.1 were simulated and evaluated: Agribusiness and Smart Farming for Remote Area; Voice and Data connectivity over long distances for remote areas; Wireless Backhaul and Local High-Quality Connections; and Remote Health Care (e-Health) for remote areas. UC3M, CPqD and Inatel worked together in the integration tasks regarding the PoC.

Regarding joint work that resulted in the dissemination of the results, we can cite that UnB and Oulu University worked together in a novel method for collaborative spectrum sensing for 5G networks. Two techniques were developed: a Markov chain-based technique that improves accuracy while reducing the reporting control traffic; a harmonic mean-based technique that mitigates Byzantine attacks in the collaborative sensing. These results are reported in a paper published and presented at IFIP Networking Conference 2020 (Table 6). This work is related to WP4 and WP6 and will be reported in D6.3. Additionally, UnB also worked together with UFC in the development of a tool in NS-3 to allow the simulation of different 5G scenarios. The tool is modular and allows the incorporation of physical layer characteristics through a pre-defined interface and JSON technology. These results are reported in a paper presented in the demos session of SBRC 2020 (see Table 6). Although UnB and UFC are the paper authors, other partners also collaborated by suppling the configurations for the channels and models. This tool is related with the integration among the software artifacts developed in the project and will be reported in D6.3. Finally, at the end of 2019, the University of Oulu and UnB signed a MOU (Memorandum of Understanding) to researchers exchange and fostering of post-graduate programs.

5.2 Communication and Dissemination Activities

Communication and dissemination of project information including achievements, results, events, demonstrations and other related information are being done via project website (http://5g-range.eu/), social networks (@5G-Range), press releases and other media coverage. The list of dissemination activities carried out from January 2020 and confirmed until December 2020, are presented in the Table 3.1.

Table 6. Dissemination activities (achievements, results, events, demonstrations, etc.).

Title	Type of publication	Title of Journal/Conference/Book	Date	Place of publication
6G White Paper on Connectivity for Remote Areas	Contribution to white paper	6G Research Visions, No. 5	2020	Oulu, Finland
MHM: A Novel Collaborative Spectrum Sensing Method based on Markov-chains and Harmonic Mean for 5G Networks	Paper	IFIP Networking Conference (Networking) - 2020	2020	Paris - France

Title	Type of publication	Title of Journal/Conference/Book	Date	Place of publication
A Framework for Performance Evaluation of Network Function Virtualisation in 5G Networks	Paper	Latin American Computing Conference – CLEI 2020	2020	Loja - Ecuador
COLAB-5: Um Modulo para Simulação de Redes 5G	Presentation and Demonstration	SBRC 2020 (Demos Session)	2020	Rio de Janeiro – Brazil
EROS-5: Gerador de Tráfego Sintético para Redes 5G	Presentation and Demonstration	SBRC 2020 (Demos Session)	2020	Rio de Janeiro - Brazil
Uma Proposta para Avaliação da Virtualização de Funções de Rede em 5G	Paper	Network and Services Operations & Management Workshop – WGRS 2020	2020	Rio de Janeiro – Brazil
Uso de Cadeias de Markov para Otimizar o Sensoriamento Colaborativo do Espectro em Redes 5G	Paper	SBRC 2020	2020	Rio de Janeiro – Brazil
DSP-Based Flexible-Waveform and Multi-Application 5G Fiber-Wireless System	Paper	Journal of Lightwave Technology	2020	
Energy Detection Based Spectrum Sensing for Rural Area Networks	Paper	EAI Endorsed Transactions on Wireless Spectrum	2020	
Implementation of a multiband 5G NR fiber-wireless system using analog radio over fiber technology	Paper	Optics Communications Journal	2020	
Fifth-generation system for long-reach and enhanced mobile broadband scenarios	Paper	Microwave and Optical Technology Letters	2020	
Sparse code multiple access on the generalized frequency division multiplexing	Paper	EURASIP Journal on Wireless Communications and Networking	2020	
Performance Evaluation of Windowing Based Energy Detector in Multipath and Multi-signal Scenarios	Book Chapter	Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering	2019	
Brazil 6G Project - An Approach to Build a National-wise Framework for 6G Networks	Paper	2nd 6G Wireless Summit (6G SUMMIT)	2020	Finland

Title	Type of publication	Title of Journal/Conference/Book	Date	Place of publication
5G-RANGE: A transceiver for remote areas based on software-defined radio	Paper	European Conference on Networks and Communications (EuCNC)	2020	Croatia
5G para Áreas Remotas: Levando Internet para Todos	Talking	Workshop virtual Conectividade 5G na Amazônia	2020	Online event
Painel Futuro do 5G no Brasil e Suas Implicações para a Sociedade Moderna	Painel	SBrT 2020	2020	Online event
6G White Paper on Validation and Trials for Verticals towards 2030	White paper	University of Oulu	2020	Finland
A 6G White Paper on Connectivity for Remote Areas	White paper	University of Oulu	2020	Finland
5G-RANGE	Demonstration	Semana Nacional de Ciência e Tecnologia	2020	Brasilia, Brazil
Desafios para as redes 5G em áreas remotas	Talking	Semana Ciência e Tecnologia SEDECTI	2020	Online event
Energy-aware management in Multi-UAV deployments: Modeling and Strategies	Paper	MDPI Sensors	2020	Online - Journal
A Multi-site NFV Testbed for Experimentation with SUAV-based 5G Vertical Services	Paper	IEEE Access	2020	Online - Journal
Special issue "Broadband Wireless Access for Rural and Remote Areas"	CFP	Wireless Communication and Mobile Computing	2020	Online - CFP
A CDL-based Channel Model with Dual-Polarized Antennas for 5G MIMO	Paper	IEEE Access	2020	Online - Journal
Consulta pública nº 48	Standardization/ Regulation activity	ANATEL's Public Consultation Regarding a New Regulatory TVWS Framework in Brazil	2020	Public Consultation

5.3 Web platform and Social Media

A web page was launched since the beginning of the project with overall information about the project's main goals and partners. The 5G-RANGE website has been designed to allow users quickly find information and insights. Figure 14 and Figure 15 illustrate the website with several dedicated sections, as follows:

- Home: general information about the project, the main goals and the partners.
- Publication: section dedicated to disseminate the scientific papers and reports developed in the context of the project, which report the main achievements in the project.
- Demos: section dedicated to the 5G-RANGE demos.
- Deliverables: this section lists the 5G-RANGE public deliverables.
- Contact us: information to contact the 5G-RANGE teams.

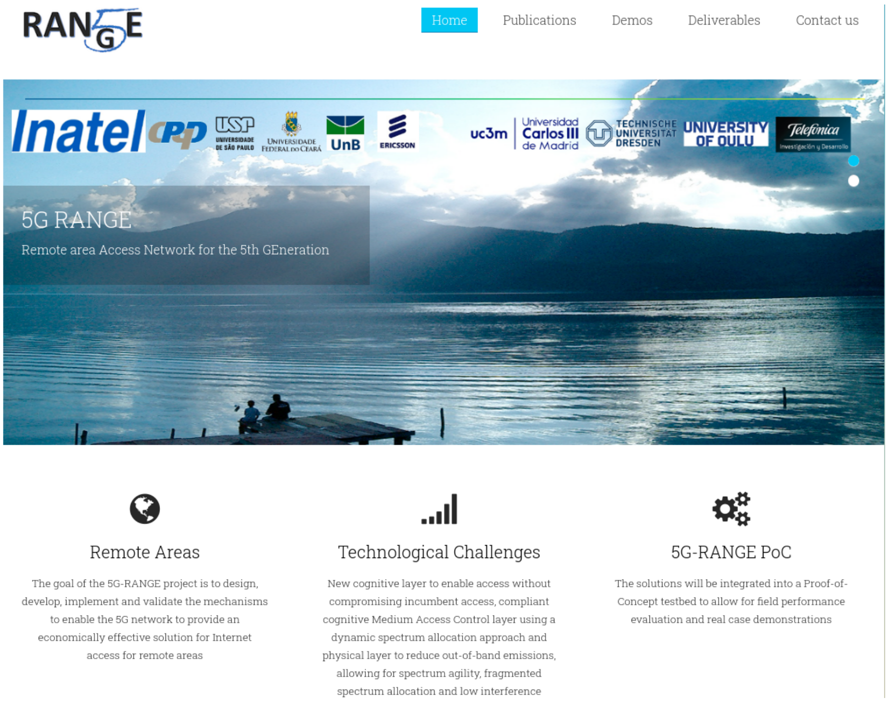

Figure 14. 5G-RANGE Website main page

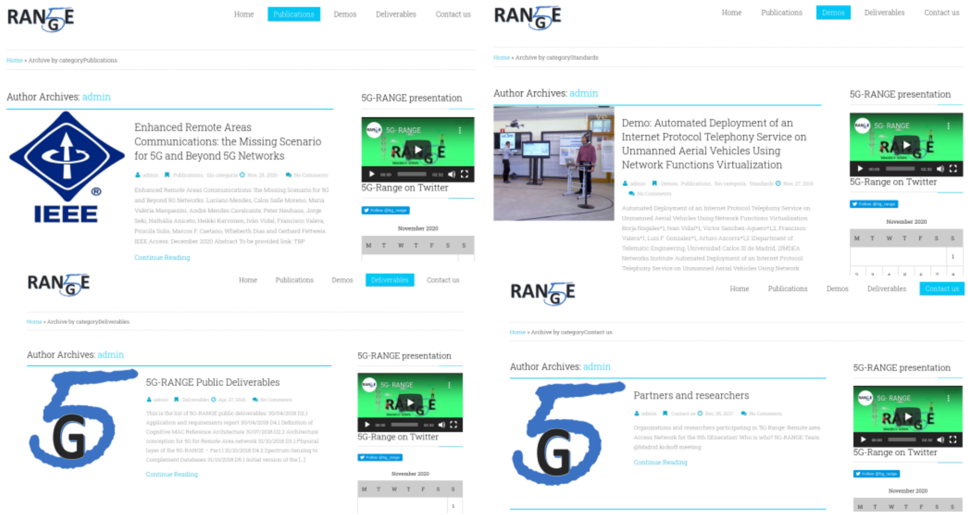

Figure 15. Sample of 5g-range.eu web sections

Regarding the performance indicators, 5G-RANGE website had a total of 830.372 visits from 55.547 different visitors (data collected in November, 2020).

In order to spread the 5G-RANGE achievements, a twitter account was also created. Figure 16 shows the 5G-RANGE twitter (@5g_range). During the project, the number of tweets and retweets were 1.482 and currently it has 157 followers.

Figure 16. 5G-RANGE twitter

6 Conclusions

The 5G-RANGE project achieved interesting results towards the integration of the eRAC scenario in the 5G Network. The technical solutions developed by the 5G-RANGE project show that the long-range coverage is possible and the new services that this technology can introduce in remote and rural areas has the potential to positively impact the agribusiness and quality of life in these regions. Also, the proposed business model in this work package has similar versions that are being successfully and sustainably implemented across Latin America and other continents like Europe to tackle specific connectivity issues.

The 5G-RANGE architecture has been designed to be easily connected to the 5G Core by using both 3GPP and non-3GPP interfaces. The PoC developed for performance evaluation and demonstrations has shown that the 5G-RANGE technology is able to address the challenging requirements of the eRAC scenario. This PoC is also being used as reference design for new products, which are being offered to different players in Brazil to be deployed in Minas Gerais State. The BS and CPE, as final products, are being negotiating with association, vendors and government and the interest in the 5G-RANGE technology is increasing.

The 5G-RANGE network has demonstrated that the mobile communication technologies have evolved to a new level, allowing the connectivity gap between urban and rural areas to be overcome by a reliable and economic feasible mobile network.

The joint work and dissemination activities show that the 5G-Range has established a solid cooperation link and this may result in future results and advances in 5G Networks.

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