ICT-601102 STP TUCAN3G

Wireless technologies for isolated rural communities in developing countries based on cellular 3G femtocell deployments

D21

Socio-economic scenarios, technical specifications and architecture for the proof of concept

Abstract:

TUCAN3G aims to develop solutions to provide 3G services in isolated rural areas of developing countries. In order to do so, this document starts by analysing the reference scenarios where TUCAN3G solutions could be applied, explaining its general situation worldwide, the Latin America case, and its specific reality in Colombia and Peru, from the socioeconomic point of view. The technologies that TUCAN3G will integrate for this purpose are also described, providing an insight of the requirements that should be provided and the methodologies that will be used for both, the access and the transport network. Based on the former analysis, a design for the demonstration platform is performed, including a proposal for target localities, a general description of test to be carried out, and the needs of existing networks.

Keyword list: reference scenarios, demonstration platform, access network, transport network

Document Revision History

DATE	ISSUE	AUTHOR	SUMMARY OF MAIN CHANGES
10-05-2013	a	Ana García	The first draft.
24-05-2013	b	Ana García	Section 2.44 added.
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Executive Summary

The first purpose of this document is to describe general socio-economic scenarios where the results of this project could be applied. It starts by describing in a qualitative way the situation of rural isolated areas of developing countries, where a 40% of the world population live, focusing on understanding its geographical and political isolation. This serves as introduction to the description of reference scenarios in Latin America, which is considered the region with most inequalities in the world. Quantitative indicators are used to explain the specificity of isolated areas of this region regarding demography, economy, infrastructures, sociology and politics. This analysis allows understanding the specificity of the environment and highlights the dimensions of the potential market for this technology.

To have a more detailed description of possible scenarios, concrete cases from Peru and Colombia are described later. Specific information about communications services in these regions is provided, trying to depict potential markets for the technologies proposed in this project (32% of Colombian population and 24.08% of Peruvian population lives in rural areas). This introductory information will help all partners to understand the context where TUCAN3G aims to operate. Data shows that the Internet access is still very little in Latin America. As example, in Peru is still rates Internet access rates separated by region are: coast, 14.8%; mountain, 6.9%, and jungle, 4.4%. Specific information on existing networks, which could be used for this project, is also provided, together with the information required to design the architecture of the demonstration platform.

The technologies that will be used in this project are explained in a descriptive way. An in depth description of the technologies and evaluation methodologies is not feasible at this phase of the project. The description has two branches: one for the access network and other for the transport network. In both cases, the perspectives of TUCAN3G regarding the system requirements, the technical scenarios, the specific technologies and the evaluation methodologies are explained. This explanation has two purposes. The first is to allow non-technical partners to understand the technological issues that will have influence on the business model. The second is to share ideas and build up a common framework for the technical research, in order to let the results of each WP to be interoperable.

Considering the specific information about Peruvian scenarios, a proposal for the architecture and location of the demonstration platform is developed. This proposal includes femtocells specifications and describes the reference architecture including all the segments from the operator's network to the access network. The selection of localities (2 from Balsapuerto Network and 3 from Napo Network) is performed based on technical and socio-economic factors. Finally, the preliminary steps for connecting the demonstration platform to the operator network are listed, and a proposal for reinforcing existing networks to support TUCAN3G services is provided.

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List of abbreviations & symbols

APEC	Economic Cooperation Forum of Asia-Pacific
AC	Access Controller (AC)
AMS	Access Point Management System
ASOMOVIL	Asociación de la Indistria Móvil de Colombia / Mobile Industry Association of Colombia
ATM	Asynchronous Transfer Mode
BAS	Banda Ancha para Localidades Aisladas - Broadband for Isolated Locations
BPSK	Binary Phase-Shift Keying
BLER	Block Error Rate
CC	Contents of Communications
CEPAL	Economic Comission for Latin America and the Caribbean (ECLAC)
CINTEL	Centro de Investigación y Desarrollo en Tecnologías de la Información y las Comunicaciones / Center for Research and Development in Information and Communications Technologies
CoMP	Coordinated Multi Point transmission
CONPES	Consejo Nacional de Política Económica y Social, National Economic and Social Policy Council of Colombia
CPICH	Common Pilot CHannel
CQI	Channel Quality Indicator
CRL Mirror	Certificate Revocation List
CSG	Closed-Subscribed Group
CVS	Certificate Validation Service
DANE	National Statistic Department of Colombia
DCH	Dedicated CHannel
DL	Downlink
DNP	National Planning Department
DPDCH	Dedicated Physical Data CHannel
DPCCH	Dedicated Physical Control CHannel
DTCH	Dedicated Traffic CHannel
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
EPS	Evolved Packet System
FDD	Feature-Driven Development
FEDESARROLLO	La Fundación para la Educación Superior y el Desarrollo / Foundation for Higher Educatior and Development
FITEL	Fondo de Inversión en Telecomunicaciones de Perú / Telecommunications Investment Fund of Peru
GDP	Gross Domestic Product
GEI	Gender Equality Index
GPRS	General Packet Radio Service
GSM	Global System for Mobile

GW	Gateways
H(e)NB	Home eNode B (Femto Access Point in LTE)
HDI	Human Development Index
HNB	Home Node B (Femto Access Point in 3G)
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
ICT	Information and Communications Technologies
IDI	ICT Development Index
IFAD	International Fund for Agricultural Development
INEI	Instituto Nacional de Estadística e Informática / National Institute of Statistics and Informatics
IP	Internet Protocol
IRI	Intercept Related Information
ITM	Irregular Terrain Model
ITU	International Telecommunications Union
LEMF	Law Enforcement Monitoring Facility
LFSR	Linear Feedback Shift Register
LI	Lawful Interception
LIPA	local IP Access
LTE	Long Term Evolution
MAC	Medium Access Control
MDG	Millenium Development Goals
MERCOSUR	Mercado Común del Sur (Southern Common Market)
MGW	Media Gateway
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MS	Mobile Station
MSC	Mobile Switching Center
NAS	Non-Access Stratum
NEMA	US National Electrical Manufacturers Association
NOS	Network Orchestration System
NTP	Network Time Protocol
O&M	General Operation and Management System
OF	Orthgonality Factor
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expenses
OSIPTEL	Organismo Supervisor de Inversión Privada en Telecomunicaciones / Supervisory Agency for Private Investment in Telecommunications
OVSF	Orthogonal Variable Spreading Factor
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator CHannel
PDCCH	Physical DL Control CHannel
PDN	Packet Data Networks

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PDSCH	Physical DL Shared CHannel
PHICH	Physical Hybrid automatic repeat request (HARQ) Indicator CHannel
PLMN	Public Land Mobile Network
PMCH	Physical Multicast CHannel
PoE	Power over Ethernet
PRACH	Physical Random Access CHannel
PTN	Public Telecom Network
PUCCH	Physical UL Control CHannel
PUSCH	Physical UL Shared CHannel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RB	Resource Blocks
RE	Resource Elements
RIMISP	Latin American Center for Rural Development
RNA	Radio Access Network
RNC	Radio Network Controllers
RoT	Rise-over-Thermal
SCH	Synchronization CHannel
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SIPTO	Selected IP Traffic Offload
SSC	Soft Structured Carrier
TDD	Test-Driven Development
TTI	Transmission Time Interval
UBN	Unsatisfied Basic Needs
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UN	United Nations
UNDP	United Nations Development Program
VDC	Volts of Direct Current
VSAT	Very Small Aperture Terminals
WCDMA	Wideband Code Division Multiple Access
WILD	WiFi Long Distance
WiMAX	Worldwide Interoperability for Microwave Access

1 INTRODUCCTION

TUCAN3G consortium is composed by partners with very different backgrounds. In order to facilitate the understanding of the problem complexity, this document aims to identify and share among the partners the information we already have (or the information that is available), and then specify the research questions this project should address.

In order to do so, reference scenarios will be described, trying to clearly identify the limits given by both the socioeconomic conditions and the technology. Based on those limits, the architecture for the demonstration platform will be proposed, trying to agree the criteria and points of view among the different partners. All this descriptions will be done in a qualitative way, trying to make the documents accessible for all partners independently of their background.

At this stage of the project it is not possible to present final conclusions, and the assertions of this document can evolve through the project live. However, this exercise has served to coordinate different expectations and perspectives, providing a common start point for the rest of work packages.

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2 DESCRIPTION OF SCENARIOS

This section aims to describe the reference scenarios for the project. It starts by depict the general situation for rural scenarios in developing countries. Later it focuses the explanation in the Latin American case, providing statistics for the region. Finally is describes the specific reality in Peru and Colombia.

2.1 Rural isolated areas of developing countries

According to the ITU (International Telecommunications Union) **a 40% of the world population live in rural and remote areas** [Klein07] which means a huge variety of rural isolated communities, so that their inclusion in one and only category is very complex. They are society organizations with subsistence models far from the occidental standard, and they usually have their own language and culture. Nevertheless, in spite of their wide diversity, some common characteristics can be defined in these areas: they have the population welfare limited and they are structured around two main concepts: geographical isolation due to the lack of infrastructures and political isolation.

Considering both concepts, [Arraiza11] establishes four rural isolated communities' types:

- Communities with an insufficient level of central or local public infrastructures.
- Communities without infrastructure but with political and administrative connections.
- Communities without political organization but with own developed infrastructures, keeping their idiosyncrasy.
- Communities with a lack of infrastructure and politically ignored.

2.1.1 Geographic isolation

In many cases, the isolated rural areas are located in geographical scenarios with difficult access or scarce resources, and adverse weather conditions, such as dessert areas, mountains, forest or remote islands far from urban centres. These areas have a low population whose marginalization is worse due to the lack of access to infrastructures, which might help to reduce the impact of the hard conditions of those spots. Indeed, these regions "are standing big natural difficulties, even stronger when they are less developed in technological and scientific areas that could be applied to fight these physical vulnerability problems and to boost their resources. Nevertheless, there is no direct cause-effect relation between the environment and their socioeconomic development. There are other difficulties apart of the environment: difficulties related to the historical evolution and the different level of dynamics regarding to the continuity and coherence of the local and national decisions" [Cepparo07]. The interaction of the geographical and social marginalization is then the key to understand the isolated condition of these regions.

Regarding to the basic infrastructures, water sanitation and drinking water supply are scarce or non-existent, being the world amount of rural people without an improved water supply five the number of urban people in these conditions [UN10]. Energy is also an issue in these regions. Despite the use of different energy sources in these areas, such as wood, vegetal coal or agricultural waste, in 2008 the International Energy Agency calculated that more than one fifth of the world population lack electricity supply –key for the welfare and the efficiency of productive processes-, being the 85% of these people located in rural areas [Arraiza11]. In the same way, besides the lack of infrastructures and telecommunication services, health and

education services have also lacks, which shows that education exclusion is more present in isolated areas, and that rural regions have a higher children mortality rate [UN10].

2.1.2   Political isolation

The role of public administrations is a key to solve the resources deficit in these regions, which is due to their isolation condition. In fact, these people is mainly committed to agriculture, fishery, and handcraft, with particular socioeconomic characteristics caused by the low income level, so poverty is frequently present causing starvation as well as health and education lack. The land difficulties along with the scarce of infrastructures raise the installation costs for other relevant services that would help to improve the quality of life in these regions. Therefore, the institutional support to cover these costs is very important for their development [Klein07]. The isolation mentioned in this case, is not meaning the geographical distance with other scenarios, but the political isolation caused by the exclusion by the decision making institutions committed to improve their living conditions [Cepparo07].

At present the World Bank estimates the total global rural population in 3.257 million people. Of these, 800 million live in extreme poverty [IFAD13]. Besides, from the point of view of telecommunications, the ITU notes that "two-thirds of the world's population, and more than three quarters of the population in developing countries, are not yet online" [ITU12a]. This offline population is located in most of the cases in rural areas. In this sense, the IDI (ICT Development Index), which measures the evolution of the worldwide digital gap in terms of access, use and skills, emphasizes that "there are large differences between developed and developing countries, with IDI values on average twice as high in the former compared with the latter". It is exactly in rural and remote zones where a number of lacks are concentrated so this gap appears in a more marked way. Next, the particular case of Latin America is described, with the socioeconomic characteristics that clearly show how different conditions, such as insufficient or inexistent public support, the scarce of investment and the technological underdevelopment in rural areas, make the isolation of these areas perpetuate. Al this makes that, at least, the 70% of the world poorest population live in these areas [Rimisp12].

2.2   Latin America case

The situation Latin America is described in this sections, attending to the characteristics of the isolated areas and the socio-economic environment.

2.2.1   Specificity of isolated areas in Latin America: overview

According to UNDP, the regional average for the HDI (Human Development Index) in Latin America and Caribe in 2013 is 0.74, being positioned in what is called the High Human Development Index classification. Nevertheless, considering the HDI Adjusted by Inequality which measures the inequalities on health, education and income distribution, the result is an Medium/regular HDI of 0,55 [UNDP13]. In this meaning, it is important to mark that "in Latin America is not indifferent where you are born or where you live. The residence place determines the socioeconomic conditions and the possibilities to access to those assets that guarantee the welfare. This rule is proven both among countries and inside of them, because in the region there are countries that have achieved higher level of growth compared to other countries of the same region, but that the growth has only happened in some territories inside of them" [Rimsip12]. In fact, the territorial variable is configured as a key tool to analyse social and economic inequalities in the Latin American societies, letting see clearly those points in the map where poverty is located. Most of these places are rural areas with a serious lack of services

and infrastructures, and a lower population size. Besides, population is mainly made up of native people and African descendant, which emphasize the powerful alliance between the territorial and ethnic division that perpetuates the social inequities.

According to CEPAL, **Latin America and the Caribbean had an average of rural population around the 21.2% in 2010, which means an approximated number of 126 million out of 600 million people** [CEPAL12a]. From a demographical point of view, is remarkable the transition happened in the middle of the 20th century, going from majority of people living in rural areas to the massive predominance of people choosing the urban areas. "Also, most of the rural population in Latin America and the Caribbean is disseminated along numerous small spots, which evolve into low density scenarios and quite a distance between populated areas" [Rodriguez02]. This dispersion also becomes a shortfall regarding the basic needs satisfaction, given that in many cases it comes along with the lack of infrastructures, which makes basic services expensive. In this way, rural territories show several lacks, such as insufficient nutrition, deficient sanitary and education services, very few job opportunities and a low level of organization and association to promote their interests. This territorial gap is usually hidden by average values of national socioeconomic indicators, hiding the straggler territories that get away of the general trends in issues like demography, policy and society [Rimisp12].

In order to address this project, it is important to highlight the poverty and lacks that affects specifically the rural population. The available resources are decisive to estimate the potential users of TUCAN3G technology, and they show that **50.2% of around 126 million people in rural areas lives above the poverty line** [CEPAL12a]. In this way, an estimation of the potential market for TUCAN3G in Latin America is around 60 million people, who could demand these technologies depending on their socio-economic conditions,. This figure will be estimated in a more precise way along this project.

In order to analyse the living conditions in these regions, is convenient to first approach the specificities of the inhabitants, the indigenous people. In this regard, in spite of the migrations to urban areas, caused by the lack of resources and the environmental spoil, **we emphasize that most of the indigenous population -650 identified groups, 40 million people- remains in the rural area**, as you can see in the following figure [CEPAL09]:
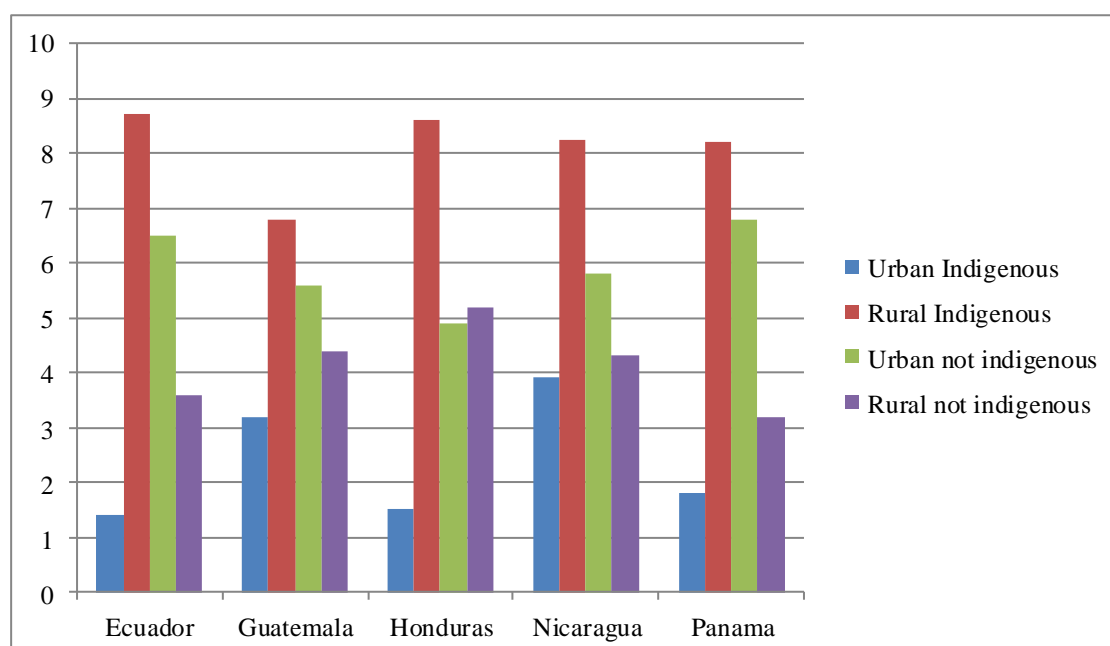
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Figure 1: Percentage of indigenous and not indigenous population, per rural and urban areas (census 2000)

The human groups considered as indigenous are those that descend from "populations that lived in the country or in the geographical region of the country before the colony, or conquest, or the establishment of the current state borders and, whatever their juridical situation is, they keep their own social, economic, cultural and politic traditional institutions, or a part of them" [CEPAL09]. Apart of the language and social habits, the original territory is one of the main variables when we are defining these groups. The fact that these territories are isolated rural areas -with difficult access even nowadays- is caused by, not only the presence of adequate natural resources for their agriculture, but also to the fact that in many cases these are places where they refugee during colony or where they were relegated to, and which have lack of communication infrastructures due to the politic and social exclusion [CEPAL06].

One of the main obstacles that are faced to analyse the social reproduction dynamic of the indigenous people is just the invisibility of these discriminated groups. Since 1990, the quality and regular data collection have been emphasized, which allows to design policies to fight the social inequities of these groups. In this sense, it is important to highlight the 2000 census rounds as a key moment to identify the indigenous population in 13 the countries of the region with different criteria, whose indicators and results will be shown throughout this chapter. These researches have helped to understand how the poverty together with the historical and social exclusion of these people, determine their demographical, social, economic and political specification.

2.2.2 Socio-economic environment

To explain the socio-economic environment in Latin America four aspects are described below: the demographic indicators, the economic features, the infrastructures and services, and the social and political features.

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2.2.2.1 *Demographic indicators*

Generally, since the mid20th century Latin America has experienced a deep demographic transformation, whose key characteristic is a decrease of the population growth. In spite of the heterogeneity of the demographical rhythms in these countries, we must stand out two common aspects which have influenced over these changes. One is the progressive decrease of mortality -with a current life expectancy of 74.2 years, 22.5 more than in 1950-. The other is the decrease of fertility -coming from standing at one of the highest rates of the world, 6 born per woman, to the current rate in the edge of the replacement level. The improvement in health services provided to the population is the key to modify a society, which is currently showing as regular patterns some characteristics that until now were only distinctive of population sectors with more resources (small families, growing life expectancy or higher integration of females in the job market). It is important to emphasize that the population group with highest growth since 1985 is composed of people over 65 years old, so the progressive aging of the population is the highest challenge, in demographic terms, to be faced by the Latin American societies in the following years [CEPAL12b].

Nevertheless, if we go back to the isolated rural areas, the population behaviour diverges from this trend in general terms. In fact, "indigenous people experience a demographic transition as part of Latin American societies, but with a temporary mismatch and with big breaks, given that the transition calendar was much shorter than the one observed in the national population" [Rodriguez02]. Regarding to the variations between countries, indigenous population has a general structure of younger age than the national average, as well as higher fertility and mortality levels, specially related to maternal and children health [CEPAL09]. In spite of the development of sanitary infrastructure in rural areas, the indigenous children mortality is almost twice the not indigenous rate, being the national average of 52.2 per 1.000 in indigenous people and of 27.6 per 1.000 in the general population (see Table 1). Regarding to fertility, in the last 20 years some transformations have happened in the reproductive cycles of women, due to an easier access to the fertility control systems. This is reflected on the reproductive life of indigenous women, which has been reduced at least in 10 years, starting now at an early age (12-17 years) and finishing at around 25 years old, and having an average of 4 children [CEPAL06].

Country and census date	Children mortality rate (per 1000 live births)					
	Total areas		Urban areas		Rural areas	
	Indigenous	Not indigenous	Indigenous	Not indigenous	Indigenous	Not indigenous
Bolivia 2001	75,9	51,9	60,5	47,4	93,2	65,6
Brazil 2000	37,1	25,0	34,8	23,3	39,0	32,7
Chile 2002	22,6	20,0	20,9	19,9	25,7	20,8
Costa Rica 2000	29,0	16,5	25,8	15,5	29,9	17,6
Ecuador 2001	59,3	25,8	34,3	21,3	64,8	32,9
Guatemala 2002	50,3	40,3	46,9	34,6	51,7	45,8
Honduras 2001	36,9	29,3	22,6	21,6	38,2	35,5
Mexico 2000	54,6	33,2	45,1	30,0	60,2	42,5
Panama 2000	54,1	16,2	29,4	14,6	58,5	18,9
Paraguay 2002	82,2	39,1	62,5	38,7	83,5	39,5

Source: Economic Commission for Latin America and Caribe (CEPAL), of the special procedures census microdatabase [CEPAL06].

Table 1: Children mortality rate (per 1000 live birth), by ethnic condition and residence area (census 2000).

Regarding to the age distribution, despite the indigenous people has a younger structure, in rural areas it stands out a population aging that derives of young people migrating to urban areas because of the subsistence crisis. **This migration of an important part of the population is a**

key demographic factor to be considered in a communications project as TUCAN3G. The aging of the demographic structures, which is result of the transfer of people searching for opportunities, is increased if we consider that migration not only differs by age but also by sex, since most of the migration to urban areas is done by young men. So it is an accelerated and notable aging followed by a feminization of the productive and social structures in the rural areas. The massive departure of population to different territories has caused a fragmentation of the residence units, which suggests questions related with social and political aspects, and with the communications needs between the migrants and the people who stay in the rural areas. Besides the maintenance of networks among relatives, we are considering the dependence relations established between the different territories where the community people live. In the case of isolated rural areas, the lack of infrastructures determines the capacity to gain resources generated by the community member abroad [CEPAL06].

To sum it up, from a demographical point of view, the current population in rural areas has several new patterns that reflect an incipient transition that is parallel to the one happening in general terms since 1950, characterized by the mortality reduction, the progressive increase of fertility control and the emigration.

2.2.2.2 *Economic features*

Latin America is considered the region with most inequalities in the world, with even more inequalities than regions with higher poverty level such us Africa or South Asia. According to the World Bank [Ferreira05], as an average, the wealthiest 10% of the Latin American population has a 48% of the total income, while the poorest 10% has just the 1.6%. Among the region, there are countries that have reached a higher level of growth, although this growth is gathered only in few areas of the territory. According to [Rimisp12] these inequalities are an obstacle for development, as they are an important cost for the country. Also, the data of this report show that, while the economic growth is helping to reduce poverty, the impact on inequalities is clearly much lower.

The contribution of rural areas to the national economies is estimated on a 12% of the GDP (Gross Domestic Product), although if we consider also the contribution of industries processing food, the per cent increases to the 21% of the GDP [Perry04]. This means that **the size of the rural sector in Latin America is approximately twice the size indicated by the official rates.** Also, this study considers that the growth of the agricultural sector is linked to the growth of not agricultural sectors, so that an increase of a 1% in the first one means an increase of 0.12% in the second one. This happens because the activities of secondary production contribute to increase the salaries and the employment of not qualified personnel in the national level [Lopez03].

The bilateral agreements, MERCOSUR (Argentina, Brazil, Uruguay, Venezuela), the Andean Community (Bolivia Colombia, Ecuador, Peru), and the agreements with the European Community and the countries from the Economic Cooperation Forum of Asia-Pacific (APEC), have contributed to a wider opening of markets and the integration of the farming sector in the region. The opening of these markets has shown the disadvantage of the small producers in isolated rural areas, with limited access to education, technology and communications, and therefore, little options to compete with big national and international producers [Echeverria00]. This makes us consider the classification proposed by [Janvry04], according to which rural areas can be sorted in two categories from the economical point of view:

1. Isolated rural areas with low demographic density, characterized by being at a long distance from the main markets and with little farming possibilities. A sample of these regions could be the Andean hills, the coast mountain chain in Mexico and Central America or the dry areas in the Northeast of Brazil.

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2. Rural areas characterized by a rich farming patrimony and relatively good access to the main urban markets, which are far from being the target for this project.

In [Schejtman07] authors analyse the economic data from different regions in Latin America and they conclude that in all of the countries in the region there are isolated areas regarding to economic dynamism, employment and income. These areas would fit exactly in the definition of isolated rural areas proposed by [Janvry04].

Until late 90s the general opinion was that the rural income was mainly agricultural. Nevertheless, from 1999, several studies, as the one done by Reardon and Berdegué, [Reardon99] show that around **the 47% out of the total rural income does not come from the agriculture**. In addition, although the agriculture was still the main employment source, non-agricultural activities were acquiring a growing relevance [Echeverria00]. Money remittances coming from emigrated family members also have a considerable importance [Perry04]. Besides, the Gini index shows that the distribution of income in the household in these areas is quite homogenous due to the low density of population and the little diversity of income sources, what is different from the urban areas [Rimisp12]. Also the sectorial and territorial variables have influence in the income and productivity of the rural households [Janvry04]. Nevertheless, most of these countries apply policies oriented to specific sectors, including the rural economy, not considering the relation between rural economy and national welfare [Perry04]. Therefore, these studies suggest the necessity to analyse the socioeconomic problems in rural areas joining the sectorial and territorial perspectives, instead of developing and analysis focused only in the farming sector.

In spite of the decentralization of competences to local governments, in most of the countries, the investment on public services in the rural areas is not enough compared with the one invested in the urban area, both in the expense per capita (despite the higher costs in rural areas) and in the results obtained in areas like education, access to drinking water, or electricity, for example. On the other hand, there are important subsidies to productive groups that according to [Perry04] are usually regressive and inefficient regarding to inequalities and creation of employment. This is caused because the human capital is the main active of population in these areas, where on the contrary, the funds for investment are scarce, no matter how profitable or worthwhile they are [WB00]. Despite the availability of assets such as cultivable lands, forest or mineral, the private investments search for a bigger profit in more accessible areas, and this is the reason why **there is a big dependence on the public sector to be able to fund new activities** [Perry04].

Since 2000, most of the Latin American countries have experienced an economic growth that was used to get an improvement of the social indicators. The international crisis and the rise of the food price, blocked or even reverted this process, but the region has recovered quite quickly from this situation, making the socioeconomic indicators to show improvement in relation to the previous decade to year 2000 [Rimisp12].

2.2.2.3   *Infrastructures and services*

Infrastructures are the base to provide services to the people and to the productive sectors that are relevant for the socioeconomic growth and the social welfare. In the past 30 years, the public investment in Latin America in transportation, energy or telecommunication have been giving up space to the private sector progressively, characterizing by the absence of an integral institutional view and the sustainability criteria regarding to these services, which causes inefficacy in the provision [Perrotti11]. There is a high heterogeneity in the situation of these services, both among countries and inside of them. There is a big gap in the access, continuity and quality of these services in the rural areas, that shows a significant backwardness.

- *Water and Sanitation*

According to CEPAL, nowadays the 8.28% of the population in Latin America and the Caribbean -47 million people- have not access to drinking water services, and 33.5 million out of them live in rural areas. In this situation, the water provision is done through wells, illegal connexion to the drinking water network or through the rain or river water collection. This causes that many times there is no access to not contaminated and quality water, which is related to the precarious health situation of people. The situation of sanitation services is even more serious, being reached the 21.50% of population with no access to infrastructures for the elimination of the sewage -121 million people-, out of this number, 59 million are from rural areas [Sanchez10]. The Millennium Development Goals try to reduce in half the per cent of people with no access to these services before 2015, indicating the prevision for the achievement.
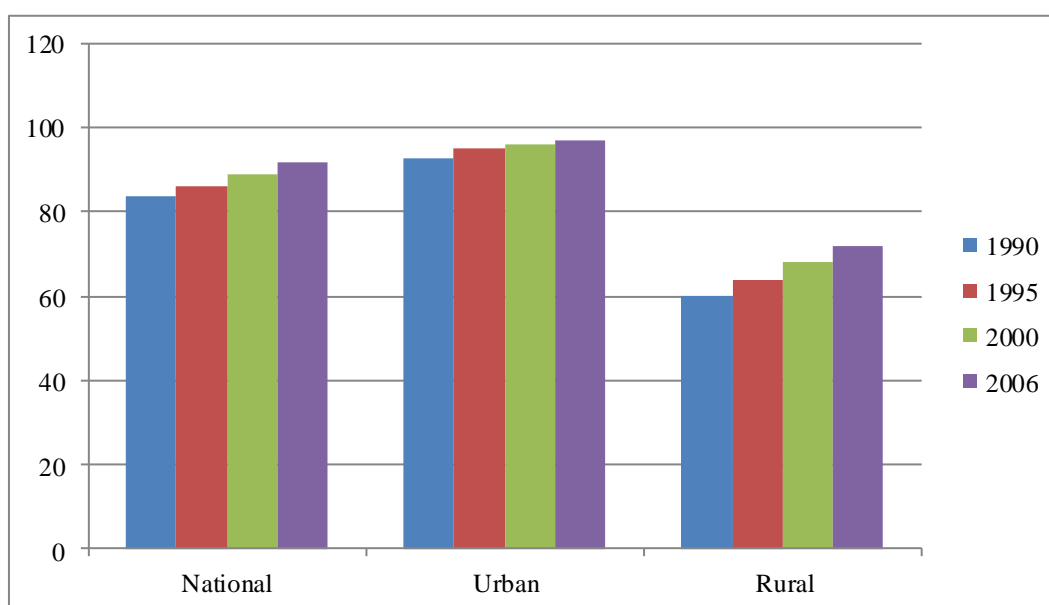
Source: Economic Commission for Latin America and the Caribbean (CEPAL), based on United Nations [UN10].

Figure 2: Percentage of population with sustainable access to drinking water supplies

- *Energy*

The electric coverage has increased in Latin America, going from the 42% in 1971 to the 70% in 1989, reaching the 93% in 2009. "In fact, there is an important amount of countries where this services reaches all the population, although the calculation shows that still 50 million people live in darkness" [Moreno11], people that it is understood to live in the most isolated areas. In this line, electricity is covering over the 80% of the families, except for Haiti, Nicaragua, Honduras and Bolivia, and, in lesser measure, Peru. Regarding to natural gas, Latin America has reached only the 4% of the reserves in the world gas market, emphasizing that the countries with more possibilities in this energy –Venezuela, Bolivia and Peru- are more likely exporter, needing still to stimulate their internal demand [Sanchez10].

- *Transportation services*

This is the sector that has experienced less progress compared to other infrastructures in Latin America, and where there exists a huge gap regarding to other parts of the world. While Asia has between a 79% and a 98% of paved roads in different regions, Latin America barely has the 15.1% (24% in Central America and only an 11% in South America). The wide, modern and signposted ones are just the 5% of the total, being most of it old roads with low quality pave or

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even not paved, with the subsequent high levels of accident rate. In the same way, train infrastructures are scarce, with unconnected lines with low maintenance. The bigger deficiencies are in the internal roads of the different countries –relevant to access to isolated areas-, as well as the crossing borders. The river transportation has many possibilities to access to the isolated areas, due to the many navigable channels that are available, being used now just the 3% of those channels in the main river basis (Orinoco, Amazonas and Tietê–Paraguay–Paraná–Del Plata) [Sanchez10]. The persistence of problems related to transportation is an impediment to the development of the poorest areas, because the existence of quality roads reduces the cost and the time, having direct impact on the economic activities and facilitating the access to job opportunities.

- *Telecommunication*

Since 1990 the telecommunication sector in Latin America has had a notable and heterogeneous growth, existing important differences in the access depending on different variables such as income, infrastructures, education and quality of the regulation. While the fix phone market has come to a standstill, the mobile phone has spread out in an accelerated way, with an introduction index of 90% in 2008. Broadband connexions reached the 34 million in 2009, with a low introduction index due to high tariffs and a network that did not reach all the places [Moreno11]. In this meaning, the phenomenon called digital gap, that combines socioeconomic factors and the lack of infrastructure in some regions, has been clearly identified. The following table shows the amount of phone lines and computers per 100 inhabitants by residence area and ethnic group, making clear the gap between the urban and the rural areas in the mentioned countries.

Country		Number of phone lines per 100 people	Number of computers per 100 people
BRAZIL			
African descent	Urban	8,1	1,3
	Rural	0,6	0,1
Rest	Urban	16,1	5,1
	Rural	2,4	0,5
COSTA RICA			
African descent	Urban	17,4	3,7
	Rural	5,3	0,7
Rest	Urban	18,2	5,2
	Rural	7,2	1,2
ECUADOR			
African descent	Urban	7,0	
	Rural	2,5	
Rest	Urban	13,1	
	Rural	3,3	
HONDURAS			
African descent	Urban	6,3	1,2
	Rural	2,1	0,6
Rest	Urban	6,6	1,5
	Rural	0,3	0,1

Source: CEPAL/CELADE. Census microdatabase processed in Redatam. (1) Preto + pardo, (2) African-Costa Rican or black, (3) Black + mulatto, (4) Garifuna + English black. Note: Ecuador is not included in its questionnaire the information about owning a computer. Excluded the category "I don´t Know". The phone number was calculated according to the main household except for Brazil, where the data was collected in all households. The number of computers was calculated according to all households, but for Costa Rica, which data correspond to the information about the main household [CEPAL06].

Table 2: Number of phone lines and computers per 100 people, by country, ethnic and residence area (census 2000)

Indeed, phone communication systems are scant in most of the indigenous communities and they are frequently replaced by community radio stations [CEPAL06]. CEPAL mentions as essential conditions to achieve the universal access to ICT in the region, the importance of introducing a minimum infrastructure in rural areas, as well as an effort to reduce illiteracy and promotion of local activities favoured by the use of ICT. Most of the Latin American countries have specific funds for the promotion of the universal access to telecommunications. Thanks to this support, many goals have been achieved, as having at least one community phone in the 85% out of the 22.242 population centres in Colombia with more than 150 inhabitants. In the case of Peru, it contributed to the deployment of the 65% of the installation of public phones in 10.000 population centres, as well as funding other rural phone projects, telemedicine projects and support independent operators of small community in isolated areas [Klein07].

2.2.2.4 *Social and political features*

The study of social issues in the rural population must be approached considering the high and persistent inequality situation in Latin America, which is just replicated in contexts with low socioeconomic movement, as the ones we are analysing. Multiple causalities are key to explain the origin of the social gaps. We cannot forget that some causes are economic and reflect the high relation between the level of assets, income and schooling of a generation and the previous one. On the other hand, other causes have a political or social origin and reflect historical features and inequality of opportunities and (direct and indirect) access to power, in a context characterized by exclusion, oppression and structural domination that demonstrate the endogenous nature of inequality [UNDP10]. Actually, an historical perspective let us locate the colony as the origin of the domination situation, which has lasted along these years and has transformed into an important inequality that still remains. This means limited opportunities and access to resources, which creates "alarming poverty index, lack of lands, low salaries, high unemployment, high illiteracy rates –particularly regarding women-, migration, school drop-out, unsatisfied basic needs and an epidemiological profile where evitable diseases prevail" [CEPAL06].

- *Health indicators*

Despite the progress done in social policy issues and infrastructures to improve the health in the general population, there is still a remarkable territorial gap regarding the health situation in rural areas. In line with this, the communities with the worse health indicators related to mortality and malnutrition in Latin America tend to be rural, of small population size and mostly indigenous.

Actually, "the health assistance coverage, that is already quite low in rural areas, even reaches the most critical level in indigenous areas. Traditional collective knowledge, customs, indigenous medicine therapies, and the community resources, even if they have an inestimable value, when facing the complex epidemiological profile, this reaches just for a part of their health needs" [CEPAL06]. One of the indicators with more relevance in the inequality of access to primary health services is the maternal and children mortality rate, as these are usually situations that can be prevented with the proper service. The proportion of child deliveries attended by qualified personnel in rural areas is lower than in urban areas, being the 20% in rural areas and the 69% in urban areas in Peru [UN05]. According to the Report 2012 about the situation of the Millennium Development Goals, children from rural areas have less possibilities to reach 5 years old, with a rate that measures the gap between urban and rural mortality of this group in Latin America, being the 1,7 on a range of 3 [UN10].

On the other hand, regardless the scarce of necessary resources for primary health assistance, the significance of poverty in Latin America also has direct influence in the health indicators, as it makes reference to the basic needs satisfaction of food consumption. In 2005 it was calculated

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that Latin America had 96 million people in extreme poverty situation -18.6% of total population- and out of them, "52 million people live in urban areas and almost 45 million in rural areas. Both amounts are quite similar, considering that the 75% of the total population live in urban areas, **showing a much higher incidence of poverty in rural (37%), compared to urban areas (13%)"** [UN05]. Despite the Millennium Development Goals progresses on poverty and hunger elimination, the rural areas still have important nutrition gaps which cause health issues, as we can see in the fact that in 2012, "the higher differences related to insufficient nutrition between children from urban areas and children from rural areas are located in Latin America and Caribe" [UN10].

- *Education indicators*

The literacy level is another issue which the territorial dimension has the influence to make inequalities clearly visible. As the education is considered as a powerful tool to boost the human development, the social and geographical coverage of primary education has been extended in all regions from Latin America. Nevertheless, there are still social gaps related to three main variables: territory, ethnic groups and gender.

The Report in 2012 about the Millennium Development Goals says that "the data analysis collected in the survey households from 2005 to 2010 in 55 developing countries shows that education exclusion is more frequent in children from less privileged groups. Poverty is decisive regarding school exclusion between young people that are on the age range to participate in the first cycle of secondary studies" [UN10]. As we can see in the table, **rural areas in Latin America have the highest illiteracy rates**, in one side due to the scarce of education centres in those areas, and on the other side due to the higher dedication to agricultural tasks, which increase the premature drop-out of the formal education. In these rural areas is where the less literacy group (the indigenous people) is concentrated.
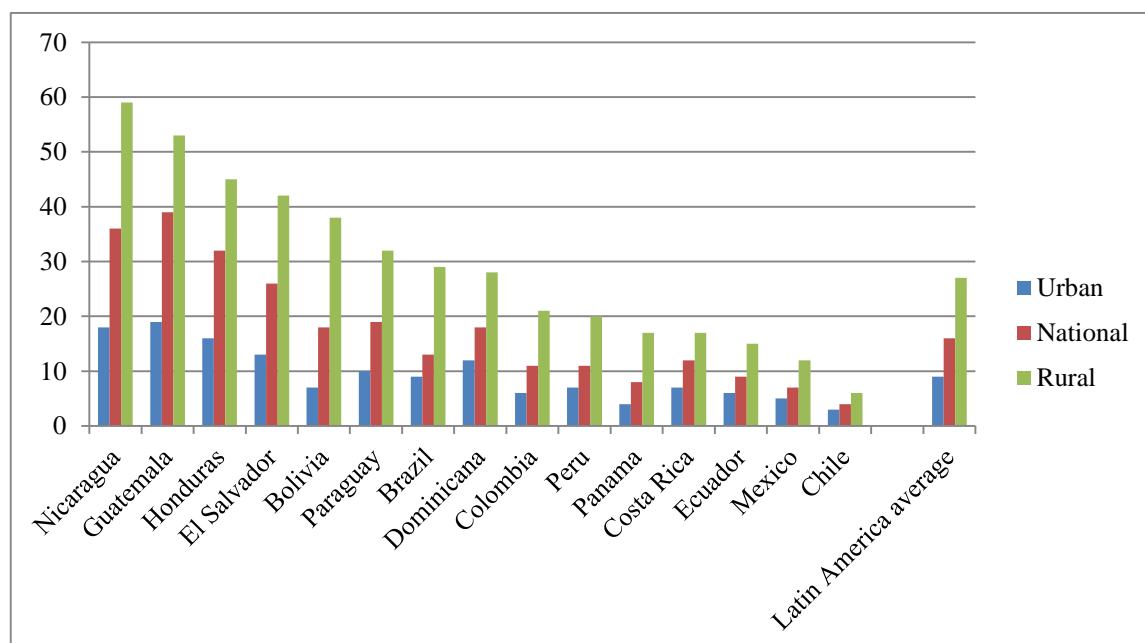
Source: United Nations Educational, Scientific and Cultural Organization, 2004 [UN05].

Figure 3. People (15-19 years old) that have not finished the primary education, per residence area (2002)

This gap is even more remarkable when we talk about secondary education, which is a limit that indigenous people haven´t been able to overcome in order to reduce the inequality with not indigenous population. There are also differences between men and women in the indigenous communities. The high illiteracy rate of women are still the proof of the exclusion of women regarding to education, as they are dedicated to domestic tasks and informal economy [CEPAL09].

The social gap related to the access to education appears too in the job market, where indigenous groups are in inequality, being able to work only in precarious jobs that do not require specialization. Education is essential for the social mobilization, and the education limitation drift into a limited access to the necessary resources to reach a minimum welfare and quality of life.

- *Gender equality*

The opportunities for women to access to resources are essential to understand the level of equality in a society. The Gender Equality Index (GEI), which measures women participation in political and economic decisions, and the access to resources and job opportunities, is clearly related to the HDI. Gender inequality is frequently linked to other development indicators for human development, so isolated rural areas still have the bigger gaps, as a consequence of the permanence of patterns that shows the traditional sexual division of tasks and the unequal power relations between males [UNDP10].

If we consider the impact of gender on the population literacy in these regions, in general the bigger inequalities occur during primary education and they are progressively reducing as the education level rises [CEPAL06].

Regarding to the job participation, women are still mostly in the informal economy and domestic sector, being the rural area in Guatemala, the one with the biggest gender gap in 2005, being the male participation 75.3% and the women participation 24.5%. Political participation in local government or in health issues are also sectors where gaps are evident and demonstrates that in general, those territories with higher GEI, tend to be the urban ones, with bigger population size and a smaller proportion of indigenous or African descent [Rimisp12].

- *Society and political participation*

Latin American Governments have chosen to transfer important competences and responsibilities to the intermediate and local governments, giving more fiscal resources and helping to boost the development with a territorial approach [Serrano11]. Local governments in rural areas must face the isolation produced by the long distances, the scarcity of population, and as a consequence, higher costs for providing basic services (education, health and social welfare, infrastructure, environmental protection and poverty fight programs). According to the study done in [Rimisp12] "neither the size of the community (population) nor the urbanization level, or the population density, seem to be relevant factors related to the management capacity of local governments in Latin America" regarding to the availability of civil servants and human resources. Nevertheless, a bigger proportion of indigenous population or African descent seems to be an important factor for the management at the moment of identifying isolated territories. Also according to [Rimisp12], the capacity of income generation of the local governments is more limited in rural areas, as in general there is low population density and scarce resources. Many of these rural municipalities depend on the funds given by superior structures of the Government to be able to face the isolation challenges.

Since the 80s, indigenous communities have been entering the political scenario of the regional and national summits, in order to claim their cultural identity and the end of their social exclusion for the full exercise of Human Rights. The intercultural dialogue that has been established oriented to the recognition of their rights, has outlined "three main elements that are

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the base to all other rights. These are: the right of territory (as a foundational element), the right of culture (which includes material aspects and also the cosmologic vision, and the spiritual and historical dimension of these communities) and the right to the autonomy of the communities" [CEPAL06].

There have been many meetings where the inequality of these groups or communities has been discussed. Among them, it was important the International Conference for People and Development, celebrated on 1994 in Cairo. This meeting meant a key moment regarding to agreements and goals related to sexual and reproductive rights –whose agenda was extended 10 years later, considering subjects like the education right and the territory right of these groups-, or also the Millennium Declaration of the United Nations in 2000, where the explicit tools to strength Human Rights of excluded groups and minorities are reassert and synthetized. In spite of these achievements, it is still necessary that authorities reassert their political commitment through specific methodologies, in order to give these people a voice to become agents of their own development according to their diversity, respecting their territory and appreciating their cultural identity.

2.3 Colombian case

This section aims to describe the Colombian case focusing on the socioeconomic environment, the potential target localities for TUCAN3G solutions, and the situation of cellular telephony and Internet access.

2.3.1 Socio-economic environment

In order to describe Colombian socio-economic environment, three categories are used: geography and population, economy, and social indicators.

2.3.1.1 Geography and population

Colombia is the third Latin American country with the greatest number of population, about 47 million according to the projected figures for 2013, after Brazil and Mexico [DANE12]. This population is divided into 32 departments with 1,123 municipalities occupying a land area of 1,141,748 km^2. The 5 most populated departments are Antioquia, Valle del Cauca, Cundinamarca, Atlantico and Santander. The most important cities, both in number of population and its economic activity are: Bogota, Medellin, Cali and Barranquilla.

Although Colombian territory had a deep transformation in the twentieth century -from being a predominantly rural area to be an urban country [CEPAL03]-, according to the 2005 population census 69% of the municipalities of Colombia (770 municipalities) have more rural than urban population. While, in 31% (349 municipalities) the urban population is higher than the rural population. In the same way, in 8 of the 32 departments of Colombia the rural population is greater than that dwells in cities, as it is shown in the following figure:
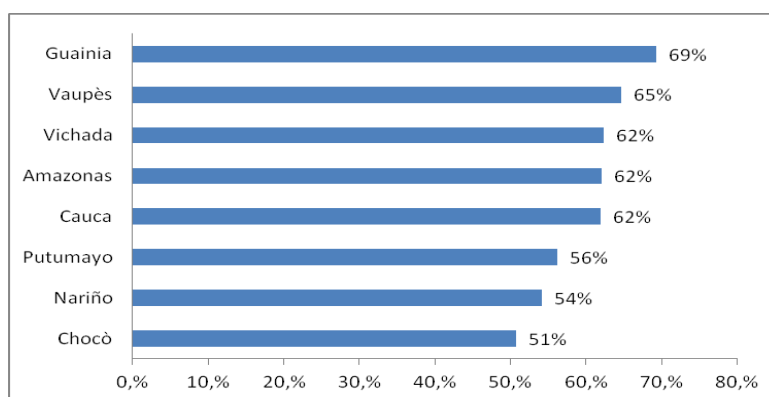
Figure 4. Departments of Colombia with more rural population

According to the National Human Development Report of 2011, **the 32% of Colombian population lives in rural areas** and typical relations of rural societies prevail in three-quarters of the municipalities [UNDP11].

In Colombia interacts culture and traditions of American, European and African people. According to the general census of 2005, 85.94% of the population doesn't identify themselves as belonging to any ethnic community, 10.62% belongs to black communities, 3.43% identifies as belonging to an indigenous community and the 0, 01% to a gypsy community.

The distribution of the population according to gender is 49% male and 51% female. From the total population 31% is under 15 years old, 26.3% are between 15 and 29 years old, 36.4% of the population is between 30 and 64 years old and 6.3% are over 65 years old.

2.3.1.2   Economy

Colombia's economy is a leading emerging economy in the international scene, thanks to the strong growth experienced in the last decade and the general attractive that offers to the foreign investment. Today is placed as the fourth largest economy in Latin America, behind Brazil, Mexico and Argentina. In the international classification it is placed within the 30 highest in the world.

The Colombian economy is based primarily on agriculture and mining, but its industrial development is important. It is one of the most important coffee producers in the world and in the warm lands grows cotton, sugarcane, cocoa, bananas and rice, while low temperatures lands, produces cereals, potatoes and beans. As for minerals, highlights the exploitation of coal, the production and export of gold, emeralds, sapphires and diamonds. The industrial sector includes textile fabrics, car industries, chemical and petrochemical industries.

According to information from the International Monetary Fund, in 2012 Colombia's GDP amounted to 500.576 million dollars and the most representative contribution to GDP is in financial sectors, services, manufacturing, commerce, mining and petroleum, construction, agricultural and livestock, electricity and gas.

The Colombian departments which have a bigger participation in national GDP are: Antioquia, Valle del Cauca, Santander, Meta, Cundinamarca and Bogota. D.C.

2.3.1.3   Social indicators

-   *Poverty*

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In Latin America, 60% of people who have less than U.S. $ 2 per day to survive are in three countries: Brazil, Mexico and Colombia. In Colombia there is near 16 million of poor population [Herrera13]. Statistics show Choco, Cauca, Cordoba and Magdalena as the four poorest departments of the country. While the national average poverty is at 34.1%, the rates of these departments exceed by lots of points this percentage: 64% (Choco), 62% (Cauca), 61.5% (Cordoba) and 57.5% (Magdalena).

In rural areas, poverty levels increases to 46.1% of the population, reflecting that approximately one of two rural habitants are poor, and the access to public services, quality education, health and social security is lower in rural areas than in urban centers, which becomes more critical the situation of rural poverty.

- *Unsatisfied basic needs (UBN)[1]*

According to the results of the 2005 census population, 27.7% of the population presented UBN. In the municipal headers this percentage is equivalent to 19.66% of the population and in the rural areas (rest of it) the percentage increases to 53.51%.

- *Illiteracy*

According to [DANE12] in 2012, 5.9% of the population over 15 years old is illiterate, in rural areas this percentage raises to 13.3% of the population. According to the ICT Department of Colombia, 39% of Colombians can be considered as digital literacy in 2010, it means, they have the skills to handle basic tools of office package and Internet [MINTIC13].

- *Human Development Index*

Colombia's HDI for 2012 stands at 0.719, which gives the country a rank of 91 out of 187 countries for which comparable data and also places it within the group of countries with high HDI. Departments with lowest HDI are La Guajira (0.619), Choco (0.731), Caqueta (0.752), Putumayo (0.759), Nariño (0.773), Sucre (0.775), Cauca (0.782) and Magdalena (0.796).

2.3.2   Potential target localities and end users

TUCAN3G target markets that are located in remote rural areas, where geographic conditions make difficult for operators to provide mobile services, so the coverage is limited or lacking. Information on this respect has been collected in order to identify potential target localities in Colombia.

The first step has been to identify the populations that have limited coverage. According to information provided by the mobile operators, 98.84% of the 1123 municipalities in the country are covered with GSM technology. However, there is no data about population reached, which it's supposed to be lower. Besides, 100% coverage is not reached in the departments of Amazonas, Bolivar, Antioquia, Cordoba and Guainia. Regarding 3.5G coverage, it reaches 93.7% of the municipalities and the departments with the lowest coverage rates are Amazonas, Vaupes, Guainia, Choco, Guaviare, Arauca, Bolivar, Meta, Nariño, Putumayo, Magdalena and Cauca. Considering this information together with the percentage of rural population shown in Figure 4, we can conclude that in Colombia is possible to find potential markets for the implementation of the solutions developed in the TUCAN3G, especially in two main regions: Amazonas region (Amazonas, Guainia, Vaupes, Guaviare, Meta and Putumayo) and Pacific region (Cauca, Choco and Nariño). The departments of Cauca and Putumayo can be considered

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[1] To determine the UBN are taken into account five variables: inadequate housing, inadequate public services, critical overcrowding, truancy and high economic dependence.

as representative of the rural Colombia, and are selected to describe in more detail the characteristics of these potential markets from a socio-economic point of view.

2.3.2.1 Cauca and Putumayo regions

The department of Cauca is located between the Andean and Pacific region in the southwest of Colombia. With a portion of 140 km of coastline in the Pacific Ocean and borders with Tolima, Caqueta and Putumayo, its area is equivalent to 2.7% of the country. According to DANE projections for 2012, it has approximately 1.543.742 habitants that are located in 42 municipalities [DANE12], organized into seven regions (see Figure 5).

It is a department with a great biodiversity which produces an extensive agriculture decisive for a big part of the department's economy. The industrial sector has the chain sub pulp, printing, chemicals, pharmaceuticals, food, agro-industrial and metalworking, among others. In addition, due to state policies, mining sector has been growing in the department with important extractions to the economy of Cauca.

Figure 5. Political division of the department of Cauca

Cauca is a department primarily rural and with basic livelihood conditions especially in rural areas of the department. While the 24% of the people living in the urban areas of Cauca have unsatisfied basic needs, in rural areas this percentage increases to 61.97% of the population. It can be told that the rural population of Cauca suffers from several limitations to access to better living conditions. Among these limitations, in addition to those measured in the NBI, is the

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difficult access to communications, because in the department, for their particular geographic, it has become difficult to achieve total mobile coverage especially in rural areas where the percentage of households with cell reaches 75.9%. Besides, it is one of the departments with lower Internet penetration (2.68%) [MINTIC13]. In this way, the regions that have more limited access to communications technologies are Caucana Boot and Pacific, both with a high rate of indigenous population. Caucana Boot represents the jungle area of the department where there three main municipalities: Piamonte, Santa Rosa and San Sebastian.

Regarding to Department of Putumayo, it is located in the south of the country in the region of the Amazonas divided into 13 municipalities. According to population projections from the DANE for 2012, the department's total population is 333,247 inhabitants. The 48% live in the municipal header and 52% in rural areas.

Source: http://www.palimpalem.com
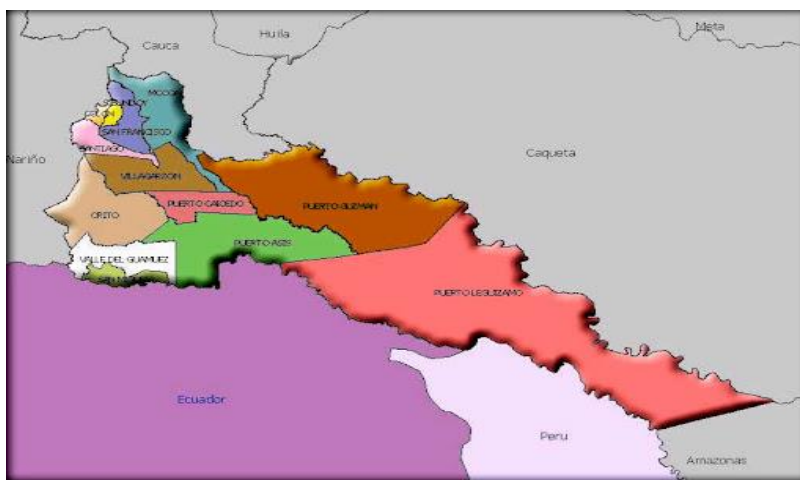
Figure 6. Political division of the Department of Putumayo

Its economy is defined by three sub-regions: high, medium and low regions with a different economic potential according to their environmental characteristics. Putumayo's economy is based mainly on agricultural production developed mainly in the piedmont, and the exploitation of oil resources and forestry in their jurisdiction. The per capita production is small compared to the neighbouring departments. However, the economy has an important dynamic, possibly because the effect of illegal coca economy, and other sources such as royalties and international cooperation.

Municipalities of Putumayo where it is possible to find target markets for the technology developed in TUCAN3G are Puerto Leguizamo, Puerto Guzman and Puerto Caicedo, since they are the municipalities that have a higher percentage of rural population with important limitations on access to mobile telephony and the Internet.

The population of Cauca and Putumayo areas presents high rates of unsatisfied basic needs and is characterized by a young demographic structure (the municipality of Santa Rosa in Cauca shows the 43% of the population under 17 years old, 49% finds between 18 and 60 years old, and only 8% of the population is over 60 years old). The migration to seek for better employment is a trend in this region. Those who remain perform agricultural work, traditional agricultural and mining, with high levels of unemployment and informal employment. In addition to migrations flows, there are other factors that cause the dislocation and poverty, such as the impropriety of the earth, the unsafe conditions by the presence of various armed actors,

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the coca culture and the lack of knowledge of how to act in this environment, factors especially important in the case of the municipality of Puerto Caicedo in Putumayo.

Regarding education, generally more than half of the population finishes the primary education in the schools, but rates are dramatically reduced as they refer to higher levels of education. With respect to health services, these regions have poor infrastructures and little medical personnel, which do not ensure the adequate provision in health services and/or customer services. Depending on the municipality, there are hospitals and health centers or health posts to attend to the most isolated areas. All these services lack of the adequate physical infrastructure required to operate, neither have the materials and staffing needed to provide quality health services. In addition, difficulties in access to health institutions caused by the absence of adequate internal roads, generates problems with the internal and external transport of patients with any degree of seriousness, as happens in the case of the municipalities of Piamonte or Santa Rosa in Cauca.

In relation to infrastructures, in addition to the shortage of electrical interconnection –there is no electric supply in the 52% of areas of Piamonte (Cauca)-, there is not a fluid mobility and road connectivity. The poor infrastructure of the roads limits growth and income, and produces agriculture of subsistence.

Regarding mobile phone services and Internet, there is a poor expansion of coverage, infrastructure and telecommunications services that affects the quality of life of the settlements scattered and isolated. Attending this need requires interagency cooperation and management of state resources [Santa12]. In general, there are no networks to facilitate the access to services of fixed telephony and Internet. Cellular services are provided by the companies Claro and Movistar, with 80% coverage in the case of the municipality of San Sebastian in Cauca. These same companies provide Internet access by modem but due to its high cost is only used by the 5% of the population. Furthermore, it should be added that the coverage of operators in these municipalities is limited to the municipal headers and does not cover remote areas of it. There are also some education facilities with Internet service provided by Compartel that works poorly, and community radio and television services supported by local governments. Some localities as Piamonte in Cauca are expected to reach the network of fiber optic thanks to the national plan Vive Digital [Piamonte12], which is very relevant for a project like TUCAN3G.

2.3.3   Cellular Telephony and Internet access

The ICT sector in Colombia guarantees connectivity of the country, is a major driver of the national economy, provides significant resources to GDP and has presented a high growth exceeding the average of the national economy. Besides, in line with global trends, the sector has been characterized by the liberalization of the telecommunications market, the replacement of fixed telephony by mobile phones, replacement of voice over data services and the development of new technologies and wireless markets [DNP10a].

According to this scene, the current Development Plan Colombia sets policy guidelines for the ICT sector to enable the inclusion of all people, people with disabilities, the elderly, ethnic and other social groups. Such guidelines are part of a series of promoting principles that are headed by the formula: "The market as far as possible, the State to the extent necessary". These principles are addressed at overcoming gaps, both in the level of infrastructure, and in the availability of devices and terminals. They also aim to generate applications and contents, seeking a widespread appropriation of ICTs, through the consolidation of a regulatory and institutional framework.

The biggest barriers to greater penetration and appropriation of ICTs (especially the Internet) in Colombian territory are associated, from the point of view of supply, to (i) the high costs and complexities to develop infrastructure, especially by the geography of the country and (ii) the

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limited public or the state resources to invest in infrastructure. From the demand perspective, the barriers associated with (iii) failure in the purchasing power of citizens, specifically to acquire terminals and Internet service pay and (iv) lack of perception of the need of Internet. The telecommunications sector in the country has been marked in recent years by the popularization of mobile services and the growing demand for dedicated Internet access.

2.3.3.1 Mobile voice service

At the end of the fourth quarter of 2012, Colombia had 49,066,359 subscribers in mobile service, which means that the country has 105.3 telephony subscribers per 100 habitant [MINTIC13].

Nationally, 94.2% of households have at least one cell phone, in urban areas these numbers rises to 96%, but in the rural sector drops to 87.9% [DANE12]. The number of phones per household, and the amount paid by the mobile phone service varies depending on the socioeconomic status of the households (see Table 3):

Stratum[2]	Number of persons per household (average)	Phones per household (average)	Monthly expenditure on mobile telephony (average) $
Low-low	3.9	1.9	6.51
Low	3.6	2.1	7.78
Medium Low	3.2	2.3	13.16
Medium	2.9	2.3	21.45
Medium High	3.1	2.5	32.62
High	3.3	2.9	44.20

Table 3. Cellular possession per home and cell phone monthly expenditures according to calculations based CINTEL -NBS, 2011

In Colombia, according to figures presented by the CONPES (National Economic and Social Policy Council of Colombia) in 2010, 22.3% of households were in the low-low socioeconomic status, 41.2% in the low, 27.1% in the middle, the 6.3% in the upper middle, 1.9% in the high and 1.2% in the high-high [DNP10a] which means that approximately 90% of Colombians stands in the stratum with social and economic conditions more deficient. Moreover, in rural distribution is even more concentrated: 92% of households live on the layer 1 and 2, 2% in the layer 3 and less than 0.5% in layer 4, 5 and 6 [FEDESARROLLO11]. However, households classified in levels 1 and 2 spend a good percentage of its income in cell phone services.

The Colombian government says that 99% of the municipalities have basic telephony and 86% have 3G networks, however no information is available about the differences on coverage between rural and header areas [UNESCO12]. It should be noted that the mobile phone market in Colombia is focused on three operators that are Comunicación Celular SA - Claro, Telefónica Móviles Colombia SA - Movistar, Colombia Movil SA - TIGO, with a share of 61.9%, 23.85%

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[2] The socioeconomic stratification is a classification into residential stratums property should receive public services. It is done mainly to charge differentially for stratum allowing household utilities allocate subsidies and collect taxes in this area. The layers 1 and 2 correspond to the lower stratums that host users with fewer resources, which are beneficiaries of subsidies on public services; strata 5 and 6 correspond to upper strata that house the more affluent users, they pay taxes (overruns) on the value of public services. Stratum 3 is classified as a medium receives a small percentage of subsidy, the layer 4 is not grantee, or to pay surcharges, pay exactly the value that the company defines as cost of providing the service.

and 13.48% respectively. There are other operators like Mobile Uff, H.S.H. and EPM Telecomunicaciones SA, which together have a participation of less than 1%.

According to the information reported by commercial mobile providers in their websites, Claro now has 100% coverage in the municipalities (urban area) of the country with GSM technology, and additionally 86% of the municipalities already have 3G networks. The municipal level coverage with 3G networks of Movistar is 38% and TIGO with voice services is present at 80% of Colombian municipalities and with 3G technology is reaching 22% of them.

2.3.3.2 *Mobile data service*

Regarding the mobile Internet services in Colombia in December 2012, the country reached a total of 3.209.059 subscribers, most of these are accessing the network with terminals Data Card of 3rd generation (37.4%), followed by the access through third generation mobile phone (34.7%) and the second generation mobile phone access (25.3%).

The niche market of mobile Internet is in large cities, where operators have begun to offer 3G and fourth generation (4G) services. 4G has only achieved a low penetration of 3.68 users per 100 people nationwide. However, this situation is expected to improve in the coming years due to the expected growth rate of ICT through the use of effective frequencies for mobile telephony [FEDESARROLLO12].

2.3.3.3 *Characterization of mobile telephony consumers in Colombia*

According to the study on Pricing and Use of Mobile Phone Services [Consenso11] and the Report of Mobile Telephony in Colombia [ASOMOVIL12], mobile phone consumption in Colombia has the following characteristics:

- The participation of men and women in the use of mobile phone is very similar, 47% and 53%, respectively.

- The level of education of mobile users is mainly secondary education (47.7%), followed by primary education (17.3%), university education (16%) and postgraduate education (3.1%).

- 37% of mobile phone users are aged between 25 and 37 years old, 28% between 38 and 55 years old, 21% are between 18 and 24 years old, 12% are aged between 13 and 17 years old and 2% are over 55 years old. This indicates that 86% of users are in working age.

- In terms of occupation, 31.9% of the respondents are self-employed, 24.6% are employed, 19% housewives and 14% students.

- Of the users surveyed, 19.5% have monthly income between U.S. $275.63 and U.S. $413.45, 21.4% have incomes less than U.S. $413.45, 20% have incomes above U.S. $413.45 but less than U.S. $1102, and only 4.7% have incomes above U.S. $1,102.

- The 35.87% of the subscribers have been classified in the socioeconomic layer 2, the 27.21% in layer 1, 25.16% of people in socioeconomic layer 3, the 5.48% to people in layer 4 and 5.9% people of the layers 5 and 6.

- The 96% and 91% of users at levels 1 and 2 respectively use prepaid lines. These data clearly confirm that prepaid is the preferred payment method for users of the lowest stratums.

- A very high proportion of users purchase minutes to third parts, instead of using their own phone. The purchase of minutes is widespread among prepaid and post-paid users of all groups, but especially among users of prepaid levels 1 and 2.

- The average monthly expenditure reported by interviewed prepaid users was U.S $8.84, closed postpaid plans users was U.S. $31.76, and open postpaid users was U.S.$ 56.35. The above data shows a striking difference among the monthly spending of users of these three modes of payment.

Both studies were conducted in principal and intermediate cities of the country like Bogota, Bucaramanga, Villavicencio, Ibague, Medellin, Cali, Pereira, Barranquilla, Monteria and Valledupar.

2.4   Peruvian case

This section aims to describe the Colombian case focusing on the socioeconomic environment, the potential target localities for TUCAN3G solutions, and the situation of cellular telephony and Internet access.

2.4.1   Socio-economic environment

In order to describe Peruvian socio-economic environment, three categories are used: geography and population, economy, and social indicators.

2.4.1.1   Geography and population

Peru has an important geographical and climatic variety, influenced by the Andes and the Humboldt bulk flow. Traditionally, Peru is divided into three natural regions: the Coast Region, the Andean or Mountains Region and the Jungle or Amazon Region.

The **Coast Region** - with an extension of 136'232,85 km² (10.6%)- is a narrow longitudinal stripe that goes from the Pacific Ocean to the west side of the Andean Chain and reaches 500 m above sea level. The presence of the Andean Chain in the east and the Humboldt Current that reaches the beaches creates a barren and dry area. It has a moderated topography, with remarkable marine terraces, fluvial fans, dunes and eolian sand deposits, along with hills which are the bottom of the western buttresses of the Andean Chain[3].

The **Mountains Region** -with an extension of 404'842,91 km² (31.5%)- is formed by the Andean Chain, which is a craggy mountain range that runs from south to north, crossing longitudinally the country and in the middle of the coast and the jungle. Overall, the Andean landscape is important and has a heterogeneous configuration with prominent peaks, deep gorges, narrow Andean valleys and wide plateaus. It is considered to be divided in three mountain chains or ranges: Western, Central and Eastern. The first of them is the most important since the peaks mean the continental division, being the watershed between the Pacific and the Atlantic Oceans. The population resides mostly at between 2,000 and 3,500 m above sea level, because this area is favourable for the development of agro-economic activities.

The **Jungle Region** -with an extension of 754,139.84 km² (57.9%)- is located at the east of the Andean Chain and belongs to the Amazonian Basin. In general, it has two main areas: the

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[3] http://www.inei.gob.pe/biblioineipub/bancopub/Est/Lib0347/N25/GEOGRAF.htm.

Highland Jungle or Flange Mountain, and the Plain Amazon or Low Jungle, separated by a chain located 400 m above sea level.

Regarding to the population, the census in 2007 mentioned that the population of Peru is 27,409.200 people. When population was divided by rural and urban areas, the result was that that the 75.92% of population live in the urban area and the rest in the rural area, 24.08% (see Table 4).

Type of locality	POPULATION (2007)			
	Nº inhabitants	Urban	Rural	Percentage
<100	1.571.362	0.01%	5.72%	5:73%
>=100 & <300	2.977.959	0.28%	10.58%	10.86%
>=300 & <1000	2.780.110	3.04%	7.10%	10.14%
>=1000	20.079.769	72.59%	0.67%	73.26%
Total	27.409.200	75.92%	24.08%	100%

Source: INEI – 2007 Census

Table 4: Population in rural and urban areas in Peru

Regarding to the localities, there is a total of 98,011 localities. The 96.85% of them are rural locations (see Table 5). The 75.08% of all rural localities have less than 100 inhabitants.

Type of locality	Distribution of populated centers (2007)			
	Nº localities	Urban	Rural	Percentage
<100	73.725	0.04%	75.08%	75.22%
>=100 & <300	17.139	0.38%	17.17%	14.49%
>=300 & <1000	5.756	1.44%	4.47%	5.87%
>=1000	1.391	1.28%	0.14%	1.42%
Total	98.011	3.15%	96.85%	100%

Source: INEI – 2007 Census

Table 5: Localities in rural and urban areas in Peru

2.4.1.2 *Economy*

Regarding the level of employment in the different regions, it is evident that there is a big gap. Figure 7 shows that near three quarters of the total population are working in the Mountain and Jungle Region. On the coast, only the 65% of the population are working (population in Metropolitan Lima reaches a similar percentage). The difference between the first group and the second is that, in the first one, most of the population that are between 14 and 18 years old also work, and often support the activities of their parents. However, in the second one, a high percentage of the population between 14 and 18 years old continue studying any technical or university careers.
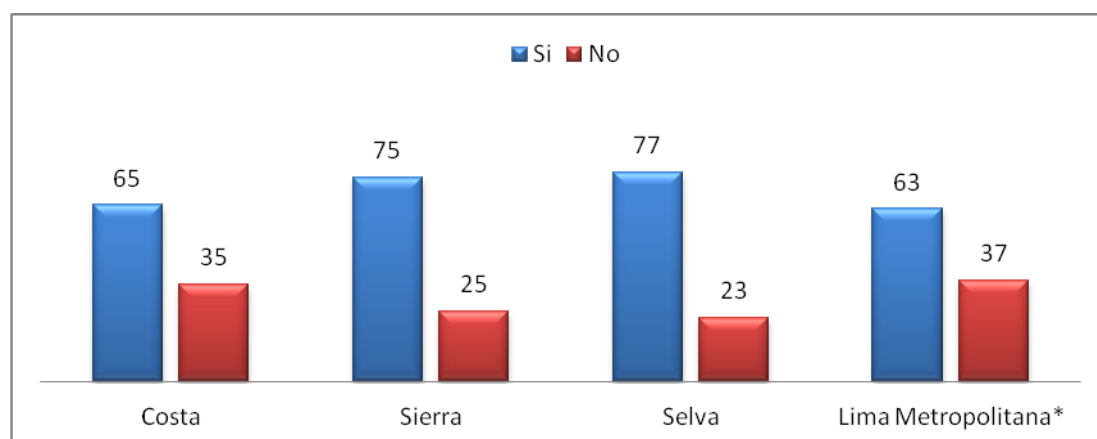
Source: Own elaboration based on INEI-ENAHO, 2011
* Metropolitan Lima is not considered in the coastline region.

Figure 7. Percentage of employed population

On the other hand, about the 36.0% of people who is employed in any region, are mostly independent workers, while in the Metropolitan Lima they barely reach the 25.9% (what is more often to be an employee, 37.1%). In the coast also most of workers work as labourers (24.7%), employees (19.8%) and unpaid family workers (11.7%). In the mountains and jungle, this proportion is inverse, being the main occupation the unpaid family workers (23.7% in the jungle), and being a lower per cent for workers and employees.

Occupation	Region			
	Coast * (%)	Mountains (%)	Jungle (%)	Metropolitan Lima (%)
Employer	4.96	4.43	6.87	4.84
Freelance	35.06	36.21	37.82	25.99
Empoyee	19.88	14.04	13.61	37.19
Temporary worker	24.77	14.85	15.86	21.23
Unpaid family worker	11.74	28.63	23.71	5.92
Domestic worker	2.76	1.09	1.43	4.62
Other	0.83	0.75	0.70	0.21
Total	100.0	100.0	100.0	100.0

Source: Own elaboration based on INEI-ENAHO, 2011
* Metropolitan Lima is not considered in the coastline region.

Table 6. Main occupations

The average for the monthly net income for the main occupation is quite similar between workers from the coast (244.17€) and from the mountains (234€), but in the jungle the income is slightly above the minimum living stipend[4] (217.5€). In the Metropolitan Lima the average of income per capita is 321€.

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[4] The minimum living stipend (RMV) is the minimum amount to be paid to an unskilled worker, labouring of private activity and working for at least four hours a day, whatever the starting date is.

Figure 8. Average monthly net income

2.4.1.3 Infraestructure

The provision of electric power[5] in dwellings is generally high in the different regions of Peru. In the Mountain and Jungle Regions there are still a significant percentage of households without electricity, 18% and 25%, respectively.

Households with electricity for lighting	Region			
	Coast * (%)	Mountains (%)	Jungle (%)	Metropolitan Lima (%)
Without electricity	4.50	18.05	25.03	0.42
With electricity	95.50	81.95	74.97	99.58
Total	100.00	100.00	100.00	100.00

Table 7. Access to electric lighting in households

Related to the access to ICT and the expenditure in households, excluding the Metropolitan Lima, the 31.1% of households in the Coast Region have landline service. In the Mountain and Jungle Regions the access to the service is very little, so the 10.9% and the 14.3%, respectively, have landline access. In the Metropolitan Lima, near the 55.6% of households have landline service.

Households with Access to ICT	Region			
	Coast * (%)	Mountains (%)	Jungle (%)	Metropolitan Lima (%)
Telephone (fixed)	31.11	10.97	14.39	55.69
Cellular	80.84	65.97	63.87	85.63
Internet	14.81	6.91	4.41	32.67
Average monthly household expenses (€)				
Telephone (fixed)	10.73	11.98	10.93	14.05
Cellular	8.50	7.19	9.61	10.20
Internet	18.72	18.15	21.06	21.17

Table 8. Households with access to ICT and monthly expense

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[5] The electric power in the coastal and mountain is constant, since almost all comes from conventional electric power. However, in the jungle, mostly the electric power is supplied by hour as it comes from unconventional electric power (generators, photovoltaic systems, etc.).

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The penetration of mobile telephony service in the past 10 years has experienced a significant growth. However, this growth has not been the same in all the three regions. Table 8 shows how the 80.8% of households in the coast has at least one family member owning a cell phone. This percentage is lower in the Mountains and Jungle region, where it reaches the 65.9% and the 63.8%, respectively. In the metropolitan Lima, the 85.6% of households have access to coverage and at least one cell phone.

The Internet access in all of the regions is still very little (coast, 14.8%; mountain, 6.9%, and jungle, 4.4%). In Metropolitan Lima, 32.6% of households have Internet access.

In the second half of Table 8 it is shown the average of expenditures per household for the different services and in all of the regions. The average spent on Internet in the jungle is greater than the one in the coast or the mountains, due to two main factors. First of all, the service is relatively scarce and expensive compared to what is offered in the other regions and second, most of the users have access to Internet through public booths. Regarding the expenditure on fixed telephone per household, it is higher in the Mountains Region. Regarding mobile telephone expenditure, it is higher in the jungle, S/. 33.14. The expenditure on cellular telephony is the biggest in the Jungle Region because it is the service with the greatest demand and use, compared to the demand for fixed telephony. The cell phone is quite appreciated by the users as it is easy to port and allow buying credit according to their affordability. In the Mountain Region, there are significant percentages of fixed phone users and, therefore, users of the Mountain Region distribute their expenses between fixed and mobile phone.

In Metropolitan Lima, the expenditure on all of these services is always higher than the expenses in other regions because the main economic, technological and educational activities are focused there.

2.4.1.4   Social indicators

Regarding to the education level attained by the adult population (older than 18 years) in all the regions of Peru, there is a 26.6% of coast residents that have completed high school, in the forest there is a 20.3% and in the mountains a 18.3%, as it is clear in Table 9. This table also shows that a fifth of the population in the Mountain and Jungle Regions have just completed full primary education. The same thing happens on the coast that barely reaches the 13.5%. In the mountains there is a 12.4% of population lacking basic education and in the coast and mountains in the percentages are around the 6.0%.

	Region			
	Coast *(%)	Mountains (%)	Jungle (%)	Metropolitan Lima (%)
People older than 18 years	71.1	66.4	63.4	74.5
Without level	5.7	12.4	6.5	2.4
Initial Education	0.0	0.0	0.0	0.1
Unfinished Primary School	13.5	20.6	20.3	6.9
Finished Primary School	12.4	13.3	18.1	8.0
Unfinished Secondary School	13.0	10.4	15.1	10.7
Finished Secondary School	26.6	18.3	20.3	32.7
Unfinished Professional Training	4.7	3.7	3.6	7.1
Finished Professional Training	9.7	7.5	7.3	11.8
Unfinished University	6.6	6.4	4.4	8.3
Finished University	7.0	6.4	3.9	9.7
Posgraduate studies	0.8	1.0	0.5	2.3
Total	100.0	100.0	100.0	100.0

Source: Own elaboration based on INEI-ENAHO, 2011
* Metropolitan Lima is not considered in the coastline region.

Table 9. Education attainment

2.4.2 Potential target localities and end users

This section provides some criteria than should be considered when identifying potential target localities for TUCAN3G solutions in Peru.

a) **Geographical environment:** the main factor to evaluate the implementation of TUCAN3G solutions is the geography of the target localities. This becomes very relevant in the Peruvian case, because as it has been explained previously, there is a bid geographical and climatic diversity, influenced by the Andean Chain and the Humboldt Flow.

b) **Electricity infrastructure:** a second factor to evaluate is the presence or lack of electric power infrastructure in the target localities.

c) **Mobile telephony coverage:** the third factor to analyse is the presence or lack of mobile telecommunications service in the target areas. In some places, where there is already experience on access and use of mobile phone, the acceptance of TUCAN3G will be faster. Additionally, investments in those cases will be more profitable for the society and sustainable in a longer term.

Moreover, the socio-economic development will be slower in those localities where there are not mobile telecommunication services yet, at least in the first years of service, due to the lack of skills on the use and management of ICT. This might generate a temporary delay in the socio-economic development of localities without mobile telephony compared to other localities that already have had experience in the use of ICT.

d) **Nearness to urban centres:** and a fourth factor to consider is the existence of the localities that are very close to urban centres. These localities near urban centres might quickly demand TUCAN3G solutions, as most of the population knows and appreciates the access to ICT. Furthermore, the inhabitants of these localities always have the expectation to introduce new and better technology to access information services.

On the other side, acceptance and demand for the TUCAN3G will be lower in those distant locations form urban centres. This happens due to the low level of knowledge that the

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population has about the potentialities that ICT show to improve local socio-economic development. Additionally, population usually has limited financial resources and they are dispersed in the territory.

The following criteria are also proposed during the selection of potential target locations:

- Localities of population less than or equal to 300 inhabitants, with a health centre.
- Localities of population less than or equal to 300 habitants, with a high school.
- Localities of population less than or equal to 300 habitants, considered as a strategic location[6].
- Localities with population over 300 habitants and less than or equal to 3,000 habitants.

As example the analysis of potential localities in the Napo River area is performed below. Considering the criteria previously described, the number of locations identified in the influence area of Napo River, along 2 miles of the riverside, between Pantoja town (District capital of Torres Causana) and Mazan town (District capital of Mazan) are detailed below:

- 97 localities of population less than or equal to 300 habitants.
- 06 localities of population less than or equal to 300 habitants with a health centre.
- 49 localities of population less than or equal to 300 habitants with a school[7].
- 14 localities of population over 300 habitants, and less than or equal to 3,000 habitants.

In this regard, according to the criteria, there would be 69 potential localities where TUCAN3G solutions could be applied. Those localities with population less than or equal to 300 inhabitants and strategic location have not been considered, since there is a lack of information and it will be evaluated after fieldwork (see Figure 9).

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[6] Strategic position due to the existence of mining, resource exploitation sites, proximity to major transportation routes, among others. This information will be obtained during the field work.

[7] The school does not distinguish between primary or secondary level.

Figure 9: Localities identified along the Napo River
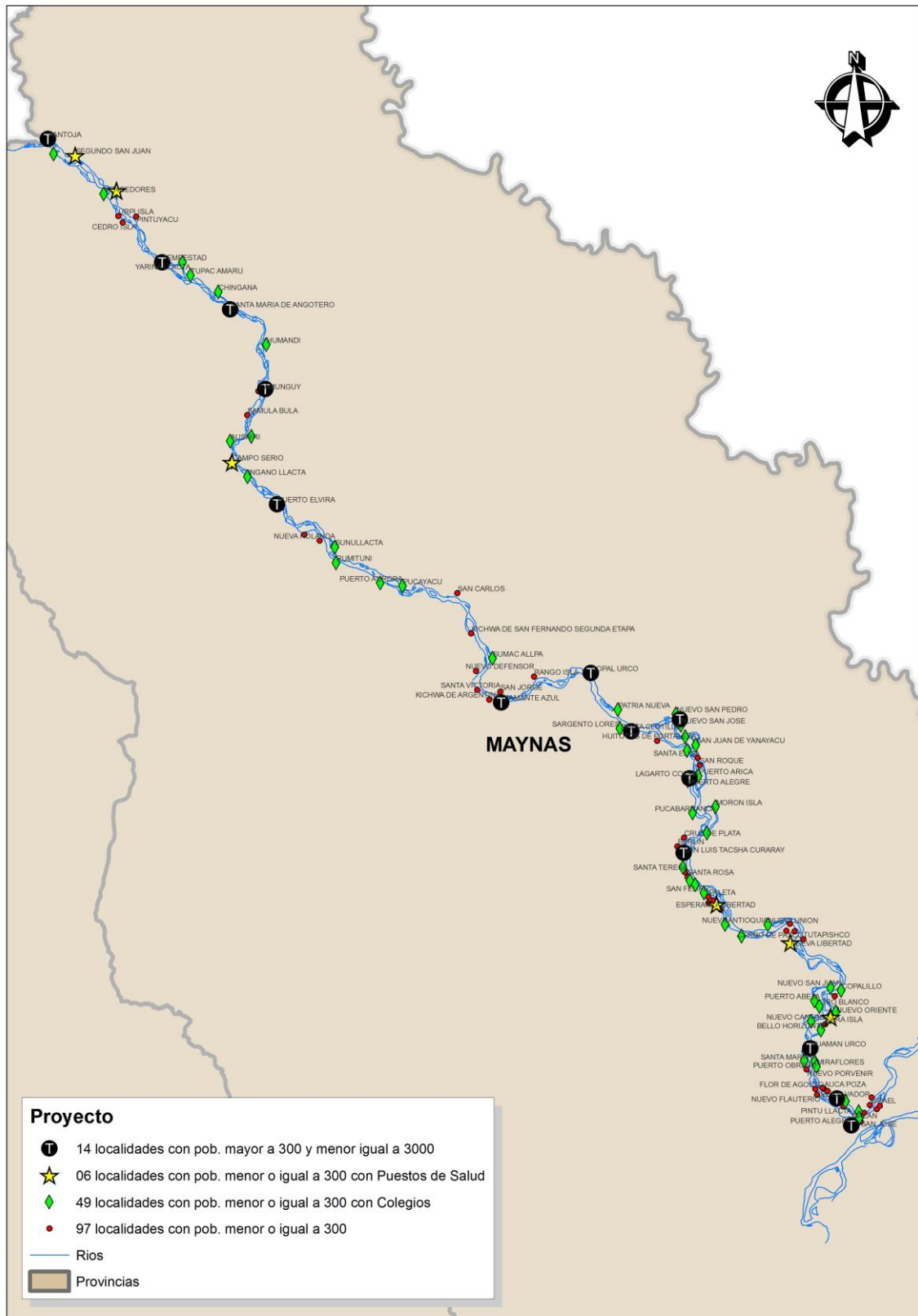
2.4.3 Cellular Telephony and Internet access

The use of ICT services was measured by the INEI in the census of poverty levels published on 2012, with the results shown in Figure 10.
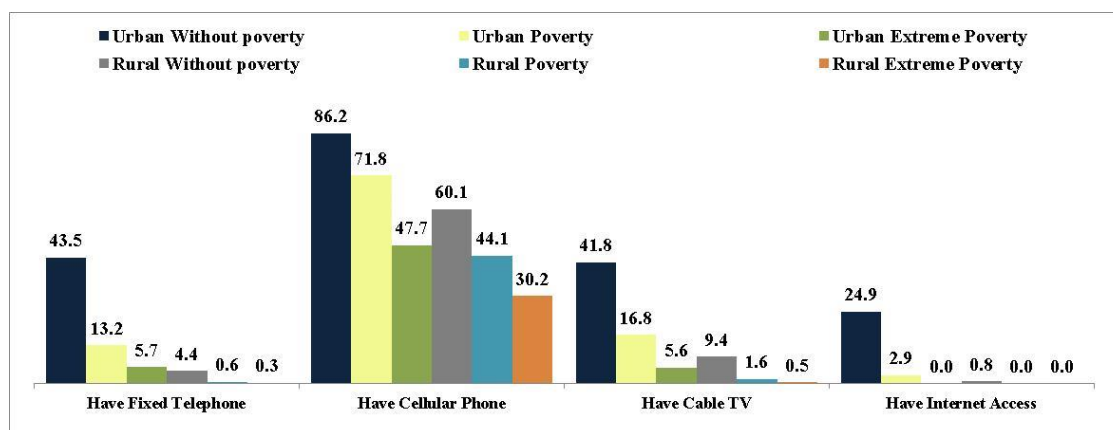
Source: INEI 2011

Figure 10: Households with ICT access by poverty level and area

Access to telecommunication services depends on three main factors: the supply of the service, the demand for the service and the possibility to have the required devices. Offer is related to the service coverage in the emplacement, its price, its sales channels, etc. Table 10 shows the coverage of different telecommunication services in Peru by area of residence (urban, rural) in 2012. The demand for the services is directly related to the poverty levels and the priority or importance of ICT or not ICT goods and services to the families and individuals. The expenses per capita are directly related to the acquisition power and poverty varies widely depending on the different geographical areas, even inside of the same geographic area. On the other hand, the importance given to some services such as mobile telephony, cable TV or Internet varies in an important way. Finally having the devices required to use some services such as Internet (PC, Laptop, Tablet, Smartphone) or Television are also a barrier to access to the service, aggravated by the lack of energy observed in many rural areas.

Service	Urban	Rural
Fixed telephony	86%	0%
Mobile + Fixed wireless telephony	92%	53%
Fixed broadband access to the Internet (ADSL)	82%	0%
Mobile access to Internet 2.5G (EDGE)	92%	48%
Mobile broadband access to Internet (UMTS)	56%	3%
Cable TV	67%	0%
Satellite TV	100%	100%
Public telephony	94%	56%

Table 10: Population living in areas with telecommunications services coverage

Now we briefly analyse the use of telecommunications services in rural areas, particularly regarding to mobile services.

Fixed telephony: Traditional fixed phone networks had its greatest growth in Peru between 1994 and 2002, after the privatization of national telecommunications enterprises. This expansion happened in the main cities of the country. Rural areas did not have access to this service until 2004, when wireless fixed telephony services were launched in the market. This

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service operates as the traditional wiring fixed phone, but uses a GSM signal to access to the telephone network. Currently the minimum cost of this service is 5.87€ per month for 150 local minutes. The cost of the fixed GSM phone device is 20.26€ which is paid only once. As concluded in Figure 10 and Table 10, while more than the 50% of rural population are covered by the fixed service, less than 5% of households have this service, due to the demand rather than supply. Since this population has had access to this service simultaneously with the access to the mobile phone service (as it is wireless fixed telephony) and they had preferred the mobile service to meet their communication needs as we will soon explain.

Mobile phone: Mobile phone networks expanded mainly between 2000 and 2008 and even if they still continue expanding gradually in the rural areas nowadays, the largest investments of mobile operators are focused on the deployment of 3G networks (UMTS) in the urban area and its fringes which are not covered yet. Currently the mobile telephony coverage rate is the one in Table 10, where still a big gap can be appreciated in rural areas. The main reason for operators to not to cover this portion of the rural areas is mainly the great dispersion of population. Figure 11 shows the number of people with and without service mobile telephony coverage by size of population; this chart remarks that most of the population without coverage live in towns of less than 1,000 inhabitants, and mainly in towns of less than 200 inhabitants. Providing mobile service in these places needs the installation of infrastructure that cannot be afforded in most cases by the phone calls flow generated in these places. The Government has somehow boosted the development of mobile service in rural areas with the support of FITEL Fund, granting mobile operators through public tenders, or through responsibilities assumed by these operators as an exchange for acquiring licenses. However, there is still a huge gap to surpass.
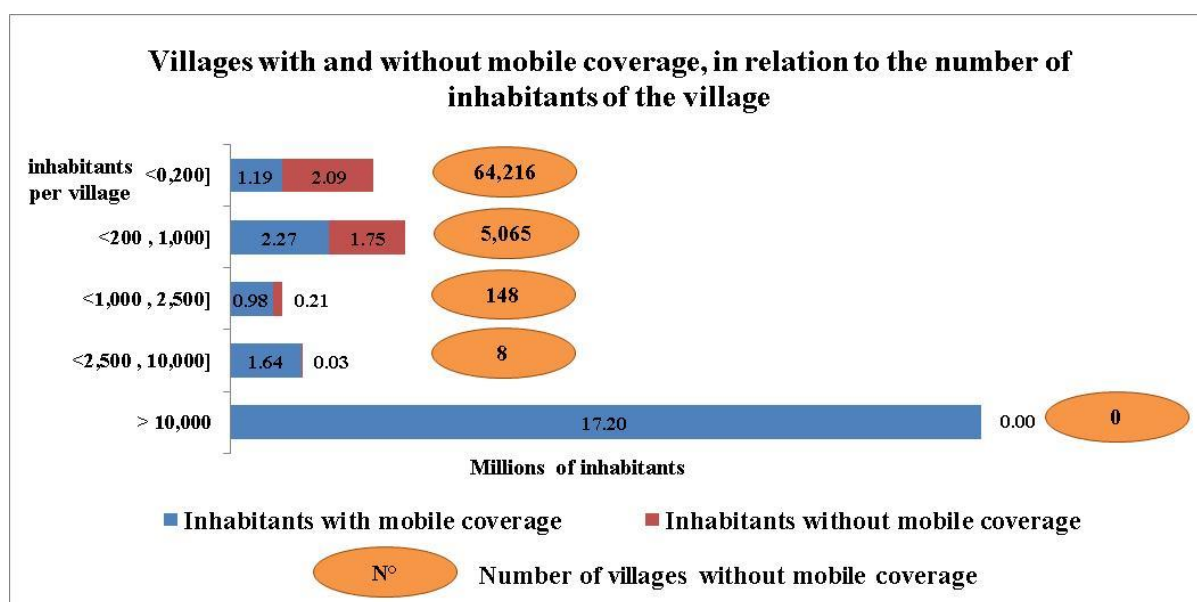
Figure 11: Population with and without coverage according to the number of inhabitants per town (at end of 2011)

Regarding to the mobile phones products that are commercialized in Peru, two types of contracts are remarked; prepaid and post-paid services. In the case of prepaid service, the customer buys a cellular terminal and a SIM card that lets access to the service and when required, a number of minutes can be purchased to talk to different destinations for a limited time, and also can receive calls for another limited time, in this case usually longer. The purchase of minutes is called prepaid credit purchase and can be done in several points of sale, spread across the country. It is estimated that there are more than 200.000 virtual points to

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purchase credit, one in almost in every town. In the case of post-paid service, the customer must sign a contract of at least 6 months duration, committing to pay a fixed monthly fee in exchange of a number of minutes. This contract requires the presentation of identification, residence and income documents. The cost of the prepaid minute is higher than the post-paid minute. Nowadays, with the current promotions the cost of prepaid minutes could be from 0.10€ to 0.15€ (depending on the amount of credit purchased and different promotions), while the cost of post-paid minute is between 0.04€ and 0.05€ depending on the plan or bundle chosen by the client (the more income, the less it will be the cost of a minute) and on the number of plans acquired. According to surveys conducted on different studies, prepaid service is much more preferred in rural areas, being more than 95% terminals on prepaid mode. The success of this plan responds to several reasons. According to customers' survey, the main reasons are: it allows the user to control the expenses (24%), it seems to be the cheapest option (38%) and it is easier to obtain than post-paid (22%). Regarding to what is affordable, the most demanded refills are the ones of 1€ and 3€.

The mobile telephony service has proved that it is the preferred telephony service in rural areas, as reflected in a study conducted by the business school ESAN in more than 300 rural towns, called "Evaluation of the results of FITEL rural projects and baseline for the services continuation supported by OSIPTEL". According to this study, the 93.8% of the population prefer to use mobile telephony service, as shown in Figure 12Figure 12: Phone services preferences (survey on 300 rural communities). The reasons for this preference is also explained in this study through the following results: 64.8% because it is available anywhere, 46.2% because it is easy to use, 19.9% because it is private, 12.1% because incoming calls are free and 6.1% because it offers promotions.
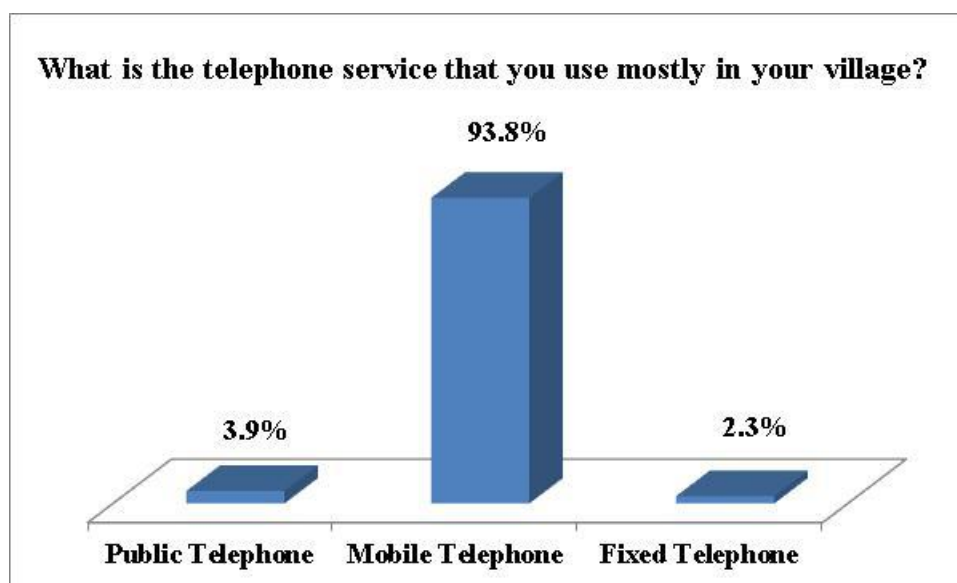
Figure 12: Phone services preferences (survey on 300 rural communities)

Regarding to the mobile telephony consumption in rural areas, similar or slightly bigger indicators than in the urban are observed. The explanation could be that mobile phones are shared at the family level as happens with fixed telephone in rural localities. Table 11 shows some consumption data of mobile telephony in rural areas.

Indicator	Value
Average amount of recharge	2.37€
Frequency of recharges (times per month)	3.7
% of phones that makes a recharge monthly	34%
ARPU	8.75€
Incoming MOU	124.4
Outgoing MOU	113.9

Table 11: Use and Consumption indicators of mobile telephony in rural areas

Mobile service is also considered by the rural population as a main tool of integration and socio-economic development. The book "Communication mobile and economic and social development in Latin America" [Fernández11] contains the results of a deep study conducted in a rural area from the southern mountains chain of Peru, in order to quantify the impact of mobile phone services in the economic development of rural population. The main conclusions of this study are:

- Mobile applications are diverse. The main use of mobile phones is the communication with family and friends, which is important for the family cohesion in the traditional context of seasonal migration of rural population. These calls include not only social reasons but also economic factors, since family and social relations are usually tied to economic relations in these poor areas. The use of mobile phones for economic activities is gradual and structured, identifying several user profiles: large producers, itinerant traders and veterinaries use intensively the mobile for the expansive markets, in order to find out prices and availability of products, and to provide information and advice. Regarding to medium and small sized producers and trades, no intensive use for coordination with economic purposes is observed. Face-to-face relations are still essential in the commercial activity, so fairs are the favourite space for this activities and the cell phone serves just as complement.

- The use of mobile phones is clearly related to the level of users´ welfare, measured by the expenses per capita. The quantified effects on the growth of expenses per capita are 20.7% when the period of the cellular use is less than a year, and 37.7% when the period of use is longer than two years, compared to the expenses per capita of other households where there are no users of this service. Also, an increase of 10% in the probability of being a user of mobile telephony, makes the expenses per capita increase between 5% and 7%, proving the endogenous character that the mobile telephony service has regarding to the economic development, i.e. the use of mobile phones improves the income and this improvement enhance a bigger use of the service.

- There are several elements that make harder an intensive use of mobile phones. Among them, services that are not affordable, lack of skills for the management of the device, and the scarce confidence on suppliers or buyers. In addition, the lack of other services provided via mobile phone, by the Government or other institutions, limit the amount of information that could be accessible.

- Beyond the economic aspect, the use of mobile as a status symbol and as entertainment is enhanced. In the first case, using a device with more features gives children and young people a status of modernity. In the case of veterinaries (generally hired by municipalities to provide assistance and advice), the fact to have phone credit to make calls gives them prestige. Children and young people basically give an leisure and entertainment use, children play with the family device and young people use it mainly to listening to music and as a digital storage. To the young, the communicative function is still restricted due to the lack of own income.

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- The alternative strategies to access to mobile telephony show how important the access to this communication service is.

We can then conclude from this analysis that there is a significant demand for mobile telephony service. Beyond the economic capacity of most of the population to pay for the service, this demand is boosted by the importance given by the rural population to this service as a tool for socio-economic development. The main limitation for a greater access to these services is the lack of coverage (offer) in some rural areas. We end this considerations pointing out another striking evidence of the importance given by the rural population to this service: according to the study by INEI 2011, around a third of rural households in extreme poverty, i.e. households with an income that does not even cover basic food needs, has at least one cell phone, as you can see in Figure 10.

- **Paid Cable Television**, this service started in the year 2000 and since then, it has been commercialised only in big cities, where cable TV operators had the access networks. However, it could be offered nationwide at any part of the country, even in rural areas, due to the satellite television, which started being commercialised in the country in 2006. Nowadays, a satellite television service can be acquired for a fee of 14.40€ per month, with 30 video channels, or 20€ per month with 65 video channels. The paid TV service is a service of entertainment, preferred by rural residents, but the poverty factor is decisive at the time of purchasing a television or paying for the installation of this service. Additionally, a factor that slows the economic growth in rural areas is the lack of electric power for a part of the population.

- **Internet**, Internet service in the country started in 1996, through the fixed telephone network through dial-up access and subsequently, since 2001, via ADSL in towns where there was coverage of fixed-wired networks. However, in rural areas Internet service coverage has not existed until the launch of 2.5G (EDGE) networks, which allowed a limited in speed access to this technology. The Peruvian Government, through the Fund FITEL, supported the development of public Internet booths in rural areas through several projects. One of these is the BAS (broadband for isolated locations) project executed by *Telefonica Peru* in 2009, which included the installation of 1,000 Internet public booths in 1,000 rural localities, using the satellite technology VSAT.

Other initiatives developed by the government in order to encourage the use of Internet in schools is the Huascaran Plan, that seeks the use of ICT in order to modernize the education, and the programme "One Laptop per child" which has equipped more than 3,000 schools with around 25,000 computers that mostly do not have connectivity to the Internet. These projects in rural areas have the level of appropriation and use of Internet as one of the main success factors. It is also observed at the national level, isolated projects of municipal governments, several institutions and local entrepreneurs, develop initiatives in order to extend access to Internet from a city with coverage of this service, up to some place in the rural areas, using wireless networks in bands without licence.

Due to the scarce coverage of mobile broadband services in rural areas, there is no statistical information about use of the service.

2.4.4 Deployed networks

As part of various projects in Peru financed by international cooperation, PUCP and EHAS Foundation have deployed and extended some WiLD networks (in Napo River, Putumayo river

and Balsapuerto district) for public use, mainly oriented to probe and validate telemedicine services.

Putumayo and Napo network were candidates to hold the demonstrative platform of TUCAN3G, but Putumayo will be replaced by Balsapuerto Network for technical reasons.

This section provides a technical description of Napo and Balsapuerto Networks, explaining its location, architecture, technologies and network elements. Information regarding Putumayo network is available in ANNEX I: Putumayo Network description.

2.4.4.1   Napo Network

Between 2006 and 2007, within the framework of the project "Malaria Control in Border Areas of the Andean Region: A Community Approach" (PAMAFRO) managed by the Andean Health Organization - Hipólito Unanue (ORAS-CONHU) and funded by the European Union, EHAS foundation and GTR-PUCP implemented a wireless telecommunication network for providing voice and data services in the Napo River basin. This network provided communication to districts of Torres Causana, Napo and Mazan, in the Loreto Region (Maynas province). It allowed access to telecommunications services to 9 health facilities located in native communities: Cabo Pantoja, Torres Causana, Tempest, Angoteros, Campo Serio, Rumi Tuni, San Rafael, Santa Clotilde and Tacsha Curaray. This implementation was one of the components of the project aimed to reduce malaria and other endemic diseases in the area.

Figure 13. Map of the Napo River.

Later, between 2008 and 2009, funds were obtained from the Municipality of Madrid and the Polytechnic University of Madrid, to enlarge this network. This funding allowed EHAS and GTR-PUCP to include the health establishments from native communities Negro Urco, Tuta

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Pishco, Huaman Urco and Mazán. It also allowed to expanded the network to the Loreto Regional Hospital "Felipe Santiago Arriola Iglesias" (HRL), the Apostolic Vicariate San José del Amazonas (VASJA) and the Regional Health Department of Loreto (Loreto DIRESA) in the city of Iquitos.

Nowadays this network is called Rural Telemedicine Network of the Napo River. Through this network the users are able to access to the Internet, use telephony, data transferand video conferencing using a Spontania local server. These services have improved the quality of health care for rural residents on Napo basin.

The Napo network is a sequential WiFi links network, with links between 25 and 50 kilometers of length, which is implemented through sixteen (16) relay stations, serving 13 rural health facilities. The table below shows the location coordinates of the relay stations:

Nodos NAPO	Coordenadas Geográficas		
	Latitud	Longitud	Altura GPS
Cabo Pantoja	00° 58' 12.8"	75° 10' 30.1"	183 msnm
Torres Causana	01° 06' 15.4"	75° 00' 15.8"	166 msnm
Tempestad	01° 16' 57.7"	74° 53' 02.3"	175 msnm
Tupac Amaru	01° 21' 47.0"	74° 44' 42.0"	158 msnm
Angoteros	01° 34' 06.8"	74° 36' 40.6"	169 msnm
Campo Serio	01° 47' 40.8"	74° 42' 28.6"	174 msnm
Rumi Tuni	02° 03' 14.0"	74° 26' 10.5"	170 msnm
San Rafael	02° 21' 53.8"	74° 06' 44.1"	155 msnm
Copal Urco	02° 20' 52.1"	73° 47' 24.7"	160 msnm
Santa Clotilde	02° 29' 22.4"	73° 40' 40.7"	146 msnm
Tacsha Curaray	02° 48' 47.6"	73° 32' 27.2"	135 msnm
Negro Urco	03° 01' 23.1"	73° 23' 31.5"	131 msnm
Tuta Pishco	03° 06' 31.4"	73° 08' 17.5"	106 msnm
Huamán Urco	03° 19' 07.6"	73° 13' 01.9"	116 msnm
Mazán	03° 29' 59.9"	73° 05' 28.0"	109 msnm
PetroPerú	03° 43' 32.3"	73° 14' 36.2"	105 msnm
HRL	03° 43' 33.8"	73° 15' 12.2"	105 msnm

From Cabo Pantoja to Mazan, the links work in 2.4 GHz (802.11g), and from Mazan to Iquitos, the links work at 5.8 GHz (802.11a) because it is an urban area. Only in one case, the relay station was installed on an existing tower belonging to an external entity (PetroPerú). In Iquitos, the station located in the Regional Hospital provides a link to VSAT, which is an additional client station that provides Internet access to the whole network.

A distribution link towards the health establisment of the community has been implemented on each repeater. The distance does not exceed 300 meters in any case, so the links are designed with low gain antennas.

The network has been implemented in two different stages, and because of this each zone has some different characteristics in relation to telecommunications equipment and dimensioning of power systems and therefore, in the performance. Nevertheless, the general model of telecommunication systems, energy and electrical protection implemented, is uniform and the criteria for the installation have been coherent.

From the administrative point of view, the Santa Clotilde health center directs the micro health network Napo, while the Mazan health center directs the micro health network of the same name. However, the micro network Napo is the most important because 11 of the 13 health facilities belong to it.

Finally, it should be noted that photovoltaic systems have been installed to supply power to all nodes of the network, with the exception of those located in the city of Iquitos.

2.4.4.1.1 Description of the Telecommunication Network

a. Operation

As mentioned, the Napo Network consists of a sequential set of long distance WiFi links, which has its point of access to public telecommunications services in the city of Iquitos, through services that are contracted by DIRESA Loreto. Repeater and clients stations are organized into four major subsystems: telecommunications, energy supply, electrical protection and computer on the client. Furthermore, towers have been installed together with mechanical supports to accommodate such equipment.
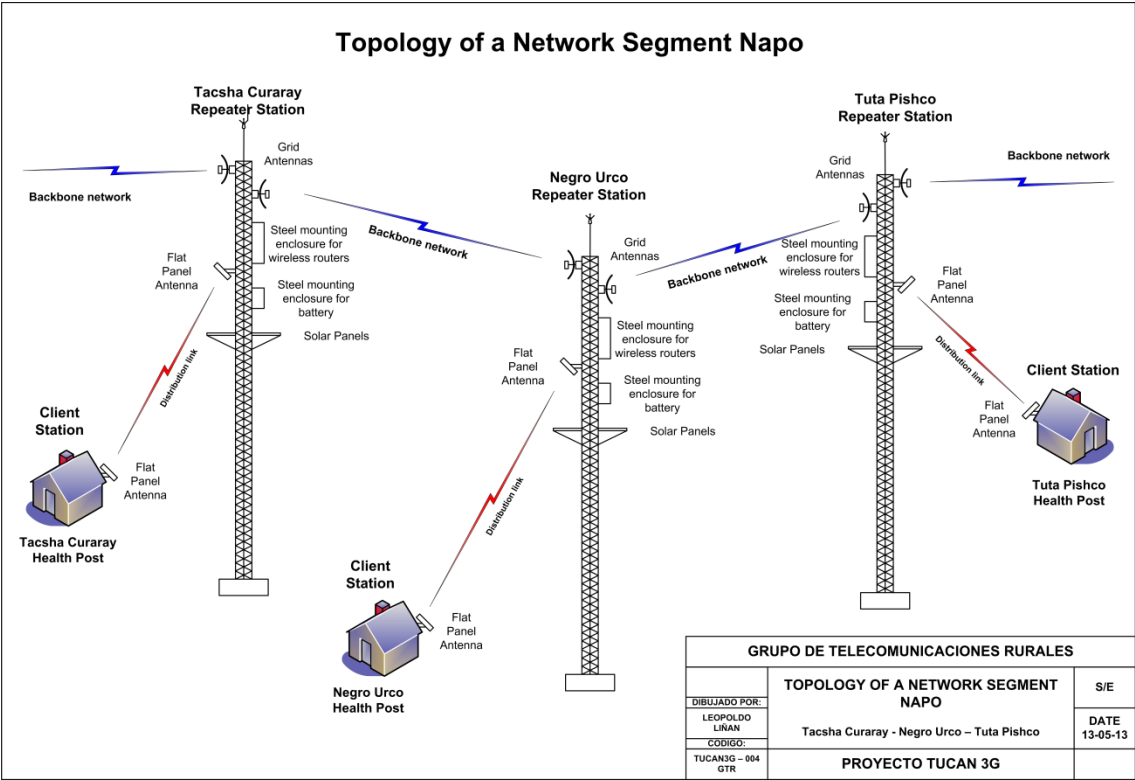
Figure 14. Topology of a segment of the Napo Network.

i.   *Telecommunication system*

As in other systems, in this case there were two basic types of telecommunications systems: one for the repeaters, and one for the customer.

In the initial project WRAP routers were used (based on Soekris 4521 boards) for the backhaul. However, in the second project, ALIX boards have been used, except for 5.8 GHz links using Mikrotik boards. Currently, Santa Clotilde is the separation point between the High-Napo (links to routers WRAP) and Lower Napo (ALIX boards). In a similar way, in almost every High-Napo´s repeaters, SR2 wireless cards are used for the backhaul and CM9 wireless cards for links to health facilities. In the Lower-Napo, also R52H wireless cards are used. Beyond this, the telecommunication systems have the same features across the Network: Two routers called n1 (facing north) and n2 (facing south) responsible for backhauling links and for connecting to the health post. The following diagram shows the typical pattern of a repeater.

Repeater Station Connection Diagram

Grid Antennas

Wireless Router 2

Wireless Router 1

Lightning protectors

Cable-glands

Ethernet crossover cable

Power cable 12Vdc

Solar regulator

Thermomagnetic circuit breaker

Riel

Steel mounting enclosure 80cm x 60cm x 20cm

Coaxial cable

Trunking

Flat panel antenna

Power cable solar panels

Power cable from the battery

GRUPO DE TELECOMUNICACIONES RURALES		
	CONNECTION DIAGRAM	S/E
DIBUJADO POR:		
LEOPOLDO LIÑAN	Repeater Station	FECHA 13-05-13
CODIGO:		
TUCAN3G – 005 GTR	PROYECTO TUCAN 3G	

Figure 15. Diagram of the repeater.

In the client station there is a lower capability router installed (Linksys) with a panel antenna. All links are in the frequency range of 2.4GHz and the typical distribution is a shown in the following figure:

LAN Client Station

Distribution link

Router

Flat Panel Antenna

ATA

Phone

PC Client

Client Station

GRUPO DE TELECOMUNICACIONES RURALES		
	LAN	S/E
DIBUJADO POR:		
LEOPOLDO LIÑAN	Client Station	FECHA 13-05-13
CODIGO:		
TUCAN3G – 006 GTR	PROYECTO TUCAN 3G	
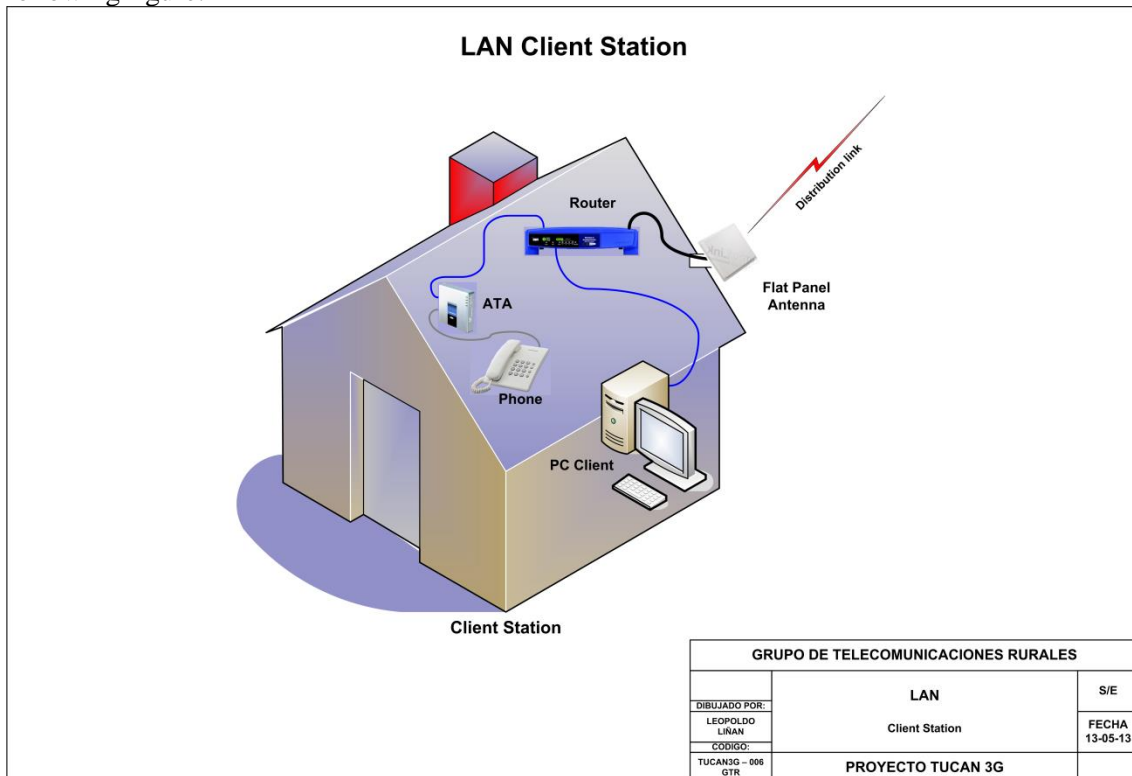
Figure 16. Diagram of the client station.

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Network Topology

We have already mentioned that the Napo Network is a sequence of wireless links covering 445 km in length, which is shown in the following diagram:
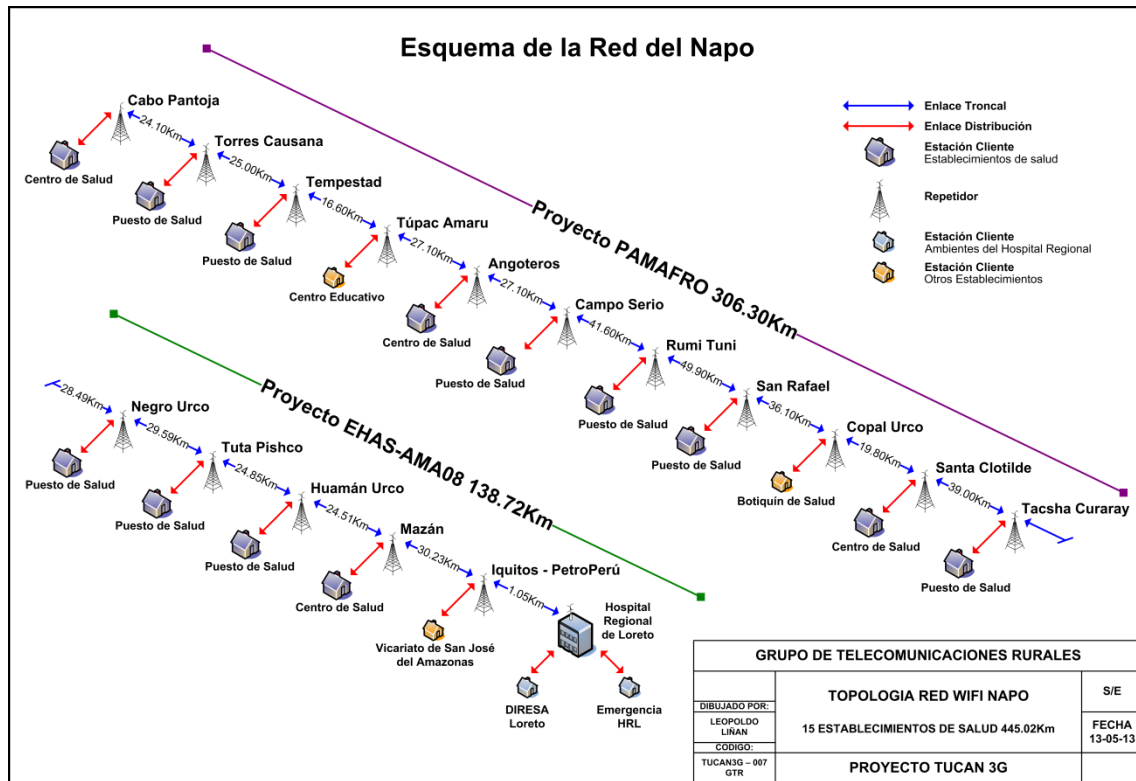
Figure 17. Napo Network scheme.

IP Addressing Plan

IP addresses in the Napo Telemedicine Network were implemented by private IP range Class A 10.0.0.0 / 8. In the design it was decided to use the address range 10.11.X.0/28 for network segments the distribution network, and the range of addresses for Ethernet 10.12.X.0/28 distribution nodes; 10.13.X.0/28 to access links and LANs 10.14.X.0/28 for health centers.

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Nodo	WRAP n1			
	ath0	ath1	eth0	eth1
Cabo Pantoja	10.11.9.2	10.13.10.1 AP	10.12.10.1	---
Torres Causana	10.11.9.1 AP	10.13.9.1 AP	10.12.9.1	---
Tempestad	10.11.8.1 AP	10.13.8.1 AP	10.12.8.1	---
Túpac Amaru	10.11.7.1 AP	10.13.7.1 AP	10.12.7.1	---
Angoteros	10.11.6.1 AP	10.13.6.1 AP	10.12.6.1	---
Campo Serio	10.11.5.1 AP	10.13.5.1 AP	10.12.5.1	---
Rumi Tuni	10.11.4.1 AP	10.13.4.1 AP	10.12.4.1	---
San Rafael	10.11.3.1 AP	10.13.3.1 AP	10.12.3.1	---
Copal Urco	10.11.2.1 AP	10.13.2.1 AP	10.12.2.1	---
Santa Clotilde	10.11.1.1 AP	10.13.1.1 AP	10.12.1.1	---

Table 12. IP Address for board Wrap in n1 interfaces.

Nodo	WRAP n2			
	ath0	ath1	eth0	eth1
Torres Causana	10.11.8.2	---	10.12.9..2	---
Tempestad	10.11.7.2	---	10.12.8..2	---
Túpac Amaru	10.11.6.2	---	10.12.7..2	---
Angoteros	10.11.5.2	---	10.12.6..2	---
Campo Serio	10.11.4.2	---	10.12.5..2	---
Rumi Tuni	10.11.3.2	---	10.12.4..2	---
San Rafael	10.11.2.2	---	10.12.3..2	---
Copal Urco	10.11.1.2	---	10.12.2..2	---

Table 13. IP Address for board Wrap in n2 interfaces.

Nodo	ALIX n1			
	ath0	ath1	eth0	eth1
Tacsha Curaray	10.11.17.1 AP	10.13.17.1 AP	10.12.17.1	---
Negro Urco	10.11.18.1 AP	10.13.18.1 AP	10.12.18.1	---
Tuta Pishco	10.11.19.1 AP	10.13.19.1 AP	10.12.19..1	---
Huamán Urco	10.11.20.1 AP	10.13.20.1 AP	10.12.20.1	---
Mazán	10.11.21.1 AP	---	10.12.21.1	---

Table 14. IP Address for board ALIX in n1 interfaces.

Nodo	ALIX n2			
	ath0	ath1	eth0	eth1
Santa Clotilde	10.11.17.2	---	10.12.1.2	---
Tacsha Curaray	10.11.18.2	---	10.12.17.2	---
Negro Urco	10.11.19.2	---	10.12.18.2	---
Tuta Pishco	10.11.20.2	---	10.12.19..2	---
Huamán Urco	10.11.21.2	---	10.12.20.2	---

Table 15. IP Address for board ALIX in n2 interfaces.

Nodo	MIKROTIK				
	wlan1	wlan2	wlan3	ether1	ether2
Mazán (n2)	10.11.22.2	10.13.21.1 ap	---	10.12.21.2	---
PetroPerú (n1)	10.11.22.1 ap	10.13.22.1 ap	10.11.23.2	10.12.22.1	---
HRL (n1)	10.11.23.1 ap	10.13.23.1 ap	10.13.30.1 ap	10.12.23.1	---

Table 16. IP Address for board Mikrotik´s interfaces.

Cliente	Linksys				
	br0	eth1	vlan1	ATA	PC
Cabo Pantoja	10.14.10.1	10.13.10.2	---	10.14.10.3	DHCP
Torres Causana	10.14.9.1	10.13.9.2	---	10.14.8.3	DHCP
Tempestad	10.14.8.1	10.13.8.2	---	10.14.8.3	DHCP
Túpac Amaru	10.14.7.1	10.13.7.2	---	10.14.7.3	DHCP
Angoteros	10.14.6.1	10.13.6.2	---	10.14.6.3	DHCP
Campo Serio	10.14.5.1	10.13.5.2	---	10.14.5.3	DHCP
Rumi Tuni	10.14.4.1	10.13.4.2	---	10.14.4.3	DHCP
San Rafael	10.14.3.1	10.13.3.2	---	10.14.3.3	DHCP
Copal Urco	10.14.2.1	10.13.2.2	---	10.14.2.3	DHCP
Santa Clotilde (Casita Azul)	10.14.1.1	10.13.1.2	---	10.14.1.3 10.14.1.4 10.14.1.6 10.14.1.7	DHCP
Santa Clotilde (Casita Crema)	10.14.1.65	10.13.1.3	---	10.14.1.67	DHCP
Tacsha Curaray	10.14.17.1	10.13.17.2	---	10.14.17.3	DHCP
Negro Urco	10.14.18.1	10.13.18.2	---	10.14.18.3	DHCP
Tuta Pishco	10.14.19.1	10.13.19.2	---	10.14.19.3	DHCP
Huamán Urco	10.14.20.1	10.13.20.2	---	10.14.20.3	DHCP
Mazán	10.14.21.1	10.13.21.2	---	10.14.21.3	DHCP

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Vicariato	10.14.22.1	10.13.22.2	---	10.14.22.3	DHCP
Emergencia HRL	10.14.23.1	10.13.23.2	---	10.14.23.3	DHCP
Radiofonía DIRESA Loreto	10.14.30.1	10.13.30.2	200.37.75.22 (acceso a Internet)	10.14.30.3	DHCP

Table 17. IP Address for board Mikrotik´s interfaces.

Next diagrams showing both the IP address of the network as specific data for wireless links and IP telephony service:

Esquema de la Red del Alto Napo

Esquema de la Red del Bajo Napo

17 Tacsha Curaray

Wi-Fi
essid: EHAS17
modo: 11g
canal : 6
veloc : 18M max
segur: wep
dista : 39000
anten: grilla 24dBi Hor.
diver : anulada

ALIX 2C0   n1
ath0: 10.11.17.1 / 28 AP SR2
        00:15:6D:53:32:F8
ath1: 10.13.17.1 / 28 AP CM9
        00:0B:6B:56:21:1A
br0 : 10.12.17.1 / 28
        eth0, eth1
ospf id: 0.0.1.17

ALIX 2C0   n2
ath0: 10.11.18.2 / 28 ST SR2
        00:15:6D:54:E2:EE
br0 : 10.12.17.2 / 28
        eth0, eth1
ospf id: 0.0.2.17
Asterisk: 1 cliente

18 Negro Urco

Wi-Fi
essid: EHAS18
modo: 11g
canal : 11
veloc : 18M max
segur: wep
dist : 28500
anten: grilla 24dBi Ver.
diver: anulada

ALIX 2C0   n1
ath0: 10.11.18.1 / 28 AP SR2
        00:15:6D:55:0F:D8
ath1: 10.13.18.1 / 28 AP R52H
        00:0C:42:1F:9B:3C
br0 : 10.12.18.1 / 28
        eth0, eth1
ospf id: 0.0.1.18

ALIX 2C0   n2
ath0: 10.11.19.2 / 28 ST SR2
        00:15:6D:54:E2:EF
br0 : 10.12.18.2 / 28
        eth0, eth1
ospf id: 0.0.2.18
Asterisk: 1 cliente

19 Tuta Pishco

Wi-Fi
essid: EHAS19
modo: 11g
canal : 6
veloc : 18M max
segur: wep
dist : 29770
anten: grilla 24dBi Hor.
diver: anulada

ALIX 2C0   n1
ath0: 10.11.19.1 / 28 AP SR2
        00:15:6D:54:E3:07
ath1: 10.13.19.1 / 28 AP R52H
        00:0C:42:1F:69:0D
br0 : 10.12.19.1 / 28
        eth0, eth1
ospf id: 0.0.1.19

ALIX 2C0   n2
ath0: 10.11.20.2 / 28 ST SR2
        00:15:6D:54:E3:03
br0 : 10.12.19.2 / 28
        eth0, eth1
ospf id: 0.0.2.19
Asterisk: 1 cliente

20 Huamán Urco

Wi-Fi
essid: EHAS18
modo: 11g
canal : 11
veloc : 18M max
segur: wep
dist : 24900
anten: grilla 24dBi Ver.
diver: anulada

ALIX 2C0   n1
ath0: 10.11.20.1 / 28 AP SR2
        00:15:6D:54:E3:02
ath1: 10.13.20.1 / 28 AP R52H
        00:0C:42:1F:81:EB
br0 : 10.12.20.1 / 28
        eth0, eth1
ospf id: 0.0.1.20

ALIX 2C0   n2
ath0: 10.11.21.2 / 28 ST SR2
        00:15:6D:54:81:81
br0 : 10.12.20.2 / 28
        eth0, eth1
ospf id: 0.0.2.20
Asterisk: 1 cliente

39.00Km   **28.50Km**   **29.60Km**   **24.90Km**

72m   75m   57m   66m

Wi-Fi
essid: NAPO17
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO18
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO19
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO20
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

P.S. Tacsha Curaray

IP por dhcp

Tópico 210

ATA GRANDSTREAM HT-502
IP   : 10.14.17.3 / 28
Proto : SIP
Codec: G711u
ID   : 210

LINKSYS WRT54GL
eth1 : 10.13.17.2 / 28
        00:18:39:CF:8E:0B
br0   : 10.14.17.1 / 28
wan   : anulada

P.S. Negro Urco

IP por dhcp

Tópico 440

ATA GRANDSTREAM HT-502
IP   : 10.14.18.3 / 28
Proto : SIP
Codec: G711u
ID   : 440

LINKSYS WRT54GL
eth1 : 10.13.18.2 / 28
        00:21:29:92:6D:C1
br0   : 10.14.18.1 / 28
wan   : anulada

P.S. Tuta Pishco

IP por dhcp

Tópico 430

ATA GRANDSTREAM HT-502
IP   : 10.14.19.3 / 28
Proto : SIP
Codec: G711u
ID   : 430

LINKSYS WRT54GL
eth1 : 10.13.19.2 / 28
        00:21:29:92:64:B8
br0   : 10.14.19.1 / 28
wan   : anulada

P.S. Huamán Urco

IP por dhcp

Tópico 420

ATA GRANDSTREAM HT-502
IP   : 10.14.20.3 / 28
Proto : SIP
Codec: G711u
ID   : 420

LINKSYS WRT54GL
eth1 : 10.13.20.2 / 28
        00:21:29:92:48:08
br0   : 10.14.20.1 / 28
wan   : anulada

21 Mazán

Wi-Fi
essid: EHAS21
modo: 11g
canal : 6
veloc : 18M max
segur: wep
dist : 24240
anten : grilla 24dBi Hor.
diver : anulada

ALIX 2C0   n1
ath0: 10.11.21.1 / 28 AP R52H
        00:0C:42:18:A2:EA
br0 : 10.12.21.1 / 28
        eth0, eth1
ospf id: 0.0.1.21

22 Petro Perú

MIKROTIK 333   n2
wlan1: 10.11.22.2 / 28 ST R52H
        00:0C:42:1F:74:17
wlan2: 10.13.21.1 / 28 AP R52H
        00:0C:42:1F:83:CD
br0 : 10.12.21.2 / 28
        ether1, ether2, ether3

MIKROTIK 333   n1
wlan1: 10.11.22.1 / 28 AP R52H
        00:0C:42:1F:81:F7
wlan2: 10.13.22.1 / 28 AP R52H
        00:0C:42:1F:9B:2E
wlan3: 10.11.23.2 / 28 ST R52H
        00:0C:42:1F:6B:DF
br0 : 10.12.22.1 / 28
        ether1, ether2, ether3
ospf id: 0.0.1.22

Wi-Fi
essid: EHAS22
modo: 11a
canal : 165
veloc : 18M max
segur: wpa2-psk
nstreme: no
anten : grilla 27dBi Ver.
diver : anulada
ospf id: 0.0.2.21

23 Hospital Regional

MIKROTIK 333   n1
wlan1: 10.11.23.1 / 28 AP R52H
        00:0C:42:1F:9B:5E
wlan2: 10.13.23.1 / 28 AP R52H
        00:0C:42:1F:7A:88
wlan3: 10.13.30.1 / 28 AP R52H
        00:0C:42:1F:9B:69
ether1: 200.10.84.221 / 28
br0 : 10.12.23.1 / 28
        ether2, ether3
ospf id: 0.0.1.23

Wi-Fi
essid: EHAS23
modo: 11a
canal : 157
veloc : 18M max
segur: wpa2-psk
nstreme: no
anten : grilla 27dBi Ver.
diver : anulada

24.60Km   **30.30Km**   **29.60Km**

69m   36m

Wi-Fi
essid: NAPO21
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO22
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO23
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Wi-Fi
essid: NAPO30
modo: 11g
canal: 6
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver: anulada

Internet

Red GOREL

Oficina de Servidores
Router Telefónica
Switch

C.S. Mazán

IP por dhcp

Tópico 410
Cómputo 411

ATA GRANDSTREAM HT-502
IP   : 10.14.21.3 / 28
Proto : SIP
Codec: G711u
ID   : 410, 411

LINKSYS WRT54GL
eth1 : 10.13.21.2 / 28
        00:1E:E5:76:08:03
br0   : 10.14.21.1 / 28
wan   : anulada

Vicariato

IP por dhcp

Dirección 510
Proveduría 511

ATA GRANDSTREAM HT-502
IP   : 10.14.22.3 / 28
Proto : SIP
Codec: G711u
ID   : 510, 511

LINKSYS WRT54GL
eth1 : 10.13.22.1 / 28
        00:21:29:92:64:52
br0   : 10.14.22.1 / 28
wan   : anulada

512 Farmacia

ATA LINKSYS SPA3102
IP   : 10.14.22.4 / 28
Proto : SIP
Codec: G711u
ID   : 512
        21 – Servidor IQT
        065-251209

Vigilancia 513
Cómputo 514

ATA GRANDSTREAM HT-502
IP   : 10.14.22.5 / 28
Proto : SIP
Codec: G711u
ID   : 513, 514

Emergencia HRL

IP por dhcp

Tópico 520
Jefatura 521

ATA SPA2102
IP   : 10.14.23.3 / 28
Proto : SIP
Codec: G711u
ID   : 520, 521

LINKSYS WRT54GL
eth1 : 10.13.23.2 / 28
        00:21:29:92:64:E8
br0   : 10.14.23.1 / 28
wan   : anulada

Red LAN del HRL

DIRESA Loreto

IP por dhcp

Radiofonía 530

ATA GRANDSTREAM HT-502
IP   : 10.14.30.3 / 28
Proto : SIP
Codec: G711u
ID   : 530

ATA LINKSYS SPA3102
IP   : 10.14.30.4 / 28
Proto : SIP
Codec: G711u
ID   : 11 – Servidor IQT
        065-251459

LINKSYS WRT54GL
eth1 : 10.13.30.2 / 28
        00:21:29:92:48:1D
br0   : 10.14.30.1 / 28
wan   : 200.37.75.22

Think Centre M71e - Servidor IQT
eth0 : 10.14.30.2 / 28
eth1 : 200.37.75.26

SWITCH D-Link DES-2108

Internet

GRUPO DE TELECOMUNICACIONES RURALES		
DIBUJADO POR:	ESQUEMA DE LA RED DEL BAJO NAPO	S/E
LEO LIÑAN RIVER QUISPE	6 ESTABLECIMIENTOS DE SALUD	FECHA 13-05-13
CODIGO:		
TUCAN3G – 002 GTR	PROYECTO TUCAN 3G	

Esquema de la Red del Napo – Estaciones Santa Clotilde y Hospital Regional de Loreto

1 Santa Clotilde

Wi-Fi
essid: EHAS1
modo: 11g
canal : 11
veloc : 18M max
segur: wep
dist : 20000
anten: grilla 24dBi Ver.
diver: anulada

WRAP 1E   n1
ath0: 10.11.1.1 / 28 AP SR2
00:15:6D:10:10:8A
ath1: 10.13.1.1 / 28 AP CM9
00:0B:6B:56:22:DC
br0 : 10.12.1.1 / 28
eth0, eth1
ospf id: 0.0.1.1

ALIX 2C2   n2
ath0: 10.11.17.2 / 28 ST SR2
00:15:6D:51:0F:47
br0 : 10.12.1.2 / 28
eth0, eth1
ospf id: 0.0.2.1
Asterisk: 9 clientes

Wi-Fi
essid: EHAS17
modo: 11g
canal : 6
veloc : 18M max
segur: wep
dist : 39000
anten : grilla 24dBi Hor.
diver: anulada

Copal Urco   ◄——— 19.80Km ———►

Tacsha Curaray   ◄——— 39.00Km ———►

Wi-Fi
essid: NAPO1
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver : anulada

Wi-Fi
essid: NAPO1
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver : anulada

Red WiFi CSSC

Casita Azul

Servidor SIS
eth1 : 10.14.1.2 / 26

Administración
IP por dhcp

Secretaria
IP por dhcp

Biología
IP por dhcp

INDECI
IP por dhcp

Digitación SIS
IP por dhcp

Switch

72m

Farmacia
IP por dhcp

RCR SIS
IP por dhcp

Consultorio Médico
IP por dhcp

Casita Crema

IP por dhcp

Casita Azul 220

Tópico 221

ATA GRANDSTREAM HT-502
IP   : 10.14.1.3 / 26
Proto : SIP
Codec: G711u
ID   : 220, 221

LINKSYS WRT54GL
eth1 : 10.13.1.2 / 28
00:18:39:CF:8E:23
br0   : 10.14.1.1 / 26

LINKSYS WRT54GL
br0   : 10.14.1.5 / 26
wlan : 192.168.5.1 / 24

LINKSYS WRT54GL
eth1 : 10.13.1.3 / 28
00:18:39:CF:9C:40
br0 : 10.14.1.65 / 26
wan : anulada

Casa Crema 225

ATA GRANDSTREAM HT-502
IP   : 10.14.1.67 / 26
Proto : SIP
Codec: G711u
ID   : 225

Afiliaciones SIS
eth1 : 10.14.1.8 / 26

Programas
IP por dhcp

Cómputo 222

Casa misión 223

ATA GRANDSTREAM HT-502
IP   : 10.14.1.4 / 26
Proto : SIP
Codec: G711u
ID   : 222, 223

ATA GRANDSTREAM HT-502
IP   : 10.14.1.6 / 26
Proto : SIP
Codec: G711u
ID   : 224, 229

Laboratorio 224

Consultorio 229 Médico

ATA GRANDSTREAM HT-502
IP   : 10.14.1.7 / 26
Proto : SIP
Codec: G711u
ID   : 226, 228

Farmacia 226

Programas 228

23 Hospital Regional

MIKROTIK 333   n1
wlan1: 10.11.23.1 / 28 AP R52H
00:0C:42:1F:9B:5E
wlan2: 10.13.23.1 / 28 AP R52H
00:0C:42:1F:7A:88
wlan3: 10.13.30.1 / 28 AP R52H
00:0C:42:1F:9B:69
ether1: 200.10.84.221 / 28
br0 : 10.12.23.1 / 28
ether2, ether3
ospf id: 0.0.1.23

Wi-Fi
essid: EHAS23
modo: 11a
canal : 157
veloc : 18M max
segur: wpa2-psk
nstreme: no
anten : grilla 27dBi Ver.
diver : anulada

PetroPerú   ◄——— 1.05Km ———►

Internet 2M

Red GOREL

Wi-Fi
essid: NAPO30
modo: 11g
canal: 6
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver : anulada

Oficina de Servidores
Router Telefónica

Switch

DIRESA Loreto

Wi-Fi
essid: NAPO23
modo: 11g
canal: 1
veloc: 9M max
segur: wpa-psk
anten: panel 14dBi Ver.
diver : anulada

Emergencia HRL

HRL - Pediatría

Think Centre M71e - Spontania
eth0 : 200.10.84.219 / 28

IP por dhcp

Radiofonía 530

LINKSYS WRT54GL
eth1 : 10.13.30.2 / 28
00:21:29:92:48:1D
br0 : 10.14.30.1 / 28
wan : 200.37.75.22

IP por dhcp

LINKSYS WRT54GL
eth1 : 10.13.23.2 / 28
00:21:29:92:64:E8
br0 : 10.14.23.1 / 28
wan : anulada

ATA GRANDSTREAM HT-502
IP   : 10.14.30.3 / 28
Proto : SIP
Codec: G711u
ID   : 530

Think Centre M71e - Servidor IQT
eth0 : 10.14.30.7 / 28
eth1 : 200.37.75.26

Tópico 520

Jefatura 521

Switch

Router Telefónica

ATA SPA2102
IP   : 10.14.23.3 / 28
Proto : SIP
Codec: G711u
ID   : 520, 521

ATA LINKSYS SPA3102
IP   : 10.14.30.4 / 28
Proto : SIP
Codec: G711u
ID   : 11 – Servidor IQT
065-251459

SWITCH D-Link DES-2108

Internet

Jefatura Pediatría 522

Gineco-obstetricia 523

Internet 512k

ATA SPA2102
IP   : 10.12.23.3 / 28
Proto : SIP
Codec: G711u
ID   : 522, 523

Jefatura Pediatría
IP : 10.12.23.7 / 28

Gineco-obstetricia
IP : 10.12.23.8 / 28

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GRUPO DE TELECOMUNICACIONES RURALES		
DIBUJADO POR:	ESQUEMA DE LA RED DEL NAPO	S/E
LEO LIÑAN RIVER QUISPE	ESTACIONES SANTA CLOTILDE Y HRL	FECHA 13-05-13
CODIGO:		
TUCAN3G – 003 GTR	PROYECTO TUCAN 3G	

ii.   *Energy System*

There are two power supplies that feed the Rural Telemedicine Network Napo. In the city of Iquitos all nodes belonging to both the backbone and client stations are powered by the electric utility network of regional electricity company Electro Oriente SA In the case of nodes located in the basin of the Napo, from Mazan to Cabo Pantoja, they have photovoltaic power systems.

Energy backhaul repeater

The photovoltaic power system for WiFi equipment on the backbone´s nodes comprises:

- 02 solar panels 85Wp (from Mazán to Tacsha Curaray).
- 02 Solar Panels 75WP (from Santa Clotilde to Cabo Pantoja).
- 01 Batería12V 130Ah.
- 01 Solar Regulator 20A.
- 01 Set of terminal blocks.
- 03 Keys thermomagnetic 12Vdc.

The system is designed with an up time of 2 days and is operational 24 hours a day.

Energy on client station

The photovoltaic power system for the client stations comprises:

- 03 solar panels 85Wp (Mazán - Black Urco).
- 03 Solar Panels 75WP (Santa Clotilde - Cabo Pantoja).
- 01 Solar Panel 75WP (Copal Urco and Tupac Amaru).
- 02 Battery 12V 130Ah.
- 01 Solar Regulator 30A.
- 01 Set of terminal blocks.
- 03 Keys thermomagnetic 12Vdc.

The system is designed with an up time of 2.5 days and is operational 24 hours a day.
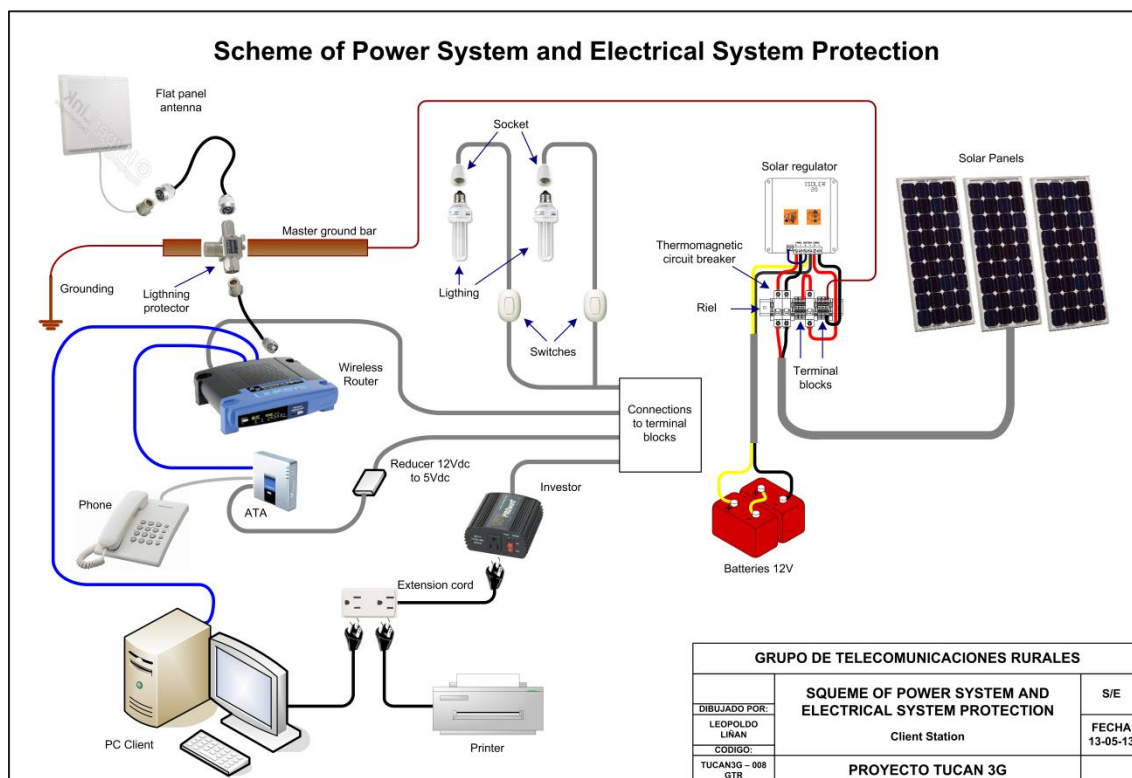
Figure 18. Scheme of the power system.

iii. *Electrical protection system*

Electrical protection systems are implemented to send electronic shocks, environmental (lightning) or accidental (shorts on computers) to the earthing systems and thus prevent damage of the telecommunication equipment. The system described is implemented in the towers and in the client stations.

Lightning protection system

This system is installed at the top of each braced tower and is comprised of:

- 01Franklin Lightning.
- 01 ceramic insulator.
- 01 metal support.
- 01 drop cable bare copper diameter 50mm ^{2}.

Grounding system

In Napo Network have been used Franklin lightning rods located on a mast or on top of the towers. The lightning rod is connected to the grounding system of ground through bare copper wire. To implement grounding systems were built horizontal wells and within them is installed a copper strip which is soldered exothermically with cables coming from the ground bar of telecommunications systems and computer. The well is covered with a mixture of farmland, salt and bentonite.

In the case of client workstations, these feature a 10 m horizontal well length. The bar is connected to the customer master station via a copper wire soldered to the copper strip using exothermic welding.

In both cases conductivity levels were lower than 10Ω resistance.

Lightning arrestors

Line Protectors are installed 2.4GHz and 5.8GHz between the antennas and routers to protect eddy current equipment. These surge protectors are connected to PAT systems.
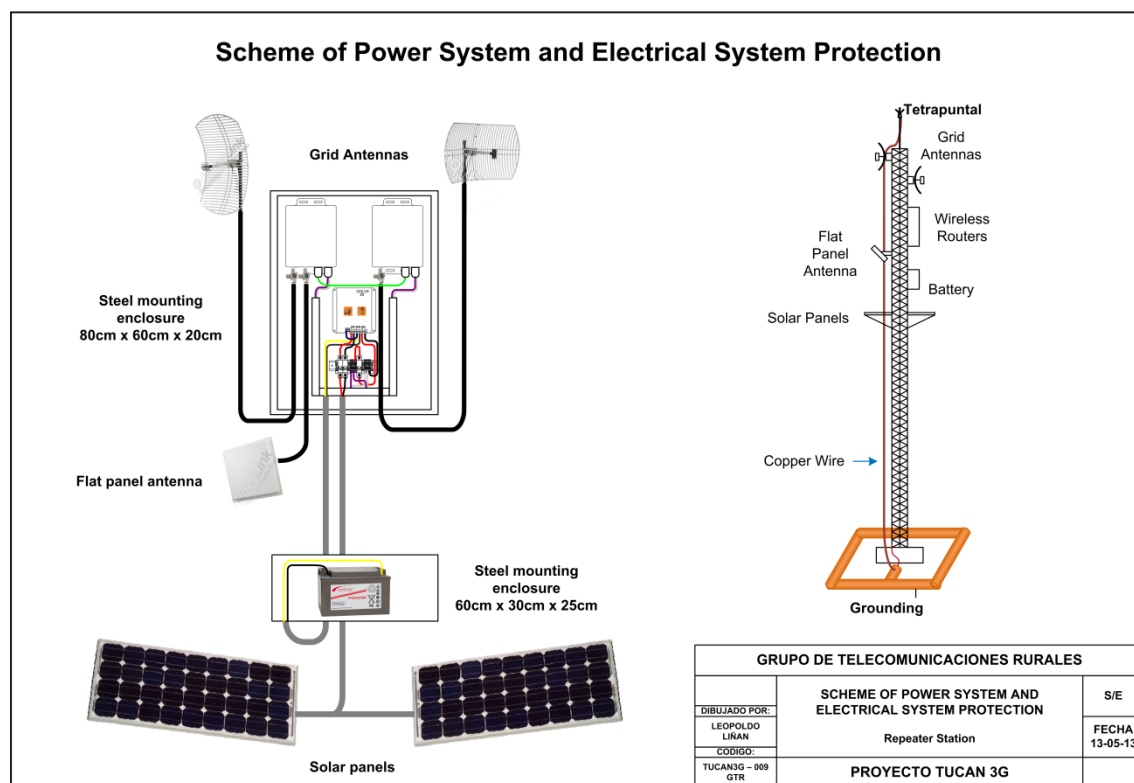
Figure 19. Power and electrical protection systems.

iv.   Services of the Network

Services deployed initially in the Napo Rural Telemedicine Network were Internet access and IP telephony in each health facility. In the last few years, some telemedicine services have been implemented in the network as a pilot project.

Internet Access

The Internet access service is provided by the DIRESA Loreto, sharing the dedicated line that has contracted to Telefonica del Peru (2 Mbps) among its headquarters in Iquitos and Napo Network. Additionally, the Loreto Regional Hospital has hired a service of Internet access through 512 Kbps leased line, shared with Napo Network exclusively for video conferences with Lima.

IP Telephony

The service allows communication between health centers, health post and the Hospital at Iquitos with no cost. Additionally, it allows communication with the Public Switching Telephone Network (PSTN). Asterisk has been used as IP telephony solution and have been installed a main server at the

headquarters of the DIRESA in Iquitos, and also local servers in each repeater. Below is the numbering plan for health center or health posts:

Health Post o Health Center	Annex
Emergency Room Hospital Regional de Iquitos	520
Emergency Hospital Regional de Iquitos – Directorate	521
Radiofonía DISA Loreto	530
Vicariate San José del Amazonas – Directorate	510
Vicariate San José del Amazonas – Procurement office	511
Vicariate San José del Amazonas – Pharmacy	512
Vicariate San José del Amazonas – Computing room	514
C.S. Mazán – Medical consulting room	410
C.S. Mazán – Computing room	411
P.S. Huamán Urco	420
P.S. Tuta Pishco	430
P.S. Negro Urco	440
P.S. Negro Urco – Medical residence	441
P.S. Tacsha Curaray	210
C.S. Santa Clotilde – "Casita Azul"	220
C.S. Santa Clotilde - Medical consulting room	221
C.S. Santa Clotilde - Computing room	222
C.S. Santa Clotilde - Laboratory	224
C.S. Santa Clotilde –" Casita Verde"	225
C.S. Santa Clotilde – Pharmacy	226
Copal Urco - Firt Aid Cabinet	230
P.S. San Rafael	240
P.S. Rumi Tuni	250
P.S. Campo Serio	260
C.S. Angoteros	350

Túpac Amaru – School	340
P.S. Tempestad	330
P.S. Torres Causana	320
C.S. Cabo Pantoja – Computing room	310
C.S. Cabo Pantoja – Medical consulting room	311

Table 18. Dialling Plan for Napo Network.

Telemedicine services

Since the beginning of 2010 a videoconferencing service has been implemented for the development of inter-consultation between health posts and health centers using Spontania software.

Between the years 2012 and 2013 some tele-diagnostic support services have been implemented as pilot applications: tele-ultrasound, tele-microscopy and tele- stethoscopy.
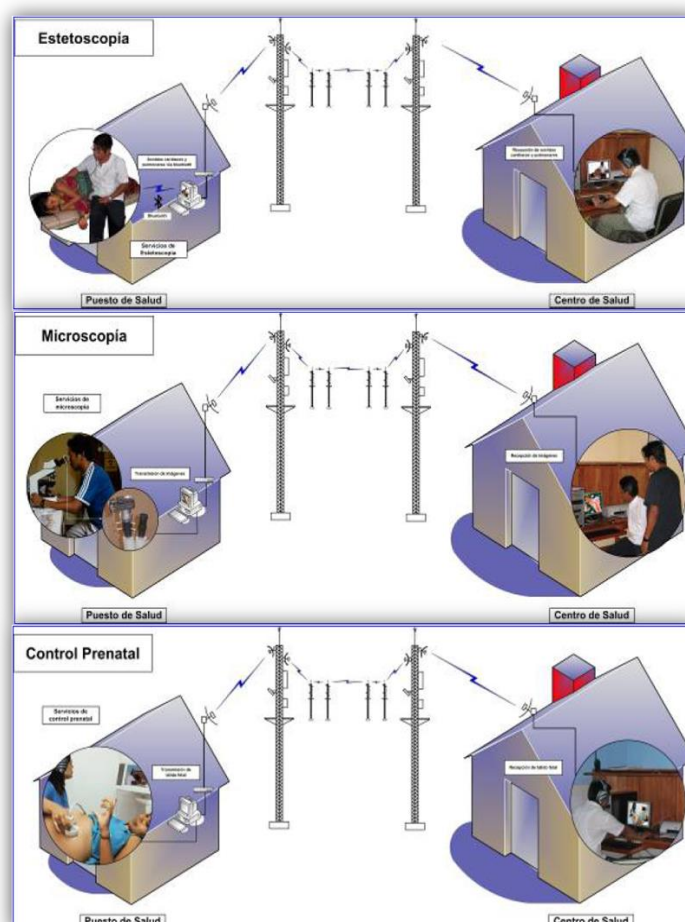
Figure 20. Telemedicine service in Napo Network

2.4.4.1.2 Technical characteristics

i. *Telecommunication equipment*

Equipment	Manufacturer	Model	Characteristics
802.11b/g Interface	Ubiquiti Networks	SR2 Super Range 2	Interface 2.4GHz 802.11b/g mini-PCI Chipset Atheros AR5213 MAC/BB Tx power of 24dBm, +/-1dB for a bit rate of 1-24 Mbps Sensibility for a bit rate of 5.5Mbps of -95dBm, (in 802.11b standard) Current Consumption @3.3V Transmission: 1-24 Mbps 1300mA, +/-100mA Reception: 350mA, +/-50mA
Antenna	Hyperlink Technologies	HG2424G	Directional Antenna 2.4GHz Band ISM 24dBi Weight: 3.62Kgs
Bajo Napo Routers	PC Engines	ALIX 2C0	233 MHz AMD Geode SC1100 CPU 128 MB SDRAM Storage via compact Flash Consumes around 3 to 5W with 12V DC 2 Ethernet Port 2 miniPCI Ports Operative System: Pebble Linux, Voyage Linux, AstLinux, AspisOS, iMedia Wrap Linux, etc. The operative system installed is **Voyage-GTR-0.4**
Alto Napo routers	PC Engines	WRAP 1E-2	233 MHz AMD Geode SC1100 CPU 128 MB SDRAM Storage: CompactFlash card (not included) Power: DC jack or passive POE, min. 7V to max. 20V Expansion: 2 miniPCI slots, LPC bus, I2C bus Connectivity: 2 Ethernet channels (National DP83816) Board size: 152.4 x 152.4 mm / 6" x 6"
Coaxial cables		Heliax SuperFlex	Characteristic Impedance : 50 Ω Loss per meter : 0.1 dB Connectors used : N macho
Pigtail	Hyperlink		An extreme of the connector: UFL (Compatible with Hirose/iPax/Mini-PCI). Other extreme of the connector: N female Length: 20cm Frequency of work: 2.4GHz – 6GHz. Attenuation: 5.38dB/meter in 6GHz

Table 19. 802.11b/g Equipment of the backhaul.

Equipment	Manufacturer	Model	Characteristics
802.11a Interface	Mikrotik	R52H	Interface 5.8GHz 802.11a/b/g mini-PCI Chipset Real transmission power 24dBm Sensibility -90dBm @ 6Mbps
Antenna	Hyperlink Technologies	HG5827G	Directional Antenna type grid 5.8GHz Band ISM 27dBi Weight: 2.4Kgs
Routers	Mikrotik	RouterBoard 333	333MHz CPU 64MB SDRAM It consumes 19W with 12V DC 3 Ethernet Ports 3 miniPCI Ports Operative System: RouterOS 3.20 License level 4
Coaxial cables		Heliax SuperFlex	Characteristic Impedance : 50 Ω Loss per meter : 0.1dB Connectors used : N macho
Pigtail	Hyperlink		An extreme of the connector: UFL (Compatible with Hirose/iPax/Mini-PCI). Other extreme of the connector: N female Length: 20cm Frequency of work: 2.4GHz – 6GHz. Attenuation: 5.38dB/meter in 6GHz

Table 20. 802.11ª Equipment of the backhaul.

Equipment	Manufacturer	Model	Characteristics
Wireless Interface	Mikrotik	R52H	Interface 2.4GHz 802.11a/b/g mini-PCI Maximum output power of the g standard: 25dBm
Antennas	Hyperlink Technologies	HG2414P-NF	2.4 GHz Band ISM IEEE 802.11b, 802.11g Wireless LAN Panel Antenna Yagi 14dBi
Routers	Linksys	WRT54GL	Router, with 5 ports Ethernet, 1 Internet port and access point Wireless-G (802.11g) to 54 Mbps Operative System: OpenWRT

Table 21. 802.11g Equipment of the distribution link.

Equipment	Manufacturer	Model	Characteristics
Solar regulator	STECA	Solarix PRS 2020, Solarix PRS3030	Voltage 12 V (24 V) Power consumption <4 mA Open circuit voltage for solar module: < 47 V Battery voltage: 9 V … 17 V Module current: 10 A / 15 A / 20 A / 30 A
Solar Panel	ISOFOTON	IS-75, IS-85	**Electrical Characteristics:** STC Power Rating Pmp (W) 75 Open Circuit Voltage Voc (V) 21.6 Short Circuit Current Isc (A) 4.67 Voltage at Maximim Power Vmp (V) 17.3 Current at Maximim Power Imp (A) 4.34 Panel Efficiency 11.2% Fill Factor 74.4% Power Tolerance -5.00% ~ 5.00% Maximum System Voltage Vmax (V) 760 **Mechanical Characteristics:** Cell Type Monocrystalline Cell Cells 36 Dimensions $1224.0 \times 545.0 \times 39.5$mm ($21.5 \times 48.2 \times 1.6$ inch) Weight 9.0Kg (19.8 lbs) Plug Connector (Type, Safety) Dose andere Frame Material Aluminium
Battery	RITAR	DG12-130	Cell per unit: 6 Voltage per unit: 12 Capacity: 104Ah@10hr-rate to 1.80 V per cell @ 25°C Max. Discharge current: 1200 A (5 sec.)
AC–DC Converter	Schneider	Xantrex XPower 300 – 12Vd – 220Vac	Output power: 300 W Output voltage: 230 VAC+/- 5% Output frecuency: 50 +/- 3 Hz Output waverform: Modified sine wave No load current draw: < 0.2 A Input voltage range: 10 – 15 V

Table 22. Description of power supply equipment.

iii.	*Infrastructure*

Certificates Cabinets

The cabinets are used to house telecommunications and energy equipment, and so electrical and data connections are made within them. Cabinets are used with IP66 certificate and were connected to the grounding bar. The following pictures show how the cabinets are installed on the nodes and client stations.

Figure 21. Cabinets on the tower and client station

Mechanical supports

Mechanical supports are implemented for photovoltaic panels and antennas. Mechanical parts are made of galvanized steel.

Figure 22. Mechanical support for solar panels.

Telecommunications Towers

Some metallic towers have been installed to locate antennas, telecommunications equipment and interconnect the health centers or health posts with WiLD networks.

The towers are made up of sections of 3 meters each, fastened by steel cables, with anti-rotation triangles and concrete bases. The tower and its accessories are galvanized and painted in red and white. In each tower is installed a lifeline for jobs safely. Additionally, in each WiLD network tower is installed low power consumption beaconing system.

In this network implements two types of towers:

- 60 meters tower system: The characteristics of this type are applicable to towers between 45 to 66 meters. Reticulated structural tower with triangular section, consisting of φ1 ½" SCH40 pipe (48.3 mm outer diameter).

- 90 meters tower system: The characteristics of this type are applicable to towers between 72 to 92 meters Reticulated structural Tower triangular section, consisting of φ2" SCH40 pipe (60.3 mm outside diameter).
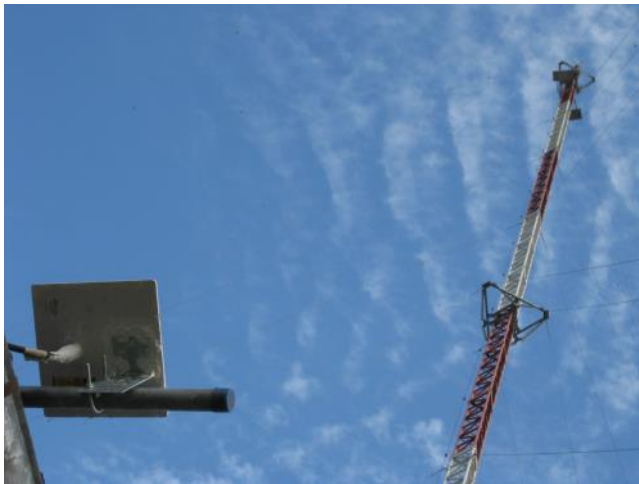
San Rafael

Mazan

The following table shows the heights of the towers installed in Napo Network:

Health center or health post	Tower type 90 m	Tower type 60m
CS Mazan		69 m.
PS Huaman Urco		66 m.
PS Tuta Pishco		57 m.
PS Negro Urco		75 m.
PS Tacsha Curaray	72 m.	
CS Santa Clotilde	72 m.	
Copal Urco		54 m.
P.S. San Rafael	90 m.	
P.S. Rumi Tuni	90 m.	
P.S. Campo Serio		66 m.
C.S. Angoteros		66 m.
Túpac Amaru		45 m.
P.S. Tempestad		60 m.
P.S. Torres Causana		45 m.
C.S. Cabo Pantoja		45 m.

Table 23. Heights of the towers.

Note: PETRO PERU telecom repeater, located in Iquitos city, has been implemented on an existing tower of 36 meters.

iv.   *Computer system at client station*

At the client stations, computers were installed DELL Laptops with 17 "screen and printer HP inkjet (Alto Napo) or EPSON LX 300 + (Bajo Napo)

2.4.4.1.3 Network current status

The Napo´s Rural Telemedicine network is operational 100%, from Iquitos to Cabo Pantoja community (near the border of Peru and Ecuador). But unfortunately they are problems on IP telephone communications because of saturation generated on internal video development and demand for Internet information.

The Internet service is paid by the Loreto DIRESA and shares it with the Napo Network. However, they have problems on their servers and sometimes they cut the service for the development of videoconferencing between different DIRESA offices nationwide. Furthermore DIRESA Loreto has implemented a policy of restrictions on access to social pages, audio and video download, online chats and games. These measures are not effective because the users have free programs that allow violate the restrictions implemented, contributing to saturate the network.

The maintenance on PetroPeru´s telecommunications systems is another important cause of Internet service interruptions. These activities primarily take place every month on Sunday mornings from 8am to 12pm.

Regarding power systems, note that all batteries of both backhaul stations and the client stations were renew on December 2011. Now there are free maintenance batteries in all the nodes. Performance results of the network in terms of throughput are shown in Table 24. Results have been obtained during night hours, when nobody was using the network locally. These results are analysed below to understand the network limitations.

Network	WiFi Link	Throughput	Latency (RTT)	Appreciation about telephony service
Napo Network	16	1.27 Mbits/sec	33.1 ms	Good *

* Surveys on the use of the telephony (Results : Excellent , Good or Bad).

Table 24. Napo Network performance.

Bandwidth limitations

According to the bandwidth test between two ends of the network, a client in Iquitos Regional Hospital and a client in Cabo Pantoja health center, the bandwidth measured using the TCP protocol was 1.27 Mbits / sec. This capability may not be sufficient to ensure the functioning of new applications.

Energy limitations

The energy system on the repeater was designed with an up time of 2 days and is operational 24 hours a day. For additional equipment, another photovoltaic system will be necessary.

Infrastructure limitations

Towers on Napo network have heights between 45 to 90 meters and they have different dimensions on their sections, as shown on the following table.

All the towers have enough space to accommodate more equipment, except on Petro Perú site, because that tower do not belongs to the network. That company gave authorization to DIRESA (Regional Health direction) for using their tower in Iquitos to install the telecommunications equipment to communicate with Napo´s repeaters.

ICT-601102 STP
Document number: D21
Title of deliverable: Socio-economic scenarios, technical specifications and architecture for the proof of concept

TUCAN3G

Node	Tower (Height)	Triangular section side
Cabo Pantoja	45.00m	450mm
Torres Causana	45.00m	450mm
Tempestad	60.00m	450mm
Túpac Amaru	45.00m	300mm
Angoteros	66.00m	450mm
Campo Serio	66.00m	450mm
Rumi Tuni	90.00m	600mm
San Rafael	90.00m	600mm
Copal Urco	54.00m	450mm
Santa Clotilde	72.00m	600mm
Tacsha Curaray	72.00m	600mm
Negro Urco	75.00m	600mm
Tuta Pishco	57.00m	450mm
Huamán Urco	66.00m	450mm
Mazán	60.00m	450mm

Table 25. Height and triangular section side on the towers.

Internet limitations

The internet service is provided by DIRESA Loreto, which is shared with different offices at DIRESA in Iquitos and the health centers on Napo River. In Iquitos the only way to access to Internet is by satellite systems. The internet service for DIRESA Loreto has a capacity of 2Mbps. Due to the large number of Internet-connected computers in the DIRESA currently is notorious a insufficiency of this connection, which could be improved (with accessible cost) only if the city of Iquitos get a connection to the national broadband network.

2.4.4.1.4 Photos

Figure 23. Client stations and users
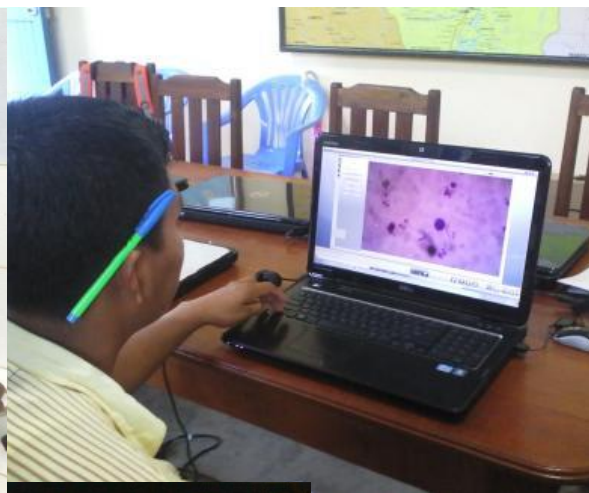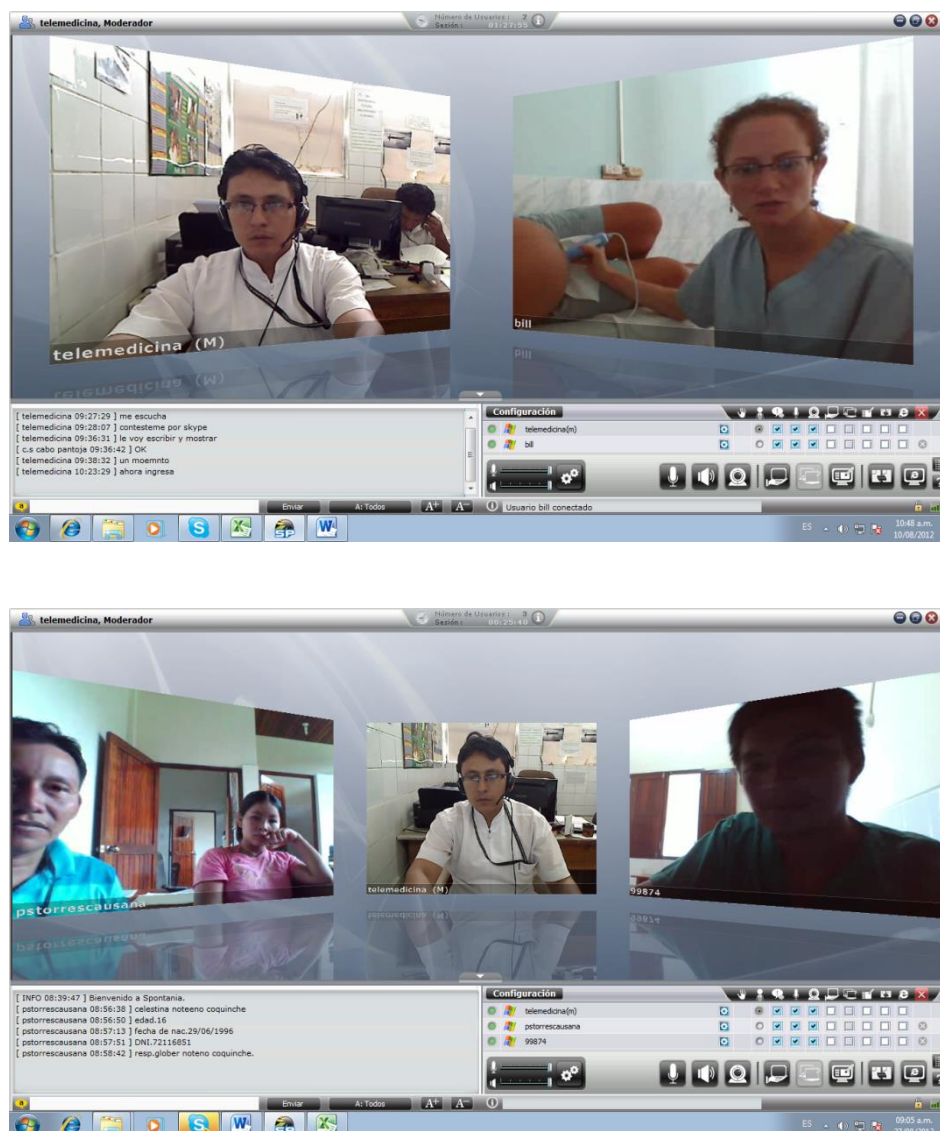
Figure 24. Telemedicine services

2.4.4.2   *Balsapuerto Network*

The Balsapuerto Telemedicine network is located in the district of Balsapuerto, province of Alto Amazonas, in the Loreto region. This network was installed by the Rural Telecommunications Group of the PUCP with funding and collaboration of IEEE-HTC, in coordination with the Alto Amazonas Health Network. Its operation stage began in July 2011.

In such abandoned communities, where access and resources are so limited, it was essential to establish a communication system to try to reduce distance problems and provide a development opportunity topeople living in them. This network has been designed to offer voice services and data transmission between health establishments. In this way, communication is established between the different nodes for medical consultations, both through phone calls and videoconferencing sessions.

Figure 25. Balsapuerto District Location

The implemented system is focused on providing the possibility that isolated health posts and centers can contact with Hospital Santa Gema in Yurimaguas, to do medical questions through audio and video. Thus, nurses and medical technicians without much experience working in these health centers can be guided and advised by specialists in the hospital, giving more confidence and security to health workers and patients in general, and improving coordination in urgent transfers if necessary. It also included distance learning services in real time, and broadcast videos and shared folders service for sending and receiving administrative documents. Through this network of health facilities involved, they can communicate directly with the Alto Amazonas Health Network for administrative matters, logistics and for delivering of medications.

On the other hand, each of the health facilities connected to the network can use the Internet access service through the ADSL service of Yurimaguas. This network enables communication among four health establishments: Balsapuerto health center, Varadero health post, San Juan health post of Armanayacu and Santa Gema Yurimaguas Hospital with the offices of the Alto Amazonas Health Department.

Item	Establishment	Latitude (S)	Longitude (O)	Elevation (msnm)
01	Balsapuerto health center	05°42'48.1"	76°24'38.3"	207.55
02	Varadero health post	05°50'04.8"	76°33'33.7"	163.89
03	San Juan health post	05°52'51.9"	76°21'34.8"	171.38
04	Hospital Santa Gema Yurimaguas	05°53'38.5"	76°06'24.5"	145.07
05	Alto Amazonas Health Network	05°53'47.1"	76°06'50.9"	144.70

Table 26. Geographical coordinates of the nodes

Figure 26 shows the geographical location of the communities involved and the distance between them.

Figure 26. Geographic location of nodes and distance between them.

Balsapuerto Health Center, is located in the community of Balsapuerto, Balsapuerto district capital. Health posts Varadero and San Juan, depend on the health center Balsapuerto. Balsapuerto and Varadero have electricity supply through diesel generators for two or three hours, when fuel is available. San Juan does not have electricity supply in the village. Santa Gema Hospital and Alto Amazonas Health Network are located in the city of Yurimaguas, with all conventional amenities: there are public and private institutions from all sectors, and it has fixed telephony, cellular services and Internet access.

2.4.4.2.1 Description of the Telecommunication Network

The telecommunication network is composed of long-distance wireless links using IEEE 802.11n technology in the 5GHz band. The network consists of point-to-point wireless links in the backbone and point-multipoint links on the local network for distribution to client stations, as shown in the topology of the network in Figure 27. The local repeater receives the signal from the backbone network and distributes it to its customers, creating, in this way, distribution links. Backbone repeaters are located in the Santa Gema in Yurimaguas Hospital, in San Juan, Varadero and Balsapuerto.

The Internet access point is in one of the Hospital Santa Gema clients, specifically in the Alto Amazonas Health Network. The link between the backbone network and customers locations are local repeaters.

In Balsapuerto, Varadero and San Juan there are no permanent energy, that's why photovoltaic systems were installed to power the equipment. Conventional energy exists in Yurimaguas provided by the local power company 24 hours a day.

i. *Telecommunication System.*

In the backhaul links from Yurimaguas to Varadero, dual polarity antennas are used in MIMO configuration (multiple input - multiple output). In the backhaul link between Varadero and Balsapuerto, grid antennas are used in polarity SISO configuration (single input – single output). In distribution links omnidirectional (Balsapuerto and Hospital) or panel (Varadero and San Juan) antennas are used. In client station panel antennas are used.

The following table shows the equipment that make up the telecommunication system, with the main elements RB433AH model Mikrotik router, wireless card R52Hn and high gain antennas (dish antennas 28.5 dBi dual polarity in the 5.8 GHz band, grid antenna gain of 27 dBi in the 5.8 GHz band and Omnidirectional or panel antennas installed in the towers).

The infrastructure of the network allows any TCP/IP service to be installed. The voice communications between health centers was implemented using Voice-Over-IP (VoIP) technology through the network infrastructure. In Varadero health post a VoIP server was installed, it registers the IP phone equipment from the different health establishments. An IP phone consists of an ATA (phone adapter) and an analogue telephone. The VoIP server was implemented using Asterisk with the SIP protocol and the G729 codec.

Description	Repeater Balsapuerto	Repeater Varadero	Repeater San Juan	Repeater Hospital	Client Balsapuerto	Client Varadero	Client San Juan	Client Hospital	Client Health network office
Grid Antenna 5.8 GHz 27 dBi (HG5827G) - Hyperlink	1	1							
Dual Polarity Antenna 5.8 GHz 29 dBi (HG5158DP-29D) - Hyperlink		1	2	1					
Omnidirectional Antenna	1			1					
Panel Antenna		1	1		1	1	1		1
Router Mikrotik RB433AH	1	2	2	1					
Router Mikrotik RB433					1	1	1		1
Wireless Card Mikrotik R52Hn	2	3	3	2	1	1	1		1
Coaxial cable N male - N male	2	4	5	3	1	1	1		1
Pigtail MMCX - N Female	2	4	5	3	1	1	1		1
Line Protector 5.8 Ghz (fourth wave) (N Male-Female)	2	4	5	3					
IP Telephony server Board ALIX 2D2						1			
ATA, Grandstream HT502					1	1	1	1	1
Analogue telepnone					1	1	1	1	1
equipment Metal Case 600 x 400 x 200	1	1	1	1		1			
equipment Metal Case 600 x 400 x 250	1	1	1						
equipment Metal Case 800 x 600 x 200					1		1		

Table 27. List of telecommunication equipment

Network topology

There are two types of networks used: the backbone network and the local distribution network. The backbone consists of a chain of repeaters that are connected by point-to-point, long distance, linking the four main nodes. The distribution network is comprised of a local repeater and client stations through multi-point links. The signal is distributed through the local repeaters reaching the clients with short-distance links. Figure 27 shows the backbone links in blue and distribution links in red.
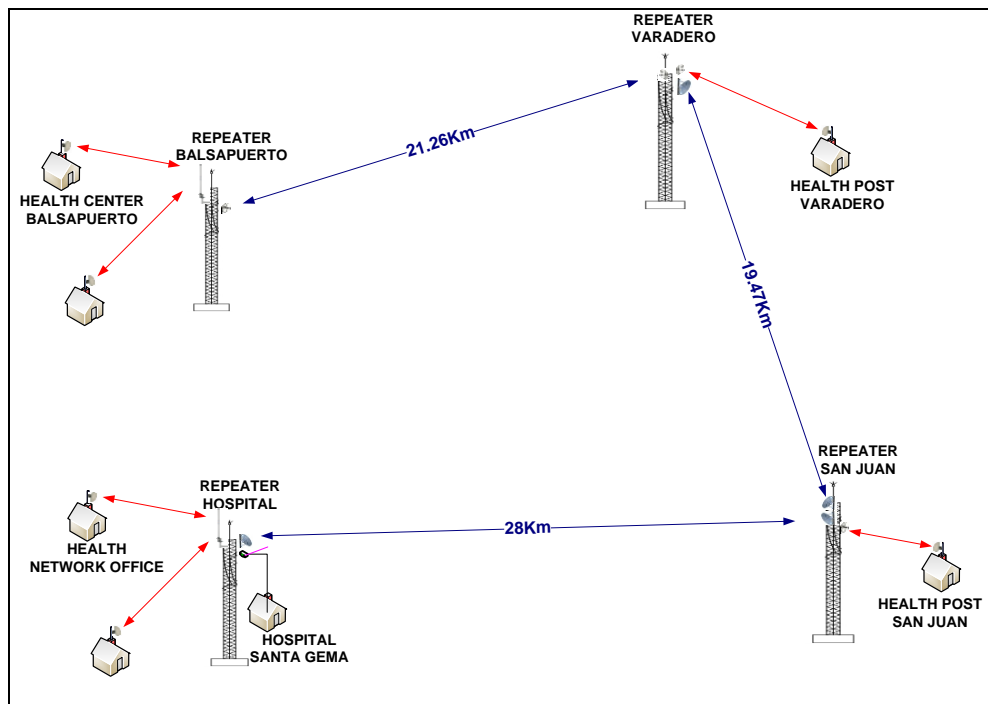
Figure 27. Telecommunication Network Topology.

IP Addressing Plan
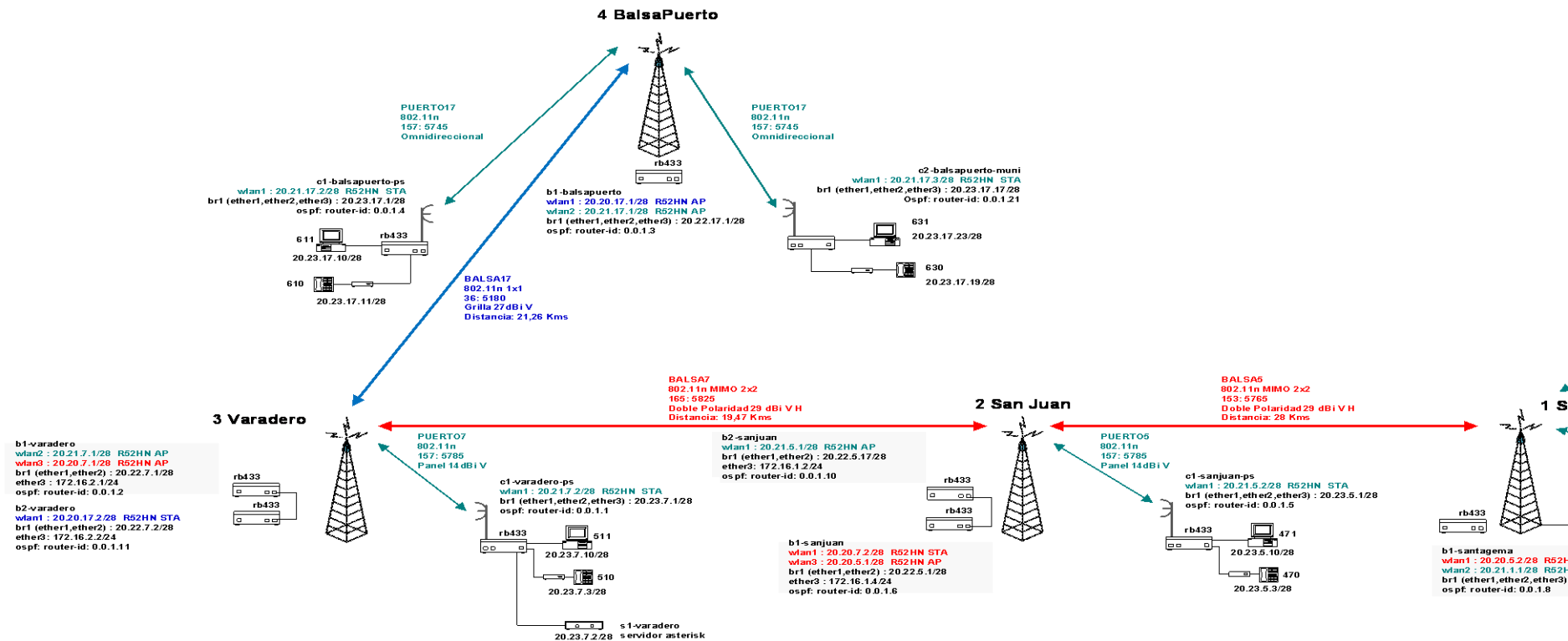
Figure 28. Shows the IP address on the network

ii. *Energy System.*

In Balsapuerto, Varadero and San Juan photovoltaic systems are used to power the repeaters and client stations.

Description	Repeater Balsapuerto	Repeater Varadero	Repeater San Juan	Repeater Hospital	Client Balsapuerto	Client Varadero	Client San Juan	Client Hospital	Client Health network office
85 Wp Solar Panel - Brand SOLAR WORLD	1	2	2		5	5	5		
Battery 12 VDC - 100 A / h - Brand RITAR	1	1	1		5	5	5		
Photovoltaic Controller - Brand Steca Model 20A	1	1	1		1	1	1		
Photovoltaic Controller - Brand Steca Model 30A					1	1	1		
Inverter 12VDC-220VAC					1	1	1		
Power over Ethernet				1					
UPS				1					

Table 28. List of energy equipments on repeater and client station.

Energy on backbone repeater and client station

For Balsapuerto, Varadero and San Juan repeaters, photovoltaic systems are used. The system was designed to operate 24 hours per day with an autonomy of 3 days. The system provides 12 VDC. In the case of Yurimaguas, they use conventional power system provided by the local electric company, 220VAC is provided.

In the client station case, the system was designed for a telephone system operating 24 hours a day and the use of the computer 6 hours a day, plus 2 low energy consumption luminaries were installed.

iii. Electrical protection system

Electrical protection systems are implemented to send electronic shocks, environmental (lightning) or accidental (shorts on computers) to the earthing systems and thus prevent damage of the telecommunication equipment. The system described is implemented in the towers and in the client stations.

On the tower the electrical protection consists of a lightning protection system, mounted on the tower connected to a grounding system. On the client station in Balsapuerto, Varadero and San Juan all the equipments are connected to a grounding system. The grounding resistance is less than 10 ohms.
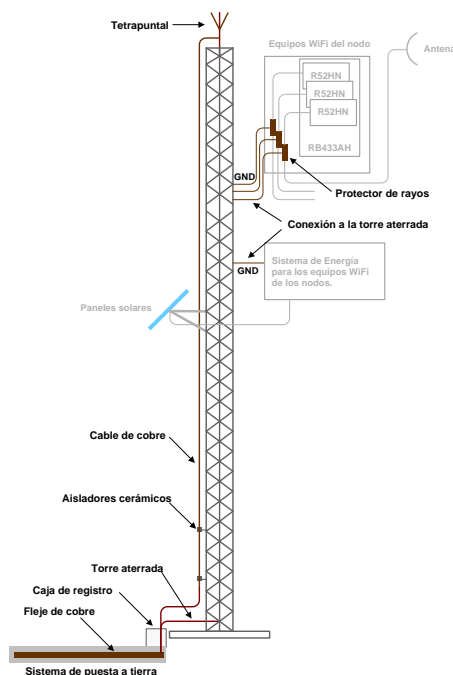
Lightning in a tower

Scheme of the protection system in a tower
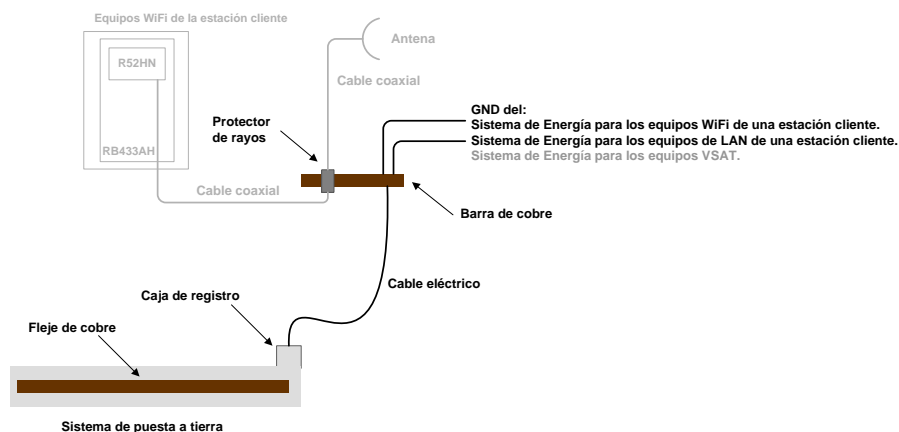
Protection system scheme in a client station

iv.   Services implemented.

The implemented services are:

- IP telephony, the service runs 24 hours a day.
- Video conferencing service. In each health facility there is a laptop with a webcam for videoconferencing, primarily used to query Support Specialists on Hospital Santa Gema Yurimaguas.
- Internet Access Service, the office of the Alto Amazonas Health Network hired an ADSL service for Internet access, which is shared by customers from Balsapuerto, Varadero and San Juan stations.

2.4.4.2.2 Technical characteristics

This section describes the equipment used, its technical specifications and what is installed nowadays in the network.

i.   Telecommunication equipments

Mikrotik Board RB 433	Router used in the end stations. - Atheros AR7130 300MHz CPU - 64/128MB DDR SDRAM memory - 64MB card data storage, NAND memory chip and microSD - Three ports Ethernet 10/100 Mbit / s with Auto-MDI / X - Three slots MiniPCI Type IIIA / IIIB - Power consumption ~ 3W without extension cards, maximum - 25 W POE 10 .. 28V DC, 16W output to cards - Operating System MikroTik RouterOS v3, License Level 5

Mikrotik Board RB 433AH
	Router repeaters used in the backhaul, local repeaters.
	
	- Atheros AR7161 680MHz CPU
	- 128MB DDR SDRAM Memory
	- Data Storage 128MB card, NAND memory chip and microSD
	  - Three ports Ethernet 10/100 Mbit / s with Auto-MDI / X
	  - Three slots MiniPCI Type IIIA / IIIB
	  - Power consumption ~ 3W without extension cards, maximum - 25 W POE 10 .. 28V DC, 16W output to cards
	- Operating System MikroTik routerOS v3, License Level 5

ALIX Board 2D2
	Embedded computer used in one of the end stations as a telephony server.
	- CPU 500 MHz AMD Geode LX800
	- DRAM: 256MB DDR SDRAM
	- Socket Storage: CompactFlash
	  - 2 Ethernet
	  - 2 slots MiniPCI slots
	  - DC power connector or POE, min. 7V max. 20V
	- Serial port I / O: DB9, dual USB2.0

 CF Memory de 2GB	Compact Flash Memory used as HDD in the embedded systems ALIX

Wireless Board R52Hn	Wireless card used in Mikrotik Routers - 802.11 a, b, g, n - Operating in the 2.4 and 5.8 GHz bands. - Supports Mikrotik Nstreme - Long distances and high speeds.
Dual Polarity Antenna	Dual Polarity Antenna 5.8 GHz 29 dBi (HG5158DP-29D) - Hyperlink
Grid Antenna 5.8GHz 27 dBi	Repeater antenna used in links with technology backhaul for SISO - Grid Antenna High Gain - Works on the 5.8GHz band - Antenna gain of 27 dBi
Omnidirectional Antenna 12 dbi	Omnidirectional antenna used in local repeaters to split the end stations - Works on the 5.8GHz band - Gain 12 dBi antenna

Panel Antenna de 19 dBi	Panel antenna used in the end stations - Works on the 5.8GHz band - Antenna gain of 19 dBi
Lightning arrestor 5.8 GHz	Lightning arrestor, quarter wave line - 5.8GHz - N male / N female - Employed in the backhaul and local repeaters, to protect the wireless routers against electric shock.
Pigtail MMCX – N Femail	Coaxial cable pigtail - Coaxial cable pigtail with MMCX connector ends on one side and N female on the other side. Usually measured 25 centimeters.
Coaxial Cable Heliax Super Flex	Low loss coaxial cable was used in all antenna connections. - Loss of 34 dB at 100 meters
ATA Grandstream HT502	Telephone adapter that is used in all installation points. - 2 FXS ports for 2 annexes - 1 Ethernet.

 Telephone Panasonic KX-TS500	Analog Telephone installed at each end station of the network

ii. *Energy equipment*

 Solar Panel SOLAR WORLD	Solar panel - 85 Wp - Brand SOLAR WORLD
 Solar Controller	Solar Controller -Make STECA -Model 20 Amps -Model 30 Amps
	Maintenance free battery - Brand RITAR - 12 VDC - 100 A / h

	Inverter Brand Morningstar, model Suresine 300 Watts – 220 VAC

iii. Electrical protection equipment

Description	On Tower repeater	ClientsStations
Lightning with insulator	1	0
Bare Copper cable 50mm2 - m per tower	According to tower	0
Ceramic insulators x tower - 1 x stretch	According to tower	0
Cables GPT 8AWG 15m	1	1
Copper strap 0.8x70mm (grounding) 20m	1	0
Copper strap 0.8x70mm (grounding) 10m	0	1
Bentonite	14	7
Salt	2	2
Manhole	1	1
Master copper bar	0	1
Lightning protectors	According to the links	1

iv. Infrastructure.

Towers:
Braced telecommunications towers are installed, whose features are the following:

- Provides required support to the telecommunications equipment.
- Sufficient for supporting the staff who work in the tower.
- A life line is installed to provide security to workers who access to the top of the tower.
- Tower sections, their accessories and the guy wires are galvanized.

Node	Tower (Height)	Description
San Juan	60.00m	Section: Triangular distance between centers: 600 mm
Santa Gema	42.00m	Section: Triangular distance between centers: 300 mm
Varadero	60.00m	Section: Triangular distance between centers: 600 mm
Balsapuerto	42.00m	Section: Triangular distance between centers: 300 mm

Equipment Cabinets:

Cabinets are used to house telecommunications and energy equipment. Himel brand cabinets are used with the following features:

- A channel-shaped groove around the enclosure keeps out water, oil or liquid, ensuring the protection up to the IP66 certification.
- Two bolts to connect to the ground.

The following cabinets are installed:

- Metallic cabinets for telecommunications and energy equipment: This cabinet contains telecommunications and energy equipment on nodes.
- Metallic cabinets for energy equipment: This cabinet contains energy equipment to LAN devices in a client station.
- Metallic cabinet for batteries: This cabinet contains batteries which are installed in the towers (Balsapuerto, Varadero and San Juan)
- Wooden enclosures for batteries: This cabinet contains batteries which are installed in client stations.

Figure 29. Himel cabinet.
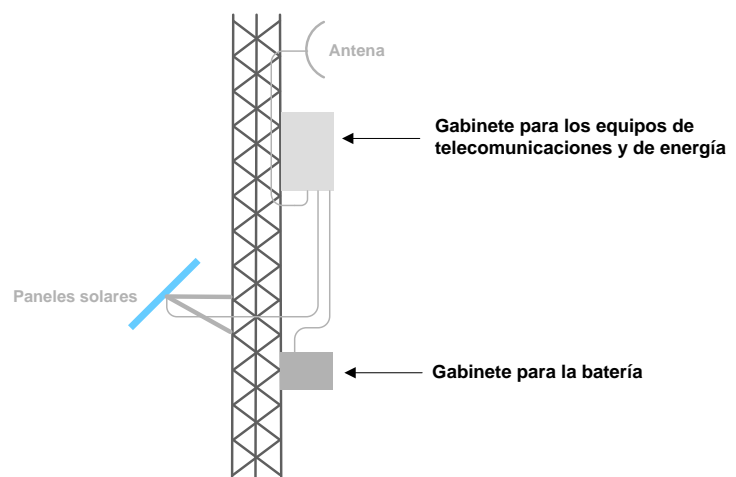
Figure 30. Cabinets on the Tower.

> *v.* *Computing system on client station*

Node	Description
Balsapuerto	1 Laptop
Varadero	1 Laptop
San Juan	1 Laptop
Hospital	1 Desktop
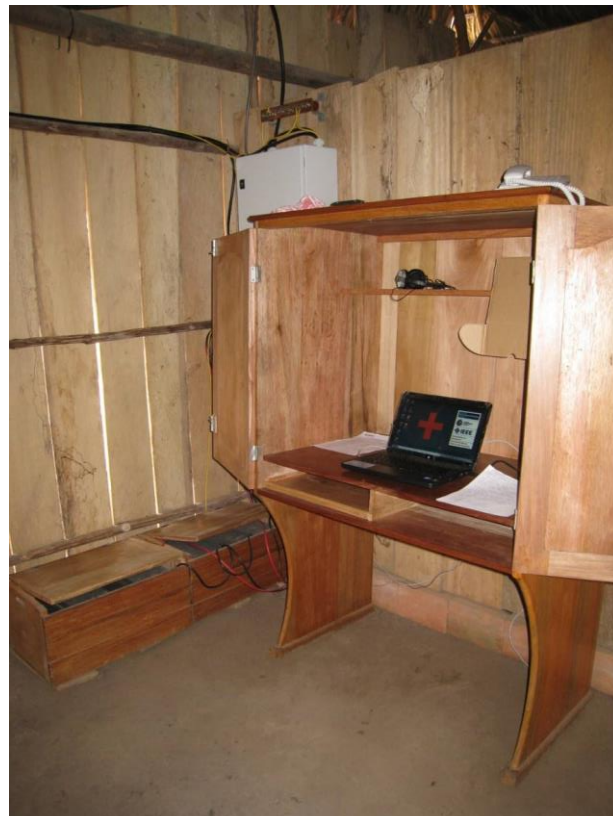
Figure 31. **Laptop on San Juan Health Post and the batteries on the left.**

2.4.4.2.3 Network current status

The network is operated by Alto Amazonas Health Network. IEEE-HTC funded the implementation, now is in transference process to Alto Amazonas Health Network. In this moment the network is in corrective maintenance, the wireless link between the Hospital and San Juan is down.

Bandwidth limits

Bandwidth tests have been performed between two ends of the network: a client located in the Hospital Santa Gema and a client located in the health center Balsapuerto:

- Using the TCP protocol: 7.61 Mbits / sec.
- Using the UDP protocol: 10.8 Mbits / sec.

Bandwidth tests have been performed between a client located in the Hospital Santa Gema and a client located in San Gabriel de Varadero health post:

- Using the TCP protocol: 9.44 Mbits / sec.
- Using the UDP protocol: 20.6 Mbits / sec.

Considering that this technology allows higher performance, it is concluded that only some adjustments are required in the aiming of the antennas and link parameters to further improve the available bandwidth.

Energy limits

In Balsapuerto, Varadero and San Juan the equipment are powered by photovoltaic systems. In Yurimaguas there is conventional energy provided by the local electricity company.

The energy provided by the photovoltaic systems on the repeater was designed with an up time of 2 days and is operational 24 hours a day. According to the above, it would not be necessary to reinforce the power subsystem because there are no plans to install new WiFi equipment.

Infrastructure limits

The towers installed in Balsapuerto and Yurimaguas are on the limit of its useful load. They are over 10 years old. They are also thinner, smaller in size (42 meters high) and do not have much space to install telecommunications equipment. Compared to the former towers, the ones installed in San Juan and Varadero (60 meters high) have more capacity, more space to house telecommunications equipment and are more robust.

In the towers located in Varadero and San Juan new telecommunications equipment could be installed to provide cell phone service to these communities.

In Varadero it is necessary to make a correction regarding the installation of the tower, since there is a slight deviation in the tower.

Ground wells have not been maintained since it was installed, so would the upgrading of these systems for electrical protection will be required.

Node	Tower (Height)	Triangular section side
San Juan	60.00m	450mm
Santa Gema	42.00m	300mm
Varadero	60.00m	450mm
Balsapuerto	42.00m	300mm

Table 29. Balsaperto towers

Internet access limits

In the city of Yurimaguas there is Internet access service provided by Telefonica through ADSL. Nowadays, the city of Yurimaguas has access to the fiber optic network, which belongs to Telefonica, and has increase people expectations on improved telecommunications services.

2.4.4.2.4 Photos

Figure 32. Dual polarity antenna on the top of the tower, below is situated a solar panel. This picture was taken in San Juan health post.
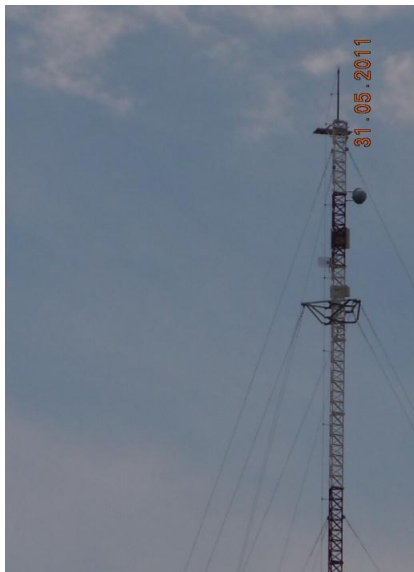
Figure 33. Tower of Varadero
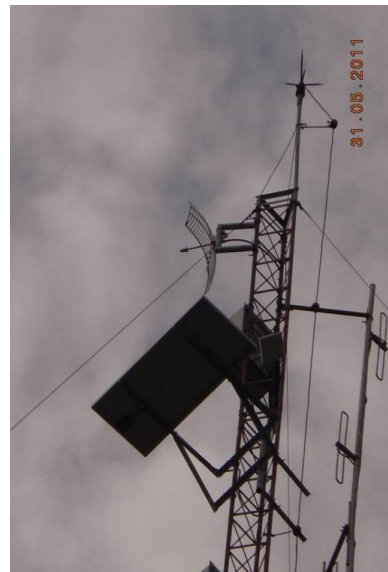
Figure 34. Tower of Balsapuerto

Figure 35. Equipment cabinet in Varadero health post. We can see the router Mikrotik on the left and the VoIP server on the right, below the are two photovoltaic controllers.

Figure 36. 60 meter tower on San Juan, on the top are installed the telecommunication and energy equipments.

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3 ACCESS NETWORKS PERSPECTIVES

3.1 System requirements

The design of a rural wireless access network in TUCAN3G is focused on providing voice and data services at a low cost, allowing an easy and progressive network upgrade as traffic demand increases. This section defines specific features and functionalities of the system that need to be complemented to meet TUCAN3G objectives from the access network perspective. Specific requirements to fit the constraint of rural communications deployments such as being inexpensive, sustainable, energy efficient, self-organized and long-term self-sufficient are to be briefly and qualitatively described here.

3.1.1 Radio requirements

The requirements of the access networks will be given by the grade-of-service for voice and data traffic, in terms of service outage. Outage is related to both coverage and channel availability of the HeNB. These aspects will define the number of HeNB, channels per HeNB and transmitted power. The local government may enforce this grade-of-service, which will be provided by Telefonica.

On the other hand, for an efficient interoperability with the transport network, the radio resource allocation in the access network should take into account the QoS constraints imposed by the wireless backhaul and defined by the transport network.

3.1.2 Security requirements &/or Legal requirements

This section considers the legal requirements for call interception. The Lawful Interception (LI) concept describes the lawfully authorized interception and monitoring of telecommunications pursuant to an order of a government body, to obtain the forensics necessary for pursuing wrongdoers [ITU-T 08].

The general requirements can be summarized as:
- The LI system must provide transparent interception of specified traffic only.
- Intercept subject must not be aware of the interception.
- The service provided to other uninvolved users must not be affected during interception.

LI may target two types of data:
- Actual Contents of Communications (CC), i.e., voice, video or text message.
- Intercept Related Information (IRI), i.e. signaling information, source and destination (telephone numbers, IP or MAC addresses), frequency, duration, time and date of communications, geographical origin of the call.

The network architecture requires that there be a distinct separation between the Public Telecom Network (PTN) and the Law Enforcement Network. In case of IP-based networks, each call consists of one or more call signaling streams that control the call. All these streams establish a "session". More details about how the LI is considered for generic network architecture can be found in [TR 101.943].

The LI requirements for H(e)NB local routing, selected IP traffic offload (SIPTO) or local IP access (LIPA) are for further study, see section 5.10 of [TS 133.106]:

When a target receives service from the PLMN via a HeNB the following applies:
- The interception capabilities shall take place as for normal PLMN use.
- HeNB information shall also be provided to the Law Enforcement Monitoring Facility (LEMF).

- If available, the location reported for the target is the HeNB location.
- Target attachment to the HeNB and handovers to/from the HeNB shall be reported.

When the target is a Closed-Subscribed Group HeNB, the PLMN operator shall report:
- Modifications of the CSG list.
- When available, the access method (e.g. via MS/UE or web) the HeNB Hosting Party used to modify the CSG list.
- CSG members handovers to/from the HeNB.
- CSG members attachments to the HeNB.
- CSG members communications via the HeNB.

When the target is the HeNB, then the PLMN operator should report the following:
- Activation and deactivation of the targeted HeNB.
- IP address information regarding the secure tunnel endpoints between the HeNB and the Femto Security Gateway in the home network.
- Modifications of the CSG list for the HeNB.
- When available, the access method (e.g. via MS/UE or web) the HeNB Hosting Party used to modify the CSG list.
- Handovers to/from the HeNB.
- MS/UE registrations on the HeNB.
- Communications via the HeNB.

3.1.3 Management and self-management requirements

Human intervention must be kept as low as possible. To that end, the following functionalities should be considered for the access network: autonomous network monitoring, self-organizing carrier selection, and interference management.

3.1.4 End-user equipment requirements

Voice and limited-data connectivity at a low cost are the initial end-user equipment requirements. Eventually, larger volumes of data traffic may become an issue when the traffic demand increases. Each type of traffic imposes the access network certain requirements in terms of availability, bandwidth, maximum delay, etc. Requirements regarding mobility should be considered as well, despite low mobility is expected in the scenarios considered.

3.1.5 Energy efficiency requirements

One of the key limiting and differentiating factors of rural deployments is based on the fact that the BS's or AP's will not have full access to unlimited energy sources as happens in urban deployments. In fact, in most cases, the only available energy source will be that coming from solar cells with a limited efficiency that charge batteries with a limited capacity. This has a number of implications from a technical and maintenance point of view. The main one is that some kind of control of the energy spending will be needed so as to avoid that the batteries providing energy to the BS's get empty unnecessarily and, therefore, no service can be given to the users, thus, decreasing the perceived QoS. In other words, the energy efficiency of the whole network should be considered and addressed as a key design strategy. This implies defining non-supervised and efficient methods for energy provision and energy saving.

One of the strategies to optimize energy efficiency and decrease the energy spending is to put femtocells in dormant mode (switch off the femtocells) when possible and considered appropriate, i.e., when the traffic demands drop. For example, let us assume a given geographical area where, during the day, the traffic demand is high. Therefore, at least 2 femtocells have to be installed to be able to provide service with a congestion probability lower than a certain prefixed value related to a QoS to be

perceived by the users. During the night, the demand for traffic drops importantly, particularly in rural areas. In such a situation, a single femtocell can attend all the traffic without increasing the congestion probability, provided that the coverage area of such femtocell is sufficient to cover the geographical region to be served. The other femtocell could change to dormant mode, which would allow saving some energy. Another way to increase energy saving is the use of directive antennas at the femtocells with radiation patterns fitting specifically the distribution of population in the geographical area. This avoids unnecessary energy radiation towards areas with no users. Note that in urban areas this would not be a possibility since users are usually uniformly distributed, whereas in rural areas population will be usually distributed in a non uniform way.

Taking all this into account, the energy efficient requirements for this kind of deployments involve the following features:

- When developing any strategy to save energy, we must ensure that the resulting congestion probability at any time period within the day is kept lower than a prefixed value. The profile of the traffic demand along the day and the target QoS to be perceived by the users must be considered to compute the congestion probability.
- According to the target QoS constraint, the positions of the femtocells must be optimized so that the coverage areas for each femtocell cover the required geographical region. When evaluating the coverage, we must taking into account explicitly that other femtocells can become dormant at some day periods.
- The algorithms to decide when the femtocells should become dormant or active should be somehow distributed and non-supervised to reduce the complexity and the need for explicit maintenance.
- If specific antennas with designed custom radiation patterns are to be used, special care should be taken when analyzing the impact on the coverage area as we must ensure that all the population can be served with a given congestion probability even when mechanisms to switch off femtocells are exploited.
- When developing all the previous strategies, the technical specifications of the concrete solar cells to be used should be considered. Specifically, we need to study which is the probability that the battery of certain femtocell becomes empty. Of course, this will depend of the technical specifications and also on the number of sun-hours per day, etc.

3.2   Technical Scenarios

TUCAN3G aims to provide voice and data connectivity to sparsely populated areas where the deployment of conventional communication infrastructure (3G macro base stations with wired backhaul) is not economically viable. We envision a scenario where the wireless access network consists in distributing multiple UMTS/HSPA (3G) femtocells (HNB) with a wireless backhaul over given rural areas as a cost-effective solution. The femto base stations in the access network are connected to a wireless transport network with tree-like topology. This section provides a qualitative description of the features of the scenario with an impact in the access network design.

3.2.1   Traffic assumptions: users and traffic density

The technical scenarios are expected to be sparsely populated areas with a low density of users. Along with the user density, the type of traffic and the traffic evolution along time are the key parameters that will impact on the network dimensioning and performance.

3.2.2 Deployment constraints

This section describes the deployment constraints when deploying the femto base stations, the different possibilities for positioning the FAPs, as placing the femto base stations in a high position or a low position, along with advantages and disadvantages for different options.

Four main requirements describe the problems of deploying a mobile network in a rural area [SCF-047.01.01]: site, power, backhaul, and planning and services.

- **Site**
  - In rural scenarios, the equipment is usually mounted either on buildings or on existing street furniture. However, it might be required to install the equipment in steel pole or towers, combining it with panel antennas like omni-directional or directional antennas.
  - The actual size of the total equipment (base station, backhaul equipment and power supplies) is an important factor to be considered.
  - The equipment packaging need to reflect local conditions but is likely to need at minimum internal protection 55 rated housing and probably 6 rating with NEMA (US National Electrical Manufacturers Association).
  - Large extended temperature range operation (for example -40 degrees to +60 degrees Celsius).

- **Power**
  - Typically the power consumption of the small cell equipment is 100 watts maximum. Hence, normal domestic single phase supplies will be adequate. In case the equipment is mounted in existing premises, it is expected to be direct feed from the premises supply.
  - Power outages (and battery backup) also need to be considered. Duration, cost and management of the battery backup system has to be taken into account for each particular scenario.
  - In case the electricity availability is limited, solar, wind, fuel cell or other alternative power sources are needed. The availability of equipment operating on 12/24 VDC will eliminate the cost and complexity of power inverter systems. In general these systems have a battery backup, guaranteeing certain level of service continuity.

- **Backhaul**

Some rural and remote small cell sites will be in locations from existing operator backhaul infrastructure (leased line, fibre or microwave). Otherwise, some possible technologies that can be used are line-of-sight and near-line-of-site microwave radio technologies [SCF-049.01.01], see a summary of properties of wireless technologies in Table 30 and Table 31.

	Millimetre 70-80 GHz	**Millimetre 60 GHz**	**Microwave (6-60 GHz)**
Latency	65-350 μs	<200 μs	< 1ms
Coverage	~ 3 km hop length	~ 1km hop length	2-4 km typical (30-42 GHz)
Equipment at small cell	Compact (all outdoor). Antenna diameter 20-60 cm	Very compact (all outdoor). Antenna diameter 7-15 cm	All outdoor. Zero footprint designs available.
Installation	Line-of sight	Line-of-sight	Line-of-sight

Table 30. Summary of properties for technologies from 6 to 80 GHz [SCF-049.01.01]

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	Sub 6 GHz	TV White space (802.11-based)	Satellite
Latency	5 ms (latency-aware QoS scheduling ensures lowest latency when required)	10 ms	300 ms one-way latency. Jitter 5-30 ms. Often requires special settings.
Coverage	1.5 to 2.5 km urban (at 3.5 GHz) and 10 km rural (3.5GHz)	1-5 km for maximum throughput Can support LoS > 10 km at 10 Mbps using 2 channels	Almost ubiquitous
Equipment at small cell	All outdoor. Zero footprint designs available.	Wi-Fi Access Point form factor	Small dish (1.2m) with outdoor RF unit + indoor satellite modem.
Installation	Very rapid. Non-line-of sight. Use of self-aligning antennas significantly reduces installation time.	Non Line-of sight or Line-of-sight	Satellite installation possible by a TV antenna engineer.

Table 31. Summary of properties for technologies < 6 GHz and Satellite [SCF-049.01.01]

- **Planning and services**
  - It is not required a handover to the macro-layer.
  - Synchronisation from existing base station signals may not be feasible. Hence, alternative solutions like sync over IP or GPS clocks are required.
  - In the event of backhaul link failure, the option to provide locally switched calls may be required (i.e. to police station, hospital, etc.)
  - In case the backhaul has a limited capacity, local caching of mobile data content may help to improve user perceptions of performance.

3.2.3   Multi-FAP deployment (single tier and multi-tier topologies)

Rural communities have not homogeneous characteristics in terms of traffic density and concentration of population. While in some, population is more dispersed in farms, others have a concentrated nucleus surrounded by disperse areas. In larger towns, it may be interesting to cover only the urban nucleus. On the other hand, the overall traffic is expected to depend a lot on the economic resources.

Clearly, multiple peer FAPs will be needed either in the case of high traffic density (capacity limited situation) or in dispersed areas (coverage limited situation). A two-tier deployment is more appropriate in some other situations with non-homogeneous traffic: outdoor traffic is mainly low-rate voice, while indoor traffic is high rate data, and hence they could be split in a single high-position BS and many closer-to-user BSs, respectively. These situations are described below in the technical scenarios in **Table 32**.

Being the traffic density a non-limiting factor, it seems more appropriate for a two-tier scenario to allocate different frequency bands to high-position and low-position BSs. While the first will connect to the backhaul through cable (they are supposed to be placed on the towers deployed for WiDL backhaul) the connection of low-position BS has to rely on WiFi short-range access, which needs careful design not to impair multihop transport backhauling.

The choice of each suitable option for deployment of BS has to be taken at the early stages of the project, when the sites for deployment in WP6 have been selected.

3.2.4 Spectrum issues: orthogonal versus co-channel allocation for FAPs

Orthogonal co-channel allocation allows keeping an acceptable signal-to-interference-plus-noise ratio (SINR) particularly at cell boundaries. It is clear the for those users experiencing large interference, orthogonal transmissions with suitable power allocation are better, even if this means reducing the system spectral efficiency of the whole system. This is actually the option used in conventional cellular networks.

A carefully frequency planning as in conventional cellular networks seems to be difficult for FAPs, particularly as the number of deployed FAPs increases. In addition to that, if users served from different FAPs experience a low level of interference, radio resources may be reused. As a consequence, the system spectral efficiency is increased.

For the scenarios considered in the project, spectral efficiency seems to be non-critical, while coverage is. Furthermore, the number of FAPs is expected to be low, at least in a first phase. Therefore, orthogonal co-channel allocation seems to be more appropriate, but both options need to be evaluated. The plan is to use in all locations the two carriers owned by Telefonica. This makes the interference management very easy in those locations with low traffic. For those locations with greater traffic where several femtos share the same channel, techniques for a dynamic management in the interference will be considered within activities 4A2 and 4A3.

3.2.5 Coverage scenarios

One of the main advantages of femto base deployments is that they allow updating the access network topology and density in an easy yet unplanned way. However, an unplanned deployment may generate a harsh interference scenario which has to be managed in order to provide large spectral efficiency, low coverage outage, and reduced energy consumption. In this subsection, we comment on the two basic types of technical scenarios to be considered: noise-limited and interference limited scenarios.

3.2.5.1 Noise-limited scenario

A noise limited scenario is characterized by the fact that the limiting factor in the quality of a given connection is the noise. In other words, that the interference produced by other cells is negligible. In such a case, the coverage of a given femtocell is restricted only by channel-dependent parameters, such as path-loss, shadowing, and multipath fading. This allows simplifying a lot the network planning procedures. Note, however, that noise-limited scenarios are given only in low-deployed areas where neighbouring femtocells using the same frequency are far enough (negligible intercell interference) and when the traffic load and number of users in the same femtocell is also low (negligible intracell interference). Note also that a given deployment could be considered noise-limited during some time periods within the day (e.g., at night) but not during high-peak traffic hours (e.g., during the day).
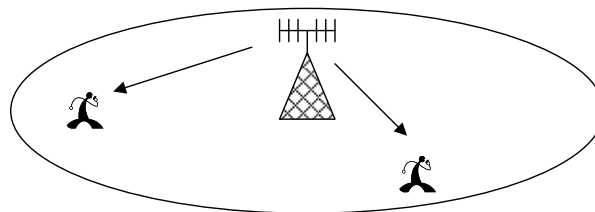
Figure 37. Intracell/noise-limited scenario

3.2.5.2 Interference-limited scenario

An interference limited scenario is characterized by the fact that the limiting factor in the quality of a given connection is the interference. This interference may come from other closely positioned

neighbouring cells using the same frequency and, therefore, generating intercell interference; or from other users in the same cell producing intracell interference. In this kind of scenarios, the coverage planning is much more complicated because the path-losses calculated by conventional tools for network planning are not enough. If the coverage in an interference limited scenario is to be calculated, these path-losses calculated by these tools should be post-processed to take into account the interference levels in order to produce realistic metrics for the quality of the connections.
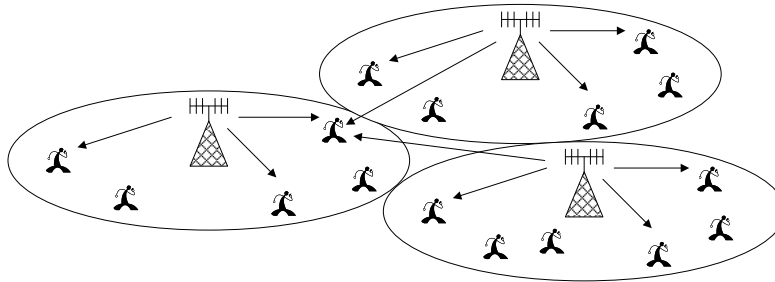
Figure 38. Intercell interference-limited scenario

3.2.6 Summary of technical scenarios in TUCAN3G

In TUCAN3G we will consider 5 basic scenarios, summarized in Table 32.

	Population features	Multi-FAP deployment	Traffic	Deployment aspects
1	Concentrated coverage area	Single HeNB with omini antennas	Low traffic	-It will be placed in a single tower at high position enlarging the coverage area -The backhaul connection could be wired connection from the WiFi router
2	Disperse coverage area	Single HeNB with multiple directional antennas	Low traffic	-It will be placed in a single tower at high position enlarging the coverage area -The backhaul connection could be wired connection from the WiFi router -Directional antennas have to be installed (multiple directional antennas combined through a single splitter).
3	Concentrated, large population	Many HeNBs in low position with omni antennas	High Traffic	-Low towers -Load balancing and interference management needed
4	Disperse coverage area	Many HeNBs in high position with omni antennas	Low-to-medium traffic	-High towers -Load balancing and interference management needed
5	Mixed hot spots and disperse coverage areas	Two-tier: one HeNB in high position and many HeNB in low position	High traffic	-One HeNB could be placed in an existing high tower, while the remaining ones should be installed in steel poles. -Power supply problem should be addressed for low position HeNB -Backhaul link between the WiFI router and HeNB is wireless. The HeNB must incorporate a WiFI adapter. -Load balancing and interference management

Table 32. TUCAN3G technical scenarios

3.3 Radio Access Technologies

TUCAN3G proposes 3G technologies to provide mobile voice service to rural areas, while 4G technologies will also be a matter of study in order to know how TUCAN3G concept will evolve

beyond the lifetime of the project. When the traffic demand increases, larger volumes of data traffic are an issue and 4G technology becomes affordable. Therefore, voice and limited-data connectivity will be addressed by means of UMTS/HSPA (3G) femtocells, while voice and high-speed data connectivity can be addressed by LTE (4G) femtocells. In the annex I and II the main features of the air interface as well as equipment capabilities are included for 3G and LTE technologies respectively. An overall description of the architecture is also presented. For the 3G case, the particularities of the equipment that will be finally installed will be described.

3.4 Evaluation Methodology

This section addresses the methodology when evaluating by simulation the solutions provided for the access network. Specific meaningful values for the simulation parameters are expected to be included here.

3.4.1 Key system descriptors (outputs from radio performance evaluation)

In order to evaluate the performance of techniques designed in subsequent work packages; this section describes the outputs from radio performance evaluation. Notice that, depending on the kind of simulation considered, mainly link level or system level simulation, the criteria may differ. Typically, link level simulation considers a single link (one transmitter, one receiver) and performance is evaluated on the basis of BER or PER as a function of signal to noise ratio (SNR). Throughput can be evaluated also when, for instance, link adaptation is considered. For more information, see [R1-125312].

3.4.1.1 System Performance Evaluation Metrics

- **Average burst rate**: The burst rate is defined as the ratio between the data burst size in bits and the total time the burst spent in the system. The total time the burst spent in the system is the time difference measured between the instant the data burst arrives at the Node B and the instant when the transfer of the burst over the air interface is completed. The total time the burst spent in the system is equal to the sum of the transmission time over the air and the queuing delay.
- **Total System Throughput**.
- **UE throughput**: Average, 50% and 5%.
- **Percentage of UEs served by HeNB**. (in case there is a Marco eNB operating in that area).
- **PDF of Radio Link Control (RLC) packet delay**: the delay is calculated as the time between when the RLC packet is constructed at the RNC until it is delivered by UE RLC receiver to upper layers; RLC packets discarded after maximum number of retransmissions should be counted separately. This metric is only applicable for scenarios as MultiFlow, where the RLC may be modelled.
- **Average and Cumulative Density Function (cdf) of Rise-over-Thermal (RoT) for UL.** RoT indicates the ratio between the total interference received on the eNB and the thermal noise power.

3.4.1.2 Link Performance Evaluation Metrics

- **Throughput** in Mbps, averaged over the duration of the simulation for specific Geometries at the UE.
- **Rank Distribution.** In 2×2 MIMO transmission there 4 rank-1 precoding vectors and 4 rank-2 precoding matrices, hence one or two streams can be transmitted. The UE reports the rank of the channel and the preferred precoding weights periodically.
- **Channel Quality Indicator (CQI) Distribution per layer**
- **BLER Statistics per transport block.**

3.4.1.3   Energy and power metrics

- **Average sum power.** It measures the amount of average power necessary at eNB.

3.4.2   Propagation channel models

The scenarios addressed in TUNCAN3G deal with the rural and urban/sub urban low rise environments, categories defined in [ITU-R P.1411] and described in Table 33.

Environment	Description and propagation impairments	Velocity
Rural	- Small houses surrounded by large gardens - Influence of terrain height (topography) - Heavy to light foliage possible - Motor traffic sometimes high	- Pedestrian: 1.5 m/s - Vehicular: 22-28 m/s
Urban / Suburban low rise	- Typified by wide streets - Building heights are generally less than three stories making diffraction over roof-top likely - Reflections and shadowing from moving vehicles can sometimes occur - Primary effects are long delay and small Doppler shifts	- Pedestrian: 1.5 m/s - Vehicular: 14 m/s

Table 33. Operating environments in TUCAN3G

3.4.2.1   Path loss Models

For modeling the path loss in the scenarios considered in TUCAN3G, we will take into account the theoretical models defined in the standards for evaluation the different transmission schemes, and for specific location, we will work with realistic data.

3.4.2.1.1 Standard-based models

Taking into account that the coverage area per each transmitter in TUNCAN3G is less than 5km, the path loss and shadow fading models for rural and suburban low rise environments have the same closed-form equations [ITU-R M.2135]. The differences in both scenarios come up with the probability of the LOS or NLOS situation, see Table 34. Those models can be applied in the frequency range of 2-6 GHz, although for the rural case the valid frequency rage becomes 450 MHz – 6 GHz. The path-loss depends on the following variables:

- d: distance between the transmitter and receiver in meters
- f_c: centre frequency in GHz
- h_{BS}: antenna height of the transmitter
- h_{UT}: antenna height of the receiver
- h: average building height
- W: street width in meters
- c: propagation velocity in free space (3×10^8 m/s)

The applicability ranges are:

$$5 \leq h \leq 50$$
$$5 \leq W \leq 50$$
$$10 \leq h_{BS} \leq 150$$
$$1 \leq h_{UT} \leq 10$$

Scenario	LOS probability as a function of distance (m)
SMa (SubUrban Macro)	$P_{LOS} = \begin{cases} 1 & if \quad d \leq 10 \\ \exp\left(-\dfrac{d-10}{200}\right) & otherwise \end{cases}$
RMa (Rural Macro)	$P_{LOS} = \begin{cases} 1 & if \quad d \leq 10 \\ \exp\left(-\dfrac{d-10}{1000}\right) & otherwise \end{cases}$

Table 34. Probability of LOS.

3.4.2.1.1.1 *Path loss and shadow fading under LOS*

The path loss is described by,

$$PL_{LOS}(dB) = \begin{cases} 20\log_{10}\left(\dfrac{40\pi f_c}{3}d\right) + a_{LOS}\log_{10}(d) - b_{LOS} + 0.002\log_{10}(h)d & if \ 10 \leq d \leq d_{BP} \\ 20\log_{10}\left(\dfrac{40\pi f_c}{3}d_{BP}\right) + a_{LOS}\log_{10}(d_{BP}) - b_{LOS} + 0.002\log_{10}(h)d_{BP} + 40\log_{10}\left(\dfrac{d}{d_{BP}}\right) & if \ d_{BP} \leq d \leq 5000 \end{cases}$$

(1)

where

$$a_{LOS} = \min\left(0.03h^{1.72}, 10\right)$$
$$b_{LOS} = \min\left(0.044h^{1.72}, 14.77\right)$$
$$d_{BP} = \frac{2\pi}{c \cdot f_c \cdot 10^9} h_{BS} h_{UT}$$

(2)

where d_{BP} is break point distance.

Additionally, the shadow fading is assumed to be log-normal with the following standard deviation,

$$\sigma_{LOS}(dB) = \begin{cases} 4 & if \ 10 \leq d \leq d_{BP} \\ 6 & if \ d_{BP} \leq d \leq 5000 \end{cases}$$

(3)

3.4.2.1.1.2 *Path loss and shadow fading under NLOS*

The path loss is given by

$$PL_{NLOS}(dB) = 161.04 - 7.1\log_{10}(W) + 7.5\log_{10}(h) - a_{NLOS}\log 10(h_{BS}) + b_{NLOS}\left(\log_{10}(d) - 3\right) +$$
$$20\log 10(f_c) - \left(3.2\left(\log_{10}(11.75 h_{UT})\right)^2 - 4.97\right)$$

(4)

Where,

$$a_{NLOS} = 24.37 - 3.7\left(\frac{h}{h_{BS}}\right)^2$$
$$b_{NLOS} = 43.42 - 3.1\log_{10}(h_{BS})$$

(5)

Moreover, the standard deviation of the log-normal shadow fading is independent of the distances and is equal to,

$$\sigma_{NLOS}(dB) = 8$$

(6)

3.4.2.1.2 Realistic path loss models
For specific locations, like for example the villages in Peru where the 3G-based network is going to be deployed, we employ the RadioMobile software [RadioMobile] to get the path loss in those areas. This

software work in the rage of frequencies between 20MHz and 20 GHz and it is based on the Irregular Terrain propagation model (ITM) or Longley-Rice model. It employs elevation maps, for example from the Space Shuttle Radar Terrain Mapping Mission. The resolution of the elevation is about 100 m.

3.4.2.2 *Small scale fading*

The small-scale fading consists in large variations on the scale of a half-wavelength due to destructive or constructive sum of propagation multi-paths. Here in TUCAN3G, we model the small-scale fading through a "tapped delay line" profile following ITU and 3GPP specifications and a set of correlation matrices according 3GPP spatial model.

Table 35 presents the delay profile of the models considered in this project. There are two models that are based on the COST 259 – {Typical Urban, Rural Area} [ETSI TR 125.943] and two based on 3GPP – {Extended Pedestrian A, Extended Typical Urban} [3GPP TS 36.101]. The delay spread of these channels is depicted in Table 36.

Tap	COST 259 – Typical Urban Relative time (µs)	Average relative power (dB)	COST 259 – Rural Area Relative time (µs)	Average relative power (dB)	3GPP – EPA Extended Pedestrian A Relative time (µs)	Average relative power (dB)	3GPP – ETU Extended Typical Urban Relative time (µs)	Average relative power (dB)
1	0	-5.7	0	-5.2	0	0.0	0	-1.0
2	0.217	-7.6	0.042	-6.4	0.03	-1.0	0.05	-1.0
3	0.512	-10.1	0.101	-8.4	0.07	-2.0	0.12	-1.0
4	0.514	-10.2	0.129	-9.3	0.09	-3.0	0.20	0.0
5	0.517	-10.2	0.149	-10.0	0.11	-8.0	0.23	0.0
6	0.674	-11.5	0.245	-13.1	0.19	-17.2	0.50	0.0
7	0.882	-13.4	0.312	-15.3	0.41	-20.8	1.60	-3.0
8	1.230	-16.3	0.410	-18.5			2.30	-5.0
9	1.287	-16.9	0.469	-20.4			5.00	-7.0
10	1.311	-17.1	0.528	-22.4				
11	1.349	-17.4						
12	1.533	-19.0						
13	1.535	-19.0						
14	1.622	-19.8						
15	1.818	-21.5						
16	1.836	-21.6						
17	1.884	-22.1						
18	1.943	-22.6						
19	2.048	-23.5						
20	2.140	-24.3						

(*) In case of the COST-259 – Rural Area, one deterministic (non-fading) path with 0.43 dB and Doppler frequency $0.7 f_{max}$ has to be added in order to get Ricean fading, see [ESTI TR125.943]

Table 35. Delay profiles considered in TUCAN3G

Channel Model	Delay spread (r.m.s)
COST 259 – Typical Urban	500 ns
COST 259 – Rural Area	140 ns
3GPP – EPA	45 ns
3GPP - ETU	991 ns

Table 36. Delay spread of channel models considered in TUCAN3G

On the other hand, Table 37 defines the correlation matrices for the eNB and UE when considering different number of transmit and receive antennas. Parameters α and β determine the spatial correlation between the antennas and its value is selected depending on the channel propagation conditions: low correlation for NLOS propagation and high correlation for LOS propagation. The selected values for α and β are depicted in Table 38. Thus, the channel spatial correlation matrix can be expressed as the Kronecker product of $\mathbf{R}_{eNB}$ and $\mathbf{R}_{UE}$ according to

$$\mathbf{R}_{spat} = \mathbf{R}_{eNB} \otimes \mathbf{R}_{UE} \tag{7}$$

	One antenna	Two antennas	Four antennas
eNB Correlation $\mathbf{R}_{eNB}$	1	$\begin{pmatrix} 1 & \alpha \\ \alpha^* & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9*} & \alpha^{1/9*} & 1 & \alpha^{1/9} \\ \alpha^* & \alpha^{4/9*} & \alpha^{1/9*} & 1 \end{pmatrix}$
UE Correlation $\mathbf{R}_{UE}$	1	$\begin{pmatrix} 1 & \beta \\ \beta^* & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & \beta^{1/9} & \beta^{4/9} & \beta \\ \beta^{1/9*} & 1 & \beta^{1/9} & \beta^{4/9} \\ \beta^{4/9*} & \beta^{1/9*} & 1 & \beta^{1/9} \\ \beta^* & \beta^{4/9*} & \beta^{1/9*} & 1 \end{pmatrix}$

Table 37. eNB and UE correlation matrices.

Low correlation (NLOS)		High Correlation (LOS)	
α	β	α	β
0	0	0.9	0.9

Table 38. Spatial antenna correlation at eNB (α) and UE (β).

3.4.3 Traffic models:

To capture the system performance in different traffic situations, three traffic models are typically considered [3GPPTR 36.814]:
- Full buffer traffic (continuous traffic).
- FTP model (bursty traffic).
- VoIP model (real time traffic).

3.4.3.1 Full buffer traffic

In the full traffic model, it is assumed that all users in the system have always data to send or receive will be used. This model allows the assessment of the spectral efficiency of the system independently of actual user traffic distribution type.

3.4.3.2 FTP model (bursty traffic)

[3GPPTR 36.814] defines two FTP models (FTP model 1 and FTP model 2), and are currently being considered for simulation in 3GPP for small cells. In FTP model 1, one user downloads a single file with a fixed packet size. The user arrival rate is characterized as a Poisson arrival process. This means

that events occur at times $t(i)$ and the inter-arrival times statistics are exponential, thus, $\tau = t(i+1) - t(i)$ is a random variable with an exponential pdf: $f_\tau = \lambda e^{-\lambda \tau}$. The parameters of FTP model 1 are shown in Table 39.

Parameter	Statistical characterization
File size, S	2 Mbytes (0.5 Mbytes optional to speed-up the simulation). One user downloads a single file
User arrival rate λ	Poisson distributed with arrival rate λ. Possible range of λ: [0.5,1,1.5,2,2.5] for 0.5 Mbytes [0.12, 0.25, 0.37. 0.5, 0.625] for 2 Mbytes

Table 39: FTP model 1 parameters

In FTP model 2, file transfer traffic is characterized by a session consisting of a sequence of file transfers, separated by reading times. The reading time is defined as the time between the end of the download of the previous file and the user request for the next file. The packet call size is therefore equivalent to the file size and the packet call inter-arrival time is the reading time.

Parameter	Statistical characterization
File size, S	0.5 Mbytes
Reading time, D	Exponential distribution, mean = 5 seconds pdf $f_D = \lambda e^{-\lambda D}$, $D \geq 0$, λ=0.2.
Number of users, K	Fixed, posible range of K=[2, 5, 8, 10, 14]

Table 40: FTP model 2 parameters

Recently, a third model (FTP model 3) has been considered which is bases on FTP model 2, with the exception that packets for the same UE arrive according to a Poisson process and the transmission time of a packet is counted from the time instance it arrives in the queue.

The Study on UMTS Heterogeneous Networks FS_UTRA_hetnet proposes a simulation methodology with an FTP traffic model slightly different: while the packet call inter-arrival time is the same, the packet size is also a random variable. The parameters for downlink and uplink bursty traffic model are given in Table 41 and Table 42 respectively [R1-125312 TP].

Component	Distribution	Parameters	PDF
File size (S)	Truncated Lognormal	Mean = 0.25 Mbytes Std. Dev. = 0.0902 Mbytes Maximum = 1.25 Mbytes	$f_x = \dfrac{1}{\sqrt{2\pi}\sigma x} \exp\left[\dfrac{-(\ln x - \mu)^2}{2\sigma^2}\right], x \geq 0$ $\sigma = 0.35, \mu = 12.368$
Inter-burst time	Exponential	Mean = 5 sec	$f_x = \lambda e^{-\lambda x}, x \geq 0$ $\lambda = 0.2$

Table 41: Downlink bursty traffic model

Component	Distribution	Parameters	PDF
File size (S)	Truncated Lognormal	Mean = 0.0625 Mbytes Std. Dev. = 0.0225 Mbytes Maximum = 0.3125 Mbytes	$f_x = \dfrac{1}{\sqrt{2\pi}\sigma x}\exp\left[\dfrac{-(\ln x - \mu)^2}{2\sigma^2}\right], x \geq 0$ $\sigma = 0.35, \mu = 10.982$
Inter-burst time	Exponential	Mean = 5 sec	$f_x = \lambda e^{-\lambda x}, x \geq 0$ $\lambda = 0.2$

Table 42: Uplink bursty traffic model

3.4.3.3 VoIP traffic

A VoIP session is defined as the entire user call time and VoIP session occurs during the whole simulation period. A typical phone conversation is marked by periods of active talking interleaved by silence/listening period. Each active state period can be treated as a packet call and inactive period as the OFF period within a session.

Typically, a two state Markov process (active-inactive) is used to model a VoIP source. The alternating periods of activity and silence are exponentially distributed with average durations of $1/\beta$ and $1/\alpha$ respectively. Hence, the fraction of time the voice source is active is $\alpha/(\alpha+\beta)$. For a voice activity factor of 40%, $1/\beta$ = 1s and $1/\alpha$ = 1.5s.

During the active state, packets of fixed sizes are generated at a regular interval. During the inactive state, a comfort noise with smaller packet sizes can be generated at a regular interval instead of no packet. The size of packet and the rate at which the packets are sent depends on the corresponding voice codecs and compression schemes.

Among the various vocoders, Adaptive Multi-Rate (AMR) is optimized for speech coding and was adopted as the standard speech codec by 3GPP and widely used in GSM. The multi-rate speech coder has eight sources rates, being the maximum one 12.2 kbps. The AMR speech coder is capable of switching its bit rate every 20 ms speech frame upon command. Without header compression, AMR payload of 33 bytes are generated in the active state for every 20 ms and AMR payload of 7 bytes are generated in the inactive state for every 160 ms.

Table 43 shows the VoIP packet size calculation for simplified AMR and G.729 vocoder with or without header compression when using IPv6.

Description	AMRC without header compression IPv6	AMRC without header compression IPv6	G.729without header compression IPv6	G.729without header compression IPv6
Voice payload	7 bytes (inactive), 33 bytes (active)	7 bytes (inactive), 33 bytes (active)	0 bytes (inactive), 20 bytes (active)	0 bytes (inactive), 20 bytes (active)
Protocol header	60 bytes = (RTP: 12 bytes; UDP: 8 bytes; IPv6: 40 bytes)	4 bytes	60 bytes = (RTP: 12 bytes; UDP: 8 bytes; IPv6: 40 bytes)	4 bytes
Generic MAC Header	6 bytes	6 bytes	6 bytes	6 bytes
CRC	4 bytes	4 bytes	4 bytes	4 bytes
Total VoIP packet size	77 bytes (inactive), 103 bytes (active)	21 bytes (inactive), 47 bytes (active)	0 bytes (inactive), 90 bytes (active)	0 bytes (inactive), 34 bytes (active)

Table 43: VoIP packet size calculation.

3.4.4 Interference models

This section provides a model for measuring the impact of the presence of interference on the resulting SNIR for a given user communication. The study will be performed both for downlink and uplink communications. It will be assumed in all cases that the receiver is based on a rake processor that is able to process all the delays of the multipath propagation, where the complex gain of each rake finger matches the amplitude of each multipath component (see [Meh03] for more details).

3.4.4.1 Downlink communication – 3G

In the downlink (DL) there are two sources of interference when analysing the quality of the communication link for a given desired user:

- *Intra-cell interference:* this interference is generated by the signals intended to other users in the same cell and, therefore, transmitted by the same femtocell BS. The signals intended to different users are allocated a different channelization (OVSF) code each from the codes-tree so that, in principle, they should be completely orthogonal even when the length of the codes is different (different users may be allocated a different bit-rate and, therefore, a different spreading factor). Note, however, that due to the fact that all these intracell signals undergo the effect of the multipath propagation, complete orthogonality is no longer true and cross-correlations are not zero. Such effect corresponding to the loss of orthogonality due to the multipath propagation has been modelled in the literature in terms of the orthogonality factor (OF). This OF depends on the channel model and propagation conditions (i.e., the power delay profile of the channel). In the literature, there are some studies that propose some numerical values for some concrete channel models [Awo03].
- *Inter-cell interference:* this interference corresponds to signals transmitted from femtocells different from the one transmitting to the desired user. The signals transmitted from other femtocells use a different scrambling code and are not synchronized with the desired signal.

Based on the two previous interference sources, the resulting SNIR for a given desired user (i-th user) in DL can be expressed as [Meh03]:

$$SNIR_{DL}^{(i)} = \frac{M \cdot P_r^{(i)}}{\beta \cdot (P_{r,in}^{(tot)} - P_r^{(i)}) + I_{out}^{(i)} + N_0}$$,

where $P_r^{(i)}$ is the received power at the i-th MT corresponding to the desired signal, $P_{r,in}^{(tot)}$ is the total received aggregated power corresponding to all the signals transmitted by the same femtocell (intra-cell), $I_{out}^{(i)}$ is the received aggregated power coming from neighbouring femtocells (inter-cell interference), β is the OF, N_0 is the noise power level, and M is the spreading factor (processing gain) being allocated to the communication with the i-th user (i.e., the desired user). All the previous powers are "received powers" and, therefore, they are affected by the channel path loss and the shadowing (the effects of the fast fading will be taken into account by means of an additional margin in the calculation of the link budget to account for the compensation of such effects). These received powers can, thus, be expressed as follows (j is the index of the serving femto-cell to which the i-th desired user is attached):

$$P_r^{(i)} = \frac{P_t^{(j,i)}}{L_{j,i}}, \qquad P_{r,in}^{(tot)} = \frac{P_t^{(j)}}{L_{j,i}} = \frac{\sum\limits_{\substack{n \in \text{intra-cell} \\ \text{users}}} P_t^{(j,n)}}{L_{j,i}}, \qquad I_{out}^{(i)} = \sum\limits_{\substack{k \neq j \\ k \in \text{inter-cells}}} \frac{P_t^{(k)}}{L_{k,i}}$$

In the previous expressions $P_t^{(j,i)}$ is the power transmitted from the j-th femto-BS to the i-th desired user, $L_{j,i}$ is the path loss plus shadowing between the j-th femto-BS and the i-th desired user, $P_t^{(j)} = \sum\limits_{\substack{n \in \text{intra-cell} \\ \text{users}}} P_t^{(j,n)}$ is the total power transmitted by the j-th femto-BS (i.e., the sum of powers transmitted by such BS to all the intra-cell users attached to the j-th femto-BS), $P_t^{(k)}$ is the total power transmitted by the k-th neighbouring femto-BS, and $L_{k,i}$ is the path loss plus shadowing between the k-th neighbouring femto-BS and the i-th desired user whose SNIR is being formulated.

The OF is a scalar factor between 0 and 1 ($0 \leq \beta \leq 1$), where $\beta = 0$ means complete orthogonality and $\beta = 1$ corresponds to no orthogonality at all. In case that the multipath delays are integer multiples of the chip duration, the instantaneous and mean OF can be calculated as [Awo03] [Meh05]

$$\beta = 1 - \frac{\sum\limits_{l=1}^{L} |\alpha_l|^4}{\left(\sum\limits_{l=1}^{L} |\alpha_l|^2\right)^2}, \qquad \overline{\beta} = 1 - \frac{\sum\limits_{l=1}^{L} p_l^2}{\left(\sum\limits_{l=1}^{L} p_l\right)^2}$$,

where α_l and p_l are the complex amplitude and the power of the l-th multipath component, respectively.

Note that the previous expression for the DL SNIR is a bit optimistic in the sense that it does not take into account the self-interference due to the inter-symbol-interference (ISI) caused by the multipath propagation (autocorrelation of two delayed versions of the same code are not completely orthogonal). The way the ISI will affect the final quality of the detection heavily depends on the kind of receiver implemented after the rake combiner (e.g., equalizer).

The previous SNIR metric will be used in link-level simulations in which a minimum SNIR (SNIR requirement) will have to be assured to guarantee a given QoS. This SNIR requirement will be increased taking into account the ISI profile associated to the concrete channel model under study and the kind of detector/equalizer used in the receiver. In other words, the ISI effect that does not appear explicitly in the previous expression will be translated into an equivalent increased minimum SNIR requirement.

3.4.4.2   Uplink communication – 3G

In an uplink (UL) transmission there will be also intra-cell and inter-cell interference. Note, however, that differently from DL transmission, in UL all the users in the same cell as the desired user will be allocated a different scrambling code, as also happens with signals coming from users allocated to neighbouring cells. In addition, there is no time synchronization between UL signals/users in the same cell and, therefore, the orthogonality between OVSF codes cannot be exploited. Based on these considerations, the SNIR for the desired user (i-th user) in UL when the signal is to be detected at the femto-BS can be expressed as [Lai06]

$$SNIR_{UL}^{(i)} = \frac{M \cdot P_r^{(i)}}{P_{r,in}^{(tot)} - P_r^{(i)} + I_{out}^{(i)} + N_0}$$

where $P_r^{(i)}$ is the received power at the femto-BS coming from the i-th MT (desired signal), $P_{r,in}^{(tot)}$ is the total received aggregated power at the same femto-BS coming from all the users in the same femtocell (intracell), I_{out} is the received aggregated power coming from users in neighbouring femtocells (intercell interference), N_0 is the noise power level, and M is the spreading factor (processing gain) being allocated to the communication with the i-th user (i.e., the desired user). As commented when presenting the metric for the DL case, all the powers in the SNIR metric for UL are "received powers" and, therefore, they are affected by the channel path loss and the shadowing (the effects of the fast fading will be taken into account by means of an additional margin in the calculation of the link budget to account for the compensation of such effects). These received powers can, thus, be expressed as follows (j is the index of the serving femto-cell to which the i-th desired user is attached):

$$P_r^{(i)} = \frac{P_t^{(j,i)}}{L_{j,i}}, \qquad P_{r,in}^{(tot)} = \sum_{\substack{n \in \text{intra-cell} \\ \text{users}}} \frac{P_t^{(j,n)}}{L_{j,n}}, \qquad I_{out}^{(i)} = \sum_{\substack{k \neq j \\ k \in \text{inter-cell k-th femto-cell}}} \sum_{n \in \text{users in}} \frac{P_t^{(k,n)}}{L_{n,j}}$$

In the previous expressions $P_t^{(j,i)}$ is the power transmitted from the i-th desired user to the j-th femto-BS, $L_{j,i}$ is the path loss plus shadowing between the i-th desired user and the j-th femto-BS, $P_t^{(j,n)}$ is the power transmitted from the n-th intra-cell user to the same j-th femto-BS, $L_{j,n}$ is the path loss plus shadowing between the n-th intra-cell user and the same j-th femto-BS, $P_t^{(k,n)}$ is the power transmitted from the n-th user attached to the k-th neighbouring femto-BS, and $L_{n,j}$ is the path loss plus shadowing between the n-th cell user attached to the k-th neighbouring femto-cell and the j-th femto-BS (i.e., the femto-BS serving the ith desired user whose SNIR is being formulated).

As in the DL case, the previous metric does not include the ISI caused by the self-interference coming from the own desired signal due to the multipath propagation. The way this ISI affects the final detection quality and how this has to be dealt with when performing link level simulations is the same as explained in the case of the DL transmission.

3.4.5 PHY-Layer abstraction

This section provides the PHY-layer abstraction to be used in the simulations according to the radio interface technology.

3.4.5.1 3G-UMTS

For the case of 3G-UMTS, the PHY abstraction model will be based on a maximum achievable rate provided by the PHY layer. In other words, upper layers will see the PHY just as a "black box" that is able to provide a given rate. Such rate is directly related with the SNIR and can be calculated in DL and UL for a given user as follows (these expressions are based on the interference models presented previously in this deliverable and approximating such interferences as Gaussian distributed):

For the downlink, the signal not noise plus interference ratio, the normalized (b/s/Hz) and the absolute (b/s) achievable rates for a given i-th user are:

$$SNIR_{DL}^{(i)} = \frac{M \cdot P_r^{(i)}}{\beta \cdot (P_{r,in}^{(tot)} - P_r^{(i)}) + I_{out}^{(i)} + N_0}$$

$$\overline{r}_{DL}^{(i)} = \log_2\left(1 + SNIR_{DL}^{(i)}\right) \quad b/s/Hz, \qquad r_{DL}^{(i)} = \frac{3.84 \cdot 10^6}{M} \log_2\left(1 + SNIR_{DL}^{(i)}\right) \quad b/s$$

For the uplink, the signal not noise plus interference ratio, the normalized (b/s/Hz) and the absolute (b/s) achievable rates for a given i-th user are:

$$SNIR_{UL}^{(i)} = \frac{M \cdot P_r^{(i)}}{P_{r,in}^{(tot)} - P_r^{(i)} + I_{out}^{(i)} + N_0}$$

$$\overline{r}_{UL}^{(i)} = \log_2\left(1 + SNIR_{UL}^{(i)}\right) \quad b/s/Hz, \qquad r_{UL}^{(i)} = \frac{3.84 \cdot 10^6}{M} \log_2\left(1 + SNIR_{UL}^{(i)}\right) \quad b/s$$

The parameters appearing in the previous expressions were already presented in the section of this deliverable devoted to the interference models.

3.4.5.2 LTE

When all the subcarriers allocated to one receiver are modulated using the same modulation and coding scheme (MCS) as in LTE, a compression function to map the instantaneous values of SNIRs to one single MCS value is required. Despite there are different possibilities, the EESM (Exponential Effective SINR Mapping) has shown to yield an accurate estimation of the AWGN-equivalent SINR (usually referred to as 'effective SINR') for frequency selective channels, so we used this metric for the simulations. The EESM method estimates the effective SINR using the following formula:

$$SINR_{eff} = EESM\left(\gamma, \beta\right) = -\beta \ln\left(\frac{1}{M} \sum_{i=1}^{M} e^{-\frac{\lambda_i}{\beta}}\right)$$

where the λ_i's are the per sub-carrier SINR values, and β is the parameter to be determined for each MCS level. This value is used to match the actual BLER and the predicted BLER from the effective SINR in the AWGN channel. For the simulation results we have considered the MCSs available in LTE-A (15 values ranging from 0.1523 to 5.5547), along with the effective SINR and β values provided in [TUWIEN13], obtained through extensive simulations using the LTE codes. For each MCS value, the effective SINR is the effective SINR required for a BLER less than 10% when using

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the MCS value. As shown in **Figure 39**, the relationship between the MCS and the required effective SINR (red points) can be approximated by the following empirical SINR-to-MCS mapping function (solid blue line), with k=1.2213:

$$MCS\left(SINR_{eff}\right) \cong k \cdot \ln\left(1 + SINR_{eff}\right)$$
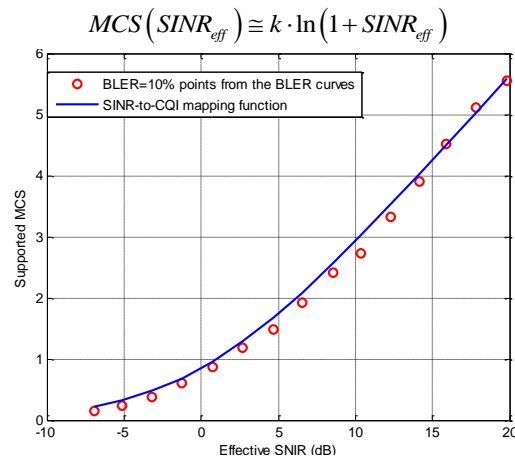
Figure 39. MCS mapping.

4 TRANSPORT NETWORKS PERSPECTIVES

4.1.1 System requirements

The transport network in TUCAN3G is seen as "anything" that can be used to connect rural femtocells providing access to telephony and broadband data services to the operator's core network. Femtocells are controlled remotely by a femtocell controller that is installed in the operator's network. This segment in an operator's network architecture is normally denominated "backhaul". Usually, technologies used for backhaul are reliable PtP links of enough capacity that can be either wired or wireless depending on the available infrastructures. When wireless technologies are used, licensed bands are commonly preferred because reliability is otherwise compromised. However, TUCAN3G focuses on isolated rural areas where the cost reduction obtained by using non-licensed bands may be considered due to the relative lack of interferences in those bands. It is also possible that the target area has already wireless communication networks deployed that can be partially used (shared under the form of virtual circuits), hence reducing even more the costs. In this scenario, the following requirements are to be considered by the transport network:

- Communication between femtos and the femto controller must be possible with the quality and reliability required by the access network.

- The transport network must provide the access network with enough capacity to transport users' traffic when connections are accepted with the quality that the operator needs to guarantee to the users.

- The transport network needs to be predictable in terms of available resources and quality of service. The access network need have a mean to know the available resources prior to accept a user's connection.

- The transport network needs to be able to distinguish between control traffic between femtos and controller, user interactive voice traffic (telephony) and other traffic classes, in order to perform priorities and differentiated end-to-end quality of service levels.

- The transport network may be formed of different segments depending on the required performance, the available infrastructures, the available bandwidths, the distances to cover and other considerations. However, any compatibility and interoperability issues shall be solved in order to provide the access network a transparent IP connection to the operator's core network of predictable capacity and end-to-end behavior.

4.1.2 Radio requirements

The frequency bands used must be appropriate for stable communications. In urban areas, this condition usually can only be met by licensed bands. However, in remote rural areas in which there are not any previous communications infraestructures some non-licensed bands may be considered as free of interferences.

Non-licensed bands will be considered in this project for the transport network, except for the case of satellite communications. This is seen as a most favorable case from the economic point of view (the operator does not need to pay for a license and equipments that operate in those bands use to be less expensive) and a worst case regarding the quality due to the possibility of suffering severe interference. Alternative solutions operating in licensed bands are seen in this project as a ultimate possibility.

The calculations of path loss in WiFi and WiMAX links will be based in ITM models, and particularly in the Longley-Rice model [Long1968].

4.1.3 Management requirements

The transport network must be manageable. It must be possible to use a network management system to monitor and control all the systems in the network. Additionally, the capacity of communications systems to adapt dynamically their operational parameters will be analysed in order to optimize performance and efficiency.

As already explained in previous sections, communications systems considered here are adaptive in terms of modulations and coding techniques used. Additionally, other strategies will be studied in order to improve performance and reduce power consumption.

4.2 Technical scenarios

The scenarios regarded by the TUCAN3G are rural areas that are far away from well-connected places. Rural femtocells may be deployed in remote villages, and the mission of the transport network is to connect those femtocells to the operator's core network. It is assumed that the transport network need to use wireless technologies to cover distances of tens or even hundreds of kilometers. In most of the scenarios, several hops will be required, and a common transport infrastructure will be used to serve several villages, and several femtocells in each village.

The use of satellite communications is considered for scenarios that need to cover extremely long distances between the operator's core network and the access network; more details will be given below. For the rest of the cases, and even for the connection of several femtos to a comon satellite comunications gateway, a combination of WiFi and WiMAX will be explored. This does not mean that other alternatives may not be used; the results of this project related to the transport and the access networks are relatively independent. Both share a common objective of proposing low-cost appropriate technologies that may help operators to provide access to sparsely populated remote villages. In the case of the transport network, the technologies considered are relatively cheap, may be used in non-licensed bands, have a low power consumption profile, may provide broadband data transport services and may support QoS at a certain level. However, other professional solutions commonly used as backhaul for small cells can be considered as an alternative in the scenarios where TUCAN3G proposals for transport networks don't show improved results.

4.2.1 Traffic assumptions

- The transport network may be dedicated or shared. In either case, the circuit connecting each femtocell to the operator's core network must transport different traffic classes. It is expected to differentiate: control traffic, telephony and data traffic as a minimum. If the access network needs to differentiate more traffic classes, the appropriate information must be given to WP5's research team. The transport network assumes that different traffic classes require different QoS levels and the QoS requirements must be specified to the WP5 as soon as possible in order to adequate the research results to the real requirements.

- It is assumed that different traffic classes must receive different priorities, and a minimum QoS support would consist of a unified end-to-end strategy in the transport network to give consistent relative priorities to the different classes.

- It is also assumed that certain traffic classes have strict requirements in terms of throughput (maximum and minimum), delay (maximum), jitter (maximum) and packet loss (maximum). It is expected to know any relevant characteristics about each traffic class. It is expected to receive this information from WP4.

- Different traffic classes have different statistical characteristics. Traffic classes must also be characterized in this sense.

- Any known behavior of traffic evolution during the day is also relevant.

For the characterization of traffic in both analytical and empirical tasks, the same traffic models proposed in section 3.4 for the access network will be used for the transport network.

4.2.2   Deployment constraints

Scenarios are considered following these rules:

- Access networks that are too far for any point of presence of the operator's core network require a terrestrial wireless transport network to connect the femtocells to a gateway (using any combination of WiLD and WiMAX links) and a satellite link that connects the gateway to the operator's network.

- Access networks that can be deployed using terrestrial hops less than 50 km long and may be connected to the operator's network following this rule will not require a satellite link.

- Links that are closer to towns and may be influenced by urban wireless networks operating in non-licensed bands will use licensed frequencies or a non-licensed band that is known to be relatively free of interferences.

- Sites don't need to have electricity. If stable electricity is available locally, it can be used, but communications systems can be powered using solar photovoltaic systems or by other alternative means.

- Links will be considered reliable under the following conditions:
    - RF planning with appropriated propagation models shows availability 99,9% of the time
    - Sites must be known to be accessible and physically protected.
    - Line of sight (LOS) must be assured for each hop. In environments where unexpected obstacles may block the LOS, extra altitude will be assured for the antennas in order to guarantee LOS.

- Links will be considered usable under the following conditions:
    - End-to-end availability meets the operator's requirements
    - Link is considered reliable
    - Link has enough stable capacity to transport expected traffic.

- Transport networks are expected to be multi-hop. Cochannel operation is not considered an option. Hence, the number of links ending to a common site is limited by the number of available non-overlapping channels.

- Redundancy is highly desirable if an availability threshold must be assured.

4.3   Radio transport technologies

There are two options in transport technologies:

- Wired networks (pair cable, coaxial cable or optical fiber): with high capacity and null interference with other networks.

- Wireless networks: with interference with other networks, with lower capacity and where the attenuation decreases the coverage, but with lower cost of network deployment.

In rural areas the deployment of wired networks is often neither reasonable nor worthwhile. In contrast, the features of the rural scenarios reduce the drawbacks of the wireless networks (lower capacity demand; and the scarce presence of other networks produce a significant decrease in the interference) and increase the advantages (the infrastructure is concentrated in selected geographical locations; no needs of maintenance or supervision out of this locations; and the network deployment is faster and with lower cost compared with wired networks).

Consequently, the options to offer voice and broadband data connectivity in isolated rural areas are radio transport technologies: WiFi, WiMAX and VSAT.

4.3.1   WiLD (WiFi-based Long Distance) networks

The first WiFi standards (IEEE 802.11a y IEEE 802.11b) [IEEE802.11-1999, IEEE802.11a-1999,IEEE802.11b-1999] were conceived for WLAN (Wireless Local Area Networks). The main obstacle to the application for long distances is their MAC (Medium Access Control) protocol: CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). This protocol is very sensitive to the propagation delay and its performance level decreases with the distance between stations.

The WiFi standards are:

- IEEE 802.11b: year 1999; frequency band: 2,4GHz; physical layer: DSSS (Direct Sequence Spread Spectrum). Bit rates may be as high as 11 Mbps with a real total capacity of less than 7,5 Mbps.

- IEEE 802.11a: year 1999; frequency band: 5GHz; physical layer: OFDM (Orthogonal Frequency Division Multiplexing). Bit rates are as high as 54 Mbps with a real total capacity of less than 30 Mbps.
- IEEE 802.11g [IEEE802.11g-2003]: year 2003; frequency band: 2,4GHz; physical layer: OFDM; and DSSS compatible with 802.11b. Bit rates are as high as 54 Mbps with a real total capacity of less than 32 Mbps.

2,4GHz and 5GHz are non-licensed bands, but not free-transmission bands. Different countries impose different restrictions in the maximum transmission power and, sometimes, in the antenna gain.

Latter amendments improve the performance of these standards. The more relevant are:

- IEEE 802.11e: year 2005; this introduces traffic differentiation and prioritization.

- IEEE 802.11n: year 2010; this increases the real bit rate theoretically up to 300Mbps under optimal conditions.

All these standards in the 802.11 family were included in a revised version of the IEEE 802.11 standard published in that year [IEEE802.11-2012].

WiFi standards define two types of nodes: AP (Access Point) and STA (Stations); and two modes: infrastructure (the STAs only communicate through an AP that performs like a base station) and ad-hoc mode (a STAs can communicate directly with others STA). The optimal behavior is achieved in infrastructure mode. Many links in the transport network considered in this project are point-to-point links, in which case WiFi can be used if one end is an AP and the other end is a STA.

In the following we provide some more relevant details about these standards:

a) **IEEE 802.11 for a normal use**

– In the 2,4 GHz band, channels are 22 MHz wide but channels are spaced 5 MHz. Hence, consecutive channels overlap. Non-overlapping channels are as much as three: 1-6-11. On the contrary, on the 5 GHz band channels are 20 MHz wide and are spaced 20 MHz. Hence, adjacent channels don't overlap.

– The standard permits also to consider 10 MHz and 5 MHz channels. The consequence of reducing the bandwidth is twofold: (i) the sensitivity is improved because the received noise is reduced, hence improving the link budget, and (ii) the bit rate is reduce in the same proportion.

– The medium access control uses a mechanism named CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). This is a distributed mechanism in which each station uses a well-known strategy that minimizes the probability of transmitting at the same time with another station, but there is not a coordinator that determines when any given station may transmit. Collisions may occur and, in such cases, retransmissions are required. Hence, normal transmissions must be acknowledged so that the transmitting station verifies whether the transmission was successful, or it collided and a retransmission is required. This mechanism has the great advantage of its simplicity but it is not efficient at all. That is why there is a big difference between the physical bit rate and the maximum available capacity in any WiFi network.

– There are several different coordination functions described in the standard (i.e. different ways the stations may coordinate with each other in order to reduce or eliminate the risk of collisions). However, some of these functions have never been implemented by the industry. Moreover, the first implemented coordination function that is widely available is DCF (Distributed Coordination Function) and it does not permit to differentiate traffic classes. Hence, only the EDCA (Enhanced Distributed Control Access) will be considered.

– EDCA (Enhanced Distributed Channel Access) defines four AC (Access Categories or traffic classes): Voice, Video, Best Effort y Background. This permits to give up to four different statistical priorities to up to four traffic classes. Other two mechanisms may be used to improve the performance and to give different opportunities to the AP: the TXOP (transmission opportunity), that permits to transmit more than one frame without contention when it is higher than zero, and Block-ACK, that permits to avoid a lot of inefficient acknowledgements.

– There is not any mechanism in WiFi that permits to ensure strict QoS support. This means that we cannot limit the maximum delay, the minimum throughput, or the maximum packet loss for a given traffic class. Only priorities can be established. Further QoS support needs complementary mechanisms at the IP layer and the assurance of being operating far from the saturation point. The network is said to be in saturation when a higher offered load does not drive to a higher throughput but to a higher number of collisions. Hence, the conditions to use WiFi systems in a network that needs to guarantee QoS parameters are: (i) EDCA is available and correctly used, (ii) advanced traffic control may be performed at the IP layer, and (iii) the access network does not offer load to the transport network beyond the saturation point at any time.

– There is not any admission control mechanism in WiFi. Such a mechanism is foreseen but it is supposed to be implemented at a higher level.

− The traffic classification from higher layers is very important. The IP packets are marked by the generating application in accord to the DiffServ model (a 6 bits value in the Type of Service octet named DSCP). The 802.11e equipment must to establish the correspondence between the DiffServ values and the priorities defined in EDCA.

− IEEE 802.11n incorporates several improvements that increase the nominal bit rate to 600 Mbps under optimal conditions. The bandwidth may be increased to 40MHz, some parameters are optimized, several mechanisms such as frame aggregation are introduced, etc. in order to foster the performance. But the most significant improvement of 11n is spatial diversity with MIMO (Multiple Input Multiple Output) transmission, that implies the possibility of spatial streams, beamforming, STBC (Space.Time Block Coding) and spatial multiplexing; and the definition of 127 MCS (Modulation and Coding Schemes).

b) **WiFi over long distances**

[Baugh2003] were the first to propose the use of WiFi over long distances in the scientific literature, but only in 2010 [Simo2010] modeled and explained completely how to adapt WiFi for long distances and how to predict its performance. The PHY layer and the MAC layer establish limits in the coverage distance.

- In PHY layer, the higher nominal bit rates are achieved with powerful modulations and low redundancy coding schemes, but it only works in short distances because the received power must be high. So, the bit rate decreases with the distance. In point to point transmissions the transmitted power is the allowed maximum and the antenna gains are high. Figure 40 shows how long distances can be reached only if high gain directive antennas are used.
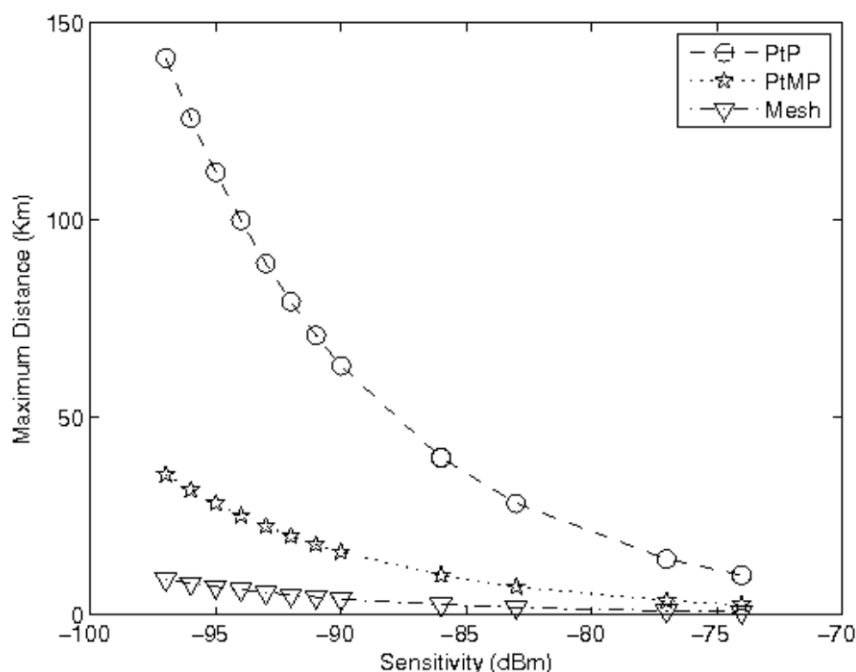
Figure 40. Achievable distance for point to point, point to multipoint or mesh WiFi links. For omnidirectional antennas, a gain of 12dBi is considered, and for directive antennas 24dBi are asumed.

- In principle, CSMA/CA is unsuitable for long distances because the propagation delay affects the contention for distances longer than a few hundred meters. The longer the distance is, the worse the performance becomes. There are three different possible strategies for adaptation of WiFi systems to long distances:

  o In the year 2007 WiFi is redefined as suitable for WMAN (Wireless Metropolitan Area Network). The standard introduces the Coverage Class, a numeric value that defines the MAC parameters to operate in diverse distances. For the highest Coverage Class, the coverage distance reaches 15Km. If the distance is shorter than 15 Km, hardware systems that are 802.11-2007 compliant may be configured this way to perform optimally. However, there is a certain loss of performance as the distance grows from a few hundred meters up to 15 Km.

  o WiLD adaptations to CSMA/CA: the loose of performance with long distances may be reduced by adapting three MAC parameters in a non-standard fashion (that is possible with certain hardware systems): the SlotTime, the ACKTimeout and the CTSTimeout. The loose of performance is a bit higher in this case than in the previous one, but the coverage distance may reach up to 105 km for 802.11b, or approximately 50 km for 802.11a/g with available hardware systems.

  o Alternative MAC systems: modern WiFi chipsets are flexible enough to replace the medium access control mechanism. Some industrial and academicals actors have proposed TDMA mechanisms that perform better for long links (or, at least, the performance does no longer depend on the distance beyond the power budget). Ubiquity AirMAX or Mikrotik Nstreme2 are some popular solutions of this kind. Moreover, products that implement these alternative MAC solutions also implement CSMA/CA (usually with EDCA) and one can chose what of the MAC alternatives must be used in a given scenario.

- The adaptation of 802.11e for traffic differentiation over long distances in CSMA/CA (either standard or the WiLD adaptation) is straight-forward. Beyond that, 11e also offers the BlockACK facility that has been demonstrated useful to improve the performance, especially over long distances. The same thing happens with frame aggregation in 802.11n.

- The use of MIMO in 802.11n may also be of some use for long links, but the benefit is more limited here than in short distances and has not still been adequately measured or modeled.

We have briefly introduced the main characteristics and limitations of WiFi and its adaptation to long links. This information can be found in a number of scientific articles and academic works. However, going more in depth we find that the information we have about each of the WiLD solutions is not enough to compare them adequately. Also the comparison of the underlying physical versions of WiFi is not obvious up to date. And, of course, the comparison of the QoS support and the performance of WiFi together with IP is still to be adequately compared with WiMAX. The goal here is to be able to propose the best suited technology (or combination of technologies) for a given scenario. This is only possible if we can compare these technologies under the same parameters, which is one of the objectives of WP5 in the TUCAN3G project.

4.3.2 WiMAX (Worldwide Interoperability for Microwave Access)

The IEEE 802.16 (currently the 802.16-2009 version) was designed for WMAN and is suitable to provide coverage to isolated areas with low cost and low time of deployment. The standard, designed by operators, provides advantages like equipment interoperability, great robustness, higher security

and the possibility to offer strict QoS support to all the communications in the network. It includes flexibility in the frequency bands (licensed and non-licensed) and in scenarios (fixed or mobile).

Network architecture:

There are three defined nodes: BS (Base Station), SS (fixed subscriber station) and MS (mobile subscriber station). SS or MS only can connect through a BS (point to multipoint connection). The BS rigorously manages the medium access and assigns the resources to the subscriber stations (and even assigns resources to each connection in each subscriber station) to guarantee the QoS required by each traffic flow depending on its nature and avoid any collisions.

MAC Layer:

The communications are connection oriented and the resource scheduling is deterministic to ensure several levels of QoS (throughput, delay, jitter…) to each connection.

- Resource management: Grant/Request. The BS allocates resources to the SS and each SS allocates its resources to its different connections depending on their specific needs.

- Admission control: The BS only accepts a new connection when it doesn't compromise all the QoS requirements.

- Scheduling services: several types of services are offered:
  - UGS (Unsolicited Grant Service): Periodic frames with fixed size. It guarantees a minimum throughput and a maximum jitter. Suitable to T1/E1 connections and telephony.
  - rtPS (real-time Polling Service): Real time traffic with periodic frames with variable size. It guarantees a minimum throughput and a maximum delay. Suitable to MPEG video coded.
  - ertPS (extended rtPS): It joins the advantages of the previous services. Real time traffic with periodic frames with variable size, like VoIP with suppressed silences. It guarantees a minimum throughput and a maximum delay.
  - nrtPS (non-real-time Polling Service): It guarantees a minimum throughput.
  - BE (Best Effort service): It doesn't guarantee any QoS parameter.

PHY Layer:

The frequency range, the modulation and the duplex method define the four PHY layers considered in the standard:

- WirelessMAN-CS: with LOS; unique carrier; 10-66GHz; TDD or FDD (Time/Frequency Division Duplex).

- WirelessMAN-OFDM: fixed P2MP without LOS; below 11GHz; TDD or FDD; multiple accesses with TDMA.

- WirelessMAN-OFDMA: below 11GHz; OFDMA to reach a tradeoff between consumption and throughput; TDMA/OFDMA.

- Wireless-HUMAN: OFDM or OFDMA in 5GHz; TDD.

Adaptive modulation: in long distances the system needs more robust modulations and the throughput or bit rate decreases.

The maximum bit rate depends on the PHY layer, the number of SS and the connection channel state.

4.3.3   VSAT

The objective of the satellite links in TUCAN3G is to serve as IP transport network between gateways and the operator's network, mainly where the distance between gateways and operator's network is longer than 50 km.

Satellite links offered by satellite service providers are very diverse as there are different satellite systems, orbits, topology designs, frequency bands, technology standards and industry implementations.

Satellite links for TUCAN3G must be selected according to a balance of performance/cost and possibilities of availability of service providers. The objective is to select a VSAT (Very Small Aperture Terminal) station for the gateway and a satellite service provider with space segment and platform so the VSAT station at the gateway could communicate to the operator's network.

In the following paragraphs, we will show the main alternatives and the best options available for TUCAN3G, for the lab test, for the proof of concept and for deployment in different scenarios.

4.3.3.1   Satellite orbit

For broadband access and IP backhauling, the group of services where the cellular backhauling needed for TUCAN3G can be considered into, and assuming that the locations for the stations are fixed, it is industry accepted that the best performance/cost solution for a satellite link is using a GEO (Geostationary Earth Orbit) satellite.

A geostationary orbit is a particular type of geosynchronous orbit. It is a circular orbit 35,786 kilometres above the Earth's equator and following the direction of the Earth's rotation. A satellite in such an orbit has an orbital period equal to the Earth's rotational period (one sidereal day), and thus appears motionless, at a fixed position in the sky, to ground observers. The satellite antennas that communicate with the satellite do not have to move to track the satellite; they are pointed permanently at the position in the sky where the satellite stays.

While it is industry accepted that GEO satellites are the best option for fixed broadband access or IP backhauling, there are also recently industry developments and studies to offer these types of fixed services using MEO (Medium Earth Orbit) satellites.

MEO is the region of space around the Earth, located above LEO (Low Earth Orbit, altitude of 2,000 kilometres) and below GEO (Geostationary Earth Orbit, altitude of 35,786 kilometres). MEO satellites are widely used for navigation and geodetic/space environment science. The orbital periods of MEO satellites range from about 2 to nearly 24 hours. Examples of satellite systems in MEO for navigation are GPS (Global Positioning System) and Galileo.

The most representative initiative for providing fixed broadband access and IP backhauling using MEO satellites is O3b ("Other 3 billion"), with it is under final deployment and it is planned to be operational by the end of 2013. With an altitude of 8,063 km, it is designed for telecommunications and data backhaul from remote locations located at latitudes no longer that ±45°.

As MEO satellites are not fixed in the sky from the point of view of a ground observer in Earth, these satellites are not single ones and the system in composed of several ones, and named constellation. If used for fixed broadband access or IP backhaul, there is the need of using at least two antennas with tracking devices. Each antenna moves and tracks one visible satellite, and a switchover of the communications link from one antenna to the other is done periodically as one antenna is losing visibility of one satellite and the other one is locked to the next satellite in the constellation.

Using MEO satellites instead of GEO satellites improve IP communications performance, as the delay is significantly reduced. IP communications trough a GEO satellite has an RTT (Round- Trip delay Time) of 600-650ms, while with MEO satellites it can be reduced four or five times (RTT estimated for O3b is 130-140ms). This improvement is especially important when backhauling GPRS/EDGE and 3G traffic, whose performance is very sensitive to delay in the transport network.

Another difference between GEO and MEO satellite systems, for broadband access and backhauling, is that GEO satellites can provide full coverage to the Earth (but Poles) with only 3 satellites (if strategically deployed in the orbit, covering 120º each one), while with MEO satellites more are needed. For example, O3b will start with 8 satellites, to be upgraded to 12 and 16.

Increase in cost of antenna subsystem to be able to track at least two MEO satellites, comparing to one single antenna pointed to a GEO satellite, makes difficult to adopt this type of solutions for backhauling in very remote areas with very low traffic needs. They will be widely used for backhauling between medium and big cities with high demand of traffic. Also, it has to be noted that energy consumption of a remote station under a MEO satellite constellation will be significantly greater than the standard energy consumption of a remote station for a GEO satellite, due to the consumption of the tracking motors of the antennas and its controllers, and the need in most of the implementations of maintaining two satellite modems working, one connected to each antenna, to switch traffic between them according to visibility of satellites.

So according to the objectives and requirements of TUCAN3G, the best option is to use a GEO satellite, as there will be more available satellites and the satellite terminal will be cheaper.

4.3.3.2 *Architecture and topology*

Regarding architecture design for the satellite link, there are three basic topologies to be considered on the GEO satellite links used for broadband access and backhauling (also valid for MEO satellites):

1. VSAT network in star-topology. It is composed of a central station, usually named HUB, and a group of remote sites, usually named VSATs. The bandwidth is shared for both TDM outbound carrier (from HUB to VSATs) and TFDMA inbound carrier (form VSATs to HUB). Standard DVB-S/DVB-S2 is commonly used for the outbound carrier, while DVB-RCS or technology-proprietary standards are used for inbound carriers. Sharing the bandwidth, reducing the remote antenna size, and massive manufacturing of remote VSAT modems, reduces pricing of the service, so this topology is widely used for satellite networks dedicated to broadband access (Internet or VPN connectivity).

2. SCPC link with point-to point topology. This is the topology most used in the past for satellite links. It is still used for different backhauling services and private communications. Main characteristic of this type of leased link is the guarantee of the bandwidth. As bandwidth is a very scarce and expensive resource, these type of links are only efficient with this guarantee is needed.

3. Hybrid MCPC/TDM-SCPC network in star-topology, with a shared MCPC or DVB-S/DVB-S2 carrier, shared by several remote sites, and leased (dedicated) SCPC return links.

This topology tries to join the best characteristics of the other two ones, and it is best suited for backhauling IP and cellular traffic, when the traffic demand is high.

While architectures 2 and 3 offer better performance for cellular backhauling (greater throughput, less delay, minimum jitter), architecture 1 has showed on several field deployments as valid for backhauling when the traffic demand is low, assuming that this architecture has characteristics that impact performance of the backhauling when the traffic demand is high.

According to the objectives and requirements of TUCAN3G, the best option is to use a VSAT terminal under a star-topology network. There are several networks of this type already deployed and available. With the needed customization and tests, this satellite link can provide enough performance. However, there is the need of analysis of the terrestrial connectivity between the HUB and the operator's network, which can be done through Internet or a private (VPN) connection.

4.3.3.3 *Frequency bands*

Regarding frequency bands on satellite links, for broadband access and backhauling, there are three frequency bands mainly used:

- C-band. The first frequency band that was allocated for commercial telecommunications via satellites. Nearly all C-band communication satellites use the band of frequencies from 3.7 to 4.2 GHz for their downlinks, and the band of frequencies from 5.925 GHz to 6.425 GHz for their uplinks. Minimum antenna size on C-band capable VSAT stations is 1.8 − 2.4 meters (diameter of the parabolic reflector), depending of satellite and network.

Band	Transmit Frequency (GHZ)	Receive Frequency (GHz)
Standard C-Band	5.850–6.425	3.625–4.200
Extended C-Band	6.425–6.725	3.400–3.625
Super-Extended C-Band (Insat)	6.725–7.025	4.500–4.800

C-band is primary selected today for satellite links when connecting locations in heavy rainfall areas (like Amazonas region) and communication's availability is critical. Attenuation caused by the rain is minimal on C-Band, so better availability in the link can be achieved. As a disadvantage, satellite C-Band can interference with terrestrial microwave systems, and the antennas are bigger than systems based on Ku-band or Ka-band.

- Ku-band. The International Telecommunication Union (ITU) splits the band into multiple segments that vary by geographical region. Commonly, transmission bands are named "standard" and "extended", while reception bands are named "low band" and "high band":

    Frequency bands for Transmission:
        Standard Ku-band: 14.00 to 14.50 GHz.
        Extended Ku-band: 13.75 to 14.25 GHz.

    Frequency bands for Reception:
        Low Ku-band: 10.70 to 11.70 GHz.
        High Ku-band: 11.7 to 12.75 GHz.

Compared with C-band, Ku-band is not similarly restricted in power to avoid interference with terrestrial microwave systems, and the power of its uplinks and downlinks can be increased. This higher power also translates into smaller receiving dishes, and broadband service is possible with antennas from 0.9 meters (diameter of the parabolic reflector) and generally cheaper than service based on C-band.

The main disadvantage of Ku-band is the degradation than occurs due to the problems caused by and proportional to the amount of rainfall, commonly known as "rain fade".

This problem is mitigated by:
- Deploying an appropriate link budget, allocating a higher power consumption to compensate rain fade loss.
- Implementing some mechanisms in the satellite network (modulators and demodulators) to dynamically adapting the mod-cod to the weather conditions and rain fade attenuation. This is named ACM (Adaptive Coding and Modulation).

- Ka-band. C and Ku bands are the most used ones in commercial satellite communications, while Ka-band is relative new and it is now starting to be adopted in new satellites, some of them partially, some of them fully configured for Ka-band.

  It is especially notorious the use of Ka-band in addition to frequency reutilization that has been applied to satellites like Viasat-1 (with coverage in USA and Canada) and KA-SAT (with coverage focused in Europe). These fully Ka-band satellites, and the ground segment infrastructure associated to them, are specifically designed to provide broadband access at high speeds (20Mbps download, 6 Mbps upload), with small antennas (0.75m) and at competitive prices, similar to terrestrial DSL.

  As a disadvantage, the Ka-band is even more affected than Ku-band by the rain fade. In these cases, the problem is mitigated by using more than one HUB station in the star-topology. The different HUB stations can handle traffic from different groups of remote VSAT stations, according to weather conditions on each HUB site. Also ACM, as developed in Ku-band systems for modulators and demodulators to dynamically adapting the mod-cod to the weather conditions and rain attenuation, is used.

Usually, the selection of satellite and frequency band is associated to the platform deployment made by the satellite service provider, so choosing a satellite service provider implicitly includes choosing of platform, satellite and frequency band.

Any of the frequency bands can be used for TUCAN3G, if the special characteristics of each one are taken into the consideration and meet the requirements.

4.3.3.4   Modulation-Codification, traffic rate and power

Traffic rate (and so bandwidth) needs to be sized as per the needs of the femto-cell to be used and tests to be done. While a voice communication do not need a big amount of traffic, 3G data communications need more traffic. A test for traffic strangling because of the effect of the satellite delay needs to be done, to optimize the maximum throughput than the small-cell can achieve due to this limitation.

Modulation-Codification, antenna size and transmit power for the VSAT remote station must be selected and calculated according to the satellite and the network where the VSAT terminal will be running. The service provider does this as a standard satellite link budged, and it is normally pre-calculated for the region where the service is available, according to the satellite footprint and the characteristics of the HUB and the network. As the antenna and transmit power of the HUB station are fixed, the possibilities of antenna/power/mod-cod for remote VSAT sites are also fixed for the different traffic rates and year availability.

If using a VSAT network based on the standard DVB-S/DVB-S2 with DVB-RCS, the availability of modulation-codification possibilities is fixed in the standard, but not all the technology providers and

its deployments support all the possibilities. If using any technology-proprietary standard, there are several other possibilities of modulation-codification, usually developed to obtain better performance under some circumstances/scenarios. For example, some satellite modem manufactures have developed their own codification techniques than get the benefits of robustness and efficiency of DVB-S2, while avoiding their lack of performance for low traffic rates because of the delay in codification. Also, different proprietary mechanisms have been developed for modulators and demodulators to dynamically adapting the mod-cod to weather conditions and rain attenuation.

The market in VSAT terminals is dominated by manufactures that do not follow the standard DVB-S2/RCS (Hughes Network Systems, Gilat, Viasat, iDirect, …). In these cases, each network only accepts their own terminals.

Also, not all the implementations adopted by satellite service providers are compatible with all the possibilities available in the technology design. It is important to select a new or recently updated network platform, with newer hardware revision and latest software upgrades. Most of the improvements with new hardware revisions and software upgrades enhance bandwidth efficiency and management of IP traffic.

If it is preferred to use a network based on DVB-S2/RCS standard, it has to be taken into consideration that not all the DVB-S2/RCS terminals are fully compatible with all the DVB-S2/RCS networks, and a confirmation of compatibility needs to be done.

4.3.3.5   *VSAT broadband access for cellular backhauling*

Standard IP interface on satellite VSAT modems is a 10/100Base-T port, usually only IPv4-compatible, with DHCP, standard routing capabilities (RIP, static routes…) and basic prioritization of the traffic. These features are usually enough to provide basic Internet broadband access or VPN connectivity, and they can also be enough to provide basic backhauling for a femto-cell.

Depending on the technology provider (manufacturer) of the satellite modem, the type of network topology and the implementation of the satellite network where the modem is operating, some additional features can be available:

- Advanced Quality of Service (QoS) features and policies, based on Diffserv, IP addresses/ports, VLANs, CIR or other rules, with possibility of dynamic assignment of bandwidth according to the type of traffic or QoS level.
- Support for compression/optimization of IP headers/payload.
- Gigabit Ethernet port, supporting Ethernet frames of 2048 bytes (jumbo frames).
- VRRP, for redundancy/backup configuration.
- Encryption.
- IPv6 support.
- DHCP Relay (in addition to DHCP Server).
- BGP (in addition to RIP).
- IGMP and Multicast support.
- Advanced NAT.
- 802.1P and 802.1Q support for end-to-end VLAN support.
- Firewall support through integrated access control lists.

These features are based on standards, but sometimes modified by the satellite technology manufacturer, so detailed study and lab test is normally needed to check compatibility and customize performance.

The major difference of a GEO satellite IP broadband access, compared to standard terrestrial broadband services based on xDSL, is the average delay of 300ms introduced by any satellite hop. This delay is due to the distance between the Earth and the GEO satellite, and causes an average RTT

of at least 600ms in an end-to-end communication (from BTS (Base Transceiver Station) to BSC (Base Station Controller), or from NodeB to RNC (Radio Network Controller), for example). All modern satellite platforms integrate "TCP spoofing" and other mechanisms (suppression of ACKs, local ACKs, etc.) to mitigate the effect of the delay of satellite communications in the TCP/IP connections.

Depending on technology provider and implementation, jitter in a satellite broadband access can vary from less than 30ms to even more than 200ms.

Usually, both the applications and the satellite platform need some fine-tuning to achieve the best performance in IP communications, and minimize the effect of delay and jitter.

Modern cellular technology can deal (trough new software releases or software patches) with satellite round trip delays of 600ms and jitter of 30ms, for voice communications as well as for GPRS/EDGE data communications, but achieve a good performance for 3G data communications need normally some lab tests and deep customization in both the cellular technology and the satellite network.

As mentioned before, standard IP broadband access through GEO satellite can be used, and it is used, to transport 2G/3G, but it is important to review the requirements of delay and jitter of 2G/3G small cells to select the proper solution.

In 2G deployments over satellite, QoS at the satellite modem is used to establish priority of HDLC signalling packets over voice packets, and priority of voice packets over GPSR/EDGE data packets, so congestion if occurs do not affect the stability of the BTS and the quality of voice communications. Also IP header/payload optimization/compression, if available, is used to reduce the overhead of IP encapsulation, compress the payload and minimize the use of satellite bandwidth.

It is important to remark that the performance of "TCP spoofing" and other mechanisms listed above, as well as the performance of QoS and IP header/payload compression/optimization features, are lost if the IP traffic is sent through an IPSEC tunnel over the satellite, as all the information is encrypted and not visible.

For this reason, for cellular backhauling over IP and satellite it is desirable to use a "clean" connection, based on a private VPN connection, instead of using an Internet broadband connection secured by an IPSEC tunnel.

4.3.4 Performance expected

4.3.4.1 Capacity

The three wireless technologies proposed in this section are adaptative. This means that, depending on the quality of the channel, transmitter and receiver may choose to communicate at different data rates. Higher data rates use more powerful modulations and more efficient coding strategies (e.g. 64QAM3/4) at the cost of a higher sensitivity. Lower data rates use more robust modulation and coding strategies (e.g. BPSK ½) that present a much lower sensitivity. This means that, depending on the received power level, the data rate may change.

In static wireless links with LOS, the main factor that determines the path loss is the distance. Even though the path loss may be partially compensated by the antenna gain, the transmission power or the use of amplifiers, this has limits. The antenna gain may be increased to a certain value at a reasonable cost, but very high antenna gains require very expensive and heavy parabolic antennae with complex alignment systems. The use of amplifiers introduces power consumption and failure points in the transmitter, or failure points and noise in the receiver. Finally, the transmission power is limited for

non-licensed bands considered in this section. Hence, one may not achieve the highest data rates for the technologies considered due to the link budget.

The adaptation of the transmission profile (modulation + coding) may be dynamic in these technologies. As the received power becomes lower, the communication slows down. The thresholds to be used when deciding the optimum transmission profile depend on the ARF (auto-rate fallback) algorithms implemented in the communication systems. In static wireless systems one may prefer not to rely on ARF algorithms and fix a conservative transmission profile that meets the requirements of capacity for that link and, at the same time, may be used in any regular situation.

Going into the details, let's see what performance can be expected from these technologies:
- WiFi standards have a low efficiency that drops with the bit rate and with the distance. This low efficiency is due to collisions, to the MAC protocol overhead and to the effect of MAC and PHY headers. The highest efficiency (higher than 85%) is achieved at 1 Mbps, it drops to 70% at 11 Mbps, it is lower than 60% at 54 Mbps and it does not achieve 50% at 300 Mbps. If the distance is not negligible, the propagation delay is higher and SlotTime, ACKTimeout and CTSTimeout MAC parameters need to be adapted. Hence the efficiency of WiFi at different bitrates is much lower than the given figures at long distances.
- The use of 802.11n dramatically increases the capacity due to three main reasons:
  - The possibility of using dual antennas for MIMO.
  - Frame aggregation, block-ACK and other advanced techniques that save waisted time at the MAC and PHY levels.
  - The use of double channels 40 MHz wide instead of normal 20 MHz channels.
- WiMAX is much more efficient and the performance is almost independent on the distance. Depending on the frame duration and other factors, the efficiency may be up to 90% at any distance. Hence, in this case the limit to the data rate is basically the power budget. Standard systems operating in 5GHz may not use legally a bandwidth higher than 10 MHz.
- Satellite links use robust transmission profiles due to the long distance from satellite to earth. However, the reduced efficiency may be compensated by increasing the bandwidth. Actually, the limiting factor here is the price. One may increase the speed but then the price paid for the service is paid proportionally.
-

From all those considerations and from experimental links deployed, the following figures are realistic:
- A short shot (<5km): real capacities may be as high as 20 Mbps with 802.11abg, 120 Mbps with 802.11n using MIMO 2x2 and double channels, and 32 Mbps using WiMAX (SISO and half the bandwidth).
- A medium shot (20km < d < 30 km): due to the link budget, the transmission profiles must be less efficient. Hence, real capacities may not depass 5 Mbps with 802.11abg, 60 Mbps with 802.11n using MIMO 2x2 and double channels, and 16 Mbps using WiMAX
- Long shots (>40 km): capacities drop to less than 3-4 Mbps for 802.11abg, 40 Mbps for fastest 802.11n configurations and 8-10 Mbps for WiMAX.

This figures are obviously not accurate and depend on the specific scenario. The next figure shows how the different bitrates provide decreasing saturation throughputs as the distances grows.

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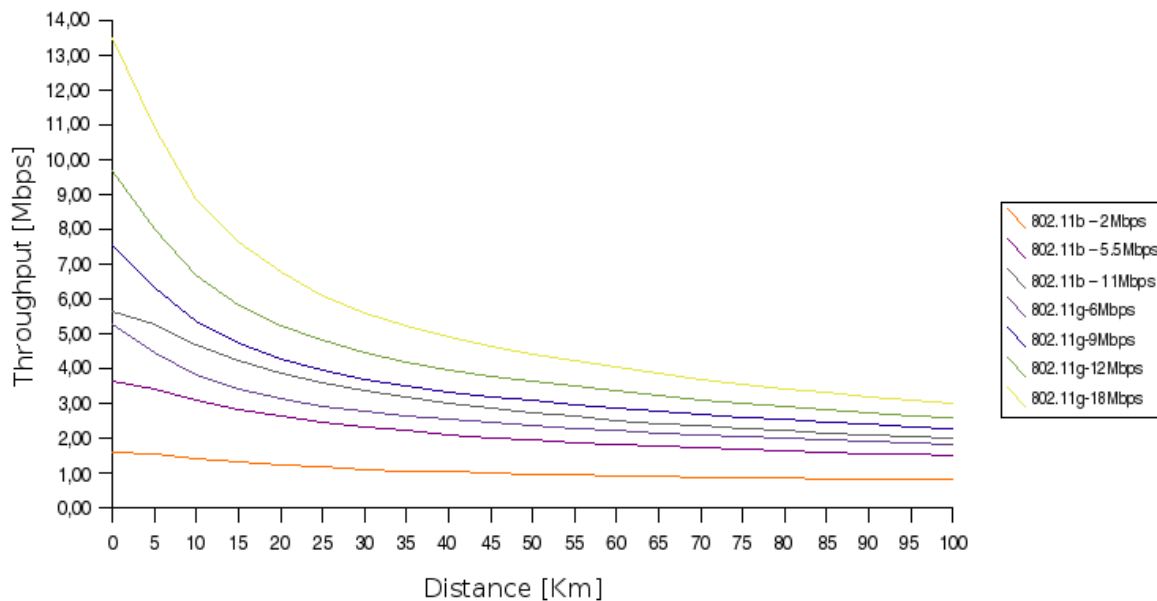
Figure 41. Saturation throughput depending on the distance and the bittrate (only for realistic 802.11b and 802.11g bitrates)

4.3.4.2   Delay

The delay in a digital wireless link has several components:

- The propagation delay is the most limiting factor because it cannot be reduced at a given distance. It should be accounted several times when the transmission of a packet requires an acknowledgement (WiFi) or a previous bandwidth request (best-effort services in WiMAX).
- Queuing times in the sender system may be significant when the offered traffic intensity is close to the saturation point of the wireless link.
- The transmission time (the time needed for transmitting all the bits of a frame) at a given bitrate. It can be signficant in WiFi for long packets at low bitrates, but it becomes much more significant in WiMAX because frames are much longer.
- Retransmissions, in the case of contention protocols (WiFi)

Delays in WiFi depend specially on the rate offered-load-to-capacity. When the link is unsaturated, delays may be as low as 2-3 ms. When it becomes saturated, delays of hundreds of ms or even seconds may be expected.

In WiMAX delays may be two or more times longer than the frame size. The shortest frame size in Wireless-HUMAN (WiMAX PHY for non-licensed bands) is 2.5 ms, and the longest is 20 ms. Obviously, the shorter the frame is, the less efficient the link becomes. Delays of 10-60 ms are normal in unsaturated WiMAX links.

Lastly, in the case of using a satellite link as a part of the transport network, the propagation delay in the spatial segment increases dramatically the minimum delay. One-way delays of 300 ms may be expected.

4.3.4.3   Packet-loss

Packets may be lost because a system drops packets that exceed their capacity for sending information, or packets that arrive to destination on disorder or with excessive delay may also be dropped.

WiFi presents much lower packet-loss rates than other technologies because lost frames are retransmitted. But this happens at a very high cost.

WiMAX and Satellite systems, together with WiFi, may all drop packets when systems present congestion because transmission opportunities happen at a lower rate that needed.

In the previous paragraphs, it is shown the importance of operating far from the saturation point. Once the offered load approaches the saturation point, the services degrades very quickly.

In general, one goal for the transport network will be to make clear to itself and to the access network what is the real capacity that can be offered and how the transport network can avoid to transport traffic beyond that threshold.

4.4 Evaluation methodology

In the TUCAN3G project a heterogeneous transport network using any combination of the presented technologies will be used. This heterogeneous solution would permit to adapt to any situation with optimal results if

- We can strictly compare previous technologies under common parameters.
- We know how to integrate these technologies in order to offer end-to-end services with an "acceptable" QoS support.
- We can measure experimentally the performance of these technologies under different circumstances in order to validate theoretical results.
- We can test the heterogeneous architecture and the integration solutions.
- We have a correct definition of the traffic to be transported and the interface expected from the access network.
- We can minimize the energy consumption of all systems.

Both for the experiments and for the demonstration, the systems considered and used must meet the following requirements:

- Operation in non-licensed bands.
- WiFi systems must be configurable for long-distance operation with CSMA/CA. Also TDMA alternative solutions must be tested.
- Advanced traffic control at the IP layer must be possible.
- Systems must be flexible enough to develop integration software blocks that implement functions, interfaces, etc. in each system.
- WiFi systems must implement EDCA, WiMAX systems must permit to create and use different scheduling services and VSAT systems must permit to differentiate and prioritize the same different traffic classes. Traffic must be marked in ingress nodes and unmarked in egress nodes, and the same marks must be correctly interpreted in the different technologies.
- Systems must be manageable in order to monitor both the laboratory testbed and the demonstration network with a NMS (network management system). For easier integration in a management system, the management protocol used for the different technologies should be the same.
- A femtocell would be operating in the laboratory, and later on in the demonstration network, with available terminals that inter-operate with it. On the other side, a femto controller must be installed in the operator's network.
- System clocks in all end systems must admit to be synchronized for correct delay measurements using a common time server. The offset of system clocks must be reduced to one order of magnitude under the expected delay measurements.

In order to achieve the foreseen goals, a laboratory will be installed with real hardware, a channel emulator, a station for measuring system power consumption, a femto and a network simulator. This will permit the following tasks:

- Theoretical study of the scientific literature and theoretical research in order to have complete information about the different technologies considered that permit to know about all of them their limits, the expected performance of all of them under the same parameters, and any other relevant characteristics that permit to rigorously compare them.

- Measure the performance of point to point links using either technology

    - With simulations, using the NS-3 network simulator
    - With hardware emulation, using a Propsym C8 emulator and RF-shielded boxes. Traffic will be artificially generated using D-ITG traffic injector.
    - With real long-distance links available in experimental testbeds (including, but not limited to, the TUCAN3G demonstrator). Traffic would be injected using either D-ITG or iperf traffic injectors.

The triple measurement system has two objectives: to cross-validate the different measurement strategies and tools, and to make sure that further results achieved in research only with simulation or emulation are reliable.
- Analyze theoretically the possible solutions that make heterogeneous transport networks predictable in terms of performance and QoS, and that permit to design optimum heterogeneous networks for given performance and QoS requirements.

- Implement those solutions in laboratory.

- Measure the end-to-end performance of a heterogeneous network as different integration techniques are tested both all the interfaces in the architecture.
    - With simulated networks in NS-3
    - With a practical testbed in laboratory
    - With the TUCAN3G demonstrator

- Test the integration with the access network.
    - With the practical testbed in laboratory
    - With the TUCAN3G demonstrator

- Propose theoretically techniques to reduce power consumption and to improve performance.

- Test techniques to reduce the power consumption.
    - With practical systems in laboratory

- Test techniques to improve performance.
    - With practical systems in laboratory
    - With simulations

In the practical tasks, results will be obtained either with simulated traffic or with injected traffic. Traces of traffic will permit to measure throughput, delay, jitter and packet-loss. This will be done either for one or several simultaneous traffic classes.

5 ARCHITECTURE FOR THE PROOF OF CONCEPT

This section will describe the architecture of the demonstration platform, whose objective is to validate some research results of the project. In order to do so, a cellular network will be implemented in rural areas of the Loreto province, in Peru. This cellular network will use 3G femtocells as access points (HNB), and for the backhaul it will use heterogeneous transport networks based on different combinations of WiLD, WiMAX and satellite communications.

The architecture of the pilots will have three main sections: the access network (composed by femtocells), the backhaul (an IP heterogeneous transport network), and the network controller that manages the cells and acts as gateway with the core network. The network controller will be installed in Lima, where hosting and communication with the core network are straightforward. This decision is also coherent with the fact that network controllers are usually deployed in a centralized way, because they usually control hundreds of cells.

The network controller (also referred as the femtocell controller or RNC in this document) that will be used in TUCAN3G pilot is the model "*nanoGW NC200 3G Blade Kit*" produced by IP Access, which provides the following applications:

- Access Controller (AC) that aggregates the traffic carried over IP from the femtocells and provides standard interfaces (Iu-CS and Iu-PS) to the core network. It supports up to 200 connected femtocells.
- IPsec gateway, which is an IPsec encryption and decryption application. It provides the capability for securing the traffic between the femtocells and the AC (the traffic that goes through the backhaul) within an IPsec tunnel.
- NOS (Network Orchestration System) that is a complete 3G provisioning and management solution with all the features needed to successfully deploy and operate a IP Access femtocells system. It includes an Access Point Management System (AMS) and Certificate Validation Service (CVS) which provides a CRL Mirror (Certificate Revocation List).

In order to connect the network controller to the core network some interfaces will need to be implemented:

- Interface IU-CS: install and configure a port in the MGW (Media Gateway) for an ATM (Asynchronous Transfer Mode) link over optic fiber to the MSC (Mobile Switching Center). The operator will need also to create licenses for the users of the IU-CS, so the amount of user for the demonstrative platform should be estimated.
- Interface IU-PS: install a Fast Ethernet router and connection route to the data core network (SGSN or Serving GPRS Support Node).
- The network controller will also need a connection with the CRL Server of TdP.
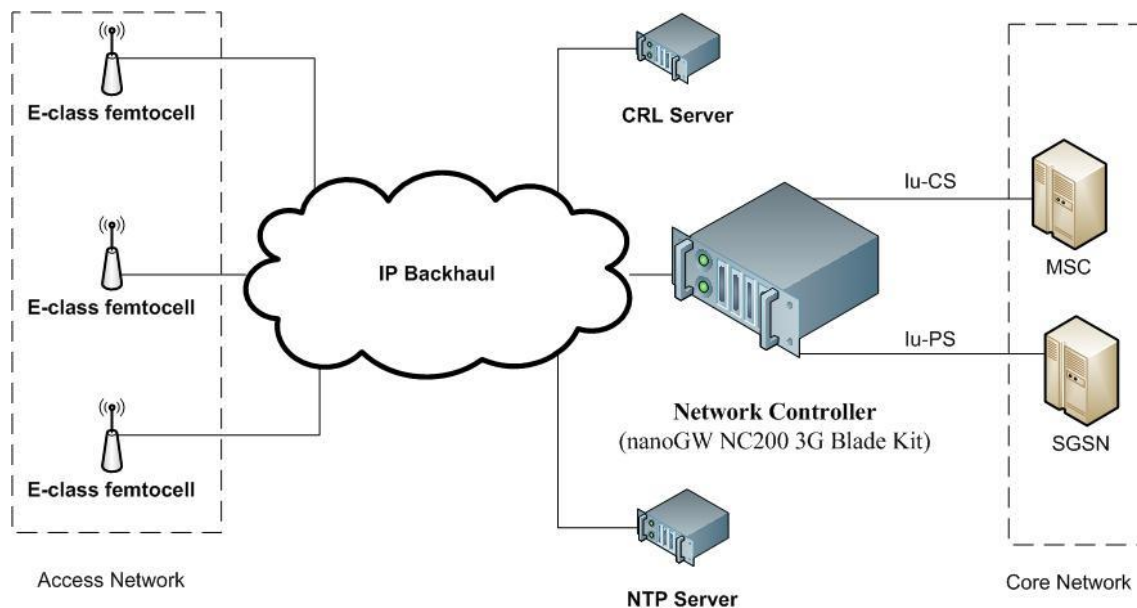
Figure 42 - Sketch of the overall network structure

The access network will be based on femtocells, which are inexpensive, energy efficient and self-organised, and therefore suitable for rural communications deployments. The proof of concept will be implemented with equipment produced by IP Access (partner of the project).

IP Access has two types of 3G femtocells in its portfolio: S-class and E-class. The femtocells will be applied to outdoor scenarios, so they will need to be installed on waterproof cases with external antenna. This requirement lives only the E-class Access Points as feasible option, given that S-class Access Points are only provided with integrated antenna. E-class products have a SMA connector that allows the attachment of external antennas once part of the case is removed. Besides, E-class equipment supports up to 16 simultaneous active users and provides +24dBm (250mW) of transmit power. With this power and the integrated antenna, its coverage range is expected to be around 500m in suitable conditions. Its power consumption is smaller than 18W and it features integrated Power over Ethernet (POE+). The femtocells of the access network and the network controller will be synchronized through sync Over IP, using a NTP (Network Time Protocol) server for that purpose.

The backhaul network will be based on WiLD technology, and the possibility of using also WIMAX for some of the links will be analysed in WP6. Not specific equipment has yet been selected for the backhaul implementation. The range of frequencies assigned to the operator (TdP) in Peru, which available for the access network, are:

Band	Frequency range (MHz)	
	Uplink	Downlink
A (824 – 849 MHz and 869 – 894 MHz)	824 - 835	869 - 880
	845 – 846,5	890 - 891,5
B (1850 – 1910 MHz and 1930 – 1990 MHz)	1870 - 1882,5	1950 -1962,5

Table 44. Table of frequencies for the access network

5.1 Proposal of target localities

The deployment area is an isolated region in the Amazon rainforest with low density of population and important communications needs. Communities in this region are placed next to the major rivers and depend on fluvial communications, which are slow and also very expensive due to fuel consumption. Moreover, distances between communities are enormous. It will be very important to consider both factors when deploying the network, given that they will increase the complexity of installation and maintenance activities.

More specifically, there will be two scenarios depending on the backhaul technologies. One deployment will use only terrestrial transportation technologies (WiLD), and the other will combine terrestrial (WiLD and/or WiMAX) and satellite transportation technologies. Each of these deployments will be located in a different area.

5.1.1 Terrestrial backhaul scenario

The terrestrial backhaul scenario will be located in Yurimaguas, where a communication infrastructure is already available (as it has been previously described in section 2.4.4.2). The 3G services will be provided in two localities, San Juan and San Gabriel de Varadero through the E-class Access Points (femtocells) of IP Access. The backhaul of these femtocells will have two sections: a WiLD section that will go from San Gabriel de Varadero, through San Juan to Yurimaguas, and an optic fiber channel from Yurimaguas to the network controller in Lima. Balsapuerto, that is the last node of Yurimaguas network, will not be used because it becomes inaccessible depending on the river level, so it is less convenient for a pilot deployment. A scheme of the proposed architecture is shown in the Figure 43.

This scenario will make use of the existing communications systems because the bandwidth of this network is high enough to share it among several services. Besides, sharing the bandwidth through virtual circuits is a very interesting option to get several actors to invest in the same network. This would be also useful in order to have an operator selling services to different customers, increasing in that way the chances to find investors for the deployment.
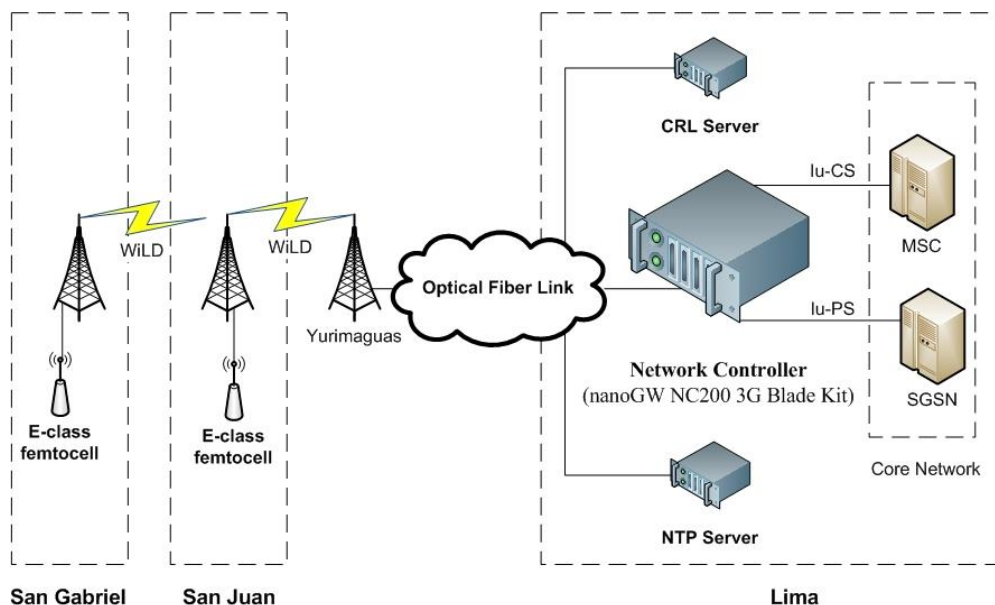
Figure 43. Sketch of the terrestrial backhaul scenario

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5.1.2 Satellite backhaul scenario

The scenario with backhaul through satellite will be installed in the lower part of the Napo River Network (already described in section 2.4.4.1). This area was chosen because it will be easier to install and maintain the equipment there. At the same time, selected communities have similar characteristics than the communities of the high part of the river, so it will be possible to generalize results. The main difference between the lower and the higher part of the river is that the former counts with daily boat service, so the traffic in the river is more intense in this part. Another advantage of installing the pilot in the lower part of the river is that it will be easier to connect it with Iquitos in the future, what would make the initiative more sustainable.

The exact localities for this scenario can change depending on the market survey results, so this proposal should be considered only as preliminary. The satellite station will be placed in Negro Urco, and it will serve to establish the connection with the network controller in Lima. This connection will be shared through WiLD and WiMAX links to Santa Clotilde and possibly Tuta Pishco (depending on the budget), to provide service to the femtocells installed in those rural localities. A scheme of the proposed architecture is shown in Figure 44. It will make use of existing infrastructure of towers, but an energy supply system based on solar energy and equipment to deploy parallel links will be required because existing ones don´t have enough bandwidth available.
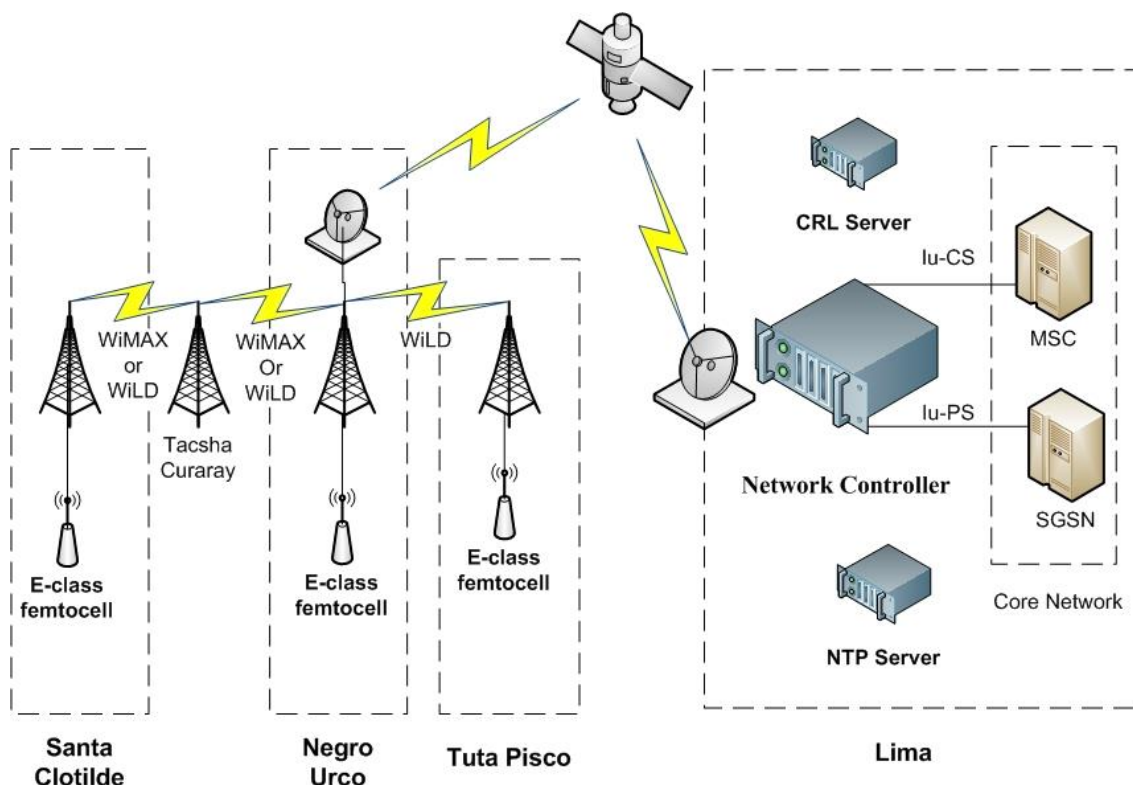
Figure 44. Scheme of the Satellite Backhaul Scenario

The satellite communication technology is still to be decided. Available options have been described in section 4.3.3.5. A crucial parameter is the satellite bandwidth required, because this is the most expensive item in the OPEX, but this parameter depends on the expected number of users that will be discussed below. The final technology will depend on local prices and WP6 budget.

In order to estimate the number of potential users, we could use existing socio-economic studies for the deployment region. Data shows that 50% of households are above the level of poverty and in 20% of the households the expenses are similar to urban area. Assuming that penetration in this last segment would be around 40% (similar to the penetration in non-poor urban households), leaves an

8% of households as potential customers of Internet services with prices similar to urban areas. If we assume that an Internet user generates 15Kbps, this would mean 600Kbps of total traffic in a community of 500 inhabitants with an 8% of penetration. Additionally, we could consider three main institutional users: health establishments, schools and local authorities.

Usually operators estimate the voice traffic assuming that one user generates 10mErlangs in the rush hour. In a village with around 500 inhabitants, and assuming a 40% of users, this would suppose 2 Erlarngs in the rush hour. Estimating 1% blocking and using Erlang B, this will require 8 channels. With an AMR (Adaptive Multi-Rate) codec of 24Kbps, this would imply 192kbps of total voice traffic in the rush hour in a community. The total expected traffic (voice and data traffic) would be 792Kbps per locality.

Target communities lack of permanent power supply, therefore a power system based on solar panels and batteries will be installed to provide energy to the femtocells. In the target areas, there exist such systems in the communication towers and in the health establishments. Emplacements with existing power supply infrastructure will be preferred if they prove to be a good location for providing the community with good coverage. Otherwise, a new location will be negotiated with the community authorities, who have already shown their interest in collaborating with this project. In new emplacements, it will be important to install lightning protection systems because thunderstorms have a very high incidence in this region.

Depending on the final emplacement, omni-directional antennas or directional/sectorised antennas will be used to provide coverage to the residential area. Rather than sectorising a single site, multiple femtocells will be preferred to increase capacity when needed, getting the chance to increase coverage at the same time.

5.2 *Compatibility tests for the femto controller*

Figure 45 shows the interfaces between the femto controller (RNC) and voice and data core networks. Please note that Iu-CS connection is over ATM and other connections are over IP
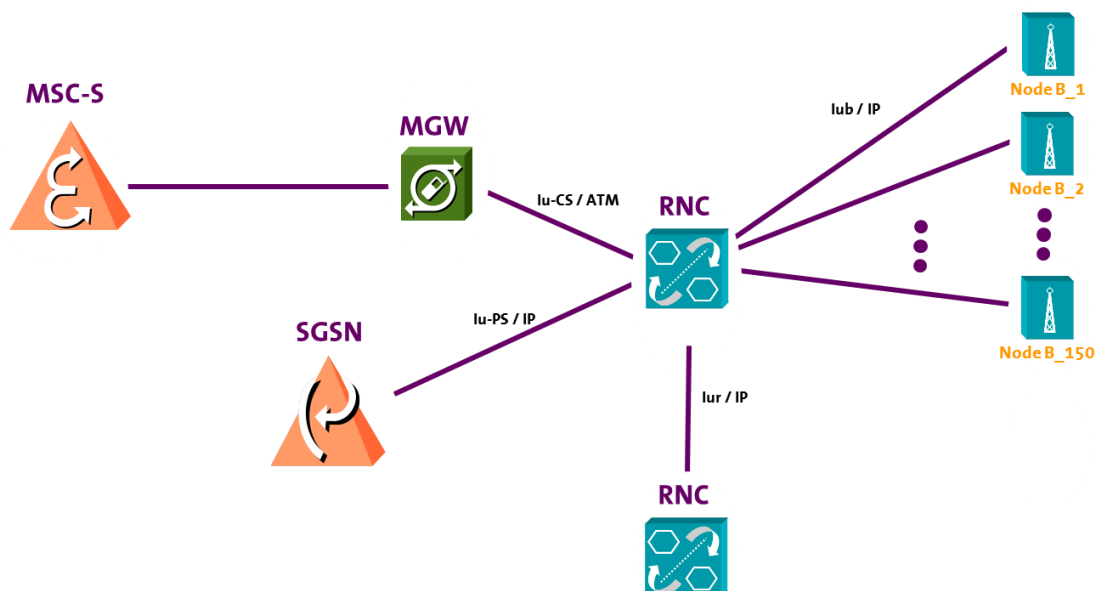
Figure 45. Femto controller connection diagram.

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Telefonica usually receive from providers their regular tests and include some other tests considered important. The following is a generic summary of tests but if IP.Access has a compatibility test for their products they can be sent and customized to Telefonica´s standard.

Installation: (Physical connection)
- Energy: Energy and Ground connections.
- External cables: Sync, Optic Fiber, Coax, data cables, interfaces.
- Cable labels.
- Installation layout.
- Housing, Racking.
- Optic and electric measures.

Functionality: (Features testing)
- Test for card redundancy.
- Upload and integrity of database: Physical switch off, hard reset of the RNC.
- MML Support: access and functionality.
- Integration: Management, service creation and deleting, measures, graphics, indicators.

Service: (Use testing)
- Voice calls testing.
- Data session testing.
- Redundancy testing.
- Redundancy testing while active phone and data call.
- Handover.
- IUR Test.

These tests, with observations and results should be placed in a document call ATP – Telefonica will send a Repair document with any observation found.

Deliverables:
- ATP.
- Photo report of the installation (included in the ATP).
- Data Fill: Excel document containing all the database of the RNC configuration.
- Topological diagrams.
- Back Up of the complete configuration..
- Manuals (electronic).
- Cabin keys.
- Workshop (Management and operation basic).

5.3 Performance tests

Performance tests have two goals: to check the functionality of the network and to validate the theoretical results of WP4 and WP5. More specifically, there will be two scenarios depending on the backhaul technologies. One deployment will use only WiLD technologies for the transport network, and the other will combine WiLD/WiMAX and satellite transportation technologies. Each deployment will be located in a different area.

The tests will be held in each of the following scenarios:

- Scenario composed by femtocells as network access and a WILD backhaul.

- Scenario composed by femtocells as network access and a Satellite/WILD/WIMAX backhaul.

In each scenario, network capabilities and femtocells coverage will be tested.

5.3.1 Network capabilities tests

There will be three independent tests according to the access network or to the backhaul.

Access network:

- Measures of signal level, distance and throughput on several points three times per day in order to check the theoretical models for the femtocells coverage (restricted by the distance, the path-loss, the shadowing, or the multipath fading).
- List wireless networks the femtocell coverage area, three times per day. The aim is to check if there are near sources that may cause interference.
- Connect ten users at the same time to a femtocell in order to verify user density.
- Check that calls are locally switched if backhaul link doesn't work.

Backhaul WILD/WIMAX:

- Measure of the throughput (maximum and minimum), delay (maximum), jitter (maximum), packet loss (maximum); three times per day. For that purpose, it could be used the iperf or the D-ITG tool.
- Measure of the Signal level and Noise level.

- Backhaul VSAT:
- Measure of the throughput (maximum and minimum), delay (maximum), jitter (maximum), packet loss (maximum); three times per day. For that purpose, it could be used the iperf or the D-ITG one.
- Measure of the Signal level and Noise level.

5.3.2 Coverage tests

In this stage, mobile services will be evaluated in the complete scenario in which all networks are integrated. Tests in this stage are divided in the three following cases:

- Test on a specific locality of the project.
- Test between different localities of the project.
- Test between a locality of the project and an external one.

Each case will be evaluated by the following tests:

- Call sessions: In order to check VoIP traffic, it will make call sessions to and from other femtocell, the PSTN (local and national), cellular and VoIP endpoints; this test will be taken three times per day.
- Videoconference sessions to check a full traffic test. This test will be performed three times per day.
- Download and upload a big size file to check bursty traffic. This test will be performed three times per day.
- Variances of the test scenarios will include atypical situations where calls on femtocells occur simultaneously with other phone o data services, e.g. Internet surfing or during peak usage time of a particular day.

5.4   Network reinforcement proposal

This section identifies the limits of the deployed networks and proposes a list of actions aimed to reinforce the sections of the networks used in the demonstration platform, based on the description of the deployed networks provided in section 2.4.4. Tentative budgets are included.

5.4.1   Napo telemedicine network

Nowadays the network´s bandwidth capacity is completely used, so the addition of more services is not possible. Additionally, the energy system for the network is enough only for actual applications.

The priority recommendation for the TUCAN3G objectives is the implementation of radio links parallel to the existing network, given that infrastructure has the capacity to support more equipment on the towers. In this case the equipment should work at 5.8GHz band to avoid the interference on the actual network, which works at 2.4GHz band. In addition, an autonomous photovoltaic system will be necessary.

For the objectives of the project, these parallel links could be implement on a segment of the network, as shown on the following diagram.
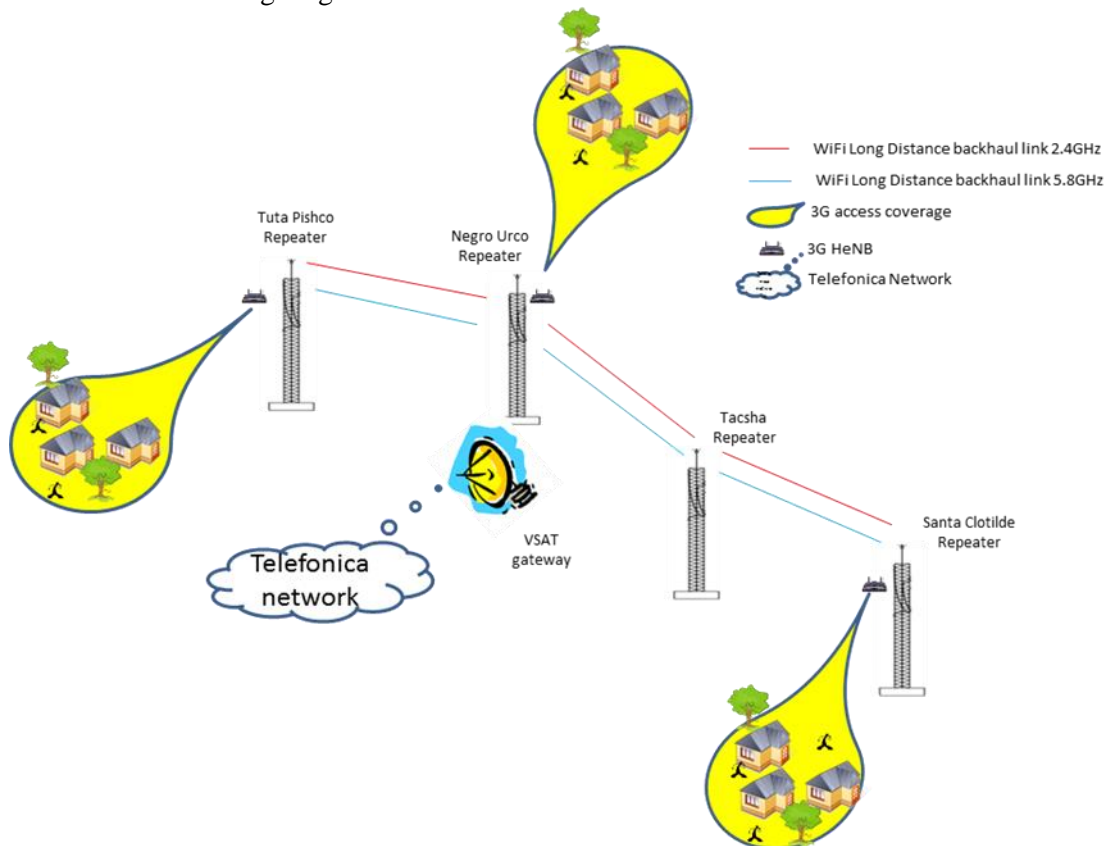
Figure 46. Proposed topology for a segment on Napo network.

The reinforcement activities would be:

 i.   Installation of parallel links in a section of the network, from Tuta Pishco to Santa Clotilde.
 ii.   Radio links tests.
 iii. Maintenance on grounding system.

The budget estimated to perform previous activities is summarized in the table below.

ITEM	DESCRIPTION	COST (US $)
01	Equipment: for telecommunication and energy	8,030
02	Metal brackets for equipment	3,628
03	Materials for grounding system maintenance	360
04	Accessories	939
05	Equipment´s transport from Lima to Napo	1,300
06	Local transport on Napo river	1,760
07	Diem: 4 people, 8 days	1,700
08	Flight tickets from Lima	1,000
	TOTAL	**18,717**

Finally, it should be noted that it is possible to make direct changes in the network installed with a low cost. However, it would mean having short periods of unavailability of the services offered and a greater complexity to the measurement and control of traffic and the performance of the solution to implement. These changes would mainly refer to telecommunications sub systems (replacement of routers, radios and antennas and reinforcement of its energy system) and represent a global estimated cost of 10,000 USD.

5.4.2 Balsapuerto telemedicine network

It is important to define the way the Red Balsapuerto would connect to the femtocell controller. As noted, there are two alternatives: hire a new Internet access to the Hospital Santa Gema or link directly the hospital tower with Telefónica's local office via a wireless link. In this area is recommended to use existing infrastructure as there is enough bandwidth available, but it would have to perform some activities of preventive and corrective maintenance.

i.   Check the radio links to try to improve the available bandwidth.
ii. Perform the upgrading of grounding systems.
iii. Perform preventive maintenance on the towers.
iv. It would have to reroute IPs to adapt the cellular equipment to the existing network.
v.   In Santa Gema Hospital, it would have to improve power backup system to ensure better service availability, if they had power cuts in the city of Yurimaguas.

On the other side, in Yurimaguas and Balsapuerto there is cell phone services, so the pilot project should be implemented in the communities of Varadero and San Juan, according to the topology shown in the following diagram.
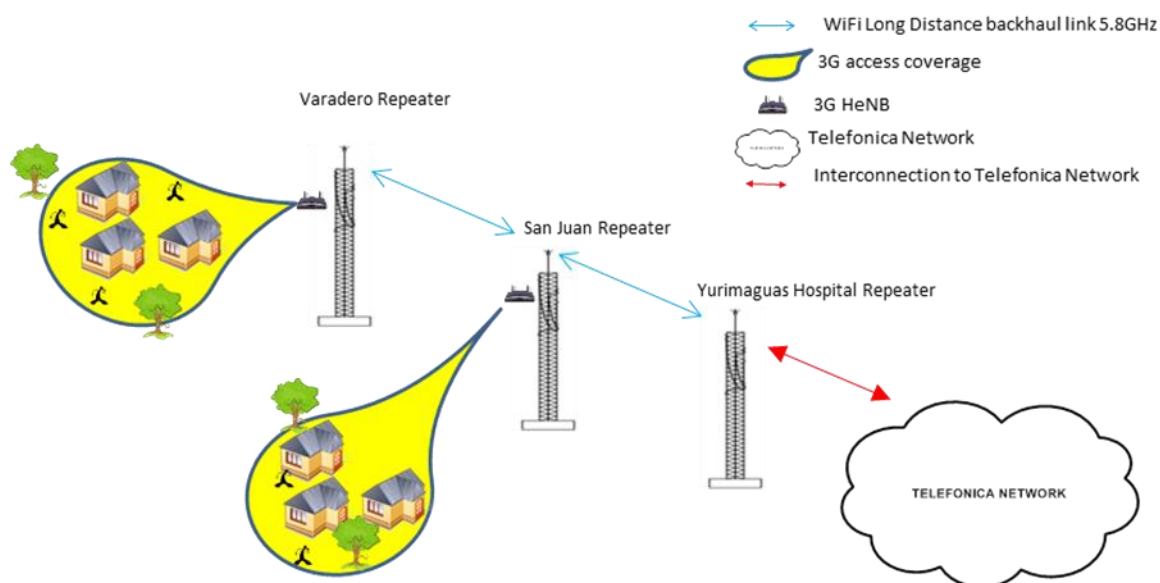
Figure 47. Proposed topology for Balsapuerto network

The budget estimated to perform previous activities is summarized in the table below.

ITEM	DESCRIPTION	COST (US $)
01	Equipment: UPS	1,000
02	Materials for grounding system maintenance	300
03	Accessories	200
04	Local transport (by boat 3 days and car)	500
05	Diem: 3 people, 7 days	1,050
06	Flight tickets from Lima to Tarapoto	750
	TOTAL	**3,800**

Table 45. Estimated budget.

It is important to note that the reinforcement proposal does not consider the equipment for the 3G telephony system, so it will be necessary to consider energy sub system when the cellular telephony service will be implemented,.

6   ANNEX I: PUTUMAYO NETWORK DESCRIPTION

The Putumayo River´s Telemedicine Network was implemented in 2011 by the Rural Telecommunications Group of the Pontificia Universidad Católica del Peru with funding from the European Community through the Organismo Regional Andino de Salud. This project aims to generate a significant positive impact on health care for the population of the Putumayo River by implementing telecommunications systems that will allow the use of telemedicine applications in health facilities beneficiaries.

Figure 48. Centers and Health Post distribution in Peru and Colombia.

Telecommunications infrastructure implemented includes 04 VSAT stations in as many health facilities in Colombia and 04 VSAT stations plus 06 WiLD stations in Peru. Implementing Network Access Service included Internet and telephony services in the 12health facilities.

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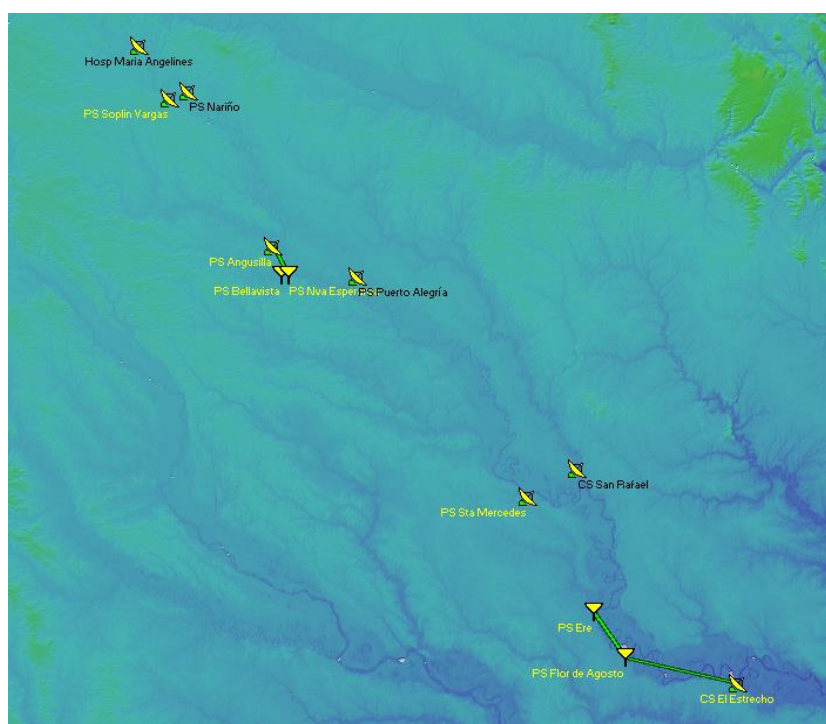
Figure 49. Nodes distribution.

For Internet access service was hired a speed of512/128Kbps, guaranteeing 70% of the speed in the worst case, plus you will have permanent access every day of the year. For phone service, only calls to phones in the public telephone network will cost, with rates depending on the country.

Location	Components
El Estrecho	VSAT station Client station WiLD Router and Access Point WiLD
Flor de Agosto	Client station WiLD Router and Access Point WiLD
San Francisco de Ere	Client station WiLD Router and Access Point WiLD
Santa Mercedes	VSAT station
Angusilla	VSAT station Client station WiLD Router and Access Point WiLD
Nueva Esperanza	Client station WiLD Router and Access Point WiLD
Bellavista	Client station WiLD Router and Access Point WiLD
Soplin Vargas	VSAT station

Table 46. Peruvian nodes

Location	Component
Hospital María Angelines	VSAT station
PS de Nariño	VSAT station
PS Puerto Alegría	VSAT station
CS San Rafael	VSAT station

Table 47. Colombian nodes

a) Description of Telecommunication Network

The solution for the interconnection of the nodes that make up the Red Putumayo, is a set of WiLD and VSAT networks with a distribution that allows to interconnect IP telephony and data transmission with high efficiency in the local network and also Internet access through VSAT stations. In this way, the project includes the installation of telecommunication systems, energy and electrical protection. Below are the technical solutions used for the interconnection of data centers or health and access to services. Then describe the design for each country.

a. VSAT Network

VSAT system allows access to the Internet via satellite platforms, ensuring availability greater than 99.6%. This system allows for voice and data connections from branch offices and remote client to your main point or central office using the Internet. The following figure shows a diagram of the parts that make up a VSAT system.
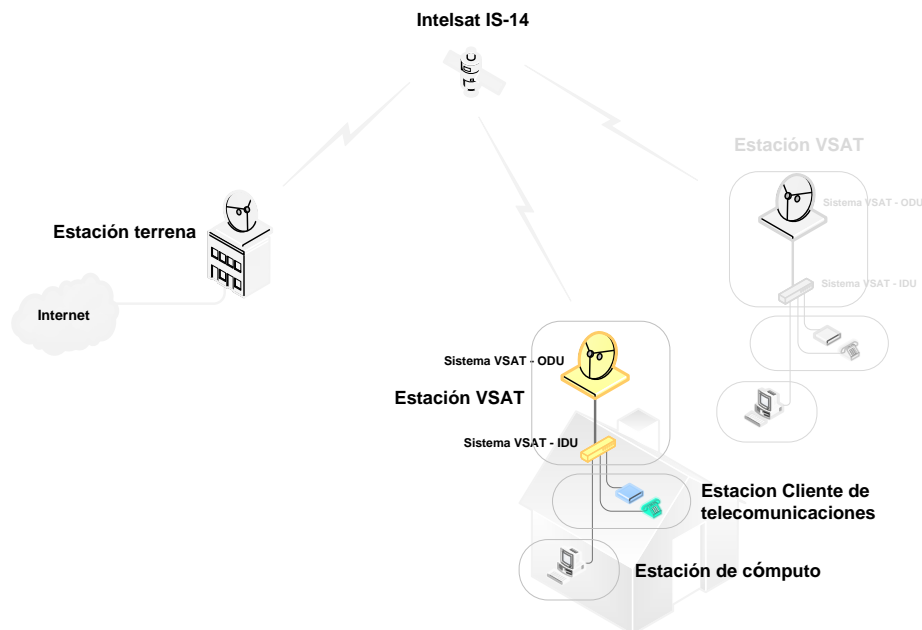
Figure 50. Scheme of a VSAT station

In this project, the VSAT router is based on Gilat Sky Edge II Extend. VSAT Stations mainly consist of an indoor unit (IDU- Indoor Unit) and an outdoor unit (ODU – Outdoor Unit). The internal drive is

the one that does all the IP routing process and gives the electronic terminal connectivity through one or two Ethernet ports, the external drive is basically composed of the antenna.

The satellite system operates with satelliteIntelsatIS-14. This satellite offers the best coverage for Ku Band for the Peruvian territory, allowing the use of 1.2m diameter antennas on land and minimize atmospheric sensitivity remote stations.

b. WiLD Network System

WiLD Networks Systems enable extending access to the services offered by satellite service to centers or health posts that do not have direct satellite access. A WiLD network system will support voice services, data and video.

WiLD Networks Systems were implemented in this project use 802.11n (WiFi). They consist of Client Stations, Access Network and Transport Network. Below is an outline of the parts that make a WiLD Network.
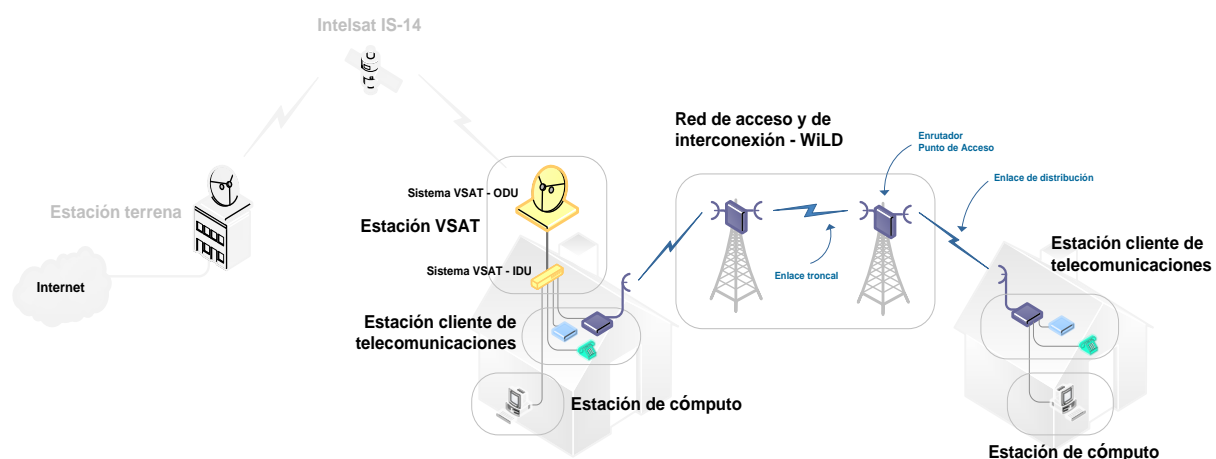
Figure 51. Interconnection between WiLD network and VSAT station

Client Station will consist of telecommunications equipment that allow access to network access and interconnection, as well as providing access and telephony services.

The Access Network allows intercommunicate Client Stations and thus provide access to services. The WiLD network is implemented with the star topology in Master- Client mode. Access links are PtM links (Point to Multipoint) to allow access to more than one client station. Transport links consist in PTP(point to point) links.

c. IP Telephony Network

To implement the telephony service, has been used voice over IP technology, over VSAT data and WiLD networks. With IP telephony network, beneficiaries can make voice communications between them and have access to the public telephone in their respective country.

The Putumayo´s IP telephony network consists in IP phones, IP telephony servers and voice gateways, distributed in schools or health post. The IP phone consists of an ATA (phone adapter) and an analog telephone. The Voice Gateway allows interconnection of IP telephony network to the public telephone network. Asterisk is used as IP telephony server using IAX and SIP protocols for voice communication over IP. Below is a diagram of the telephone.
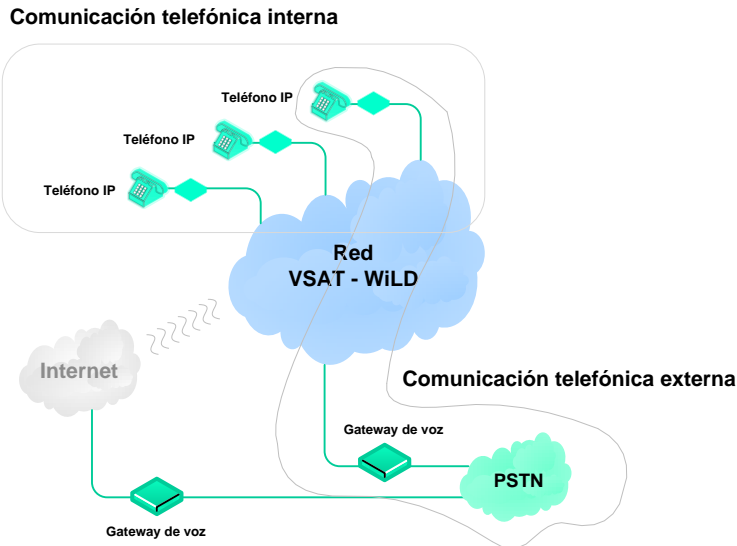
Figure 52. TelephonyServiceScheme

b) Operation

    a.   Telecommunications Systems in Perú

The telecommunications network in Peru consists of four VSAT stations and two WiLD networks. Through these networks users can exchange information and access to Internet. For voice communication are installed telecommunications client stations that allow communication between health or post centers through WiLD/VSAT network and also access the public telephone.

The two WiLD networks are installed allow PS Flor de Agosto and PS Ere access to services through the CS El Estrecho, whereas PS Nueva Esperanza and PS Bellavista accessing services through PS Angusilla. The following table lists the systems to be installed and the interconnection scheme of the network.

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Health Post o Health Center	VSAT Station	Telecommunications Client Station	WiLD Access Network
CS El Estrecho	1	1	1
PS Flor de Agosto	0	1	1
PS San Francisco de Ere	0	1	1
PS Santa Mercedes	1	1	0
PS Angusilla	1	1	1
PS Nueva Esperanza	0	1	1
PS Bellavista	0	1	1
CS Soplin Vargas	1	1	0

Table 48. Stations in Perú

b. **Network Topology in Perú**

In the diagram below you can see the topology of the network WiLD/VSAT deployed in Peru and IP addressing information, equipment and design of the wireless links.
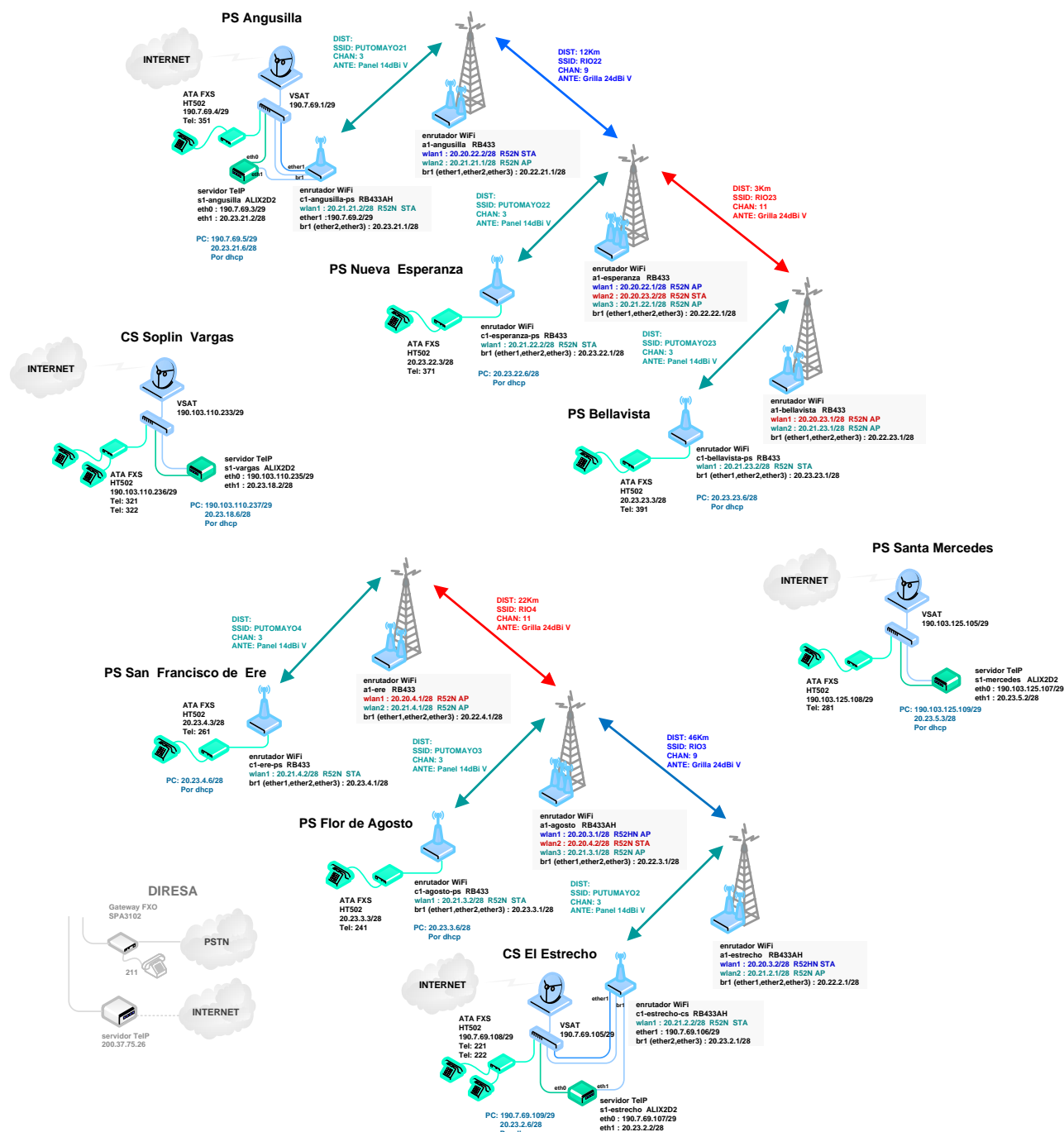
Figure 53. Network topology in Perú

c. **Network Topology in Colombia**

The telecommunication network for Colombia consists of four VSAT stations that allow voice communications between Health Post. Below is where you installed VSAT stations and interconnection scheme of the network.

Health Post o Health Center	VSAT Station	Telecommunications Client Station	WiLD Access Network

María Angelines Hospital	1	1	0
PS Nariño	1	1	0
PS Puerto Alegría	1	1	0
PS San Rafael	1	1	0

Table 49. Nodes in Colombia

In the diagram below you can see the VSAT network topology deployed in Colombia and IP addressing information, equipment and satellite access.
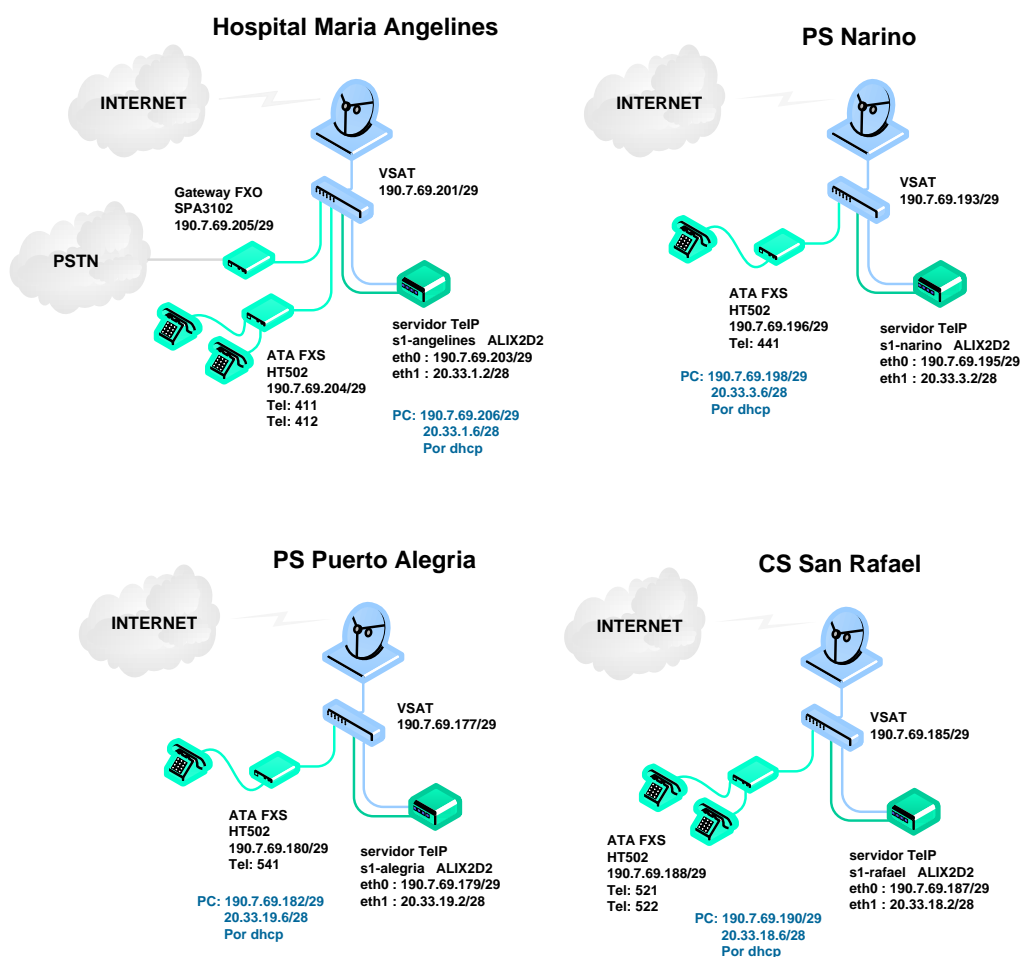
Figure 54. Network topology in Colombia

c) **Energy System**

In many places there is no commercial power, for this reason, photovoltaic systems were implemented. Energy System provide energy for VSAT telecommunications and computing systems. Putumayo network has different power systems installed, which are shown below:

Energy System 1: For VSAT equipment

- Power requirements: 45W
- 04 solar panels 85W
- 04 batteries 12VDC, 115AH
- 1 solar controller, 30A
- Autonomy: about 4 days
- Availability: 24 hours a day.
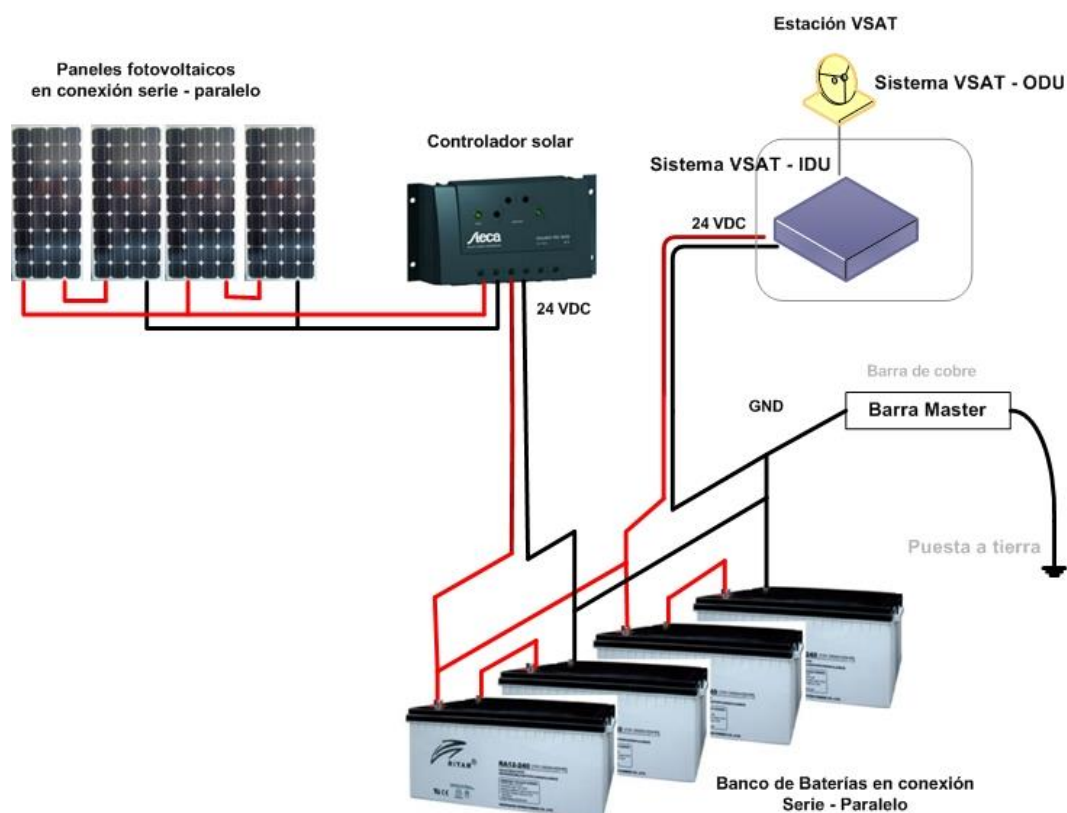
Figure 55. Energy system 1 diagram.

Energy System 2: Used for equipment of Client Stations and Computing Stations VSAT Network

- Power requirements: 170W
- 03 solar panels 85W
- 03 batteries 12VDC, 115AH
- 1 solar controller, 30A
- Autonomy: about 4 daysdepends on the use of equipment.
- Availability: 04 hours in a day
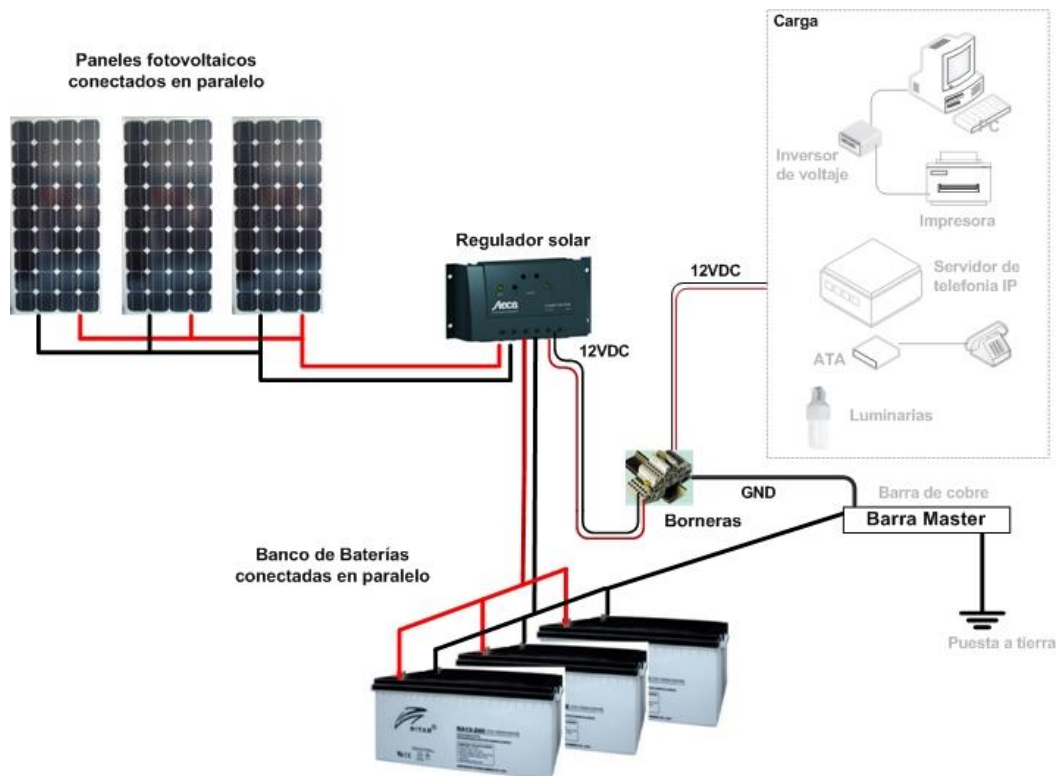
Figure 56. Energy system 2 diagram.

Energy system 3: Used for Client Stations equipment and Computer Stations at WiLD stations

- Power requirement: 175W
- 04 solar panels 85W
- 04 batteries 12VDC, 115Ah
- 01 solar controller, 30A
- Autonomy: about 4 days, depends on the use of equipment.
- Availability: 04 hours in a day
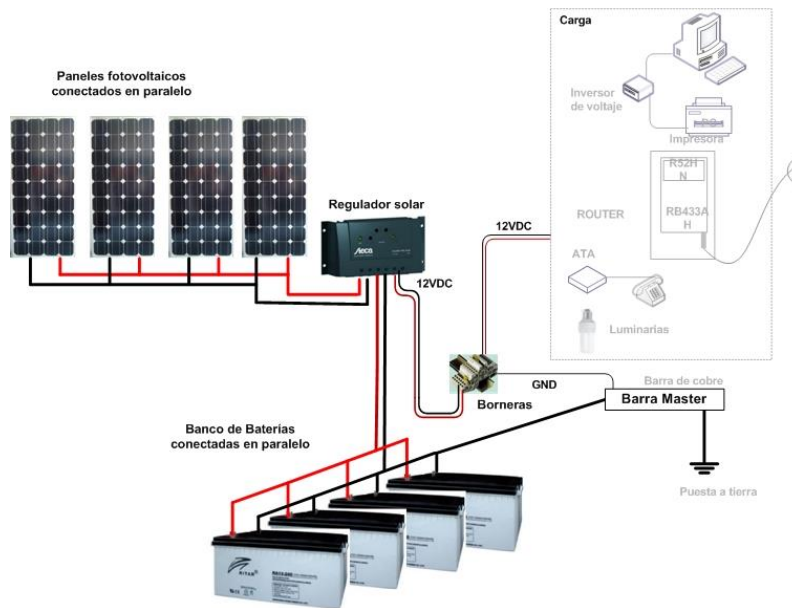
Figure 57. Energy system 3 diagram.

Energy System 4: Used for Network Access and Interconnection Equipment, located in the towers.

- Power requirement: 12W
- 01 Solar panel 85W
- 01 battery 12VDC, 115Ah
- 01 solar controller, 10A
- Duration: about 4 days
- Availability: 24 hours a day.
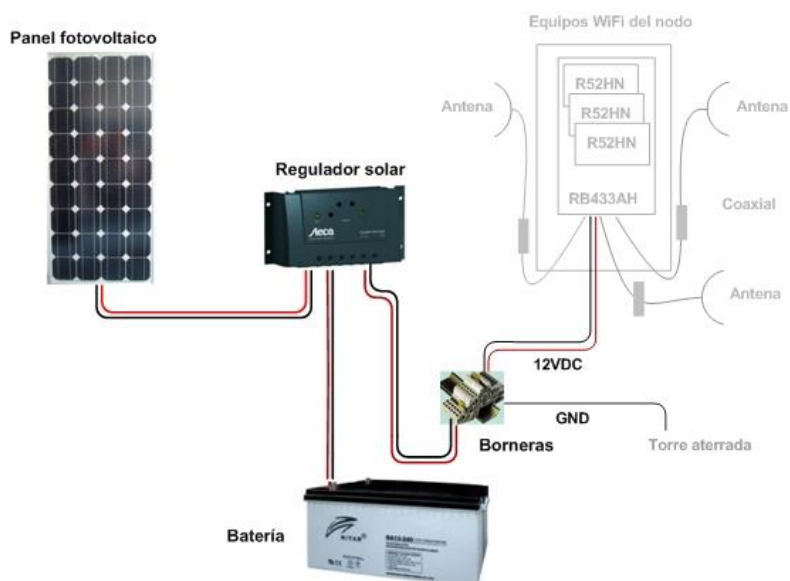
Figure 58. Energy system 4 diagram.

a. Energy System in Colombia

For client stations (telecommunications equipment, computing and the VSAT IDU) the project implemented a photo voltaic system. The following table shows the systems that are installed in each center or health post.

Health Post o Health Center	Energy System 1	Energy System 2	UPS
Hospital María Angelines	0	0	1
PS de Nariño	1	1	0
PS Puerto Alegría	1	1	0
CS San Rafael	1	1	0

Table 50. Energy systems in Colombia.

María Angelines Hospital has commercial power supply between 10:00 am and 00:00, so a power stabilization system has been installed only for telecommunications equipment consisting of a 1 KVA UPS and external battery bank consisting of 4batteries of 12Vand 8.5Ahwhich includes its own connection to the electrical network. This power stabilization system allows uninterrupted operation of telecommunications equipment.

b. Energy System in Perú

For client stations (telecommunications equipment, computer and the VSATIDU) and telecommunications equipment located in the towers, a photo voltaic system has been implemented. The following table lists the systems to be implemented in each center orhealth post inPeru:

Health Post o Health Center	Energy System 1	Energy System 2	Energy System3	Energy System4
CS El Estrecho	1	0	1	1
PS Flor de Agosto	0	0	1	1
PS San Francisco de Ere	0	0	1	1
PS Santa Mercedes	1	1	0	0
PS Angusilla	1	0	1	1
PS Nueva Esperanza	0	0	1	1
PS Bellavista	0	0	1	1
CS Soplin Vargas	1	1	0	0

Table 51. Energy systems in Peru.

d) Grounding system

The telecommunications system and computing stations are protected against both environmental shock (lightning) and accidental (short equipment circuitry) using a power protection system consists of two grounded systems separate (one for lightning and other to the client station). It uses a Franklin

lightning rod located on a mast or on top of the towers. The lightning rod is connected to the grounding system of ground through bare copper wire.

To implement grounding systems were built horizontal wells and within them is installed a copper strip which is soldered exothermically with cables coming from the ground bar of telecommunications systems and computer. The well is covered with a mixture of farmland, salt and bentonite. In each well was installed an electrical box that indicates the place where the copper strap binding with the bare wire.
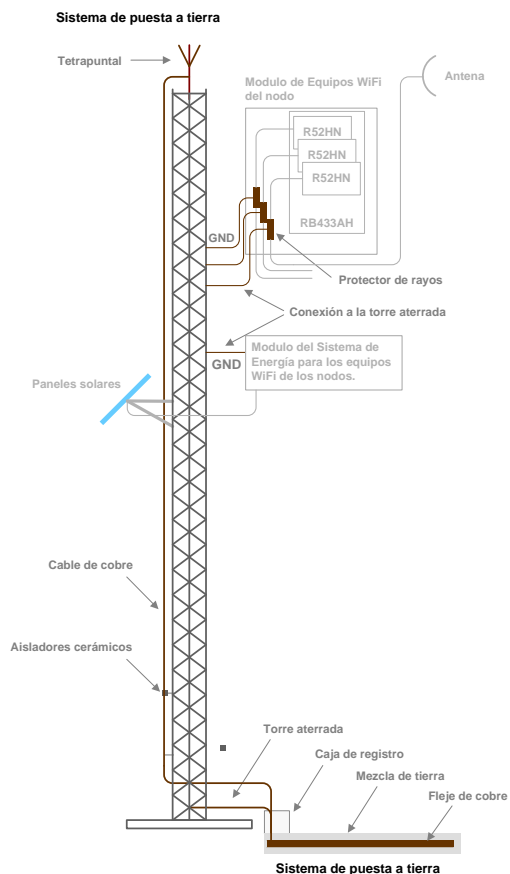
Figure 59. Diagram of power protection system for a tower.
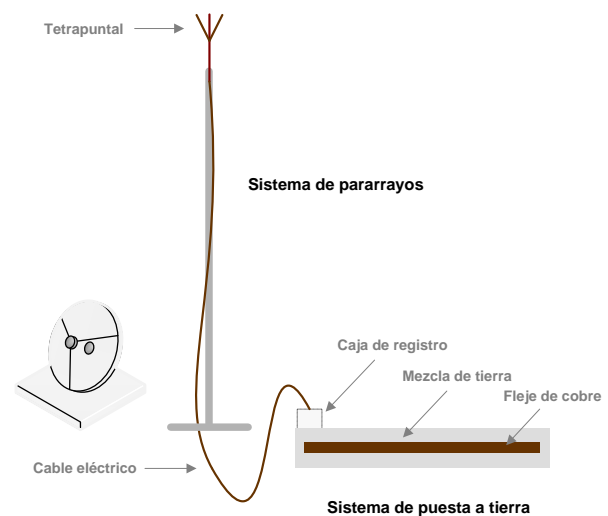
Figure 60. VSAT power protection system.

e) Services of the Network in Perú

a. Internet access

For Internet access service were installed four VSAT stations with a contracted rate of 512/128Kbps.The list of localities with VSAT stations has been included in a previous frame. Thus, the PS Flor de Agosto and PS Eré access to the Internet via VSAT station of CS El Estrecho, and PS Nueva Esperanza y PS Bellavista access to the Internet via VSAT station of PS Angusilla.

The level of service guaranteed by the satellite operator is at least 70% of the contracted bandwidth, corresponding to a very low overbooking (about 1 to 1.5) In addition, both, VSAT stations and WiLD links, are designed to operate 24hours a day.

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b. Telephone Service

This service allows communication between health centers and health post and also communicate with the public telephone network in the respective countries. The Centers and Health Posts of Peru access to the public network via Voice Gateway installed on the DIRESA Iquitos. The following table shows the phone access for this case. To communicate with the public network the beneficiaries must to use a prepaid card. Below is the numbering plan for health center or health posts Peru.

Health Post o Health Center	Annex
PS Angusilla	351
PS Nueva Esperanza	371
PS Bellavista	391
CS Soplin Vargas	321 Medical consulting room 322 Administrative office
PS Santa Mercedes	281
PS San Francisco de Ere	261
PS Flor de Agosto	241
CS El Estrecho	221 Directorate 222 Emergency

Table 52. Numbering Plan for Perú

f) Services in Colombia

a. Internet access

For Internet access service were installed four VSAT stations with a contracted rate of 512/128 Kbps. The list of localities with VSAT stations has been included in a previous list. The level of service guaranteed by the satellite operator is at least 70% of the contracted bandwidth, corresponding to a very low overbooking (about 1 to 1.5).

b. Telephone Service

This service allows communication between health centers and health posts and also communicate with the public telephone network in the respective countries. The Centers and Health Posts of Colombia access to the public network via Voice Gateway installed on theMaría Angelines Hospital. Below is the numbering plan for health center or health posts of Colombia:

Health Post o Health Center	Annex
Hospital María Angelines	411 Telemedicine office 412 Emergency
PS Nariño	441
PS Puerto Alegría	541
CS San Rafael	521 Medical consulting room 522 Admission

Table 53. Numbering Plan for Colombia

g) Characteristics of Installed Equipment

a. Telecommunication equipment

To WiLD network implementation Mikrotik equipment is used, the router is RB433 family and the wireless interface is R52N family (23dBm/25dBm @MCS2@-90dBm) Panel directional antennas (14dBi) were used for distribution links and grid directional antennas (24dBi) for backbone links. This solution can be deployed up to 3 links to the same router. To design the links Radio Mobile program (Based on the Longley Rice Irregular Terrain Model) has been used. Below are reliability parameters for wireless links.

For all links:
    •Minimum frequency(MHz): 2400MHz
    •Maximum frequency (MHz): 2483.5MHz
    •Statistical Mode: Accidental(90% time/70% situations)
    •Climate: Equatorial
    •Line Loss: 3 dBm.

For routers that form the backbone links (WiFi Routers);
        • System used: 25dBm @ MCS2 @-90dBm
        • Antenna type: 24dBi grid type directive gain
        This system can achieve more 50Km links.

For routers that form distribution links (Client Station and Access Point)
        • System used: 23dBm @ MCS2 @-90dBm
        • Antenna type: 14dBi grid type directive gain

The longest link WiLD network is linking CS El Estrecho with PS Flor de Agosto (46Km). Below is the design of the radio link.
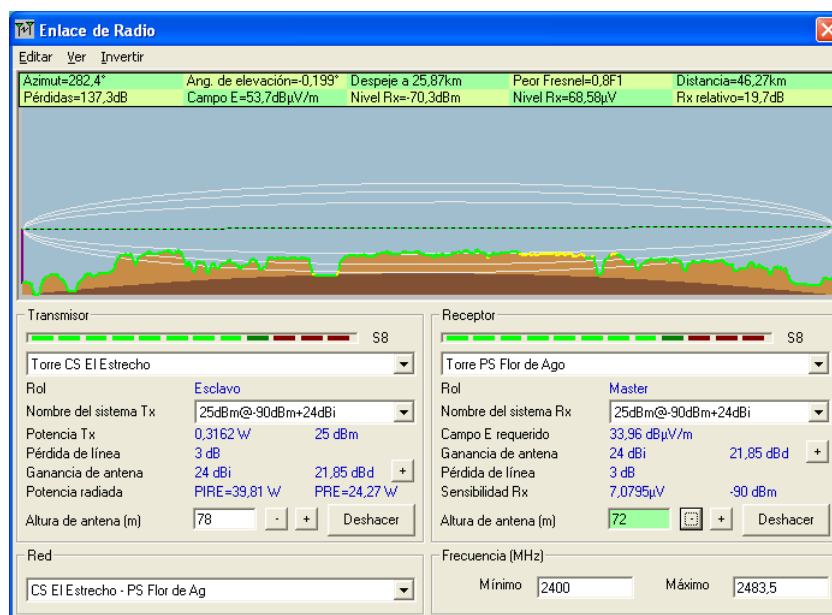
Figure 61. CS El Estrecho - PS Flor de Agosto link

For links of the CS El Estrecho WiLD network, the end to end performance is greater than 7 Mbps and for PS Angusilla network the end to end performance is greater than 12 Mbps. Distribution links have a end to end performance greater than 24 Mbps. Finally, for the IP Telephony service are used embedded boards for the Asterisk servers (ALIX model 2D), which are installed at all points where there is a VSAT station.

h) Infrastructure

a. Certificates Cabinets

The cabinets are used to house telecommunications and energy equipment and within them, electrical and data connections are made. Cabinets are used with IP66 certificate and were connected to the grounding bar. The following pictures show how the cabinets are installed on the nodes and client stations.
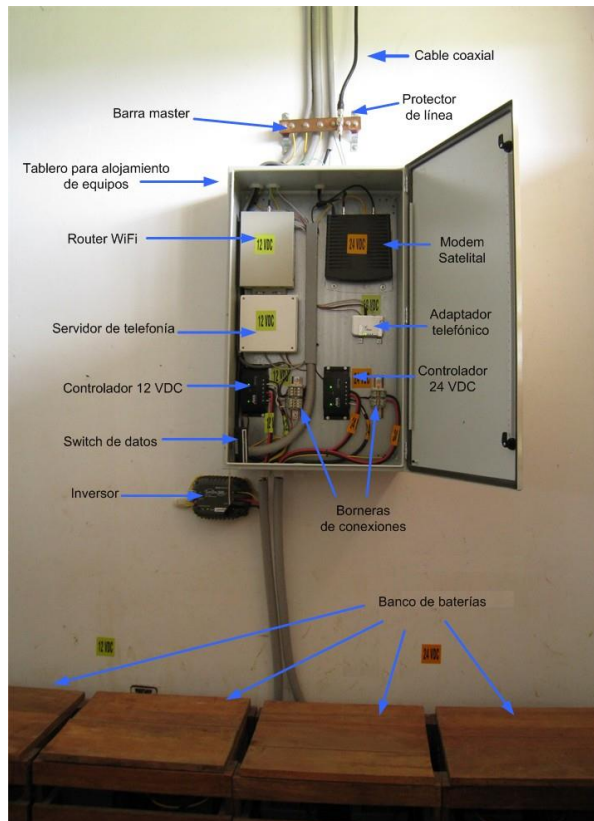
Figure 62. Client station.

Figure 63. Tower.

b. Mechanical supports

Mechanical supports are implemented for photovoltaic panels and antennas. Mechanical parts are made of galvanized steel.

Figure 64. Mechanical support for solar panels.

c. Telecommunications Towers

This system is only installed on the villages of Peru to locate antennas, telecommunications equipment and interconnecting the health centers or health posts of WiLD networks. The towers are braced type. The towers are made up of sections of 3 meters each, fastened by steel cables, with anti-rotation triangles and concrete bases. The tower and its accessories are galvanized and painted in red and white. In each tower is installed a lifeline for jobs safely. Additionally, in each WiLD network tower is installed low power consumption beaconing system. In this network implements two types of towers:

- 60 meters tower system: Applicable to towers of 45m, 54m, 60m and 66m. Reticulated structural Tower triangular section, consisting of φ1 SCH40 pipe ½ "(48.3 mm outer diameter and 3.68 mm. Thick).
- 90 meters tower system: Applicable for towers of 72-92 m. Reticulated structural Tower triangular section, consisting of φ2 SCH40 pipe "(60.3mm outside diameter and 3.91mm. Thick.

Figure 65. Braced tower.

Figure 66. Equipments in a tower.

The following table shows the heights of the towers installed in Putumayo network:

Health center or health post	Tower type 90 m	Tower type 60m
CS El Estrecho	81m	
PS Flor de Agosto	75 m	
PS San Francisco de Ere		69 m
PS Santa Mercedes		
PS Angusilla		45 m
PS Nueva Esperanza		45 m
PS Bellavista		45 m
PS Soplin Vargas		

Figure 67. Heights of the towers

i) **Photos**

Figure 68. PS Santa Mercedes

Figure 69. CS El Estrecho

Figure 70. Tower of PS Eré

Figure 71. PS Bellavista

7 ANNEX II: 3G RADIO ACCES

7.1 3G air interface

3G standard supports both TDD and FDD. Note, however, that the most extended mode deployed in current networks is FDD and also that the equipments to be provided by IPA in the TUCAN3G project are FDD-based. Consequently, when needed, we will particularize the description to the case of FDD referring the reader to the own standard in case there is some particular interest in TDD. It is important to emphasize that the objective of this subsection is not to provide a full exhaustive description of the air interface for 3G, but just an overview of the key elements that are potentially significant to the TUCAN3G project.

The following list provides the main and **basic characteristics** of the air interface (commonly referred as UTRA in 3G) as will be assumed in the TUCAN3G project:

- Chip rate: 3.84 Mcps
- Channelization bandwidth: 5 MHz
- Frame length: 10 ms, Superframe: 720 ms (composed of 72 frames)
- Slots per frame: 15
- Duplexing modes: FDD and TDD
- Reuse factor: 1
- Power control: 1500 Hz
- Modulation scheme in FDD: W-CDMA (BW: 5 MHz in DL and 5 MHz in UL)
  - Rel-99: QPSK (DL), BPSK (UL)
  - Rel-5: it incorporates 16-QAM (DL) - HSDPA
  - Rel-6: it incorporates 16-QAM (UL) - HSUPA
  - Rel-7: it incorporates MIMO with 16-QAM (DL), 64-QAM (DL) and 16-QAM (UL) – HSPA+
- Receiver detection scheme: usually rake receiver
- Inter-cell asynchronous operation
- Channel coding: convolutional and turbo codes

7.1.1 Channels in FDD

In FDD there are three channel levels: logical, transport, and physical channels. The three levels of channels are mapped among them.

- *Logical channels*:
  - Control channels: BCCH, PCCH, DCCH (Dedicated Control Channel), CCCH.
  - Traffic channels: DTCH (Dedicated Traffic Channel).
- *Transport channels*:
  - Dedicated channels: DCH (Dedicated Channel).
  - Common channels: BCH, FACH, PCH, RACH, CPCH, DSCH.
- *Physical channels*:
  - Dedicated channels: DPDCH (Dedicated Physical Data Channel), DPCCH (Dedicated Physical Control Channel).
  - Common channels: PRACH, PCPCH, CPICH (Common Pilot Channel), P-CCPCH, S-CCPCH, SCH (Synchronization Channel), PDSCH, AICH, PICH.

7.1.2 Frame structure in FDD

The following figure shows the frame structure composed of slots and how the traffic data and control channels are multiplexed in UL and DL.
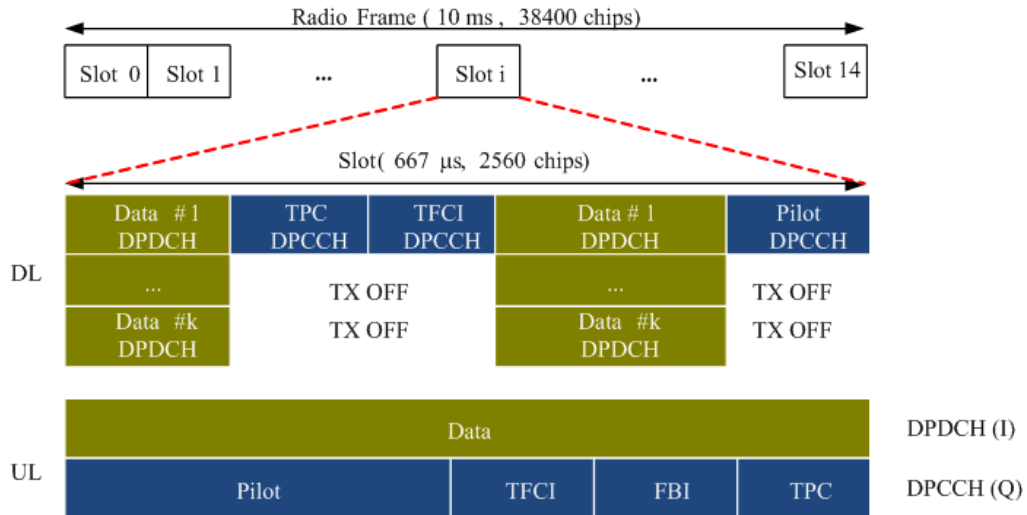

Figure 72. Frame structure for 3G.

7.1.3 Codes

In WCDMA there two codes: the channelization codes and the scrambling codes. Both codes are combined at the same chip rate (3.84 Mcps) according to the following scheme:
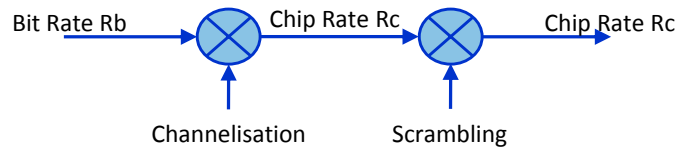

Figure 73. Combined use of the channelization and scrambling codes.

The characteristics for both code types are as follows:

	Channelization code	Scrambling code
Generic usage	UL: separation of physical data (DPDCH) and control channels (DPCCH) from same terminal	UL: separation of terminals (each user within the same cell uses a different code)
	DL: separation of DL connections to different users within one cell	DL: separation of cells (each cell is assigned a different code)
Length	UL: 4-256 chips (1.0 – 66.7 μs) DL: 4-512 chips (1.0 – 133.3 μs)	UL: 38400 chips (10 ms: 1 frame) – there also short scrambling codes but they are not usually used DL: 38400 chips (10 ms: 1 frame)
Number of	It depends of the selected spreading	UL: several millions

codes	factors	DL: there are 2^{18}-1 although only 512 are used (to facilitate cell search)
Code family	Orthogonal Variable Spreading Factor (OVSF)	Gold family (duration: 10 ms)
Chip rate	3.84 Mcps	3.84 Mcps

The use of the **channelization codes** is different for UL and DL in relation with the data and the control channels:

- *Uplink*: control (DPCCH) and data (DPDCH) are multiplexed using different channelization codes:
  - o DPCCH: fixed spreading factor of 256, BPSK, channel uncoded rate 15 kbps. In particular, DPCCH contains the "pilots" necessary for channel and SIR estimation, for example.
  - o DPDCH: selectable spreading factor between 4 and 256. The spreading factor can be changed every TTI (transmission time interval). The minimum TTI is 10 ms in Rel-99 and 2 ms in Rel-6 and beyond
  - o DPDCH modulated in phase (I), DPCCH modulated in quadrature (Q)
- *Downlink*: control (DPCCH) and data (DPDCH) are multiplexed in time using the same channelization code. The spreading factor is selectable between 4 and 512. The spreading factor can be changed every TTI. The minimum TTI is 10 ms in Rel-99 and 2 ms in Rel-5 and beyond. In particular, DPCCH contains the "pilots" necessary for channel and SIR estimation, for example.

The bit-rates that can be achieved in UL and DL depend on the selected spreading factor and on the modulation that can be supported. Such supported modulations depend on the release (see the list of characteristics for each release in terms of supported modulations at the beginning of this subsection devoted to the description of the 3G air interface).

The channelization codes are based on OVSF. Such family of codes is based on a tree so that if a given code with a certain spreading factor M is selected, the codes with a higher spreading factor hanging in the tree from such selected code cannot be employed. This procedure assures that orthogonality is preserved between any pair of used codes, even if they have different spreading factors. The minimum possible spreading factor is 4 and the maximum is 256 in UL and 512 in DL. The codes can be reassigned (and, thus, the spreading factors can change) every TTI (see the table at the end of this subsection to see the minimum possible value of the TTI in DL and UL for each release).
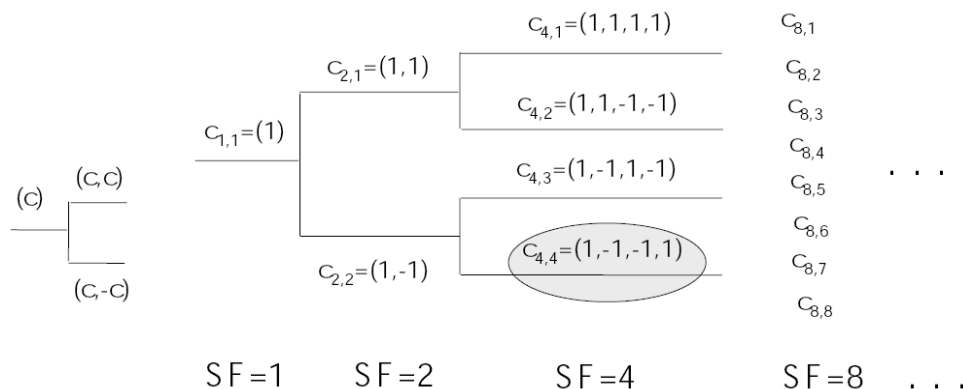

Figure 74. Beginning of the code tree for OVSF codes.

Scrambling codes

- *Uplink*: they are Gold sequences with an original length of $2^{25}-1$ (where 25 is the degree of the generator polynomial of the LFSR based on which the Gold sequences are created) but truncated with a final length equal to 38400 chips. There are millions of codes.
- *Downlink*: they are Gold sequences with an original length of $2^{18}-1$ (where 18 is the degree of the generator polynomial of the LFSR based on which the Gold sequences are created) but truncated with a final length equal to 38400 chips. Within the set of resulting sequences, only 512 are kept to facilitate the cell search (otherwise the cell search procedure described in the physical layer procedures section would become excessive). Each cell is allocated a different scrambling code out of the 512 possibilities. Since the number of scrambling codes is so high, the scrambling code planning is a trivial task and can be done automatically by the network planning tool. The 512 primary scrambling codes are expected to be enough for the cell planning. Such 512 codes are divided into 64 groups of 8 codes each. Each of these groups is allocated a different SSC (secondary synchronization code), that will be used in the synchronization and cell search procedures, as explained in what follows.

7.1.4 Synchronization and cell search

The synchronization and cell search is implemented in 3 stages:

(a) *Slot synchronization*: Each BS transmits the SCH, which is repeated every frame (10 ms). The SCH is divided into 2 subchannels: P-SCH (Primary SCH) and S-SCH (Secondary SCH). The P-SCH is exactly equal for all the cells and consists of a predefined subsequence of 256 chips that is repeated at the beginning of each slot (see ac_p in Figure 75). Since the receiver knows a-prior this subsequence, it can correlate the received signal with such subsequence and look for the positions of the peaks, which will allow to the detect the beginning of the slots (slot synchronization).

(b) *Frame synchronization*: It is based on the S-SCH. The S-SCH carries the secondary synchronization code (SSC) corresponding to the given cell. There are 64 unique possible SSC's (different among them). The SSC is repeated every frame and defines a group of 15 subsequences of 256 chips. Each of these subsequences is transmitted at the beginning of each slot (see $ac_s^{i,j}$ in Figure 75). The receiver correlates the received signal with the 64 possible SSC's. Looking at the peaks, it can discover when the frame begins (frame synchronization) and also which is the group (out of the 64 possible groups) to which the scrambling code of the given cell belongs to.
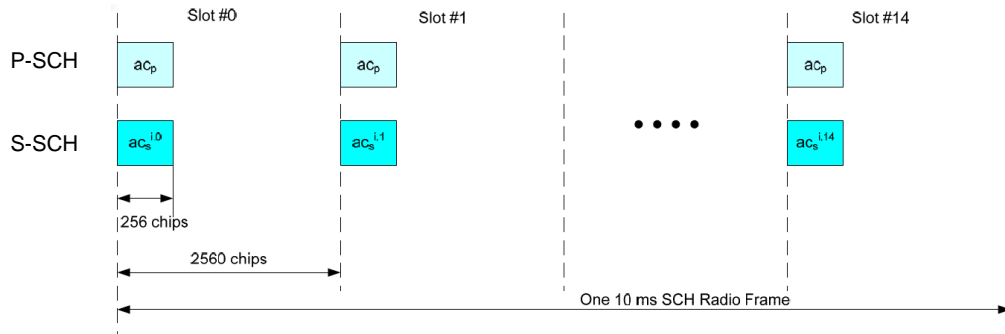

Figure 75. Structure of the SCH (Synchronization Channel) composed of the P-SCH and the S-SCH.

Once procedures (a) and (b) have taken place, the receiver knows when each frame begins and also which is the group (out of the 64 possibilities) to which the scrambling code of the cell belongs to. In each group, there are still 8 possible scrambling codes. The last stage is, therefore, in charge of deciding which is the exact scrambling code (out of these 8 possibilities) assigned to the cell under analysis. This will finish the synchronization and cell search procedure.

(c) *Cell search*: It is based on the CPICH (Common Pilot Channel). This channel sends some control and pilot information and uses a fixed spreading factor of 256. The receiver can then correlate with a window of 256 chips of the 8 possible scrambling sequences within the group. The maximum peak among the 8 correlator outputs indicates finally which the exact scrambling code used by the cell.

7.1.5 Brief release history

Release	Functional freeze	Main feature of Release
Rel-99	March 2000	UMTS 3.84 Mcps (W-CDMA FDD & TDD).
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA).
Rel-5	June 2002	HSDPA.
Rel-6	March 2005	HSUPA (E-DCH).
Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL). LTE & SAE Feasibility Study.
Rel-8	Dec 2008	LTE Work item – OFDMA air interface. SAE Work item. New IP core network. Edge Evolution, more HSPA+.
Rel-9	Dec 2009	UMTS and LTE minor changes, LTE-Advanced feasibility study.
Rel-10	Q1 2011	LTE Advanced fulfilling IMT Advanced 4G requirements. Backwards compatible with release 8 (LTE). Multi-Cell HSDPA (4 carriers).

After the previous releases, HSPA+ has been evolving ("HSPA+ Advanced" or "Beyond HSPA+") in parallel with LTE by means of new releases, increasing the maximum data rates for DL and UL. This has been carried out by including new capabilities, some of them inspired by the techniques proposed for LTE, such as multi-flow transmission, multicarrier across bands schemes, enhancements for HetNets deployments, multiple antenna advanced solutions, etc. The complete details of these new releases are not described in this document as the scope of it is just to show the basic and fundamental characteristics of the air interface of 3G to be considered in the TUCAN3G project.

Minimum value of Transmission Time Interval (TTI)	DL (ms)	UL (ms)
Rel-99	10	10
Rel-5	2	10
Rel-6	2	2
Rel-7	2	2

Figure 76. Brief release history for UMTS (source: Agilent).

7.2 3G architecture

The radio access network for 3G-UMTS, also called UTRAN (UMTS Terrestrial Radio Access Network), is based on a hierarchical topology where the network functions are allocated to two different types of nodes: base stations (also called NodeB's) and Radio Network Controllers (RNC's). The RNC's are the elements containing the control plane functionality of the air interface (control signalling) in addition to multiple functions of the user plane. Some functions allocated to the RNC's are: radio resource management, admission control, congestion control, code management, outer power control, scheduling, headers compression, etc. The NodeB's are in charge of the radio transmission (physical layer) towards/from the UE's and their operation is controlled remotely by the RNC's. The NodeB's carry out functions related to the channel coding, modulation, spreading, inner power control, etc.

The interconnection between the NodeB's and the RNC's is based on the Iub interface in a way such that the network follows a star logical topology. The RNC's can also be interconnected among them using specific interfaces called Iur. Such interface allows the implementation of macrodiversity between NodeB's connected to different RNC's.

The interconnection of the radio access network with the core network is carried out through the interfaces Iu-PS (connection between the RNC's and the SGSN's for the packet data services) and Iu-CS (connection between the RNC's and the MSC's for the circuit based voice services).
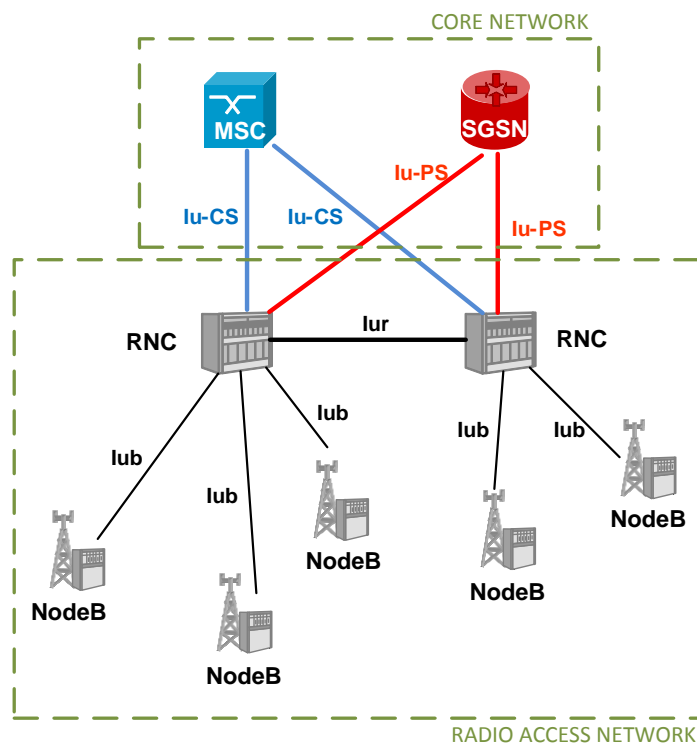
Figure 77. 3G architecture [Agu10]

The concrete system architecture for the network will be based on the reference architecture provided by IPA for the equipments that will be used in the TUCAN3G project.
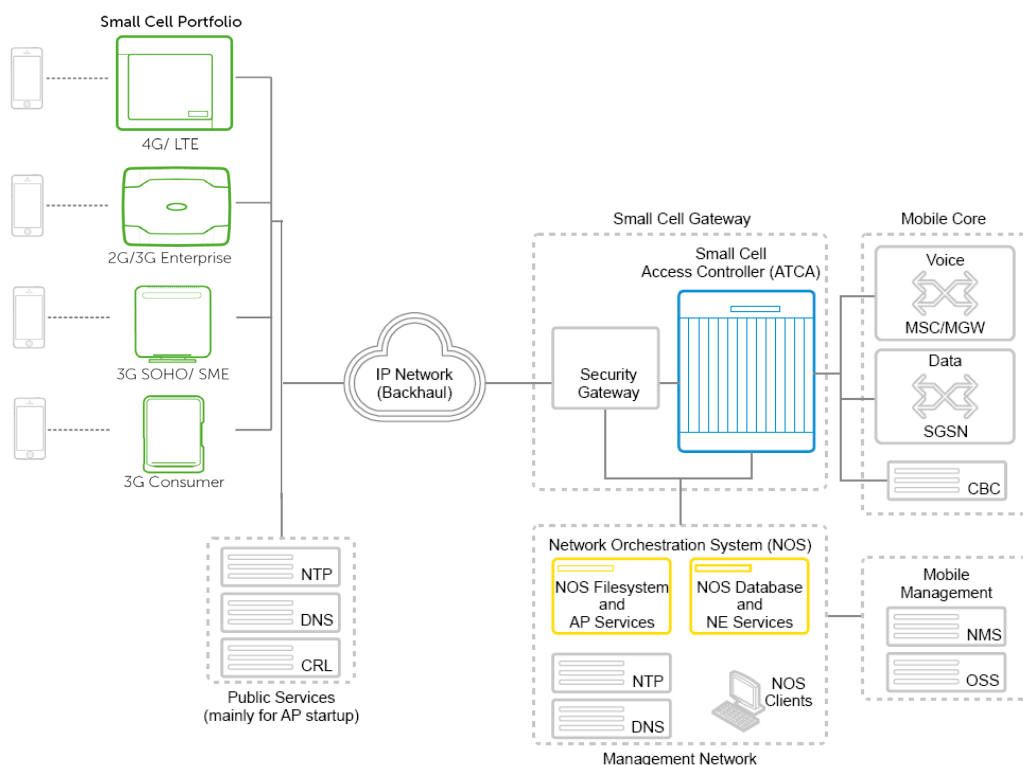

Figure 78. IPA architecture

8 ANNEX II: 4G RADIO ACCES

8.1 *LTE air interface*

With the goal of increasing spectral efficiency and reducing latency, GSM/UMTS standards evolved to Universal Mobile Telecommunications System (UMTS) Long Term Evolution (LTE) in 3GPP (3rd Generation Partnership Project) Release 8. LTE Release 8 is one of the primary broadband technologies based on OFDM and provides multi-antenna support and flexible bandwidth operation. It is mainly deployed in a macro/microcell layout.

Minor enhancements regarding the air interface were introduced later in Release 9. Such enhancements include features like dual-layer beamforming and time-difference-of-arrival-based location techniques.

LTE Release 8 and 9 were significantly enhanced in LTE Release 10 (much higher peak rates, higher throughput and coverage, and lower latencies), also known as LTE-Advanced (LTE-A). LTE-A introduces bandwidth extension via carrier aggregation to support deployment bandwidths up to 100 MHz, coordinated multi point transmission (CoMP), uplink spatial multiplexing including extension to four-layer MIMO, and heterogeneous deployments where low-power nodes comprising picocells, femtocells, relays, remote radio heads, and so on are placed in a macrocell layout.

IMT-Advanced requirements [ITU08] require a technology well beyond UMTS. Actually, some of the requirements cannot be fulfilled by LTE Release 8, but can be met or exceed by LTE-A. For such a reason, despite the equipments to be provided by IPA in the TUCAN3G project are 3G based, this section provides a basic description of LTE standard as it is considered that an eventual evolution of TUCAN3G network will be surely based on such technology. The section consists on a summary of the overview provided in [Gho10] for LTE and LTE-A.

The following list provides the main and basic characteristics of the air interface:
- **Bandwidth:** Scalable up to 20 MHz (1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz are allowed). LTE-A includes bandwidth extension via carrier aggregation to support deployment bandwidths up to 100 MHz
- **Duplexing** modes: FDD and TDD
- **Subframe structure** (common for both FDD and TDD): two slots of 0.5 ms (7 OFDM symbols for normal cyclic prefix).
- **Downlink**
  - DL Multiple Access: OFDMA
  - DL subframe: Each DL subframe contains reference signals, control information, and data transmission:
    - *Reference signals*: the DL subframe several reference symbols located within each slot (without spanning the whole bandwidth)
    - *DL control channels*: DL control signalling is located in the first n OFDM (symbols), where $n<=3$ can be dynamically changed every subframe. The control channels are:
      - PCFICH (Physical Control Format Indicator CHannel): used to indicate the size of the control region in number of OFDM symbols
      - PHICH (Physical Hybrid automatic repeat request (HARQ) Indicator CHannel): used to carry ACK/NACK for the UL data transmission.
      - PDCCH (Physical DL Control CHannel): used for DL and UL scheduling assignment. It contains control information needed for data reception and demodulation, as well as power control. Users are assigned data allocation in terms of resource blocks (RB). Each resource block is defined as 12 resource elements (RE) by one slot. Each RE is composed by 12 carriers. After determining that no data assignment is given to it in this subframe, a user can turn off its power amplifier (micro-sleep) to save energy.

- *Data transmission*:
  - The PDSCH (Physical DL Shared CHannel) is used to carry user data in the DL.
  - The PBCH (Physical broadcast channel) carries broadcast information
  - The PMCH (Physical multicast channel) carries multicast services.
- o DL MIMO transmission schemes**:**
  - *In Release 8*, supported DL MIMO transmission schemes include transmit-diversity and open-loop and closed-loop spatial multiplexing with up to 4 layers.
    These MIMO schemes are supported by common reference signals which are available for 4 antenna ports.
    Codebook-based precoding is used to support closed-look spatial multiplexing.
    In addition, a single layer of a UE-specific reference signal (dedicated pilots) is available. This can be used to enable single-layer beamforming in TDD scenarios where the DL spatial channel information may be obtained by the eNB[8] using channel reciprocity (in such a case there is no restriction on the number of transmit antennas that can be employed at the eNB).
  - *In Release 9*, 2 layers of orthogonal UE- specific reference signals are introduced in the DL (they are separated by code in a resource block). The eNB may transmit two layers of data to an UE using spatial multiplexing in a closed-loop mode by constructing antenna weights using reciprocity.
  - *In Release 10*, 8 layers of UE-specific reference signals are introduced for demodulation. This can be used to enable DL spatial multiplexing using up to eight-layer multiple-input multiple-output (MIMO) employing 8 or more transmit antennas.
    The maximum number of transport blocks transmitted over eight layers will remain two with support for separated modulation and coding schemes (MCSs) and separate HARQ ACKs.
    In addition to UE-specific reference signals, additional reference signals will be broadcast. These common reference signals are called channel state information reference signals (CS-RSs). The CS-RSs are used for demodulation but to support feedback measurements for up to 8 transmit antennas. They will be designed to be sparse in time and frequency with an overhead of 1% or less. They may interfere with the data transmission of a Release 8 and 9 users in the same subframe.
- o Multiuser MIMO
  - *In Release 8*, despite a multi-user MIMO transmission scheme may applied based on codebook feedback, MU-MIMO does not provide performance gains compared to SU-MIMO. This is due to the course quantization and the lack of support for cross-talk suppression at the UE.
  - *In Release 9,* the two layers of orthogonal UE- specific reference enable the transmission of two layers to two UEs (one layer each) using the same time-frequency resource (the eNB is able to from transmit beams using reciprocity-based techniques.)
    The UE, after subtracting out its channel estimate, may estimate a covariance matrix for the interference (from a co-scheduled UE and outer cell transmission).
    In addition to that, up to four layers of quasi-orthogonal UE-specific reference signals is available for MU-MIMO enabling co-scheduling of up to 4 UEs in the same time-frequency resource.
  - *In Release 10,* high-resolution spatial channel feedback is considered to support MU-MIMO when channel reciprocity is not reliable.

- o DL CoMP support
  DL intracell CoMP transmission and reception is supported in Release 10 (LTE-A), with the goal of reducing interference for a UE in the network that is close to multiple eNBs. In particular, the CS-RSs design will potentially enable the UE at the cell edge to measure CS-

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[8] eNB stands for Evolved NodeB (eNodeB) which is the base station for LTE radio.

RSs transmitted from adjacent cells (for CoMP support). Closed loop beamforming or precoding-based transmission will be supported in CoMP.

- **Uplink**
  o UL Multiple Access: SC FDMA implemented via discrete Fourier transform spread OFDM (DFT-S-OFDM).
  o UL subframe:
    - One *reference symbol* is located within each slot (spanning the whole bandwidth) for transmitting the demodulation RS, which is used for channel estimation and demodulation of UL data or control.
    - **UL control channel**: UL control signalling is located in the system band-edge. The UL control channel, PUCCH (Physical UL Control CHannel), is used to carry ACK/NACK for the DL data transmission and channel state feedback (e.g CQI, precoding matrix indication, or rank indication). It contains the sounding reference (SR) signal, which is another type of reference signal used for UL frequency selective scheduling and dedicated-reference-symbol based beamforming on the DL
    - **User data** is carried within the PUSCH (Physical UL Shared CHannel)
    - Finally, the PRACH (Physical Random Access CHannel) carries out **random access** transmission.
  o UL MIMO transmission schemes:
    - *In Release 8*, only 1 antenna is supported in the UL.
    - *In release 10* (LTE-A), UL spatial multiplexing using 4-layer MIMO is supported. Open-loop and closed-loop spatial multiplexing are supported.
      In the case of closed-loop operation, code-book based precoding will be used. The codebook will provide the capability to turn off certain antennas (for power saving) at the instruction of the eNB.

8.2   LTE architecture

LTE architecture presents some important differences with respect to UTRAN [Fir13], [3GPP TS 36.300]:

- LTE is a complete an IP (Internet Protocol) system. All services are transported by IP (Internet Protocol). Therefore, the EPC does not have a circuit-switched domain anymore
- To make the scaling independent, user data (also known as the user plane) and signalling (also known as the control plane) are separated in the LTE architecture.
- Different from UMTS architecture which is a hierarchical architecture, with base stations and controllers that control these base stations, LTE architecture is a "flat architecture".

According to the general architecture of 3GPP systems (GSM, UMTS and LTE) the complete architecture of the LTE system, known as Evolved Packet System (EPS), is composed by the user equipment (UE), the Radio Access Network (RAN), also known as evolved UTRAN (E-UTRAN), and the core network, known as Evolved Packet Core (EPC). The E-UTRAN architecture and the EPC features are summarized below.

8.2.1   E-UTRAN architecture

GSM and UMTS networks are based on a hierarchical architecture, where RAN functions are distributed between two types of nodes: base stations (node B) and radio network controllers (RNC). E-UTRAN, however, defines a flat architecture without any level of hierarchy. In E-UTRAN, the base station, known as evolved NodeB (eNB), performs all the functionalities of the RAN, providing the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE. Other radio interfaces such as IEEE 802.11 and WiMAX integrates the physical and link layer radio protocols in the base station as well.

There are several reasons that motivated the transition to a flat architecture. Firstly, the evolution of technology has made possible having complex base stations with very powerful processing capabilities and reduced cost. Secondly, H-ARQ and scheduling techniques executed in the own base stations allow low round trip times. Finally, the existence of a critical element with a high cost such as the RNC limits the robustness and scalability of the RAN. It limits the robustness because of a failure in the RAN that may control hundreds base stations can affect a very high number of users. It limits the scalability because of, in case we need to install a new base station to increase capacity or coverage, we may need to introduce a new RNC if the RNC was in its capacity limit just to introduce a new base station.

Summarizing, the E_UTRAN contains only one network entity: the base station, known as eNB in E-UTRAN. The RNC is not longer considered in LTE.

8.2.2   EPC network

The EPC is composed by the following network elements:

- **Gateways** (GW). They deal with the user plane, transporting the IP data traffic between the User Equipment (UE) and the external networks.
    o   The Serving GW is the point of interconnect between the radio-side and the EPC. It is the anchor point for the intra-LTE mobility (i.e. in case of handover between eNodeBs) and between LTE and other 3GPP accesses. It is logically connected to the other gateway, the PDN GW.
    o   The PDN GW is the point of interconnect between the EPC and the external IP networks, also known as Packet Data Networks (PDN). The PDN GW also performs various functions such as IP address / IP prefix allocation or policy control and charging.
    Despites 3GPP specifies both gateways independently, in practice, they may be combined in a single "box" by network vendors.
- **Mobility Management Entity (MME)**. The MME deals with the control plane, handling the signalling related to mobility and security for E-UTRAN access. The MME is responsible for the tracking and the paging of UE in idle-mode. It is the termination point of the Non-Access Stratum (NAS).
- **Home Subscriber Server (HSS)**. It is a database that contains user-related and subscriber-related information. It also provides support functions in mobility management, call and session setup, user authentication and access authorization. It is based on the pre-3GPP Release 4 - Home Location Register (HLR) and Authentication Centre (AuC).
- **General Operation and Management System (O&M),** including CSG (femtocell, HeNB, Closed Subscriber Group)

The EPS also allows non-3GPP technologies to interconnect the UE and the EPC. Non-3GPP means that these accesses were not specified in the 3GPP. These technologies includes e.g. WiMAX, cdma2000®, WLAN or fixed networks. Non-3GPP accesses can be split into two categories: the "trusted" ones and the "untrusted":

- Trusted non-3GPP accesses can interact directly with the EPC.
- Untrusted non-3GPP accesses interwork with the EPC via a network entity called the ePDG (for Evolved Packet Data Gateway). The main role of the ePDG is to provide security mechanisms such as IPsec tunnelling of connections with the UE over an untrusted non-3GPP access.

3GPP does not specify which non-3GPP technologies should be considered trusted or untrusted. This decision is made by the operator.

8.2.3 LTE Interfaces

Every entity in the EPS is connected to other/s entity/s through specific interfaces. The interfaces defined in LTE are:

- Uu (LTE air interface): eNB and UE.
- S1 connects the eNBs to the EPC. It is divided in two
    - S1-U: eNB and SGW (user data)
    - S1-MME: eNB and MME (control)

    The S1 interface support configurations where an eNB can be simultaneously connected to multiple MME and/or multiple S-GW (many-to-many eNBs and MMEs/Serving GWs). This feature makes the network dimensioning (eNBs in the RAN and MME and S-GW in the EPC) more flexible, as the traffic through the enBs can be sent to the best EPC node according for instance to load balancing criteria. This feature cannot be considered in a hierarchical structure.
- S11: MME and SGW (control)
- S5/S8: PGW and SGW (data)
- X2 interconnects eNBs for
    - low latency hand-over
    - load and RRM signalling

Thanks to the X2 a eNB can be connected (optionally) to a subset of eNBs and exchange of control and data information. Such an option is not possible in UTRAN.

Support for femto cells:

When HeNB are considered, the E-UTRAN architecture may optionally deploy a Home eNB Gateway (HeNB GW) to allow the S1 interface between the HeNB and the EPC to scale to support a large number of HeNBs.

The HeNB GW appears to the MME as an eNB. The HeNB GW appears to the HeNB as an MME.

The HeNB GW shall connect to the EPC in a way that inbound and outbound mobility to cells served by the HeNB GW shall not necessarily require inter MME handovers. One HeNB serves only one cell.

The S1 interface between the HeNB and the EPC is the same whether the HeNB is connected to the EPC via a HeNB GW or not.
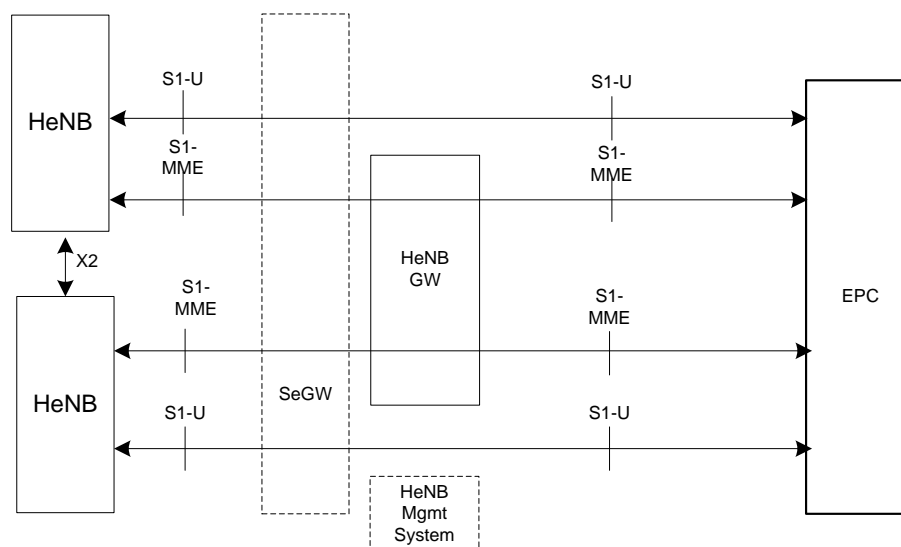

Figure 79. Overall E-UTRAN Architecture with deployed HeNB GW [3GPP TS 36.300]