Small rural operators techno-economic analysis to bring mobile services to isolated communities: The case of Peru Amazon rainforest

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**ABSTRACT**

A large number of rural communities in developing countries do not have access to communications services, unlike urban areas where these services have rapidly grown. This connectivity gap is mainly caused by the urban-oriented business models of traditional operators, which are not cost-effective in regions that are characterized by isolation, low population density, and scarcity of resources.

This paper analyzes a feasible and sustainable strategy to deploy mobile communications services (voice and data) in isolated communities in developing countries with less than 1000 inhabitants by combining appropriate low-cost technologies and an innovative business model fostered by recent regulation. This innovative model is based on the legal figure of the SRO (Small Rural Operator), which is specifically oriented to reach small communities in isolated rural areas.

The results are based on a real deployment in 6 communities of the Peruvian Amazon, which was carried out by a consortium of universities, NGOs (Non-Government Organizations), and cellular operators. This deployment allowed us to obtain practical information on the cost structure of mobile networks in isolated areas, characterize the rural demand and the revenues associated with it, and understand how the business model of traditional operators could be adapted. This information permitted us to propose, implement and validate the SRO approach. The paper shows the results of this research and provides some lessons learned.

The main conclusion is that the recent Peruvian regulation opened a niche market for SROs who want to offer services in isolated communities with less than 1000 inhabitants.

1. Introduction

Living conditions in isolated rural communities are harsh because of the lack of access to essential services such as electricity,
This explains why governments have a great interest in expanding Information and Communication Technology (ICT) services in isolated communities in developing countries with less than 400 inhabitants. To do so, they should properly combine revenues associated with it, and understand the business model of traditional operators to propose new approaches. The economic costs of some elements of the network such as the base station controller; not always providing a solution to interconnect to other community-owned access networks: while some use WiFi (Rey-Moreno et al., 2015), others have been allowed to use standard 2G/3G/4G RAN, for which they use open solutions such as OSMOCOM OpenBSC (Barela et al., 2016) or OpenBTS (Heimerl et al., 2013) in the infrastructure. In all cases, from the business model point of view, community-owned access networks may lower the cost of access to communications services and provide the community with some additional advantages. An excellent analysis in this sense can be found in (Heimerl et al., 2013) with a short-term evaluation of a community-driven 2G infrastructure. These initiatives face a variety of difficulties such as the shortage of technical personnel; the high cost of some elements of the network such as the base station controller; not always providing a solution to interconnect to other operators’ networks; and the regulation on the use of frequencies for mobile services. This last aspect is one of the most substantial restrictions for this type of project, although some initiatives have already proposed solutions to this question. In one of these projects, Rhizomatica (Wade, 2015) obtained from the Mexican Government a license to use mobile bands in pilot communities, considering that these bands were not used locally (there was no coverage from the big operators). In another scenario, in South Africa, it was decided to deploy a network based on WiFi devices (IEEE 802.11), thus avoiding the use of licensed mobile frequency bands (Rey-Moreno et al., 2015). The community network paradigm is also becoming very relevant in developed countries, Guifi.net (Baiget et al., 2015) being one of the most successful initiatives adopting this approach. However, it is still necessary to monitor the evolution and scalability of these initiatives overtime before exporting this model to other rural areas in developing countries.

In regions where initiatives such as the ones cited above do not exist, telecommunications companies usually limit their services to areas where financial benefit can be ensured. Hence, operators systematically exclude small communities in sparsely populated areas. This paper analyses a case where governments promote collaboration between traditional MNOs and SROs to obtain a more immediate and scalable solution for those communities. With this analysis, we intend to show that SRO can offer broadband communications services in isolated communities in developing countries with less than 400 inhabitants. To do so, they should properly combine appropriate low-cost technologies with innovative business models that align with strategies public investment and financing aimed at promoting local development.

2. Materials and methods

The analysis here presented is based on the results of a pilot in 6 communities of the Peruvian Amazon (deployed by the TUCAN3G project) which has allowed to study the costs structure of 3G networks in isolated areas, characterizing the rural demand and the revenues associated with it, and understand the business model of traditional operators to propose new approaches. The economic
viability was verified by comparing the costs derived from deploying and operating the service with the income obtained by offering the service, using the following business indicators:

- The Total Cost of Ownership (TCO) has served to compare deployment costs when using different backhaul solutions. This indicator includes both installation costs (CAPEX) and operation and maintenance costs (OPEX) for a given period. The period used in this study is 5 years, and a 9% discount rate has been used to calculate the cost of capital when discounting to today.
- To evaluate the profitability of the project, we use the Net Present Value (NPV) and the Internal Rate of Return (IRR), assessed in 5 years and with a discount rate of 9%.

The models here proposed are not intended to reflect the detailed business model of a mobile operator, but rather to identify the main costs of the deployment in rural areas and to verify if it can be offered without incurring losses. In fact, the challenge being analyzed is to provide service in the rainforest communities, which are only part of the market.

For the deployment of the access network, femtocells from the manufacturer IPAccess were used, and for the transport network, WiFi-based technologies from the manufacturer Mikrotik were tested. The infrastructure of towers previously deployed by the EHAS Foundation and the GTR-PUCP in the Napo river basins (Napo network) and the Paranapura river (Balsapuerto network) in Peru was also used.

In the next sections, we will first explain in detail the SRO model and how it can contribute to expanding 3G/4G services to isolated communities. Then, we will describe the cost analysis of the pilot (Martinez-Fernandez et al., 2016) (Simo-Reigada et al., 2015). In order to prove the economic viability of this model, we will later present the financial results obtained in the TUCAN3G pilot. Finally, we will explain how the SRO model has been adapted for scaling the TUCAN3G pilot, and we will present the conclusions of this work.

3. Results

The TUCAN3G partnership (Barela et al., 2016) proposed a low-cost solution for bringing broadband connectivity to isolated rural areas in developing regions. It employs femtocells for the access network and a WiFi multi-hop backhaul to connect the access network with the operator’s core network. To evaluate its proposals, two pilots were deployed since October 2015 for one year in 2 communities of the Paranapura river and four communities of the Napo River, both in the Peruvian Amazon rainforest. The Paranapura pilot consists of three 3G small cells (2 in Varadero and 1 in San Juan) and 3 WiFi point-to-point links. Two femtocells are required in some communities because households are scattered, and it is not possible to provide the needed coverage using one femtocell with low radiation power and low consumption. The pilot deployed 3G femtocells (instead of 4G) because the market research found that 68.9% of the households in these communities already had a 3G device and forcing these low-resource inhabitants to purchase 4G devices was identified as a significant barrier for the service success. A VSAT service was initially used for research purposes and provided information on satellite costs but was later replaced by a terrestrial backhaul because satellite costs proved unaffordable, as will be
explained.

The Napo pilot (Fig. 1) consists of six 3G femtocells placed at Tacsha Curaray (with two femtocells), Libertad, Negro Urgo and Tuta Pishco (with two femtocells), all connected with four multi-hop WiFi links. The multi-hop structure of the transport network might affect the QoS parameters, which may drop below unacceptable levels if one of the links is congested (due to an increase of traffic or adverse weather conditions affecting propagation). Hence, end-to-end traffic differentiation is applied (i.e., prioritizing voice and signalling traffic over data traffic), as well as an admission control system that limits the traffic entering the transport network at each link. This allows for keeping the whole multi-hop network operating with low end-to-end latency and negligible packet drop probability. Specific technical details are available in (Martinez-Fernandez et al., 2016) (Simo-Reigadas et al., 2015), and therefore the rest of this paper will focus on other aspects such as traffic measurements and economic sustainability of the solution.

Both pilots employed existing WiFi networks deployed in previous projects, which identified sustainability as an essential challenge in this kind of deployments (Sura et al., 2008). The EHAS Foundation and the PUCP university implemented the Napo network in 2008, and ensuring long-term sustainability was one of the main challenges from the beginning, so a sustainability plan was designed considering economic, institutional, technological and cultural aspects (Bebea et al., 2011, pp. 157–164). The network is still providing services and is supported by health institutions and the communities, so sustainability has proven successful in most of these aspects. However, economic viability has strongly depended on foreign subsidies. This proposal addressed this issue by using the existing infrastructure to provide mobile services that allow covering the OPEX of the network. However, rural deployments are not a priority for most mobile operators, and therefore new actors are needed to operate the network, as described in the next section.

### 3.1. Small Rural Operator model

Governments consider that telecommunication services in rural areas are strategic to improve public services and institutional presence, and therefore, they demand operators to expand their networks to these areas. However, MNOs are not willing to invest in small communities because the opportunity cost is high since urban deployments offer a much higher Return on Investment (ROI) (Trendovet al., 2019). At the same time, competition among operators is very aggressive in urban scenarios, and high investments are required to maintain its market share. On the other hand, operators consider unserved areas as their best opportunity to increase the number of customers, amounting to billions, waiting for service. To solve this contradiction, this paper proposes to promote the SRO as an actor responsible for deploying and maintaining mobile rural infrastructure (both transport and access networks), while using the MNOs’ core network. Under this paradigm, MNOs act as virtual operators in the rural area, so they may use the SRO’s infrastructure to reach rural customers. The SRO obtains a percentage of the revenues generated by the network, which is transparent for the final user (who contracts services with the MNO). The main differences between the SRO and the MNO are summarized in Table 1.

In this low-competition scenario, SROs could reduce investment costs (CAPEX) by taking advantage of low-cost wireless technologies for backhaul as already explained (Simo-Reigadas et al., 2015) (Rademacher et al., 2013, pp. 1–11), and by using innovative access solutions that get the most of new paradigms such as virtualization of the Radio Access Network (RAN). A virtualized RAN may be more flexible, easily maintainable and scalable, potentially allowing the SRO to bear the services of several MNOs over the same RAN infrastructure. Moreover, by focusing on rural areas, they can optimize local resources and even get support from communities for maintenance activities or find synergies with local services such as energy providers who share the need for local technicians or supplies.

At the same time, the SRO avoids expenditures on advertising campaigns (because the MNO is responsible for the relation with final customers), which contributes to reduced operational costs. Likewise, the financial and management structure of SROs is much lighter, which also means lower SGA (Selling, General & Administrative) costs. The SRO also avoids expenditures on spectrum licenses almost

| Table 1 | Main differences between the MNO and the SRO. |
|---------|-----------------------------------------------|
| MNO     | SRO                                           |
| Main business goal | To obtain new customers and keep existing ones by competing with other MNOs in areas where there is a clear business case. |
|         | To obtain and serve new clients for the MNOs by providing coverage in sparse communities previously unconnected, where a particular business strategy is needed and infrastructures may need to be shared. |
| Frequencies | They pay for the frequencies they use. They deploy a whole network with equipment for the core, transport and access segments. |
| Infrastructure | They use the unused frequencies of the MNO under an agreement. They deploy the access network and the segment of the transport network required for the interconnection of users with one or several MNO networks. |
| Customers | Their customers are the users of mobile networks. Their customers are the MNOs who are willing to expand their coverage to uncovered communities. |
| Main expertise | To deploy and maintain mobile networks in urban areas with a high density of clients and high traffic demand. |
| Mean Time To Repair (MTTR) | It is must be very low to prevent customers from migrating to another MNO, but it is easy for technical staff to repair the access network in a short time. |
| Threats | The MNO can cancel the contract if the quality of the service, very related to the MMTR, is insufficient. |
| Energy | There is not always access to a power grid. |
completely. Although licensed spectrum may be needed in other contexts for the transport network, that is usually not necessary in isolated areas due to the lack of interference in the 5 GHz band. Additionally, the SRO uses licensed frequencies for the mobile (2G/3G/4G) access network, thanks to an agreement with the MNO that owns those licenses but doesn’t use them. Hence, the SRO uses those frequencies freely to generate the traffic and to sell it to the MNO. In the SRO paradigm, MNOs share the benefits from rural communities with SROs, so the economic incentive for them in the short term is very low (especially when compared with urban revenues). However, this model is, in fact, a win-win solution which allows MNOs to increase their client portfolio in strategic areas and meet the government’s demands of expanding rural coverage to small communities while avoiding significant risks:

- Regulators sanctions for a service failure in rural areas, where repair time is usually higher than in urban areas due to access difficulties.
- Addressing resources (staff, investment, network resources) for rural deployments instead of focusing on urban scenarios, which are much more competitive and profitable.

However, before asking MNOs to share their benefits, we must verify if revenues from rural communities suggest the implementation of this model.

3.2. Cost analysis

The first step towards the evaluation of the economic sustainability of the SRO solution was to develop a cost model for the provision of mobile access to rural areas. This model should include the main costs considered by an SRO when deploying and operating a rural network in a remote area. Likewise, the model mainly considers the additional infrastructure required: access points in the community, a backhaul network, photovoltaic power systems and the cost of installing and configuring those new systems, as presented in (Simo-Reigadas et al., 2015). Table 2 shows the estimated values for the CAPEX needed in a community. This data is based on data from the TUCAN3G project but also from previous experience of TUCAN3G partners in highland communities (Simo-Regigadas et al., 2008) (Simo-Reigadas et al., 2010). One of the main conclusions of this table is the critical influence of orography on the cost structure: high towers are needed in rainforest areas because it is necessary to overcome the height of the trees (30–40 m) and the curvature of the Earth to get line-of-sight for the backhaul network. However, in highland areas, towers can be installed on the top of mountains to reduce the minimum height of the towers, and significantly lower the CAPEX.

Another important cost for the deployment is installation costs, which include the cost of transporting, installing and configuring the equipment. Most of these costs are directly related to the number of communities and do not change significantly with the scale of deployment, but transportation costs do, as shown in Table 3. When deploying a network in a set of nearby rural communities, transport costs are more efficient by sending a vehicle with the whole load, and it is not feasible to obtain this cost based on the number of communities. Table 3 also shows that transportation costs are much lower in highland areas because access is much cheaper thanks to the presence of roads, and this also affects the operational expenses (OPEX), as will be later explained. Moreover, tower installation costs are related to the height of the tower and, therefore, are higher in terrestrial rainforest.

When analyzing the network deployment, the fixed costs are the sum of the tower costs (C_{tw}), the cost of the main elements of the access and the backhaul networks and the total installation costs (C_{in}), which in this analysis correspond to the installation in 6 communities. The cost of deploying the access and the backhaul networks will both depend on the number of subscribers or users (N_u) of the mobile service and the number of communities (N_c):

\[ N_c = \text{CEIL}(N_u \cdot 0.1/16) \]  

(1)

And then, the cost associated to the femtocells required in the access network (C_a) is given by Eq. (2) where C_f is the cost of one femtocell and the required energy system, and it is reflected in Table 2.

\[ C_a = N_f \cdot C_f \]  

(2)

Regarding backhauling costs, each user requires a minimum bandwidth of 0.5 Mbps (including signalling), and the backhaul

| Table 2 |
|---|---|---|
| **CAPEX** | **Satellite jungle** | **Terrestrial highland** | **Terrestrial jungle** |
| **Tower cost (C_{tw})** | 4000 | 4000 | 38,000 |
| **Backhaul link cost (C_{bl}) - radio equipment, network equipment, antennas, photovoltaic system** | 4000 | 1685 | 2550 |
| **Femtocell cost (C_{f}) - Femtocell, photovoltaic system** | 2310 | 2000 | 2310 |
| **TOTAL (USD)** | 10,310 | 7685 | 42,860 |
network should provide that. When using terrestrial wireless links, and considering a maximum capacity of 100 Mbps per link, the number of backhaul links by the community ($N_l$) is:

$$N_l = \text{CEIL}(N_f \cdot 16 \cdot 0.5/100)$$  \hspace{1cm} (3)

and therefore, the cost of deploying the terrestrial backhaul in a community ($C_{tb}$) will be:

$$C_{tb} = N_l \cdot C_l.$$  \hspace{1cm} (4)

where $C_l$ is the unit cost of one backhaul link of 100 Mbps capacity and is provided in Table 2.

Summarizing, the terrestrial deployment cost ($C_{td}$) for a set of communities is:

$$C_{td} = C_{in} + C_{tw} \cdot N_c + C_a \cdot N_c + C_{tb} \cdot N_c.$$  \hspace{1cm} (5)

Eq. (5) assumes that the number of femtocells, the backhaul requirements and the tower height are the same for all communities. Although this is not necessarily true, it helps to simplify the notation and to make a comparison between costs in different scenarios, as will be shown later. However, the equation can be easily adapted to a case in which each community has different requirements.

To obtain the OPEX as a function of the number of users, we have estimated the annual OPEX for the service provided in an area of 6 communities (Table 4). Two maintenance trips are planned, but trips in rainforest deployments are 8 times more expensive than in the highlands because access to the latter is much cheaper thanks to the presence of roads.

Taking into account the deployment costs ($C_{td}$) and the total operation costs ($C_o$) shown in Table 4, the TCO for a terrestrial backhaul in a set of 6 communities and considering a 9% discount rate is then provided by Eq. (6).

$$\text{TCO}_t = C_{td} + \sum_{i=1}^{5} C_o \cdot (1 + 0.09)^{-i}.$$  \hspace{1cm} (6)

If a satellite backhaul replaces the wireless terrestrial backhaul, then the costs of the access network still depend on the number of femtocells. The expenditure on the backhaul equipment is a fixed cost and the total deployment costs ($C_{sd}$) are:

$$C_{sd} = C_{in} + C_{tw} \cdot N_f + C_a \cdot N_f + C_{lb} \cdot N_f.$$  \hspace{1cm} (7)

The satellite operation costs ($C_{so}$) are usually expressed in USD/Mbps ($C_{Mbps}$) and the required capacity is similar to the terrestrial scenario (10% of users in the Busy-Hour with 0.5 Mbps per user). The TCO when using the satellite backhaul is then:

$$\text{TCO}_s = C_{sd} + \sum_{i=1}^{5} (C_o + N_u \cdot 0.1 \cdot 0.5 \cdot C_{Mbps}) \cdot (1 + 0.09)^{-i}.$$  \hspace{1cm} (8)

It is important to note that the capacity provided by a satellite link has an upper limit and that the term $N_u \cdot 0.1 \cdot 0.5$ in Eq. (8) cannot exceed that limit. The limit depends on the specific bands (Ku, Ka, C) and satellite technology. Still, in the calculations provided in this work, the maximum capacity considered is 14 Mbps, which is a realistic figure for backhauling satellite services.

Fig. 2 shows these cost functions for a set 6 of communities in different scenarios using information from Tables 2–4, and an average of 91 users has been considered in each community. Only C-band a Ku-band are available in rainforest communities, and in that case, $C_{Mbps}$ is estimated to be USD 470, which is, in fact, a low price. In highland communities, $C_{Mbps}$ is USD 80, which is the price for the MNO in the Ka-band. When communities have more than 1000 inhabitants (270 users), then deploying femtocells is not the right solution, and both costs are revenues are different from those obtained in TUCAN3G, and that’s why they are out of the scope of this

| Table 3 | Installation costs for a set of 6 communities for three scenarios. |
|---------|---------------------------------------------------------------|
| Concept | Units | Satellite rainforest | Terrestrial highland | Terrestrial rainforest |
| Femtocell install & conf | 6 | 6000 | 6000 | 6000 |
| Backhaul install & conf | 6 | 6000 | 6000 | 6000 |
| Transport | 1 | 2000 | 4000 | 8000 |
| Tower installation | 6 | 6000 | 6000 | 24,000 |
| Total Installation costs (USD) | 20,000 | 22,000 | 44,000 |

| Table 4 | Annual OPEX for a set of 6 communities. |
|---------|-----------------------------------------|
| OPEX (annual) | Satellite rainforest | Terrestrial highland | Terrestrial rainforest |
| Operation | 3600 | 3600 |
| Maintenance trips | 3333 | 800 | 5000 |
| Travel allowance | 600 | 360 | 900 |
| Personnel | 12,000 | 12,000 | 12,000 |
| Total operation costs ($C_o$) | 15,933 | 16,760 | 21,500 |
study.

The previous cost functions are defined for small communities with less than 1000 inhabitants where a couple of femtocells are enough to cover the demand in the Busy Hour. In these calculations, we are assuming that different communities cannot share a tower, which may not be the case but is the most frequent situation in the rainforest and provides an upper limit for highlands. The number of subscribers per community is supposed to be similar in order to make the model less complicated.

The cost analysis showed that satellite backhaul has a high OPEX in rainforest areas. Because of this, satellite TCO is higher than the TCO of wireless terrestrial networks when evaluated over 5 years. Nevertheless, MNOs are not willing to perform the investment on tall towers, and they only provide service in areas where the satellite backhaul is profitable. This strategy leaves a large number of communities without connectivity, which may become an opportunity for SROs.

To reduce the investment risk of a rural 3G/4G service (Wade, 2015), proposes to share the wireless backhaul network infrastructure among different stakeholders in order also to share these costs. However (Simo-Reigadas et al., 2015), does not suggest a specific mechanism to implement this sharing strategy. This issue will be addressed in this paper.

### 3.3. Revenue analysis

TUCAN3G pilot was designed to obtain information about the voice and data traffic patterns in small isolated communities, where no previous information was available. This pilot also provided firsthand knowledge on the complexity of such deployments in rainforest areas and on the extra costs associated with isolation and served to identify what conditions make a mobile service in rural areas economically sustainable. However, it is essential to point out that the SRO paradigm was not adopted in the pilot because at that stage, the risk was very high for an SRO (which was included in the next phase, as explained below). The pilot was instead deployed by a consortium including an MNO (Telefonica), aiming to verify that the extension of mobile coverage to these areas might be feasible and sustainable.

In order to estimate income, Fig. 3 shows the data regarding the weekly evolution of voice and data traffic for 11 weeks. This data was collected 6 months after installing the mobile base stations when the traffic growth was already stable in each community. The voice traffic is lower than the data traffic because we used a voice codec of 54 Kbps, so a minute of voice is equal to 0.405 MBytes, but the price of voice services is instead higher, and in fact, the primary source of revenue is voice traffic. Moreover, when using satellite backhaul, the bandwidth required to offer data services is very costly and makes the service less sustainable. These facts explain why MNOs prefer to focus on voice services in isolated communities. However, data services are in high demand and mobile network operators know that they must offer them to build customer loyalty. Another relevant result of the pilot was to find out that the average penetration of mobile services in these communities was 27% and that most of the customers employed a prepaid service. It is difficult to find studies in similar communities to compare this result. Therefore, we can only compare it with the general statistics of cell phone penetration in rural areas of Bolivia (87%) (Government Agency for Inf, 2017), Peru (68.7%) (Ruiz Calderón and Castro Angeles, 2019), Colombia (58.3%) (Departamento Administrati, 2018), Ecuador (46%) (Equipo técnico Encuesta N, 2019) or Mexico (27%) (Martínez-Domínguez & Mora-Rivera, 2020). We can conclude that the penetration in our project is lower than the average in rural Peru. Likewise, Colombia or Ecuador show a higher penetration in rural areas, but significantly lower than the average in Peru. Finally, the case of Mexico is striking because cell phone penetration is very low in rural areas, similar to the Napo communities. The incidence of monetary poverty is 75.8% (Peru National Institute o, 2020) in the Napo District, and this poverty rate can explain the low penetrations of mobile services.

Based on the traffic volume measured in the pilot, the revenue was calculated using a price of USD 0.072 per minute of voice call

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**Fig. 2.** TCO evolution with the average number of users in 6 rural communities for different scenarios.
and USD 0.01 per MByte of data, which are coherent with current prepaid tariffs in Peru (Tariffs of the Peruvian M). With these tariffs, we obtain an Average Revenue Per User (ARPU) of USD 10.6. This ARPU represents 15.7% of the average income per family, which is USD 70 (United Nation Development, 2013).

The ARPU allows depicting an income function over the number of subscribers. However, the income of the network has to be shared between the MNO and the SRO. According to the agreement among the SRO and Telefonica, Telefonica keeps 30% of the income from the rural network and pays the rest to the SRO. Therefore, the actual ARPU for the SRO is USD 7.42.

### 3.4. Income analysis

The economic sustainability of the pilot was analyzed by estimating the revenue and calculating the evolution of the NPV and IIR. Table 5 shows the respective results of the financial analysis of the rainforest and highlands cases, for a community of 336 inhabitants (the average number of inhabitants per village in the pilot) and a service penetration of 27%. In this analysis, we assume a discount rate...
of 9% (Dirección General de Prog, 2012), and a depreciation of 20 years for the tower and 5 years for the other network elements. There was no debt and not working capital in this case study. It should be noted that, in the following calculations, the model was adjusted to include most of the costs usually considered by an SRO, as previously described. However, the pilot was not designed to offer SGA costs and, in this model, they are estimated as 10% of the revenue.

Given that deployment costs (CAPEX) in rainforest communities are considerably higher, the business model in these areas will only be profitable in large populations or with some subsidy. In Table 3 a grant equal to 75% of the CAPEX is assumed in the financial analysis for rainforest scenarios. This 75% represents the average cost of the tower, which could be built with funds from local or international institutions or could already exist in the area.

Based on the ARPU previously calculated, we estimate the income per community and then we obtain the net cash flow for each year. Since the resulting NPV is USD 5802 and the TIR is 11.93%, we can assert that the initiative creates value and generates benefits in this specific case study.

Using the data from the rainforest pilot, we can estimate the case of the highland (Table 6) assuming the traffic generated is similar because they are low-income areas too. No subsidy is supposed in highlands deployments, and the results show that the NPV would be 16,612 and the IRR 18.4%.

By studying the VPN against the number of subscribers (Fig. 4), we can conclude that no subsidies are needed in the highland communities to get benefit with a low number of users. In contrast, in rainforest communities, about 70 users with a 75% subsidy will be required to obtain a positive NPV.

If we assume that the NPV should be positive in 5 years, we can analyze the relationship between the rate of public subsidy and the population to be served. This relationship is shown in Fig. 5, which would allow an SRO to study what funding would be required depending on the average size of the community where it intends to offer 3G/4G services.

This analysis shows that some of the main parameters affecting mobile service in rural areas are: terrain orography (having the rainforest and highlands as extreme cases), the existence of infrastructure, the percentage of public subsidy obtained, and the number of customers expected in the network. By connecting nearby communities, the SRO can supplement the income from large villages with the income from small ones, which satellite backhauling doesn’t incentive.

3.5. Expansion of the SRO model

The sensitivity analysis shows the potential profit for SROs in highlands communities. An SRO (Mayu) is already providing mobile services (2G/3G/4G) to more than 75,000 rural inhabitants in different regions of Peru (Ucayali, Loreto, Junin, Huanuco y Amazonas). However, the rainforest case is more complicated: while the expected revenue can cover the operational costs, it requires additional support to deploy the infrastructure and make it sustainable in the long term. To verify that the SRO paradigm can be useful in rainforest areas, we designed a new phase to expand the pilot and involve an SRO in the Napo River. A critical aspect of the SRO model is that it requires collaboration between MNOs and SROs. In this new phase, a small company registered as a Rural Mobile Infrastructure Operator (RMIO) performed the SRO role. The RMIO is a legal entity defined in Peru for SROs (through Supreme Decree number 004-2015-MTC in August 2015). According to this law, MNOs are obliged to use the RMIO network to provide mobile public services in rural areas, provided they do not have their own infrastructure and if the RMIO requests it. The MNO is responsible for managing (and charging) mobile end users, lending their radio spectrum and core network infrastructure (Radio Network Controller, Mobile Switching Centre, etc.), and paying the RMIO a percentage of the revenue generated with the RMIO infrastructure. If the RMIO does not reach an agreement with the MNO, the regulator intervenes as an arbitrator to enforce a fair deal. The latest complementary regulations of April 2017 (L and “Complementary N, 2017, p. 3), allow the MNO and RMIO to agree on the provision in urban or rural

| Table 5 |
| Financial analysis for 6 rainforest communities of 339 inhabitants with 27% penetration. |
| Terrestrial rainforest | Year 0 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
| + Revenues | 48,616 | 48,616 | 48,616 | 48,616 | 48,616 | 48,616 |
| - Cost of revenues | 21,500 | 21,500 | 21,500 | 21,500 | 21,500 | 21,500 |
| - SGA (10%) | 4862 | 4862 | 4862 | 4862 | 4862 | 4862 |
| EBITDA | 22,254 | 22,254 | 22,254 | 22,254 | 22,254 | 22,254 |
| + Depreciation | 17,232 | 17,232 | 17,232 | 17,232 | 17,232 | 17,232 |
| EBIT | 5022 | 5022 | 5022 | 5022 | 5022 | 5022 |
| - Income Tax Expense (28%) | 1406 | 1406 | 1406 | 1406 | 1406 | 1406 |
| Net Operating Profit After Taxes | 3616 | 3616 | 3616 | 3616 | 3616 | 3616 |
| + Depreciation | 17,232 | 17,232 | 17,232 | 17,232 | 17,232 | 17,232 |
| Cash Flow | 20,848 | 20,848 | 20,848 | 20,848 | 20,848 | 20,848 |
| - Investment | 301,160 | 301,160 | 301,160 | 301,160 | 301,160 | 301,160 |
| + Subsidy (75%) | 225,870 | 225,870 | 225,870 | 225,870 | 225,870 | 225,870 |
| Free Cash Flow to Firm | - 75,290 | 20,848 | 20,848 | 20,848 | 20,848 | 20,848 |
| Net Cash Flow | - 75,290 | 20,848 | 20,848 | 20,848 | 20,848 | 20,848 |
populated centres that do not meet the mandatory conditions. For example, when the MNO is interested in providing mobile public service through the network facilities of an RMIO, even if another MNO already offers coverage. This favours the RMIO because it increases its potential intervention area.

Before the end of the TUCAN3G project in May 2016, the Development Bank of Latin America (CAF, for Corporacion Andina de Fomento) approved a grant to test this business strategy as an innovative solution to improve living conditions in isolated regions of Latin America through public-private partnerships. This new phase is known as The NAPO Project and has involved an MNO (Telefonica), an SRO (Mayu), two universities (the Catholic University of Peru and Rey Juan Carlos University), and two NGOs (EHAS Foundation and Pango Association) with the support of the Regional Government of Loreto that provides the existing supporting towers.

In this new phase, the SRO is already providing the mobile service in 8 isolated communities with more than 3000 inhabitants in the Napo river and plans to reach up to 12 communities throughout this year. The deployment in the first 8 communities has provided financial results very similar to those reported in the previous section and contributed to verify RMIO’s interest in this strategy. The use of existing towers could seem a limitation, but there are other basins in Peru with similar towers that are not being used. In other cases, local authorities are willing to installs towers if that helps to bring mobile services to their communities. In other words, financing the towers makes it easier for administrations to promote rural mobile services in a decentralized way, which can also be complementary to national strategies such as coverage requirements on licenses. Another advantage of deploying towers is that, after the initial

Table 6
Financial analysis for 6 highland communities of 339 inhabitants with 27% penetration.

| Terrestrial highland | Year 0  | Year 1  | Year 2  | Year 3  | Year 4  | Year 5  |
|----------------------|--------|--------|--------|--------|--------|--------|
| + Revenues           | -      | 48,616 | 48,616 | 48,616 | 48,616 | 48,616 |
| - Cost of revenues   | -      | 16,760 | 16,760 | 16,760 | 16,760 | 16,760 |
| - SGA (10%)          | -      | 4862   | 4862   | 4862   | 4862   | 4862   |
| EBITDA               | -      | 26,994 | 26,994 | 26,994 | 26,994 | 26,994 |
| - Depreciation       | -      | 5622   | 5622   | 5622   | 5622   | 5622   |
| EBIT                 | -      | 21,372 | 21,372 | 21,372 | 21,372 | 21,372 |
| - Income Tax Expense (28%) | -      | 5984   | 5984   | 5984   | 5984   | 5984   |
| Net Operating Profit After Taxes | -      | 15,388 | 15,388 | 15,388 | 15,388 | 15,388 |
| + Depreciation       | -      | 5622   | 5622   | 5622   | 5622   | 5622   |
| Cash Flow            | -      | 21,010 | 21,010 | 21,010 | 21,010 | 21,010 |
| - Investment         | 65,110 | -      | -      | -      | -      | -      |
| + Subsidy (0%)       | -      | -      | -      | -      | -      | -      |
| Free Cash Flow to Firm | -65,110 | 21,010 | 21,010 | 21,010 | 21,010 | 21,010 |
| Net Cash Flow        | -65,110 | 21,010 | 21,010 | 21,010 | 21,010 | 21,010 |

Fig. 4. Evolution of the NPV versus the number of subscribers.
investment in towers, increasing links capacity in the terrestrial backhaul is much cheaper than in the satellite backhaul. Moreover, once the tower is installed, the risk for the MNO or the SRO is smaller than when covering the OPEX, because they don’t depend on an annual subsidy that could change with the administration’s priorities or budget.

Other important results it that, thanks to the Napo network, the NGOs and universities involved are implementing telemedicine services for primary health care (teledermatology, telestethoscopy, and teleultrasonography). In exchange for access to the towers, the wireless network connects the rural health establishments, and it reaches the Regional Hospital in Iquitos, where the Internet connection is shared for health applications. All this justifies the presence and support of the regional government in the project, as it will be able to significantly improve both the quality and the efficiency of the public health care services.

Getting approval for such a project and involving such diverse actors proves that it is possible to develop innovative business models that do not depend exclusively on traditional MNOs. They also shows that offering services that impact the quality of life of people, such as telemedicine, helps to involve governments and funders. In this line, it is also important to note that Telefonica has replicated this model with its Internet for Everyone (IpT) strategy. IpT is a company created as an RMIO with the participation of Telefonica, Facebook, the Development Bank of Latin America (CAF), and the Inter-American Development Bank. Its objective is to bring mobile services to communities without coverage in Peru and Latin America (where they estimate a potential market of more than 100 million people).

4. Conclusions

In countries like Peru, there are still many communities without cellular or fixed network coverage. This work shows that there is a niche market for operators willing to offer services in isolated populations with less than 1000 inhabitants and a low traffic demand (as shown in the results of this paper). The importance of this conclusion is that it is precisely in these regions where mobile services can have a higher impact because they allow people to overcome isolation barriers, contribute to economic development, and improve the living conditions. Based on this result, SROs and public institutions can analyze each case to assess which communities are sustainable because revenue is high or there exist towers, which would require public support and for which there are no viable solutions yet.

As MNOs are reluctant to invest in rural deployments, the Peruvian regulator decided to open the market to new actors (the SROs) through the RMIO figure. SROs can specialize in deploying networks in unserved areas. In this way, they will be able to address in a more efficient way the reduction of costs (both CAPEX and OPEX) needed in low-income environments. This cost reduction can be achieved with existing low-cost technologies, finding synergies with local stakeholders to reduce deployment and maintenance costs, sharing infrastructures with other local actors or using existing ones, or getting public subsidies. When designing deployments with this approach, it is essential to consider the complexity of initial agreements among MNOs and SROs, which are time-consuming. Still, this experience proves this strategy is also feasible from the institutional point of view.

This paper presents results that prove the model’s profitability in highland communities (without subsidies) while involving additional stakeholders or getting grants is needed in rainforest communities. In low-resource settings, such as the Napo river basin, deployment costs can make the project unfeasible. Therefore, a substantial subsidy or access to existing towers is essential for the project to be sustainable. In such a high-risk scenario, we have managed to engage the main stakeholders in the proposed model: an MNO such as Telefonica del Peru, an SRO registered in Peru as an RMIO, and a development bank such as CAF. If these organizations have taken the risk of participating in this project, it is because their strategic analyzes show that it has great potential. This conclusion
is supported by the fact that Telefonica has created its own OIMR in 2019 and is scaling this solution to other regions of Peru.

Although this research has focused on Latin America, other regions of the world facing similar challenges could benefit from the strategies here proposed.

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Declaration of competing interest

The authors declare that they have no competing interests.

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