IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received December 4, 2020, accepted December 30, 2020, date of publication January 11, 2021, date of current version January 20, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3050742

5G for Remote Areas: Challenges, Opportunities and Business Modeling for Brazil

ANDRÉ MENDES CAVALCANTE[1], (Member, IEEE), MARIA VALÉRIA MARQUEZINI[1], (Member, IEEE), LUCIANO MENDES[2], AND CARLOS SALLÉ MORENO[3]

[1]Ericsson Research, Indaiatuba 13337-300, Brazil
[2]National Institute of Telecommunications, Santa Rita do Sapucai 37540-000, Brazil
[3]Accenture Madrid, 28020 Madrid, Spain

Corresponding author: André Mendes Cavalcante (andre.mendes.cavalcante@ericsson.com)

This work was supported by the European Union's Horizon 2020 Research and Innovation Programme (5G-RANGE Project) under Grant 777137.

ABSTRACT Globalization, digitalization, and urbanization are progressing at a fast pace in cities and regions across the world. New technologies and innovations typically reach urban regions first, where Return on Investment (ROI) tends to be higher than in remote or rural areas, which are characterized by low population densities, low potential revenues, and large distances to urban clusters and societal service. This process has consistently increased the digital urban-rural gap. As an example, the Fifth Generation of Mobile Network (5G) has recently started to be rolled out, starting in the cities. Many challenges remain to bring broadband connectivity to the rural and remote regions. Particularly in Brazil, there is still a big digital gap between urban and rural areas. Urban areas have an internet penetration of around 65% while the rural figure is at just 34%. There are also important differences concerning the geographical location in the country. The North and Northeast regions of Brazil have lower internet penetration than the South, Southeast, and Center. In this paper, we present opportunities for connecting the unconnected in Brazil by defining a new alternative and scalable business model to deploy networks in ultra-low density areas. We present an analysis of show stoppers, rural opportunity sizing, business case, including deployment model for a 5G network, costs incurred, and generated revenues. A central element to bring scalability and sustainability into the business model for rural connectivity is the association between a Mobile Network Operator (MNO) and Rural Mobile Infrastructure Operator (RMIO), in which RMIOs run their network on a slice of a network that is connected to incumbent operators. Profit and Loss (P&L) analysis shows that a fair split of the value generated between the MNO and RMIO can be achieved.

INDEX TERMS 5G, remote areas mobile network, business model.

I. INTRODUCTION

The Fifth Generation of Mobile Network (5G) has been heavily researched during the last years to support all applications and requirements foreseen for the future mobile technologies [1]. According to the International Telecommunication Union (ITU) nomenclature for IMT-2020 [2], 5G targets three main use case families with distinct connectivity requirements: enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), and Ultra-Reliable Low-Latency Communications (URLLC).

The eMBB addresses human-centric use cases such as mobile telephony and media delivery, enabling large volumes of data transfer and extreme data rates [3]. The mMTC and URLLC target machine-centric use cases. The focus of mMTC is on providing connectivity to a massive number of low complexity power-limited devices that infrequently send or receive small volumes of data [4]. Internet of Things (IoT) applications are the main targets of this use case. The URLLC presents stringent requirements on reliability and latency and will allow several new applications to run over mobile networks (e.g., mission-critical applications, factory automation, real-time control of real and virtual objects, etc.) [5]. In reality, the division among the three use case families has been made to particularly ease the understanding of the requirements. However, 5G is targeted to support a plethora of services and applications that can have hybrid requirements from one, two, or three use case families.

The associate editor coordinating the review of this manuscript and approving it for publication was Eyuphan Bulut.

Due to its high flexibility in providing new services and applications, the adoption of the 5G technology shows promise as a means of offering Internet services for unconnected remote/rural residents, which is a significant market opportunity considering that almost 50% of the world's population (around 3.9 billion people) is not connected to the Internet [6]. 5G can be exploited to support rural services for entertainment, education, social media, and many IoT applications (e.g. in agribusiness, logistics, road service, mining, and environment, cattle, and disaster monitoring). However, offering Internet services for this market segment presents several challenges, mainly from the Mobile Network Operator (MNO) perspective. There are various reasons which hinder internet adoption in rural areas. In this sense, the World Economic Forum (WEF) [7] outlines four main areas to focus on:

1) **Infrastructure**, including both mobile towers and access points as well as adjacent required infrastructure such as access to electricity;
2) **Affordability**, both from a demand perspective about the number of people that can afford a mobile phone and a recurrent top up and the supply cost of that mobile phone and mobile data internet plans;
3) **Skills, Awareness and Cultural Acceptance**, referring to the level of literacy and digital education required to benefit from internet access and
4) **Content**, which is both in the right language and relevant for those accessing the internet.

Each country or region has its particular mix of challenges around these main focus areas. For example, one of the key factors for internet access and adoption across Latin America is extending the reach of the mobile network infrastructure as a first step towards closing the digital divide (i.e. access to the Internet). As expressed by GSMA [8], most of Latin America's total population is covered by the Second Generation of Mobile Network (2G). However, the digital divide is still there: more than 50% of the rural population remains uncovered by a Mobile Broadband (MBB) capable network, so pretty much all of the unserved in Latin America live in rural and/or remote areas. The economic rural challenge is that deploying telecommunications infrastructure in far-flung territories can be about 2 to 3 times more expensive than doing so in urban areas, while revenue opportunities will be much smaller and uncertain due to the purchasing power of the rural population and the relative dispersion in population concentration.

This situation calls for the development of cost-efficient solutions and new network operating models to better address challenges related to remote areas' connectivity [9]. In this context, this work presents opportunities for connecting the unconnected in Brazil by defining alternative and scalable business models to deploy 5G networks in remote areas. We present an analysis of show stoppers, opportunity sizing, business case, including deployment model for a 5G network, costs incurred, and generated revenues.

The paper is organized as follows: Section II covers the main showstoppers for mobile internet access in remote areas. Section III presents an estimate of the market opportunity in Brazil. Section IV shows the business modeling, its main elements, deployment scenarios, and value chain. Section V details the cost structure, profit and loss, considering the assumptions and adopted deployment scenarios. At last, the main conclusions of the work are presented in Section VI.

II. SHOWSTOPPERS FOR MOBILE INTERNET SERVICE ACCESS IN REMOTE AREAS IN BRAZIL

Brazil is a great example of the urban-rural divide faced in most developing regions. The country still lacks internet coverage in large areas. The main showstoppers for telecommunications companies to deploy mobile networks in rural areas of Brazil are described:

A. HIGH INVESTMENT PER COVERED INHABITANT

A common trait of the rural populations across the world, which is no different in Brazil, is that they live in more dispersed, less densified towns as compared to urban ones. They are spread over a larger area, which effectively makes reaching every single dweller a harder enterprise. The more advanced the connectivity sought, the higher the infrastructure costs. These infrastructure costs can vary depending on multiple factors such as the technology being deployed, which translates into Capital Expenditure (CAPEX), labor/installation costs, population density, and terrain topography (each topography has specific connectivity challenges and different adequate solutions, e.g. mountains have difficult Line-of-Sight (LOS) while jungles have good LOS above the canopy). As an example, the Organisation for Economic Co-operation and Development (OECD) found that high urban density in South Korea leads to an installation cost for Fiber to the Home (FTTH) of \$110 to \$170 per home, whereas the worldwide average exceeds \$1,000 per home [10].

Although costs have been declining thanks to the emergence of cost-efficient solutions (edge computing, network virtualization, open-source interfaces, etc.), most of these are still experimental or in a process of implementation, so they have not been yet widely adopted. The fact that rural coverage is more costly per inhabitant makes it a second priority, at best, for network operators. This is also true for more developed markets such as the European Union (EU), even considering that the capacity to create a positive business case (with a relatively short payback) in those markets is higher due to higher Average Revenue per User (ARPU) per subscriber.

B. OPERATIONAL COMPLEXITY AND COST

An often-overlooked challenge for rural connectivity goes beyond the actual cost of the equipment deployment, which is the cost to operate and maintain the equipment once it is integrated and turned on. Operations & Maintenance (O&M) is one of the main Operational Expenditure (OPEX) costs for network operators. These can be minimized by reducing the area of operation (fewer trips and less distance to reach sites). However, rural connectivity is spread across a much wider and harder to reach area. Any malfunction which requires a site visit will be costly and will take long to be resolved because of the sheer distance. This is exacerbated once taking into account the precarious road infrastructure that populates most rural regions (trucks get stuck in the mud or roads are not kept clean and drivable). The cost to operate and maintain rural sites grows exponentially with the remoteness of the location and the lack of proper infrastructure to reach the site, no matter where in the world is that site.

On top of that, there is another critical challenge for the operation of rural connectivity, which is the lack of a stable energy supply. Network sites require constant power to work, however, in most rural towns the power supply is intermittent and down for considerable lengths of time. In some cases, more than 80% of the faults in rural sites is not caused by a tower malfunction, but by a power outage [11]. The only way around this is to both improve and strengthen the whole electric grid to the rural area or to add an alternative energy source such as solar panels. Both options increase the overall deployment costs of rural sites even further.

C. LACK OF ACCURATE DATA

Population data and population profiles are something that most countries monitor on an ongoing basis. Most countries have public censuses in which they recount and locate their respective population. However, these endeavors require a massive effort on the government's side, which needs to deploy a considerable operation across every household in the country. Due to that, country censuses do not occur very often, which is a shame since the dynamics in rural populations are ever-changing. This holds particularly true for developing nations, which on one hand experience a rural to urban population migration and, on the other hand, have sudden shifts in the rural populations that cause them to concentrate in particular towns. Therefore, any population census older than a couple of years makes it outdated and practically unusable from a rural standpoint. Towns that seemed to have only a few hundred people can contain tens of thousands of people in a span of 2 to 4 years, making the census unreliable and inaccurate for rural population analysis. Operators have tried to overcome this lack of accurate data with new information sources.

D. REVENUE UNCERTAINTY

Since most of the data compiled by network operators and industry bodies such as the GSMA [8] is based on their current customer base (the vast majority of which are urban dwellers), limited information about the rural revenue opportunity is available to them. On top of that, it is hard to extrapolate the little they know across different topographies, countries, and rural population segments. This makes the analysis of the potential revenue a difficult and inaccurate estimation for them. For a business that is based on high CAPEX (sunk costs), all these uncertainties make the approval of rural deployments a very difficult challenge. When it comes to building a business case for connectivity for a given region or country, the revenue parameter in the model is highly dependent on the revenue per user (ARPU) and the achieved adoption rate once coverage is provided. These are two drivers, which are particularly shaky for the rural population:

1) **Rural ARPUs:** Purchasing power in rural areas is generally lower than in urban areas, which means that the expected ARPU in rural areas is automatically lower. Nevertheless, connectivity plays a more crucial part of the share of wallet of rural dwellers when compared to urban dwellers, since mobile connectivity is the gateway to reach other key daily activities such as getting the latest news, watching a video, or discussing issues around work. This goes in reverse to general thinking, which expects a high drop in rural versus urban ARPUs. Additionally, the available cash at hand for the rural population in a given moment is less: most rural dwellers manage day-to-day or week-to-week economies. This means that rural subscribers will not be able to pay for a whole month of connectivity even though the average cost per MegaByte (MB) is lower in the monthly plan. They require a special day or weekly plans to cater to their available cash at hand. This causes the rural dweller to pay more for a given amount of data or minutes when compared to the urban dweller. As one can see, there are opposing dynamics that boost and hinder rural ARPUs. However, the overall effect on these is hard to determine if there have not been previous deployments in similar areas. This is the approach taken by this work when analyzing potential rural ARPUs: looking at similar greenfield sites that previously had no mobile data connectivity and the ones that got upgraded to a 3G+ network. The importance is on tracking both the average revenue per deployed site and the average ARPU of the recurring rural subscribers to that site (to take away non-recurrent subscribers or "travelers"). This can give an estimation of the local potential ARPU in similar greenfield sites. However, there is very limited historic data of the ARPU evolution beyond a few months, which makes rural ARPU projections an additional challenge to build the business case.
2) **Rural Subscriber Adoption Rates:** The other key driver for rural revenues is the rate at which the operator is able to onboard new subscribers once a deployment is switched on. Beyond the lack of coverage, there are other reasons why a rural dweller might not be able to get mobile connectivity. These include lack of:
   - Access to a recharge/top-up point of sale;
   - A mobile internet compatible phone (3G+);
   - Access to electricity or intermittent supply (to recharge a phone or for cell site to work);

- Daily/weekly income to create the top up and;
- Customer support for any Subscriber Identity Module (SIM)/phone malfunctions.

These issues are overlooked in urban areas, which usually have local shops and distributors that can help solve most of these situations. In any case, some of these hindrances have proven less of a showstopper for rural subscribers than initially thought. For example, from some observed network data [11], mobile phones compatible with 3G+ systems are much more prevalent in rural areas than previously thought, even in greenfield areas with no data coverage. This is because most rural dwellers are in a constant move across towns for work, shopping or trading, so even though they do not have data coverage in their homes, they do access a mobile data coverage area throughout their daily or weekly activities. Again there are opposing dynamics that foster and hinder overall rural mobile internet adoption. Developed economies such as the EU have a much higher revenue certainty per inhabitant, so this is less of a showstopper in the EU than in Brazil.

E. TELCO INVESTMENT PRIORITIZATION

The combination of a high-CAPEX intensive business in which most investment is done upfront, a fierce competitive dynamic between network operators in the urban fight (where customers are more profitable), a higher investment per covered inhabitant in rural areas and higher operational costs and the uncertainty of the potential rural revenues to be achieved, create a situation in which a private, profit-minded network operator will not be able to prioritize rural deployments above other more profitable and risk-adjusted business cases. For rural, the required infrastructure is simply too expensive for the covered opportunity, and this will always be the case, particularly when compared to the urban population. This causes the rural business case to have a much longer and uncertain payback. The next years expect a massive roll-out of 5G starting with urban markets resulting in an even higher concentration of the investment towards dense urban markets. To date, unless operators are forced to, by regulatory obligations or penalties, or unless there is a concerted approach to incentivize rural coverage across other stakeholders such as regulators and governments, there is little point to expect a private network operator to push for the rural opportunity and solve the digital gap single-handedly. This holds for every country, including the EU. In the case of Brazil, a report [12] points out that the private sector had invested about $80Bn in telecommunications over a 12-year span before 2011, but that the telecommunications infrastructure had limited success in penetrating rural areas. This trend of intensive investment is not forecasted to stop. The GSMA [8] expects CAPEX investment to remain strong across the region as Fourth Generation of Mobile Network (4G) networks continue to build up to keep up with the growth in data usage. According to [8] annual CAPEX was expected to exceed $17Bn from 2018 onwards, and cumulative CAPEX over the remainder of the decade was forecast at nearly $70Bn. However, Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA) margins were expected to continue eroding.

F. SPECTRUM REGULATORY FRAMEWORK

Spectrum continues to be a vital asset for mobile operators. In order for them to meet the increasing demand for data and the unstoppable progress towards universal broadband access, operators require access to sufficient and affordable spectrum [13]. Spectrum allocation has been improving in Latin America, but there is still a need for a better way to redistribute and pay for spectrum. One of the key spectrum bands is 700MHz, which has been adopted in a few countries but not all [14]. Spectrum prices have been increasing in the region, making excessive-high prices more and more common, mostly caused by national political factors such as the need for higher tax collection or budget constraints [15]. The higher the spectrum prices go, the more negative impact they have on consumers through a more expensive, lower quality mobile internet experience. In some cases, high spectrum prices can also cause bands to continue unsold, which fails to benefit the digital economy overall. Beyond spectrum licensing and allocation, there are other ways in which current regulation hinders investment in rural coverage. These usually have to do with the level of regulatory obligations either attached to the winning bids of spectrum bands or the general quality levels of service expected for mobile connectivity.

In the first case, the regulator obliges winning spectrum bidders to also bring connectivity in certain rural areas or towns as part of the terms and conditions to license the spectrum. Network operators usually bake these types of obligations in the price paid for the spectrum. This is because most network operations and network equipment are not prepared to profitably sustain business cases in low-density, low and uncertain ARPU areas, which might lead to delays in complying with these obligations. Being obliged to cover certain non-attractive regions with urban-minded operations only perpetuate the belief from network operators that the digital divide is a non-attractive segment (or at the very least, not a priority). This further hinders the case for rural connectivity.

In the second case, there are various regulatory service levels dictated on a country level that have been established with the urban client in mind, securing a certain quality and provision of service to the end customers. The problem comes when regulation does not differentiate between urban (high-density, easy to upgrade and monitor) and rural (low-density, hard to reach and difficult to monitor) sites. This makes it very hard for the network operator to test innovative yet experimental technologies to try to bring rural coverage (for example, using low-earth orbiting satellites, balloons, or drones). By continuing to require the same level of service without differentiating the different types of scenarios that network operators face, it fails to incentivize testing and innovation in that area.

Brazil is one of the very few countries of Latin America to have implemented a universal service regime, with network expansion and quality obligations imposed on concession holders in accordance with binding universal service plans (the so-called Plano Geral de Metas de Universalização (PGMU) [16]). PGMU has been revisited every five years, being rigorous and strict. The current universal service obligations of concession holders include the provision of individual fixed telephony access in localities with over 300 inhabitants within 120 days. From 2012, the individual access obligation has been extended to rural communities within a radius of up to 30 km from the nearest municipality. Additional obligations are collective access to rural schools, health establishments, and indigenous communities, amongst others.

III. SIZING MARKET OPPORTUNITIES

The total unconnected opportunity in a country (or worldwide, for that matter) is directly related to the total population not currently covered by Mobile Broadband (MBB – Third Generation of Mobile Network (3G) and/or 4G) services. Although this is one of the key questions to answer, several other questions need attention to come up with a refined estimation of the opportunity, as follows:

1) **How is the population distributed in a country?**
   In order to answer this question is needed to have an accurate vision of where unconnected people live. This is no easy task due to two reasons:
   - **Reason 1:** The unconnected people cannot be mapped with user or network data from the operator's perspective, since they do not have access to their services. For the connected people, it is easy to estimate population density at a given location based on network data and market share. This is one of the methodologies used by operators to prioritize network densification (especially when ARPU is put into the equation);
   - **Reason 2:** Census data are usually insufficient because of:
     - Outdated data sets: census are done every decade or more;
     - Lack of accuracy: sometimes processes are not rigorous enough to obtain data that has the accuracy in numbers or geographical location that is needed to solve this problem;
     - Lack of granularity: most census data sets are gathered at an aggregated level that does not give enough granularity to map the exact location of a given population. For instance, in Brazil, the census includes only 6,000 population points for a total area of 8.5 million square kilometers. This gives a granularity of 1,417 km^2 per population point. In the last census, the average population associated with each data entry is of 37,000 people, which gives an idea of the aggregation level this data set has.

   These two reasons leave operators ill-equipped to use their internal data to estimate where the unconnected people live and the public data is not enough to solve this issue. Therefore, different approaches are needed.
2) **Where is there MBB service?**
   If the population distribution of a country were known, the next step would be to determine which parts of that population have access to MBB services and which parts do not. This requires an estimation of which areas of a country are currently covered by MBB service. Crossing the questions 1) and 2) would result in knowing how many people in the country lack access to MBB services and where they are, which is the main step towards estimating the overall opportunity.
3) **What is the best connectivity solution for each unconnected settlement that optimizes sustainability and guarantees good quality of service at the same time?**
   Knowing where unconnected people are located is a key step towards estimating the opportunity in a country. However, there is a huge variety when it comes to the complexity level for connecting the unconnected settlements. For instance, a given unconnected settlement may have a population of 20,000 people while another settlement may have a population of 2,000 [17]. At first glance, the first one seems to have a more appealing opportunity. However, it may be in the middle of the jungle and may need the deployment of two microwave intermediate sites plus the access point with their respective towers, including all the complexity and costs associated with the deployment in a jungle environment. On the other hand, the second settlement may be in a flat area, 35 km away from a fiber Point-of-Presence (PoP). For this settlement, one would only need to deploy one site with one microwave hop and the Radio Access Network (RAN) on the same tower. If the first settlement needs a total investment of $1M and the second one needs $50K, the investment per person would be $50 in the first settlement and $25 in the second. Depending on factors as ARPU and penetration curves, one may be economically sustainable while the other may not. Sustainability is key to tackle the lack of connectivity in a scalable way. This is a fundamental principle, if connectivity is deployed regardless of sustainability, it probably will not scale and will not last.

Answering the aforementioned questions will allow determining how many people are not connected in a given country, where they live, what is the optimal way to connect them to ensure sustainability and scalability, and therefore, what is the overall impact of connecting them.

A. TOTAL ADDRESSABLE MARKET (TAM)

In order to estimate the Total Addressable Market (TAM), we have adopted a data-based methodology as described in [11] to estimate the amount and distribution of unconnected population in a given country. This methodology leverages data with information around demography (where do people live?), coverage (where is there 2G, 3G, and/or 4G service?), and infrastructure (how far away is a given settlement from the nearest point of presence?) to estimate the best way to tackle the deployment of new connectivity where required.

Once this data has been integrated, the methodology generates the needed insights around the opportunity. It is important to highlight that, although this is a robust bottom-up methodology, the results have been validated with different classical top-down methodologies for TAM estimation [17]. Results showed that the TAM in Brazil is between 10 and 20 million unconnected people for a given MNO, most of which are Greenfield (meaning there is no Internet access in that given area) and a small amount is 2G (meaning there is very limited Internet access), as illustrated in Fig. 1.

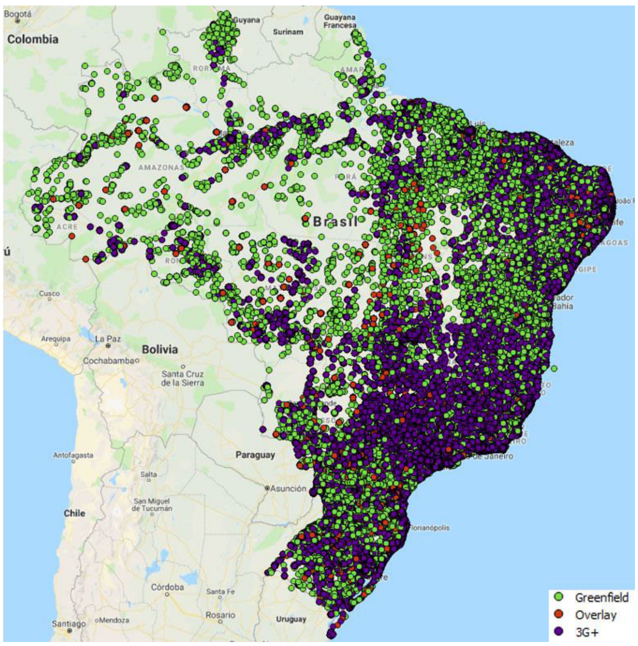


FIGURE 1. Total Addressable Market (TAM) in Brazil.

According to the methodology, there is a total of around 34,000 settlements where the unconnected people live (hundreds of people per settlement), which shows some of the scattering problems mentioned in [11]. Also, more than 20,000 4G sites should be deployed to cover the whole opportunity and there is an uneven distribution of the opportunity: less than 37% of the sites concentrate more than 75% of the opportunity.

IV. BUSINESS MODEL

In general, business models help to answer the question of what companies are offering to their customers in terms of products/services and value proposition, how and where they are planning to do that in practice, and why and how do they think they can do it profitably. Also, all business models should meet three key requirements; they should be scalable, adaptable to new business contexts, and sustainable [18].

As discussed by the World Economic Forum in [19], while data traffic growth soars, the business case for network operators to invest in upgrading mobile networks is weak because operators have only a small share in the value created by this traffic growth. As explained in section II, the barriers for rural connectivity today are generating further uncertainty on the sustainability of the business case.

Revenues for network operators depend on multiple factors, for example, consumer purchasing power, competition intensity, the quality of mobile networks, and regulatory frameworks. Subscriber numbers in emerging markets are still growing but at low ARPU levels. New projects, such as upgrading existing infrastructure, might be hard to justify based on the business case for a network operator. But the broader economic and social benefit – and short payback period – should encourage other types of players to get involved in the business of rural connectivity.

In this way, to generate a scalable and sustainable model that focuses on rural connectivity, the MNOs cannot organically address the problem alone. The traditional business models and ecosystem roles should be changed by introducing wireless networks that can be operated by different stakeholders [18]. In this context, different business models and analyses have been proposed in the literature, considering different types of network sharing [18], [20]–[22].

Network sharing refers to opening a private network infrastructure of an MNO to another MNO who in turns open their private network infrastructure, so both MNOs can benefit from a greater network footprint and be able to capture clients across a much wider area and at the same time achieve savings across CAPEX and OPEX costs. Infrastructure sharing enables MNOs to deploy networks more efficiently, optimize asset utilization, and reduce the running operation costs. Network sharing can be a key component to build a sustainable 5G network operation across rural areas. Because the 5G network deployments are expected to be more costly and to have more complex operations when compared to previous mobile technologies, network sharing can be the answer to make business cases work across various private mobile operators. They can concentrate deployments in a particular given area of the country and share networks across the other areas. Despite this positive aspect, some barriers limit network sharing deals among MNOs. The main reason for MNOs to avoid network sharing being the economic reason. Some MNOs consider that the upfront costs (transformation costs) are too high. Others consider that, if they are coming into a potential deal with different network sizes or different network profiles, the one with a larger or more advanced network believes it stands little to gain since most sunk costs have already been incurred. Also, if the network assets are transferred into a new entity, this could trigger taxation to apply and have a negative impact across sharing companies. Some of these barriers can be lifted, e.g., studies reveal that any initial or upfront costs will be offset quickly by the savings over the life of the deal [17]. Even if the parties come into the deal with very different network assets and size, a balanced deal can still be structured as long as both sides recognize the differences between networks, compensating the MNO with better/more assets. On the taxation issue, creating a new entity and transferring assets could be a great opportunity to bring in external third-party financing from infrastructure investors who understand the risk profile. They can put up the capital for the upfront costs and then be a participating party in the revenues generated by the shared network. This also has another side effect, which is the mitigation of antitrust concerns from regulators on market domination. Booz&Co [23] created an estimation of a Normalized 10-year Cash profile of a typical network sharing deal, adding CAPEX and OPEX costs. In this estimation, MNOs would reach the break-even point after two to three years.

Despite the possibilities for lifting the barriers presented above, in reality, network sharing deals are simply too complex to bring about in a short time frame and then be executed successfully between two rival companies.

In this paper, we focus on a solution based on the cooperation of an MNO and a Rural Mobile Infrastructure Operator (RMIO). The business model proposed here to tackle the unconnected opportunity is based on decoupling the MNO value chain. Local third parties would deploy and operate the access and transport network which are CAPEX intensive and require extended geographic capillarity whilst MNOs maintain client interfacing, product control, and core network which are highly benefited by a bigger scale. The RMIO can be seen as a particular case of the micro-operators concept discussed in [18], [24], [25], but focused on the rural scenarios. A micro-operator can be considered as an entity that offers 1) mobile connectivity combined/locked with specific, local services, is 2) spatially confined to either its premises or to defined (but narrow) area of operation, and is 3) dependent on appropriate available spectrum resources [18].

It is important to note that, in our model, the RMIO does not own the final customers. These continue to be customers of the licensed mobile network operators (MNO). Equally, the RMIO does not own a licensed mobile spectrum to communicate between its direct access site to mobile phones. This also continues to be owned by the MNO, who in most cases own a certain spectrum band for usage across the country without differentiating between urban or rural. To work, the RMIO needs to interconnect its infrastructure to an MNO's network core. This is what will allow the MNO to provide mobile services to its users through the RMIO infrastructure. The RMIO leverages on the MNOs to give it access to its licensed spectrum for the target area of the RMIO and the MNO leverages on the RMIO to capture new users in the RMIO's target areas.

In a nutshell, RMIOs run their network on a slice of a network that is connected to incumbent operators. The RMIO would operate the remote network, evangelize on the use of connectivity services, and could help commercialize services. End-users are customers of the incumbent operator, who provides the SIM and the commercial channel. A critical element for success will be generating the technological operating enablers to foster the creation of RMIOs and facilitate the sustainability and scalability of their network.

From an operational business model perspective, this is an attractive setup for both sides. On the RMIO side, it can deploy non-competing and value-added infrastructure in a rural area, with the assurance that it can then force MNOs to partner and close a commercial agreement to capture its potential clients in the area. On the MNO side, it allows to focus CAPEX on high-density, urban areas where competition is fierce and at the same time expand user adoption in rural areas in partnership with the RMIO with limited additional investment and making use of its licensed spectrum which was not being capitalized in the RMIO unserved area to date. In other words, the RMIO is renting its remote access network to the incumbent cellular operator and cellular operators become "virtual operators" on this slice of the network. The traffic generated by any subscriber using the RMIO's network is measured and the incumbent operator pays for it on a revenue-sharing basis. Additionally, the capillarity of the RMIOs would also allow them to be distributors of connectivity.

A. VALUE CHAIN

The value chain's goal is to clarify the split of responsibilities as well as the flows of value. The following illustration in Fig. 2 explains this chain, which we further detail below. Bear in mind that black circles indicate actions while yellow circles indicate monetary transactions.

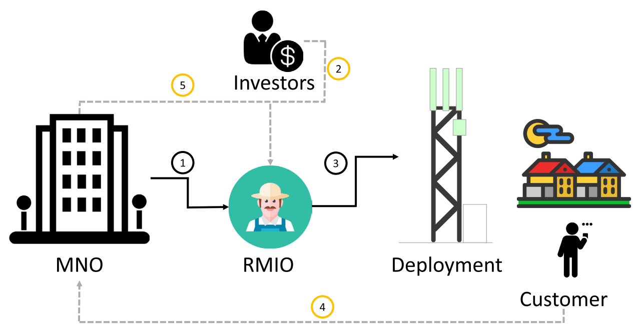


FIGURE 2. Value Chain.

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 previously, 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

upon. This can be done in several 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 Business-to-Consumer (B2C) customers as well as Business-to-Business (B2B) such as farmers. These consumers see the connectivity the same as they would in the city. The spectrum, the brand, and 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.

A summary of MNO and RMIO responsibilities is presented in Table 1:

TABLE 1. MNO and RMIO responsibilities [17].

	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	

B. USE CASES AND DEPLOYMENTS

For our analyses, we have assumed that a 5G system can provide broadband rural connectivity at 50 km distance from the Base Station (BS). Some works show that there are already solutions available to meet such a requirement [26], [27]. In [26], a 5G system based on 3rd Generation Partnership Project (3GPP) technologies was proposed for providing a high-capacity and long-range cost-efficient solution. Such a system operates in mid-band (3.5GHz) and makes use of high towers and high-power BSs. Another innovative solution is the one proposed in [27], called as Remote Area Access Network for the 5th Generation (5G-RANGE). It operates in Very High Frequency (VHF) and Ultra High Frequency (UHF) vacant TV bands, also known as TV White Space (TVWS) [28], and uses a Cognitive Radio (CR) approach, where up to 24 MHz can be aggregated to provide up to 100 Mbps at 50 km distance from the BS.

Since the use of TVWS dovetailed with 5G infrastructure for rural coverage has been presented as a promising solution for yielding cost-effectiveness from a service provider's perspective [29], we have considered the 5G-RANGE network as our adopted 5G solution, where four core use cases are targeted:

1) **Voice & Data** – users purchase devices compatible with 5G-RANGE and they connect directly to the solution. In this case, the technology would be used as RAN;
2) **Backhaul** – the technology would provide backhaul to standard 4G sites. Users would use standard LTE devices to connect to voice & data services;
3) **e-Health** – the connectivity provided enables e-Health products and services and
4) **Smart Farming** – the connectivity provided enables Smart Farming products and services

There is a big difference between use cases (1) and (2) with respect to use cases (3) and (4). The first two impact the very way that connectivity is provided, while the latter are Over-The-Top (OTT) services, agnostic to how connectivity is provided. In short, as long as there is connectivity, both OTT use cases will happen. On the other hand, use case (1) and use case (2) differ on how to use the technology, and using one implies not using the other. To account for this, we have structured our analyses in two different implementation modes:

- **Direct Connectivity:** Full deployment of 5G-RANGE as RAN technology and only as RAN technology;
- **Backhaul Connectivity:** Full deployment of 5G-RANGE as Backhaul technology and only as Backhaul technology for 4G sites.

In the first implementation (Direct Connectivity), we will be analyzing use cases (1), (3), and (4), while in the second implementation (Backhaul Connectivity) we will analyze use cases (2), (3), and (4). Although in terms of measuring the financial impact, these two types of deployment are kept separate, the model is very similar for both of them, i.e., the business case models the scenario where an RMIO tackles the opportunity defined by an MNO. The RMIO executes the deployments, the MNO gets the gross revenues and there is a revenue share between both parties, ensuring that the value generation is fair for both parties. The time frame of the Business Case is 10 years and OTT revenues are modeled as a mark-up on top of Gross B2B revenues. Also, Business Case has been defined in such a way that we can consider an optimistic and a realistic scenario by changing some of the key inputs and hypotheses. Furthermore, the real implementation may be a hybrid of both, for it can be deployed as RAN technology in some places and as Backhaul in others.

V. REVENUE AND COSTS ANALYSES

The goal of this section is to translate the TAM into financial impact, which is usually referred to as the business case of an opportunity. This means modeling how deploying 5G in rural areas would work, including costs incurred and revenues generated. The end goal here is to present the Profit & Loss (P&L) of the business, which gives information about its financial impact.

The starting point of the business model is the TAM presented in Section III-A. Once the TAM is known, the next step is to define the pace and structure at which the deployments will happen. A deployment plan should be done along with the business case timeframe (e.g., ten years). Based on the unitary characteristics for each type of deployment (more on this later), such as unitary costs, the unitary population covered, etc., one can model what are the incurred costs each year. Also, knowing the basic characteristics of the service provided (again more on this later), such as penetration, ARPU, etc., one can model the stream of revenues to be achieved thanks to the deployments done. Once the costs and the revenues for all the years within the scope are known, and considering some further information around things like taxes or Depreciation & Amortization (D&A) policies, one can directly obtain the P&L. The general flow in the business model is shown in Fig. 3.

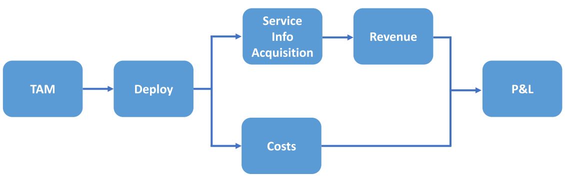


FIGURE 3. The general flow of the business model.

A. DEPLOYMENT ANALYSIS

1) **Direct Connectivity:** In this implementation mode, voice & data connectivity could be provided as far as 50 kilometers away from the site [17], [27]. With this in mind, the goal here is to determine how much of the TAM could be tackled with this technology and where the technology should be deployed. To do this, we have used a variation of the general clustering methodology described in [11]. In this case, we look to locate all 5G deployments in such a way that we minimize the number of sites deployed to cover the maximum amount of population. There are two further constraints to add concerning the general methodology:
   - The coverage radius is now 50 kilometers instead of the 1-5 km of standard 4G (Long-Term Evolution (LTE)) [17], [27];
   - To provide connectivity to all the unconnected people contained in the coverage area, the site should be deployed in a place where high capacity is guaranteed (i.e. near a Fiber PoP).

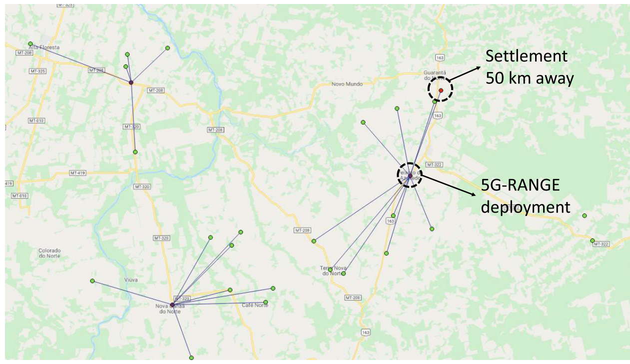


FIGURE 4. Clusters of 5G Direct Connectivity.

   Fig.4 shows a specific area where there are several 5G deployments.
   With these specifications in mind, the opportunity was segmented based on the amount of unconnected population covered by the specific site. We have defined four different segments for a specific 5G deployment based on size:
   - **Huge:** when the unconnected population within the 50 km radius circle is higher than 50,000 people;
   - **Big:** when the unconnected population within the 50 km radius circle is between 10,000 and people 50,000;
   - **Medium:** when the unconnected population within the 50 km radius circle is between 5,000 and 10,000 people;
   - **Small:** when the unconnected population within the 50 km radius circle is lower than 5,000 people.

   We have added an extra segmentation variable, which is the existence of infrastructure in the selected location. This has a significant impact on costs and whenever possible one should use existing infrastructure. This segmentation will allow us to determine which segments are more interesting to deploy and which ones should be discarded.
   The results of the simulation are shown in Table 2.
   As the numbers show, 5G could cover around 75% of the unconnected population with direct connectivity. Doing this would require deploying less than one thousand of 5G sites (with several sectors each), which is lower than 5% of the required 4G sites [17].
2) **Backhaul Connectivity:** This implementation mode assumes that each 5G deployment will provide backhaul connectivity to standard 4G sites. For each 5G site deployed, there are a number of 4G sites to deploy, which makes this implementation mode more complex in terms of execution, financing, and modeling. One advantage of this mode to be considered is the fact that users can connect to the network with standard

TABLE 2. Total opportunity for Direct Connectivity.

With existing infrastructure		
Pop. Segment	Req. 5G Sites (%)	Covered Pop. (%)
Huge	2	10
Big	6	6
Medium	3	1
Small	15	1

Without existing infrastructure		
Pop. Segment	Req. 5G Sites (%)	Covered Pop. (%)
Huge	8	29
Big	19	22
Medium	10	3
Small	36	3

With + Without infrastructure (Total)		
Pop. Segment	Req. 5G Sites (%)	Covered Pop. (%)
Huge	10	38
Big	25	28
Medium	13	4
Small	52	4
Total	100	75

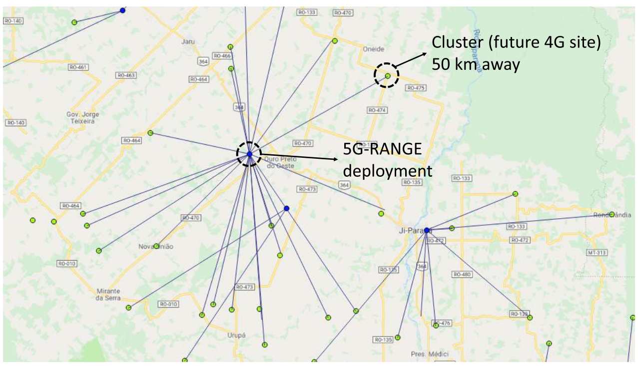


FIGURE 5. Clusters of 5G Backhaul Connectivity.

LTE phones. For this use case, the clustering methodology is very similar to the one used in the first implementation, with the following variations: Instead of creating clusters where the centroid is a 5G site and the nodes are settlements, the settlements are replaced with 4G sites. Each 5G site has a limitation of the number of 4G sectors it can connect. Current results assume a maximum of twenty 4G sectors per 5G site. Fig.5 shows the clusters of 5G Backhaul Connectivity.

With these specifications in mind, the results of the simulation are shown in Table 3. The label WI means "With existing Infrastructure" and WOI means "Without existing Infrastructure". For the WI case, it is considered that there is a tower at least 50-m high for 5G, and there is an access tower for 4G nodes.

As the numbers show, the population around the selected 5G sites is very similar to the Direct Connectivity case (around 75% of the unconnected population). However, in this case, only around 48% can be connected because of the limitations of 4G sectors per 5G site. It is important to note that lower TAM does not imply a lower number of connected people since the penetration of standard vs non-standard service will play a big role. This opportunity would require deploying less than one thousand 5G sites and a few thousand LTE sites [17].

At last, regarding the deployment plan, we have considered the following strategy for both modes:

- Not to deploy the segment small regardless of the existence of infrastructure;
- Concentrate the deployments as much as possible in the first 2-5 years.

B. REVENUES

The assumptions in this section are critical to determining the dynamics of service adoption and revenue generation. Some of the main inputs/hypotheses are described, as follows:

- **Penetration of Connectivity:** It measures the percentage of the population that would eventually access MBB services. Usually, this excludes very young and very old people. In rural Latin America, this usually evolves from 50-60% the first year of deployment to 70-80% in the long term.
- **4G Adoption:** It measures how many of the users who can access MBB would be able to use LTE. This accounts for access to LTE-compatible smartphones, affordability, etc. In rural Latin America, this usually starts somewhere around 50%-60% in the first years and reaches 100% in the long term (actually, when it is defined as the number of SIM cards per person, it can reach values well above 100%. This is not considered here).
- **5G-RANGE Adoption:** It is equivalent to the previous one, but applied to direct connectivity provided by a 5G-RANGE site. As there is yet no ecosystem of devices compatible with 5G-RANGE, today the penetration would be somewhere around zero. For this business case, we assume that deploying 5G-RANGE would come together with the creation of compatible devices. We have estimated an optimistic curve that would start somewhere around 0.5% the first year and evolve until almost reaching 10%. This would mean that 10% of the people would be purchasing 5G-RANGE-compatible devices. The realistic curve accounts for the same but starts at 0.5% and ends at 7.5%.
- **ARPU:** the information from pre-paid and post-paid ARPU comes from several public sources that measure ARPU for all countries and all customer segments.

TABLE 3. Total opportunity for Backhaul Connectivity.

With existing infrastructure				
Pop. Segment	Req. 5G Sites (%)	50 km Pop. (%)	4G WI Pop. (%)	4G WOI Pop. (%)
Huge	2	9	0.00	11
Big	6	7	0.09	4
Medium	3	1	0.04	1
Small	13	1	0.01	1
Without existing infrastructure				
Pop. Segment	Req. 5G Sites (%)	50 km Pop. (%)	4G WI Pop. (%)	4G WOI Pop. (%)
Huge	8	29	0.01	12
Big	20	22	0.07	14
Medium	9	3	0.07	3
Small	38	3	0.02	3
With + Without infrastructure (Total)				
Pop. Segment	Req. 5G Sites (%)	50 km Pop. (%)	4G WI Pop. (%)	4G WOI Pop. (%)
Huge	10	38	0.01	23
Big	26	29	0.17	18
Medium	12	4	0.11	4
Small	51	4	0.03	4
Total	100	75	0.32	48

TABLE 4. Revenue assumptions.

Input	Y1	Y10
Penetration of Connectivity (% of population who can access)	60%	78%
4G adoption (optimistic)	60%	100%
4G adoption (realistic)	50%	100%
5G-RANGE adoption (optimistic)	0.10%	10%
5G-RANGE adoption (realistic)	0%	7%
RMIO Revenue share (% of gross revenues that go to RMIO)	70%	70%
Smart Farming Revenues (% on top of B2C Gross Revenues) - Optimistic	6%	15%
Smart Farming Revenues (% on top of B2C Gross Revenues) - Realistic	5%	12%
eHealth Revenues (% on top of B2C Gross Revenues) - Optimistic	5%	14%
eHealth Revenues (% on top of B2C Gross Revenues) - Realistic	4%	11%

- **Revenues of OTT services:** these values are estimated from MNO's experience on how to model these kinds of services and the order of magnitude they generate.

Table 4 summarizes the inputs and assumptions for revenue. The ARPU pre-paid and ARPU post-paid are not shown in this table since they are MNO-dependent. However, for our analysis, we have assumed that both ones have an increase of around 11% from year 1 (Y1) to year 10 (Y10). Some further elements need to be highlighted, as shown in Table 5. These inputs come from internet sources and estimations or widespread heuristics in the industry.

TABLE 5. Additional assumptions/inputs for Revenues.

Input	Y1	Y10
Minimum tower height needed to consider existing infra in 5G-RANGE deployments	50 m	50 m
USD vs BRL (Dec 2019)	4.17	3.75
% of pre-paid users in rural areas	76%	67%
Price of KWh in Brazil in 2019	$0.18	$0.18
Compound Annual Growth Rate (CAGR) inflation of energy prices in Brazil	8%	8%

C. COSTS

In Table 6, we present the main cost inputs for every element in the deployment modes and the O&M process of the RMIO and the MNO in two scenarios (Optimistic and Realistic). There are also some important sizing hypotheses to highlight here (they are included in Table 6 but some further explanations are in order):

TABLE 6. Cost assumptions.

Input	Y1	Y10
Capacity needed per 5G-RANGE site (Mbps)	300	300
Capacity per 4G sector (Mbps)	15	15
RAN sectors per 5G-RANGE site - Huge & Big	4	4
RAN sectors per 5G-RANGE site - Medium & Small	3	3
RAN sectors per 4G site	1.5	1.5
Max 4G sectors per 5G-RANGE node	20	20
Max 4G sites per 5G-RANGE site	13	13
Energy mix - off-grid for 5G-RANGE Huge & Big sites (%)	0%	0%
Energy mix - off-grid for 5G-RANGE Medium & Small sites (%)	0%	0%
Energy mix - off-grid for 4G sites (%)	25%	10%
CapEx - 5G-RANGE Base Transceiver Station (BTS) (Optimistic) ($)	16500	13200
CapEx - 5G-RANGE Base Transceiver Station (BTS) (Realistic) ($)	17250	13800
CapEx - 4G Base Transceiver Station (BTS) ($)	10000	10000
CapEx - Infrastructure Huge & Big ($)	60000	60000
CapEx - Infrastructure - Medium & Small ($)	30000	30000
CapEx - Energy off grid - Huge & Big ($)	10000	10000
CapEx - Energy on grid - Huge & Big ($)	3000	3000
CapEx - Energy off grid - Medium & Small ($)	7000	7000
CapEx - Energy on grid - Medium & Small ($)	2000	2000
CapEx - 5G-RANGE Customer Premises Equipment (CPE) ($)	1500	1500
OpEx - Energy - 5G-RANGE - Huge & Big ($/year/sector)	432	432
OpEx - Energy - 5G-RANGE - Medium & Small ($/year/sector)	432	432
OpEx - Energy - 5G-RANGE Customer Premises Equipment (CPE) ($/year)	194	373
OpEx - O&M - 5G-RANGE ($/year/site)	16418	13135
OpEx - Energy - 4G ($/year/sector)	700	700
OpEx - O&M - 4G ($/year/site)	16418	13135
Taxes - % over EBITDA	30%	30%
Depreciation & Amortization (D&A) - Years to D&A new CapEx	10	10
MNO cost - Commercial channel commission (% of Gross Revenues)	15%	15%
MNO cost - HR (% of Gross Revenues)	10%	10%
MNO cost - IT upgrade - Optimistic (one-off $)	$ 2M	
MNO cost - IT upgrade - Realistic (one-off $)	$ 5M	

- **Sizing of 4G as RAN:** based on the distribution of population for each LTE site, and knowing the widespread heuristics in the telecom industry, we have determined that, on average, the LTE sites need 1.5 sectors to work as a RAN in our model [17];
- **Sizing of 5G as RAN:** for the deployment mode where the 5G-RANGE sites are used as a RAN solution (i.e. Direct Connectivity), we have assumed that each 5G site has an available capacity of $\approx$ 300 Mbps, and an optimal amount of sectors of 4 [17]. However, for the cases of medium and small sites, we have reduced the number of sectors to 3, to make them financially viable. Fig.6 illustrates a sizing example of Direct Connectivity.
- **Sizing of 5G as Backhaul:** for the deployment mode where the 5G-RANGE sites are used as a backhaul solution (i.e. Backhaul Connectivity), we need to determine how many LTE sites can be connected to each 5G-RANGE site. To do that, we have assumed (based on industry rural standards) that we will be providing 15 Mbps per LTE sector. Assuming 300 Mbps of available capacity for each 5G-RANGE site and 1.5 sectors (on average) for each LTE site, we will be able to connect 20 LTE sectors per 5G-RANGE site,

TABLE 7. Profit & Loss for Direct Connectivity.

	Optimistic		Realistic	
	RMIO	MNO	RMIO	MNO
Total Net Present Value (NPV)	$134,451,907	$12,105,318	$44,703,379	$3,133,466
Payback (Free Cash Flow accumulated > 0)	< 7 years	<5 years	textless 9 years	< 9 years
Peak Funding	$38,334,012	$1,994,352	$41,535,491	$5,000,000
Breakeven (Free Cash Flow > 0)	Year 3	Year 2	Year 4	Year 2

TABLE 8. Profit & Loss for Backhaul Connectivity.

	Optimistic		Realistic	
	RMIO	MNO	RMIO	MNO
Total Net Present Value (NPV)	$547,761,960	$81,081,468	$276,568,175	$59,107,482
Payback (Free Cash Flow accumulated > 0)	< 7 years	< 2 years	< 8 years	< 3 years
Peak Funding	$184,279,303	$902,920	$212,322,726	$4,102,239
Breakeven (Free Cash Flow > 0)	Year 4	Year 2	Year 4	Year 2

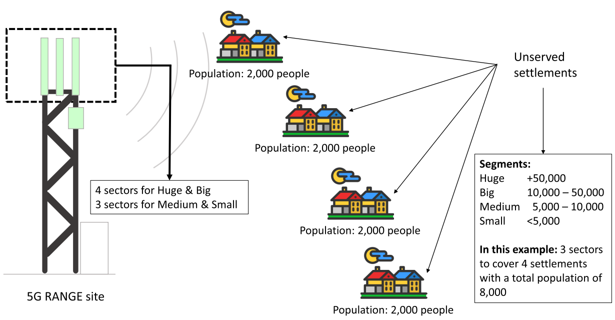


FIGURE 6. Sizing example for Direct Connectivity.

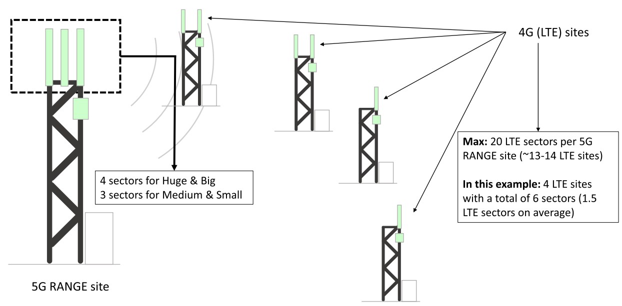


FIGURE 7. Sizing example for Backhaul Connectivity.

i.e. ∼ 13-14 LTE sites per 5G-RANGE site. Fig.7 illustrates a sizing example of Backhaul Connectivity.

D. PROFIT & LOSS ANALYSIS

Once all the inputs and hypotheses have been introduced and tuned into the model, a thorough analysis of Profit & Loss (P&L) has been done. The main results are summarized in Tables 7 and 8 (more detailed information can be found at [17]).

As we can see, there is a fair split of the value generated by this opportunity between the RMIO and the MNO in both deployment modes and both scenarios (Optimistic and Realistic). Also, as could be expected, although Direct Connectivity and Backhaul have similar Paybacks, Backhaul is more capital intensive than Direct Connectivity. In other words, as the penetration of 5G-RANGE connectivity is supposed to be lower than standard LTE, Direct Connectivity will be less intensive in investment but will also generate fewer revenues while Backhaul Connectivity will be more costly and also generate higher revenues.

It is worth to mention that in this financial analysis, the spectrum issue is not explicitly taken into account because we consider that this is an asset that the MNO already owns regardless of the new deployments. Along with the brand, the commercial channel, customer management, etc., it is one of the key assets brought to the table by the MNO and is included in the revenue share. On another hand, the use of TVWS, as proposed in 5G-RANGE [27], has also been suggested to alleviate the spectrum issue in conventional cellular networks [29]. However, a clear definition of how the TVWS usage will benefit/impact the business model for rural coverage depends on the TVWS regulation, that in the case of Brazil, it is progressing with no fixed decisions yet [17].

VI. CONCLUSION

The sizing of the addressable market is of the utmost importance for evaluating the market opportunities for 5G solutions deployments in remote and rural areas. In Brazil, we estimate that there are between 10 and 20 million unconnected people for a given MNO, most of which are Greenfield, i.e., not even covered by 2G networks. According to the adopted methodology, more than 20,000 LTE sites should be deployed to cover the whole opportunity.

In the deployment analyses, two main deployment modes where 5G technology could be used were selected: 1) Direct Connectivity, that means full deployment of 5G as RAN technology and only as RAN technology and, 2) Backhaul Connectivity, that means full deployment of 5G as Backhaul technology and only as Backhaul technology. Simulation results show that a tailored 5G system for remote areas (e.g., 5G-RANGE) could attack 75% of the unconnected population with Direct Connectivity. Doing this would require deploying less than one thousand 5G sites (with several sectors each). For Backhaul deployment, the population around the selected 5G sites is very similar. However, in this case, only around 48% of the unconnected population can be connected because of the limitations of LTE sectors per 5G site. This opportunity would require deploying roughly the same amount of 5G sites as for the Direct Connectivity and several thousands of LTE sites. Although the addressable market is smaller for Backhaul Connectivity deployment mode, it does not translate to a lower number of connected end-users since the penetration of standard (i.e., LTE) *versus* non-standard (i.e., 5G-RANGE) service will play a significant role.

Based on the sizing of the market and after a detailed analysis of the show-stoppers, a Business model has been presented. This model is centered on the cooperation of an MNO and an RMIO, i.e., local third parties that would deploy and operate the access and transport network. The model was applied to 4 use cases (voice and data, backhaul, e-Health, and smart farming) and for each deployment mode, an analysis of costs incurred and revenues generated has been performed. Once all the inputs and hypotheses had been introduced, and the model had been properly tuned, the P&L of that business was analyzed, which provided information about its financial impact.

Results showed a fair split of the value generated by this opportunity between the RMIO and the MNO in both deployment modes. This holds for the optimistic as well as for the realistic scenario. Also, as could be expected, although the two deployment modes have similar Paybacks, the Backhaul Connectivity is more capital intensive than the Direct Connectivity.

REFERENCES

[1] S. E. Elayoubi, G. Zimmermann, D. Martin-Sacristan, M. Fallgren, Y. Qi, C. Yang, S. Jeux, P. Agyapong, L. Campoy, P. Spapis, and S. Singh, "5G service requirements and operational use cases: Analysis and METIS II vision," in *Proc. Eur. Conf. Netw. Commun. (EuCNC)*, Jun. 2016, pp. 158–162.

[2] IMT, *IMT Vision—Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond*, Int. Telecommun. Union (ITU), document M.2083-0, Recommendation ITU, 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

[3] D. Demmer, R. Gerzaguet, J.-B. Dore, and D. Le Ruyet, "Analytical study of 5G NR eMBB co-existence," in *Proc. 25th Int. Conf. Telecommun. (ICT)*, Jun. 2018, pp. 186–190.

[4] C. Bockelmann, N. Pratas, H. Nikopour, K. Au, T. Svensson, C. Stefanovic, P. Popovski, and A. Dekorsy, "Massive machine-type communications in 5G: Physical and MAC-layer solutions," *IEEE Commun. Mag.*, vol. 54, no. 9, pp. 59–65, Sep. 2016.

[5] G. Pocovi, H. Shariatmadari, G. Berardinelli, K. Pedersen, J. Steiner, and Z. Li, "Achieving ultra-reliable low-latency communications: Challenges and envisioned system enhancements," *IEEE Netw.*, vol. 32, no. 2, pp. 8–15, Mar. 2018.

[6] (2018). *ITU Releases 2018 Global and Regional ICT Estimates, ICT for Sustainable Development—Broadband/Connectivity*. [Online]. Available: https://www.itu.int/en/mediacentre/Pages/2018-PR40.aspx

[7] *Internet for all, a Project of the the World Economic Forum's*, World Econ. Forum, Cologny, Switzerland, 2017.

[8] *The Mobile Economy. Latin America & the Caribbean*, GSM Assoc., London, U.K., 2017.

[9] NGMN Alliance. (Jun. 2019). *Extreme Long Range Communications for Deep Rural Coverage (incl. Airborne Solutions)*. [Online]. Available: https://www.ngmn.org/wp-content/uploads/Publications/2019/190606_NGMN_5G_Ext_Long_Range_D1_v1.7.pdf

[10] *The Development of Fixed Broadband Networks*, OECD, Paris, France, 2014.

[11] 5G-RANGE. *Deliverable D7.1: Exploitation, Communication, Dissemination and Standardization—Part I*. Accessed: Jul. 30, 2020. [Online]. Available: https://5g-range.eu/wp-content/uploads/2018/04/D7.1-Exploitationcommdisseminationstandarization-.part-I.pdf

[12] M. Jensen, "Brazil-broadband in Brazil: A multipronged public sector approach to digital inclusion," World Bank Group, Washington, DC, USA, Tech. Rep. 69173, Jan. 2011, vol. 1.

[13] *Broadband Policies for Latin America and the Caribbean: A Digital Economy Toolkit, Chapter 3*, Organisation Econ. Co-Operation Develop. (OECD), Paris, France, 2016.

[14] 4G Americas Association, "700MHz spectrum processes in Latin America," White Paper, Aug. 2015. [Online]. Available: https://www.5gamericas.org/wp-content/uploads/2019/07/4G_Americas_700_MHz_Spectrum_Process_Lat_Am.pdf

[15] *Effective Spectrum Pricing in Latin America: Policies to Support Better Quality and More Affordable Mobile Services*, GSM Assoc., London, U.K., 2018.

[16] ANATEL. (2020). *Plano Geral de Metas de Universalização (PGMU)*. Accessed: Nov. 20, 2020. [Online]. Available: https://www.anatel.gov.br/setorregulado/plano-geral-de-metas-de-universalizacao

[17] 5G-RANGE. *Deliverable D7.2: Exploitation, Communication, Dissemination and Standardization—Part II*. Accessed: Jul. 30, 2020. [Online]. Available: https://5g-range.eu/wp-content/uploads/2019/12/D7.2-Exploitationcommdisseminationstandarization-.part-II.pdf

[18] P. Ahokangas, M. Matinmikko-Blue, S. Yrjola, V. Seppanen, H. Hammainen, R. Jurva, and M. Latva-aho, "Business models for local 5G micro operators," *IEEE Trans. Cognit. Commun. Netw.*, vol. 5, no. 3, pp. 730–740, Sep. 2019.

[19] *Financing a Forward-Looking Internet for all*, World Econ. Forum, Cologny, Switzerland, 2018.

[20] D.-E. Meddour, T. Rasheed, and Y. Gourhant, "On the role of infrastructure sharing for mobile network operators in emerging markets," *Comput. Netw.*, vol. 55, no. 7, pp. 1576–1591, 2011.

[21] K. K. Larsen. (2012). *Fundamentals of Network Sharing*. [Online]. Available: https://www.slideshare.net/KimKyllesbechLarsen/fundamentals-of-mobile-network-sharing

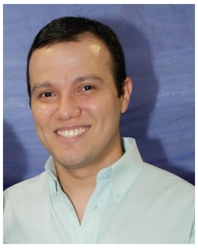
[22] T. Sanguanpuak, S. Guruacharya, E. Hossain, N. Rajatheva, and M. Latva-Aho, "Infrastructure sharing for mobile network operators: Analysis of trade-offs and market," *IEEE Trans. Mobile Comput.*, vol. 17, no. 12, pp. 2804–2817, Dec. 2018.

[23] R. Friedrich, S. Pattheeuws, D. Trimmel, and H. Geerdes, "Sharing mobile networks: Why the pros outweigh the cons," Booz Company, McLean, VA, USA, Tech. Rep. 2012, 2012.

[24] M. Matinmikko, M. Latva-aho, P. Ahokangas, S. Yrjölä, and T. Koivumäki, "Micro operators to boost local service delivery in 5G," *Wireless Pers. Commun.*, vol. 95, no. 1, pp. 69–82, Jul. 2017.

[25] J. Vartiainen, M. Matinmikko-Blue, H. Karvonen, and L. Mendes, "Spectrum sharing and operator model for rural and remote area networks," in *Proc. 16th Int. Symp. Wireless Commun. Syst. (ISWCS)*, Aug. 2019, pp. 53–57.

[26] N. Jalden, J. Lun, P. Frenger, A. Furuskar, S. Venkatasubramanian, and E. Trojer, "Full coverage with 3GPP technologies on the feasibility of providing full rural cellular coverage," in *Proc. IEEE 91st Veh. Technol. Conf. (VTC-Spring)*, May 2020, pp. 1–6.
[27] W. Dias, D. Gaspar, L. Mendes, M. Chafii, M. Matthe, P. Neuhaus, and G. Fettweis, "Performance analysis of a 5G transceiver implementation for remote areas scenarios," in *Proc. Eur. Conf. Netw. Commun. (EuCNC)*, Ljubljana, Slovenia, Jun. 2018, pp. 363–367.
[28] D. Noguet, M. Gautier, and V. Berg, "Advances in opportunistic radio technologies for TVWS," *EURASIP J. Wireless Commun. Netw.*, vol. 2011, no. 1, p. 170, Dec. 2011.
[29] M. Khalil, J. Qadir, O. Onireti, M. A. Imran, and S. Younis, "Feasibility, architecture and cost considerations of using TVWS for rural Internet access in 5G," in *Proc. 20th Conf. Innov. Clouds, Internet Netw. (ICIN)*, Mar. 2017, pp. 23–30.



ANDRÉ MENDES CAVALCANTE (Member, IEEE) received the Ph.D. degree in electrical engineering from the Federal University of Pará (UFPA), Brazil, in 2007. From 2007 to beginning of 2016, he was a Coworker with the Nokia Institute of Technology (INDT), Brazil, where he was involved in several Research and Development projects related to wireless communications. He is currently a Senior Researcher with Ericsson Research, Brazil. His main research interest includes mobile transport network for future wireless communication systems.

MARIA VALÉRIA MARQUEZINI (Member, IEEE) received the D.Sc. degree in physics from the State University of Campinas–UNICAMP, Brazil, in 1995. From 1995 to 1997, she worked as a Postdoctoral Researcher with the Materials Science Division, Lawrence Berkeley National Laboratory. From 1997 to 1999, she worked as an Associate Researcher with the Physics Institute, UNICAMP, conducting research activities in the field of electronic processes in semiconductors. Since 2000, she has been working with the Research Department, Ericsson, Brazil. She has been involved in many research projects in the telecommunications domain.

LUCIANO MENDES received the Ph.D. degree in electrical engineering from the State University of Campinas, Brazil, in 2007. Since 2001, he has been a Professor with the National Institute of Telecommunications (Inatel), Brazil, where he acts as a Research Coordinator of the Radiocommunications Reference Center. He is also the Research Coordinator of the 5G-Brasil project. His main research interest includes physical layer for future mobile networks.

CARLOS SALLÉ MORENO has a background in Industrial Engineering, Universidad Politécnica de Madrid and CentraleSupélec. He has worked with Telefónica, for four years, with special focus on Rural Connectivity, Innovation, and Data Science. He currently works with Accenture in the Applied Intelligence area implementing Data Science and AI projects.