ICT-601102 STP TUCAN3G

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

D41

UMTS/HSPA network dimensioning

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Abstract:

Based on the definition of the access network architecture and the voice and data traffic evolution forecast, this document derives engineering rules for dimensioning the number of open-access femtos, as a function of the frequency bands adopted for access, as well as the solar cells units. Dimensioning is based on service provision and energy consumption evaluation. Two deployment cases have been studied: the case of single HNB with different antennas types, and the case of two co-located HNB operating at different frequencies with directional antennas. The considered deployment sites are the five specified in document D21 in the Napo river and Paranapura river. The required backhaul bandwidth is determined for all cases.

Keyword list: Cell planning, network dimensioning, WCDMA, energy supply dimensioning

Document Revision History

DATE	ISSUE	AUTHOR	SUMMARY OF MAIN CHANGES
15/08/2013	a	UPC	The first draft includes dimensioning for voice traffic and problem statement and analysis for mixed voice and data traffic
23/10/2013	aa	UPC	Draft version with voice and data traffic
30/10/2013	ab	UPC, URJC	Deliverable version addressing all remarks by the technical coordinator (URJC)
11/11/2013	ae	UPC	Final version

Executive Summary

A network planning exercise is done in this document for the locations and 3G voice and data services envisioned in TUCAN3G. The network items to be decided in each location are the number of HNBs and their configuration, the associated required backhaul and the energy units (batteries and solar panels). We make a number of constraining assumptions that include: 1) only three types of HNB as provided by ip.access, characterized by the transmitted power and number of channels 2) measured traffic models for voice and data in rural areas of Peru, including its evolution along the day and through 5 years. In each location, up to six scenarios (defined with the type of antenna and number of HNB) are tested, with either one or two HNB and different antenna configurations. It has been observed that HNB deployments on a single high tower (already available in the locations) provide the coverage and service, except for Santa Clotilde where 3G data traffic can be served provided that voice traffic is routed through the existing GSM network. For each configuration, three types of HNB are assumed.

Due to the limitations in power and number of channels in the provided ip.access equipment, we have performed a complete study that includes not only the congestion probabilities associated to the limited number of circuits but also the impact of coverage associated to radio coverage and to intracell interference both in UL and DL.

From the evaluated results, we draw recommendations for each location, by adopting the following criteria. Among all configurations fitting the specified blocking probability of 2%, select:

1. For each year, choose the configuration, which supposes a minimum number of HNBs, giving preference to those ones that use HNB S-Class 16 or E-Class 24 (as off-the-shelf products).
2. If several solutions are still valid, choose the one requiring the least backhaul bandwidth.
3. If more than one configuration requires the same backhaul, then choose the configuration with lower energy consumption.
4. If more than one configuration still survives, choose the one with the lowest cost.
5. Whenever no configuration using HNB S-Class 16 or E-Class 24 cannot provide service for a particular year, chose HNB E-Class 24*.
6. Finally, if the configuration and/or HNB has to be changed starting from the second year, this configuration and/or HNB for the second year will also be selected for the first year.

Finally, sections 8.2 contain the backhaul requirements for each location over the 5 years period, and section 8.3 lists the materials to be purchased for activities in WP6.

DISCLAIMER

The work associated with this report has been carried out in accordance with the highest technical standards and the TUCAN3G partners have endeavoured to achieve the degree of accuracy and reliability appropriate to the work in question. However since the partners have no control over the use to which the information contained within the report is to be put by any other party, any other such party shall be deemed to have satisfied itself as to the suitability and reliability of the information in relation to any particular use, purpose or application.

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References

[3GPP TS 125.101] 3GPP TS 125.101; Technical Specification Group Radio Access Network; “User Equipment (UE) radio transmission and reception (FDD)”, Release 11, v11.5.0, April 2013.

[3GPP TS 125.104] 3GPP TS 125.104; Technical Specification Group Radio Access Network; “Base Station (BS) radio transmission and reception (FDD)”, Release 11, v11.5.0, April 2013.

[3GPP TS 125.133] 3GPP TS 125.133; Technical Specification Group Radio Access Network; “Requirements for support of radio resource management (FDD)”, Release 11, v11.4.0, April 2013.

[Awoniyi03] O. Awoniyi, N.B. Mehta, and L.J. Greenstein, “Characterizing the orthogonality factor in WCDMA downlinks”, *IEEE Trans, Wireless communications,* vol. 2, no 4, p. 621-625, 2003.

[Bertsekas 92] D. Bertsekas, R. Gallager, *Data Networks*, Second Edition, Prentice Hall, New Jersey 1992.

[EARTH-D23] G. Auer, et al, “Energy efficiency analysis of the reference systems, areas of improvements and target breakdown”, *deliverable report D23*, ICT-247733 EARTH project, January 2012.

[ETSI TR 125.943] Technical Report. Universal Mobile Telecommunications System (UMTS); Deployment aspects (3GPP TR 25.943 v 11.0.0 release 11). October 2012.

[Holma00] H. Holma, and A. Toskala, “Wcdma for Umts” (Vol. 4). New York, Wiley, 2000.

[ITU-R P.453-10] Recommendation ITU-R. P.453-10, “The radio refractive index: its formula and refractivity data”, P Series, Radiowave progagation, February 2012.

[ITU-R P.527-3] Recommendation ITU-R. P.527-3, “Electrical characteristics of the surface of the Earth”, P Series, Radiowave progagation, 1992.

[ITU-R P.832-3] Recommendation ITU-R. P.527-3, “World atlas of ground conductivities”, P Series, Radiowave progagation, February 2012.

[Kleinrock 75] L. Kleinrock, *Queueing systems. Volume I: Theory*, John Wiley & Sons, 1975

[Laiho01] J. Laiho, A- Wacker, and T. Novosad, editors. “Radio Network Planning and Optimization for UMTS”. John Wiley & Sons Ltd., 2001.

[NTIA-82-100] G.A. Hufford, A.G. Longley, and W.A. Kissick. “A guide to the use of the ITS irregular terrain model in the area prediction mode”, *technical report 82-100*, NTIA, 1982.

[RAD] http://www.cplus.org/rmw/english1.html

[Rendon11]	A. Rendón, P. Jeanneth, A. Martínez, *Tecnologías de la Información y las Comunicaciones para zonas rurales. Aplicación a la atención de salud en países en desarrollo*, CYTED 2011
[SCF 047.01.01]	Document 047.01.01, “Extending rural and remote coverage using small cells”, Small Cells Forum, www.smallcellforum.org, Feb 2013
[Sipila99]	K. Sipila, J. Laiho-Steffens, A. Wacker, M. Jasberg, "Modeling the impact of the fast power control on the WCDMA uplink", *Vehicular Technology Conference*, *1999 IEEE 49th* , vol.2, no., pp.1266,1270 vol.2, Jul 1999.
[SRTM]	http://www2.jpl.nasa.gov/srtm/
[TUCAN3G D21]	A. Garcia, et al., “Socio-economic scenarios, technical specifications and architecture for the proof of concept”, *deliverable report D21*, ICT-601102 STP TROPIC, May 2013
[Wang00]	Y.-P.E. Wang, and T. Ottosson, "Cell search in W-CDMA", *Selected Areas in Communications, IEEE Journal on* , vol.18, no.8, pp.1470,1482, Aug. 2000.

List of abbreviations & symbols

3GPP	3rd Generation Partnership Project
AMR	Adaptive Multi-Rate
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
BPSK	Binary Phase-Shift Keying
CPICH	Common Pilot Channel
CRC	Cyclic Redundancy Check
DL	Downlink
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
FDD	Frequency Division Duplexing
HNB	Home Node B
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
OVSF	Orthogonal Variable Spreading Factor
PRACH	Physical Random Access Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of service
QPSK	Quadrature Phase-Shift Keying
RF	Radio frequency
SF	Spreading Factor
SINR	Signal to Interference plus Noise Ratio
UE	User equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access
α	Orthogonality factor
E_b/N_o	Energy per user bit divided by noise plus interference spectral density
E_c/I_o	Energy per chip divided by the total received power spectral density
G^{ms}	UE antenna gain
G^{bs}	HNB antenna gain
P_{mn}	Transmitted power by terminal *m* to terminal *n*
P_{mn}^{r}	Received power at terminal *m* from terminal *n*
P_{BS_i}	Total transmitted power by HNB *i*
$P_{BS_i}^{r}$	Total received power from HNB *i*
$P_i^{cpich(r)}$	Received CPICH power from HNB *i*
P_i^{comCH}	Transmitted power by HNB *i* for downlink common channels
R	Service rate
SM	Shadowing margin
σ^2	Thermal noise power
v	Activity factor

W	Chip Rate
ψ	Received inter-cell interference in the downlink
χ	Received inter-cell interference in the uplink

1 INTRODUCTION

Network planning is the first stage towards the deployment of 3G services envisioned in TUCAN3G. This activity is sustaining business case study in WP3 (in terms of the evaluation of business case study), the requirements for the backhaul in WP5 and the estimation of equipment needed for the platform in WP6.

Based on the definition of the access network architecture and the traffic evolution forecast, as defined in WP2, we derive engineering rules for dimensioning the HNB-based access network satisfying the requirements of coverage and grade-of-service. A number of possible technical solutions (assuming the operator has the exploitation rights of two carriers) are evaluated for actual voice and data traffic models provided from network measurements in the Telefónica del Peru network, and for socio-economic parameters of the communities involved in Napo and Paranapura river. The position of the HNB is not optimized, instead it is assumed that HNBs are placed on top of the existing towers deployed by PUCP and EHAS in the region.

The document is organized as follows: section 2 describes the traffic (voice and data) assumptions for the target communities in rural areas, as well as their geographical and socio-economical characteristics. Section 3 contains a detailed description of the system assumptions contemplated in the study, including the channel models, air interface and HNB relevant deployment specifications. Section 4 describes in detail the methodology used to evaluate the key performance indicators, using the Radio Mobile [RAD] freeware, the link level evaluation principles and queuing theory, when mixed voice and data traffic are contemplated. Section 5 lists the network planning results for all the target communities. Section 6 contains an evaluation of the backhaul requirements for each site. In section 7, a study of the energy supply units dimensioning based on solar cells is given, in which energy consumption models are used for the HNB consumption.

Finally, Section 8 collects the conclusions and recommendations generated in this activity, to be forwarded to WP5 and WP6.

2 STUDY CASES

This section describes the characteristics of traffic assumed for all sites under consideration. To that end, we first introduce some considerations on voice and data usage observed in the EC-funded EARTH project. This project is focused on rural areas in Europe so the results reported need to be considered carefully, and adopted whenever the measurements taken by Telefonica del Peru (TdP) in rural areas in Peru are not concluding.

Figure 1 presents the percentage of population on different areas of Peru that have a cellphone. In the target rural areas, we assume that 53% of the population has one cell phone. Additionally, in the rural areas the number of population in itinerancy tends to be significant, in this regard we can assume that the total population of a given community is enlarged by 20%.

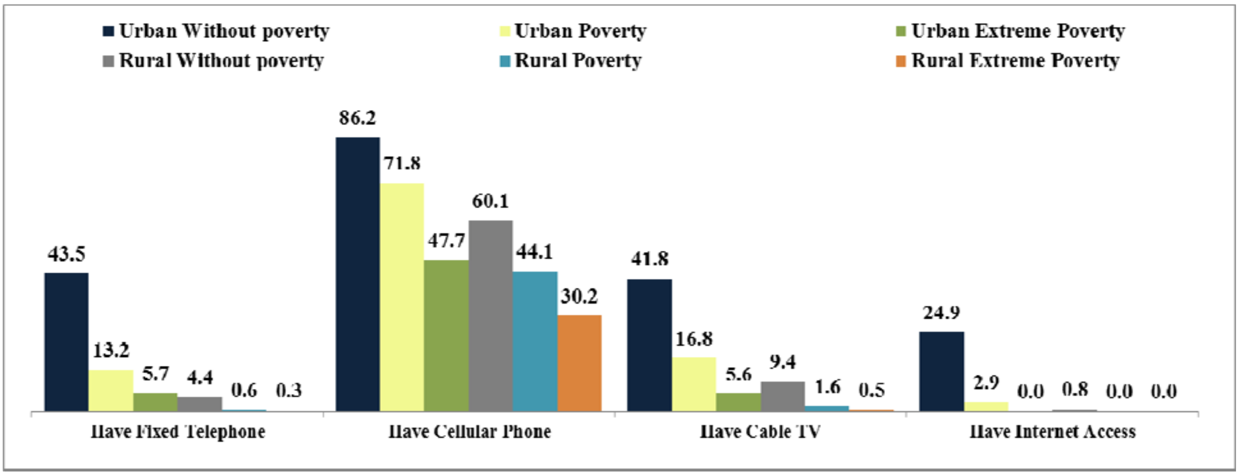


Figure 1. Households with access to TIC by poverty level and type of residential area (according to INEI reports, 2011)

2.1 General day-time traffic evolution models

Models for the data user activity, voice traffic and data traffic are provided in [EARTH-D23] for different areas in Europe. The EARTH-project defines the following categories:

- Dense Urban Areas: 3000 citizen/km^2 on average
- Urban Areas: 1000 citizen/km^2 on average
- Suburban Areas: 500 citizen/km^2 on average
- Rural Areas: 100 citizen/km^2 on average
- Sparsely populated & wilderness : 25 citizen/km^2 on average

Additionally, the EARTH-project characterizes the distribution of the areas associated to each category:

- Dense Urban Areas: 1%
- Urban Areas: 2%
- Suburban Areas: 4%
- Rural Areas: 36%
- Sparsely populated & wilderness : 57%

2.1.1 Voice traffic

2.1.1.1 EARTH project voice traffic model

Although the voice activity may differ from one region to another in the world, we consider in this section, the model elaborated in the EARTH-project; for completeness and comparison purposes, that takes into account the typical European rural user behaviour. The model assumes a voice traffic daily profile presented in Figure 2 (averaged conveniently over many users and scenarios) and a voice usage of 180 minutes/month/subscriber. Note that the *peak* is not a single hour, but there is a significant activity between 9 AM and 19 PM.

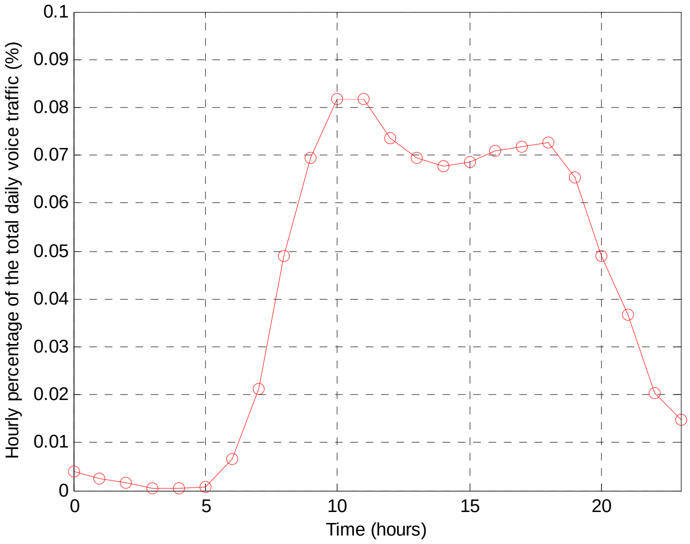


Figure 2. Day-long model for the percentage of the total daily voice traffic for rural population in Europe

The percentage of traffic during the busy hour shown in Figure 2 (10 AM) is the 8% of the total traffic of the day, which corresponds to the following offered traffic in mili Erlangs per subscriber:

$$\rho = \lambda_v \cdot h = \frac{\lambda_v}{\mu_v} = 0.08 \times 180 \frac{\text{min}}{\text{month}} \frac{1}{60} \frac{\text{hour}}{\text{min}} \frac{1}{30} \frac{\text{month}}{\text{day}} = 8 \text{ mEr}$$

We obtain an average arrival call rate of $\lambda_v = 8.88 \times 10^{-5}$ calls/s, and average served call rate of μ_v = 0.0111 calls/s for an average call duration h = 90 seconds, The average daily traffic profile per user can be obtained by scaling Figure 2 so that the maximum at the busy hour is 10 mEr. The voice traffic characterization fits a Poisson arrival law (the time between new incoming calls follows an exponential distribution) and exponential service time.

2.1.1.2 Telefónica del Perú voice traffic model

The first voice traffic measurements performed by Telefónica del Peru (TdP) in the rural areas of Peru reveal that the EARTH model could not be accurate enough for our purposes. TdP provides an estimated voice traffic model for the localities selected in section 2.3. These have been taken from real traffic measurements obtained in FITEL's project "Rural and Social Preferent Areas Integration to the Mobile Service Network", started on January 2012 through June 2013.

In this project, the villages were grouped in four categories:

- *Category 1*: Population $p \leq 500$ inhabitants, average is 242 inhabitants.
- *Category 2*: Population $500 < p \leq 1000$ inhabitants, average is 717 inhabitants.

- *Category 3*: Population $1000 < p \leq 1500$ inhabitants, average is 1227 inhabitants.
- *Category 4*: Population $1500 < p$ inhabitants, average is 1985 inhabitants.

The average voice traffic measurements in Erlangs as a function of the time of the day is depicted in Figure 3, in the first year (year 0), in June 2013 (year 2) and in the 4th year, see Table 3.

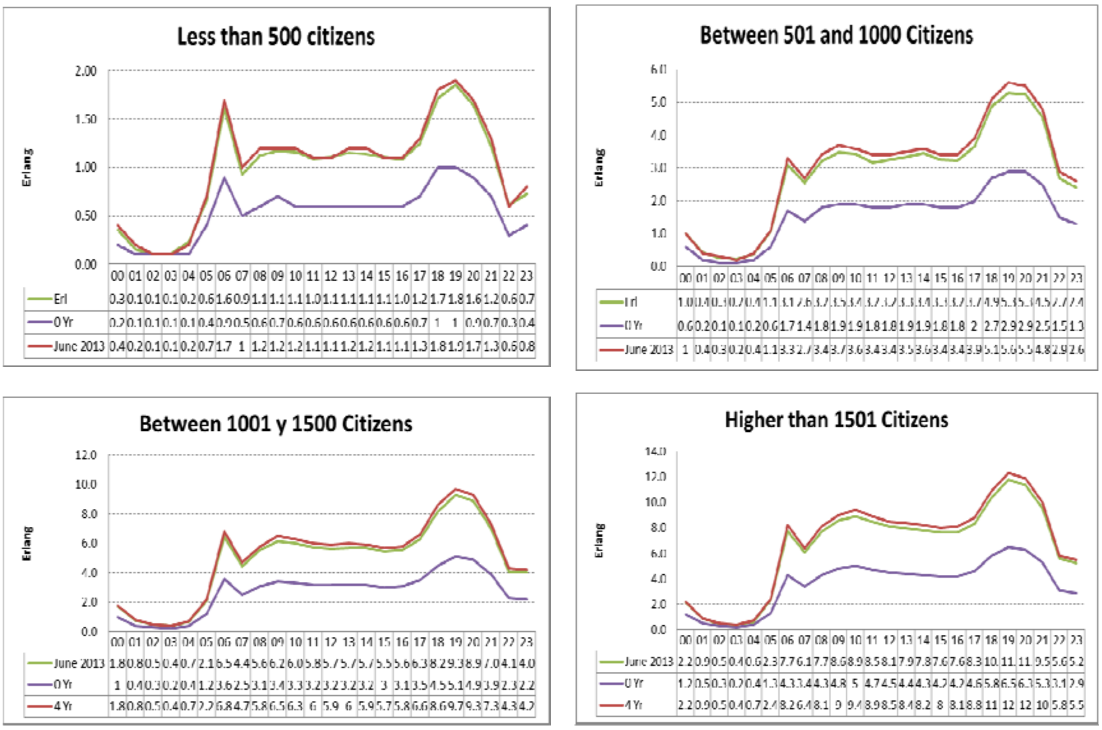


Figure 3. Voice traffic measurements for the four categories of villages

With the objective of deriving the hourly daily traffic per mobile terminal or user, we have to take into account that, according to [TUCAN3G-D31]:

1. The mobile phone penetration in Peru is 53%
2. The total population in the villages considered for the voice traffic measurements can increase up to 20% due to the itinerancy
3. TdP is the only providing 2G voice traffic services in the area of measurements

Hence, processing accordingly the measured data shown in Figure 3, we can obtain the hourly daily voice traffic per mobile terminal presented in Figure 4 for the four categories of villages. We can observe that the voice traffic per user in the villages of categories 1 ($p \leq 500$), 2 ($500 < p \leq 1000$) and 3 ($1000 < p \leq 1500$), i.e. up 1500 inhabitants, is quite similar getting around **12 mErl** in the busy hour (19.00 PM). In contrast, in the villages for more than 1500 inhabitants, the traffic generated per user tends to be smaller than in the other categories villages, for example **9.4 mErl** in the busy hour.

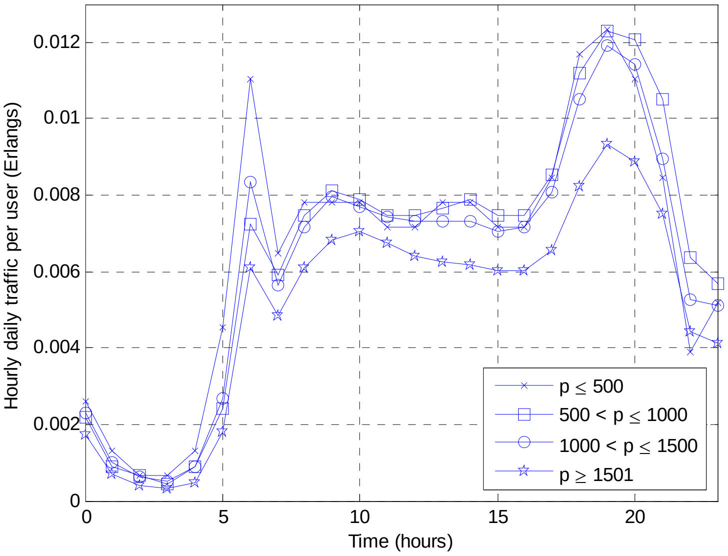


Figure 4. Hourly daily voice traffic profile per mobile terminal

In order to provide a simple voice traffic model to be representative for all rural villages in Peru, we propose a single hourly daily traffic per user for all villages in Table 1. It has been obtained by scaling the average voice traffic profile of villages with less than 1500 inhabitants in order to have **10 mErl** at the busy hour. For an average call duration of 90 seconds, we obtain an average arrival call rate of $\lambda_v = 1.11\times10^{-4}$ calls/sec, and average served call rate of $\mu_v = 0.0111$ calls/sec.

Time (hours)	**mErl**
00.00 – 01.00	1.9425
01.00 – 02.00	0.8762
02.00 – 03.00	0.5331
03.00 – 04.00	0.4381
04.00 – 05.00	0.8411
05.00 – 06.00	2.6411
06.00 – 07.00	7.2823
07.00 – 08.00	4.9412
08.00 – 09.00	6.1377
09.00 – 10.00	6.5281
10.00 – 11.00	6.3980
11.00 – 12.00	6.0301

Time (hours)	**mErl**
12.00 – 13.00	5.9950
13.00 – 14.00	6.2328
14.00 – 15.00	6.2928
15.00 – 16.00	5.9248
16.00 – 17.00	5.9599
17.00 – 18.00	6.8610
18.00 – 19.00	9.1364
19.00 – 20.00	10.0000
20.00 – 21.00	9.4441
21.00 – 22.00	7.6466
22.00 – 23.00	4.2449
23.00 – 00.00	4.3853

Table 1. Voice traffic model per user for the rural areas in TUCAN3G

Figure 5 shows the comparison between the traffic voice model defined for the TUCAN3G project and the one defined in the EARTH project. It is important to highlight the differences between the EARTH European model and the adopted model in TUCAN3G.

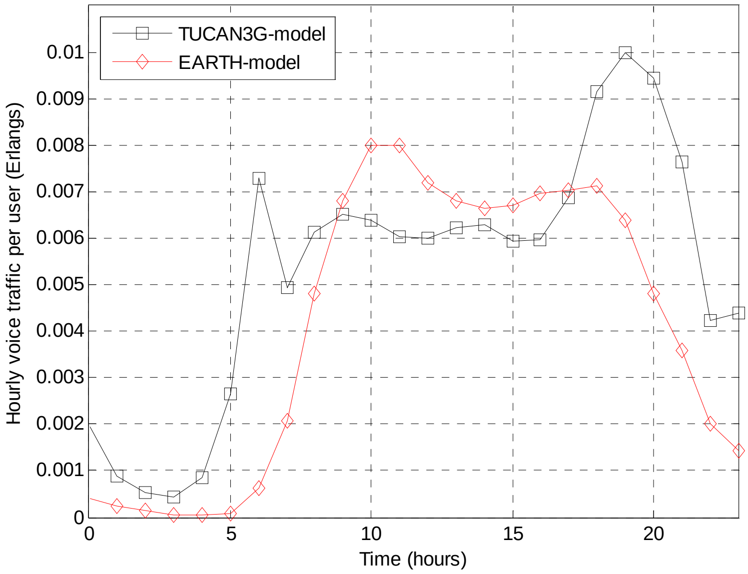


Figure 5. Comparison of voice traffic models obtained in TUCAN3G and in EARTH projects

2.1.2 Data traffic

2.1.2.1 Earth project data traffic model

With the objective of characterizing the volume of data traffic, it is important to elucidate the number of active users at every moment. The EARTH project found two important properties of the total traffic evolution:

- The daily variation of the number of active users is proportional to the daily variation of the traffic.
- 10-30% of the data subscribers are active in the busy/peak hours in today’s networks. The EARTH project assumes a reference value of 16%. On average over a day, the activity level is 9.64%. Figure 6 depicts the reference curve considered by the EARTH project to model the percentage of active data users along the day.

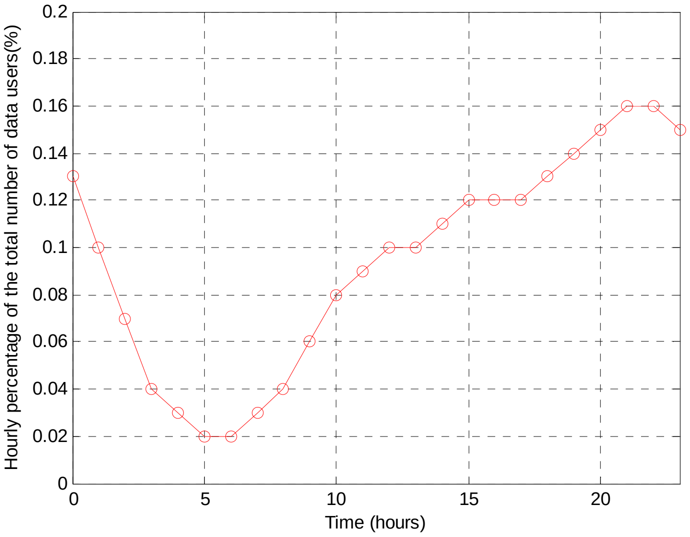


Figure 6. Day-long model for the percentage of the total data users per hour for rural population in Europe

The EARTH project also provides the following estimation on the type of terminals and services for the year 2015 in the European region (assumed all population are subscribers of data services):

- Mobile PC 20% of the population
- Smartphones 50% of the population
- Tablet 5% of the population

The remaining 25% of population hold voice-only cellphones. Two different types of users are considered:

- *Heavy user* requests an hourly average data rate of 2 Mbps, 250 Kbps and 1 Mbps for Mobile PC, Smartphone and Tablet, respectively.
- *Ordinary user* requests an hourly average data rate of 250 Kbps, 31.25 Kbps and 125 Kbps for Mobile PC, Smartphone and Tablet, respectively.

These user average data rate is assumed to be measured as the total number of bits received by all active users during the busy hour (3600 seconds) divided by the number of active users ,

$$r = \frac{N_{bits}}{N_{users} \times 3600} \quad bits/s$$

By tuning the ratio of heavy and ordinary users, different scenarios can be considered:

- Scenario A (scenario #4 in [EARTH-D23]): Contemporary traffic demand. 10% of the population is reference as PC user, of which 10% are classified as heavy users using 125 Kbps. The remaining 90% users are ordinary and consume 31 kbps.
- Scenario B (scenario #1 in [EARTH-D23]): Most relevant scenario for 2015. 20% of the subscribers are classified as heavy users.
- Scenario C (scenario #2 in [EARTH-D23]): 50% of the subscribers are classified as heavy users.

Since the data volume per subscriber does not depend on the deployment scenario, the area traffic demand for a given deployment is given by (in Mbps),

$$R(t) = p\alpha(t)\sum_{k} r_k s_k \tag{1}$$

where r_k and s_k are the average data rate demand and the ratio of subscribers for terminal type k respectively, $\alpha(t)$ denotes the percentage of active data users (see Figure 6),and p is the population (in number of users).

2.1.2.2 Telefónica del Perú data traffic model

In early 2013, TdP started to deploy 3G in some specific rural places in Peru. However at the time of writing it was too early to determine a data traffic model for rural areas from the measurements obtained by TdP. To this end, it was decided to build a data traffic model from the measurements performed over several small urban areas with less than 3000 inhabitants. From those measurements we can obtain a normalized hourly daily data traffic, which could be used for rural areas. The actual values of the traffic along the day will be obtained as a function of the number of inhabitants, percentage of active users during the busy hour, user penetration, and average traffic per user.

Data traffic model in urban areas

The measurements have been performed in a sub-urban/urban area where there are 26 Base Stations (BSs). Each BS is equipped with both 3G and 2G technologies. Figure 7 presents the aggregated number of bits (downlink plus uplink) at each hour served by all the BSs for 2G and 3G technologies, respectively.

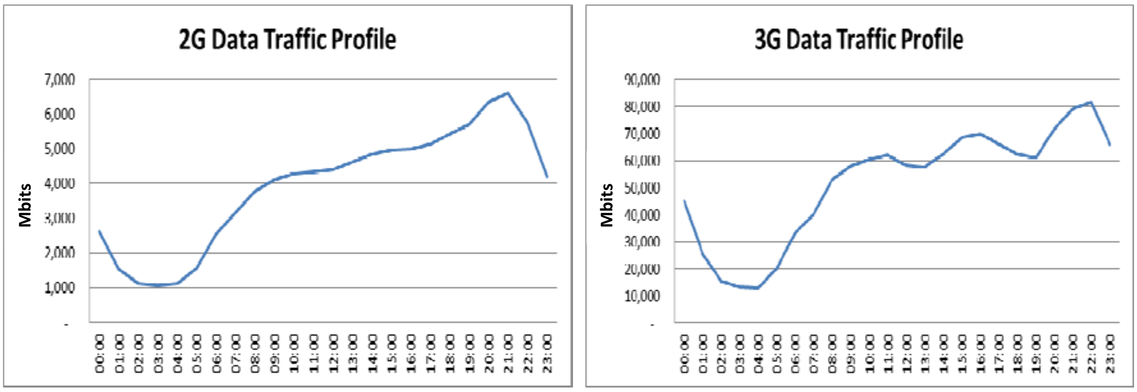


Figure 7. Aggregated served data traffic for downlink and uplink per hour (over the 26 BSs) in Mbits

The following considerations have to be taken into account for the interpretation of the obtained measurements:

- The estimated total population that uses 3G is 49.633 inhabitants while the estimated population served using 2G is 66.045 inhabitants. The difference is due to larger coverage area of 2G technology.
- Only TdP is operating in 2G technology. However, there are other mobile operators using 3G technology in the area of measurements. The penetration ratio of TdP in that area is around 60%, i.e. the measured 3G data traffic corresponds just to the 60% of the total mobile traffic in that area.
- The target population for data traffic in urban/sub-urban areas is 25%, i.e. 25% of the mobile terminals is estimated to use data traffic.
- The estimated 3G traffic per mobile terminal is in average 15 kbps in downlink and 5 kbps in uplink. At the time of writing there is not an estimation of the average 2G traffic.
- The measurements are given in terms of total bits received/transmitted at each hour. They also include the total raw bits (payload) transmitted/received in the downlink and uplink transmission, i.e. without considering the signaling overhead.

Figure 8 compares the normalized daily traffic profile for 3G and 2G traffic in the same area. It can be observed that both traffics follow a similar pattern, clarifying also that the busy hour for data traffic (at 21.00 PM – 22.00 PM) is different from the busy hour for voice traffic (around 19 PM in Figure 4). For the sake of a complete comparison, Figure 9 presents the data traffic pattern profile selected for TUCAN3G and it is compared with the one obtained in the EARTH project.

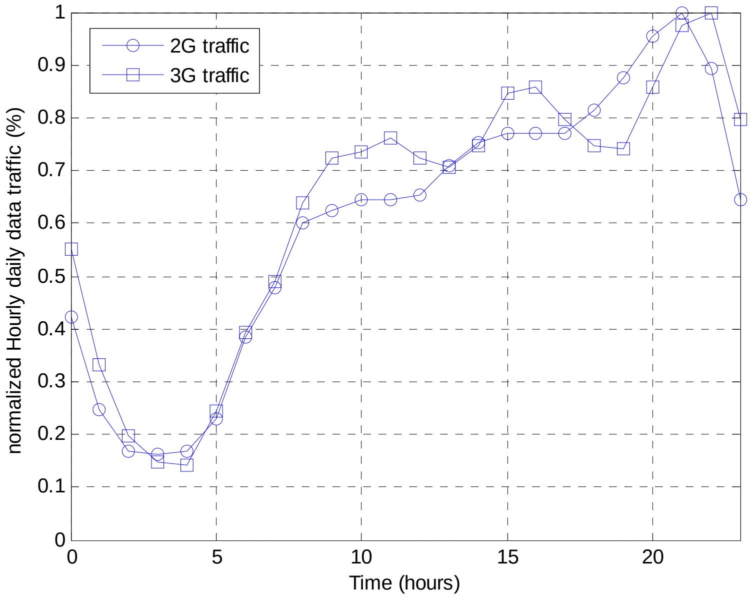


Figure 8. Normalized hourly daily data traffic profile

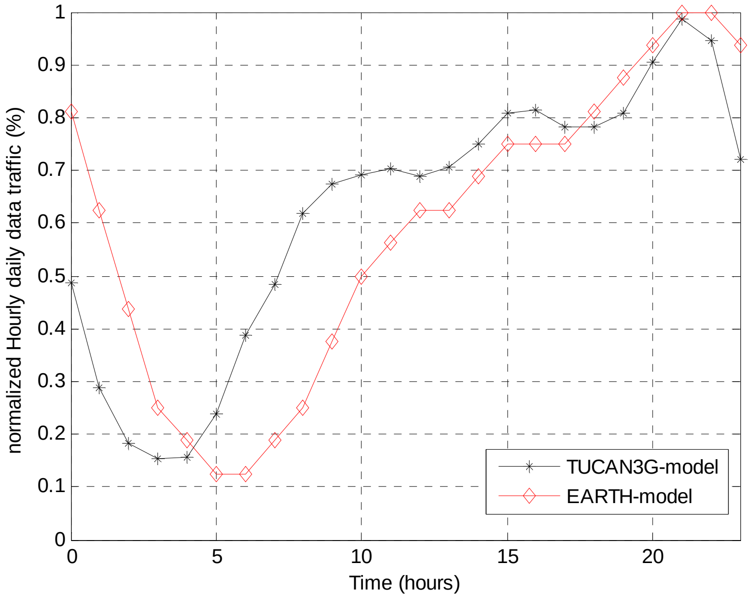


Figure 9. Normalized hourly daily traffic profile for TUCAN3G and EARTH projects for urban and suburban areas

Regarding the number of active data terminals in the peak hour, in the EARTH project it was observed that this value could range between 10% and 30%. When deriving this value for the Peruvian urban/sub-urban area from 3G traffic measurements:

1. The total traffic measured in the busy hour is 80.000 Mbits, i.e. around 22 Mbps.
2. The total population in the area is 49.633 inhabitants.
3. It is assumed that 53% of the total population has a mobile terminal, i.e. 24.819 mobile terminals.

4. The measured traffic only considers the 60% of the whole number of mobile terminals due to the user penetration of TdP, i.e. 14.889 mobile terminals are subscribed to TdP.
5. It is assumed that 25% of mobile terminals will use data traffic in urban/semi-urban areas, i.e. 3.723 mobile terminals will generate data traffic.
6. The average data traffic per user in the busy hour is assumed to be **15 kbps for downlink and 5 kbps for uplink**, in accordance with Small Cells Forum documents [SCF 047.01.01].
7. Hence, the average number of active mobile terminals will be **30% of the all mobile terminals in busy hour**.

Data traffic model in rural areas

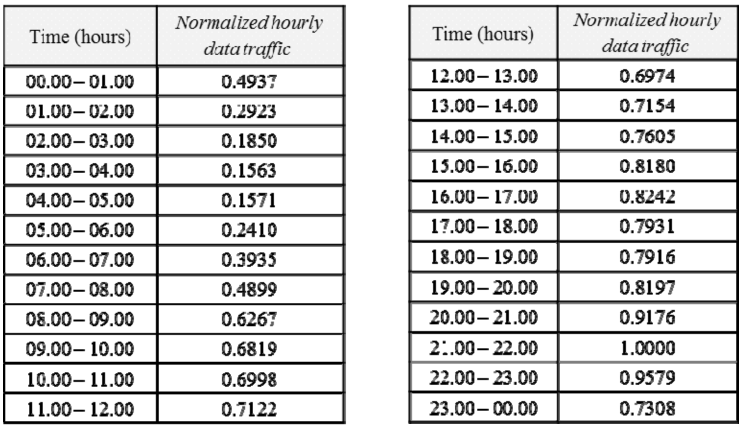
For rural areas we will adopt the same data traffic profile as the one shown in Figure 9. However, the following aspects will be assumed in contrast to the urban/semi-urban areas:

1. Target mobiles terminals for data traffic 5%.
2. Itinerancy 20%

Hence, the aggregate data traffic demand for a rural area where only one operator is active will be given by,

$$R(t) = p \times 0.53 \times 1.2 \times 0.05 \times 0.3 \times \beta(t) \times r \quad [\text{Mbps}] \tag{2}$$

where t is the time in hours, p is the total number of inhabitants, factor 0.53 is the mobile terminal penetration rate, 1.2 is associated to the increase of inhabitants due to itinerancy, factor 0.05 assumes that the target of mobile terminals for data traffic is 5%, factor 0.3 takes into account the fraction of active terminals during the busy hour, $\beta(t)$ is the normalized hourly data traffic shown in Table 2 (also shown in Table 2) and finally r is the average data rate demand per user (15 kbps for downlink and 5 kbps for uplink).



Time (hours)	*Normalized hourly data traffic*
00.00– 01.00	0.4937
01.00– 02.00	0.2923
02.00– 03.00	0.1850
03.00– 04.00	0.1563
04.00– 05.00	0.1571
05.00– 06.00	0.2410
06.00– 07.00	0.3935
07.00– 08.00	0.4899
08.00– 09.00	0.6267
09.00– 10.00	0.6819
10.00– 11.00	0.6998
11.00– 12.00	0.7122
12.00– 13.00	0.6974
13.00– 14.00	0.7154
14.00– 15.00	0.7605
15.00– 16.00	0.8180
16.00– 17.00	0.8242
17.00– 18.00	0.7931
18.00– 19.00	0.7916
19.00– 20.00	0.8197
20.00– 21.00	0.9176
21.00– 22.00	1.0000
22.00– 23.00	0.9579
23.00– 00.00	0.7308

Table 2. Normalized rural data traffic model in TUCAN3G, $\beta(t)$

2.1.2.3 Adopted data traffic model

Adopting the values mentioned above, FTP model 2 (see section 3.4.3.2 in [TUCAN3G D21]) is assumed for the data traffic characterization, where the packet arrival fits a Poisson law and size is constant B Kb/packet. Even though the service time is deterministic, it is still possible to model the traffic using a *birth-death* Markov model [Bertsekas 92]. The per-user average number of packets in the busy hour is given by:

$$\lambda_d = \frac{C\ [\text{Kbps}]}{B\ [\text{Kb/packet}]} \tag{3}$$

where C=15 Kbps for the downlink and C=5 Kbps for the uplink. Assuming that packets are delivered using 128 kbps service in UMTS, the transmission time to deliver one packet is:

$$T_s = \frac{B\ [\text{Kb/packet}]}{128\ [\text{Kbps}]} \tag{4}$$

In order to determine the packet service rate, the probability of departure from one state in the Markov model in a time frame with δ duration has to be evaluated.. Assume $A(t)$ is a counting variable that represents the total number of arrivals that occurred from time 0 to time t, and hence $\Pr\{A(t - T_s + \delta) - A(t - T_s) = 1\}$ is the probability of one packet arrival in the interval $[t - T_s,\ t - T_s + \delta]$. Then,

$$\begin{aligned}
&\Pr\left\{\text{Packet delivered in } \tau \in (t, t+\delta) \middle| \text{server busy at } t\right\} = \\
&= \frac{\Pr\left\{\text{Packet delivered in } \tau \in (t, t+\delta), \text{server busy at } t\right\}}{\Pr\{\text{server busy at } t\}} = \\
&= \frac{\Pr\left\{\text{Packet delivered in } \tau \in (t, t+\delta)\right\}}{\Pr\{\text{server busy at } t\}} = \frac{\Pr\{A(t - T_s + \delta) - A(t - T_s) = 1\}}{\Pr\{A(t) - A(t - T_s) \geq 1\}} = \frac{\lambda_d \delta \exp(-\lambda_d \delta)}{1 - \exp(-\lambda_d T_s)}
\end{aligned} \tag{5}$$

If the time frame δ is small enough compared to $1/\lambda_d$ we can approximate (5) by:

$$\Pr\left\{\text{Packet delivered in } \tau \in (t, t+\delta) \middle| \text{server busy at } t\right\} = \frac{\lambda_d \delta \exp(-\lambda_d \delta)}{1 - \exp(-\lambda_d T_s)} \cong \frac{\lambda_d}{1 - \exp(-\lambda_d T_s)} \delta = \mu_d \delta \tag{6}$$

Note that $1/\mu_d$ is the average service time per packet, which turns out to be T_s under the condition of the packet generation rate λ_d being much smaller than $1/T_s$. This is also the average delay per packet at low load, which we would like to keep below a reasonable value ε for a good user experience:

$$\frac{1 - \exp(-\lambda_d T_s)}{\lambda_d} \leq \varepsilon \quad \Rightarrow \quad B \leq \frac{C\ [\text{kbps}] \cdot \varepsilon}{1 - \exp\left(-C\ [\text{kbps}] / 128 [\text{Kbps}]\right)}$$

A value ε of 2.6 seconds is associated to an FTP packet size B of 512 Kb for the downlink, and 387 Kb in the uplink (which we round up to 512 Kb for simplicity). Then λ_d = 0.2344 s^{-1} and μ_d = 0.3853 s^{-1} are calculated for the downlink, and λ_d = 0.0781 s^{-1} and μ_d = 0.2911 s^{-1} for the uplink. The assumption $\lambda_d << 1/T_s$ in (6) is approximately matched, where in in our case λ_d / T_s = 0.0586 for the downlink and λ_d / T_s = 0.0195 for the uplink).

2.2 Long-term traffic evolution

Table 3 describes the evolution of traffic over the following 5 years after the deployment of wireless services, which is calculated using the actual measurements from Telefónica del Perú 2G and 3G networks annual plan.

Year	Traffic increase	Comment
2	180%	Month 13th of operation (mainly in the first 6 months of operation)
3	5%	Month 25th of operation (estimated from the first six months of real traffic)
4	2%	Estimated from Telefónica del Perú´s Annual Planning
5	2%	Estimated from Telefónica del Perú´s Annual Planning

Table 3. Long-term traffic evolution in rural areas in a 4 years forecast

2.3 Socio-economic characteristics and offered traffic of the target sites

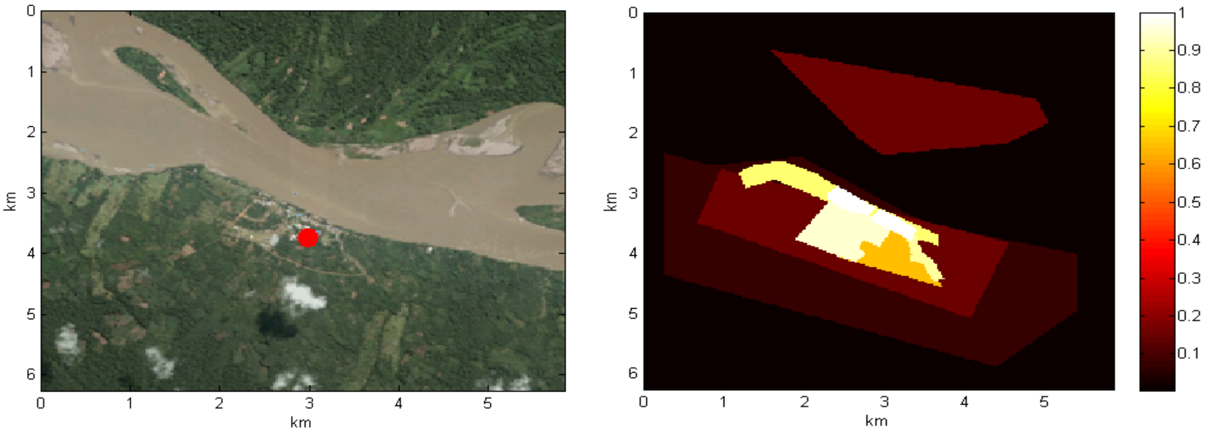
This section defines the locations where the HNB will be deployed in terms of geographical coordinates of towers, areas where population live and the traffic generation probabilities depending on the specific areas for each village, socio-economical parameters including population, itinerancy, approximate average incomes, etc. Finally, expected voice and data traffic values for each location are presented.

The locations where HNB will be deployed are decided to be Santa Clotilde, Negro Urco and Tuta Pisco in Napo river region, and San Gabriel and San Juan in Paranapura river region. Table 4 shows the GPS coordinates of the towers in each location.

Location	Tower GPS coordinates		Height of towers
Santa Clotilde	02º29'22.4"S	73º40'40.7"W	72 m
Negro Urco	03º01'23.1"S	73º23'31.5"W	75 m
Tuta Pisco	03º06'31.4"S	73º08'17.5"W	57 m
San Gabriel	05°42'49.99"S	76°24'39.59"W	60 m
San Juan	05°52'35.13"S	76°21'21.73"W	60 m

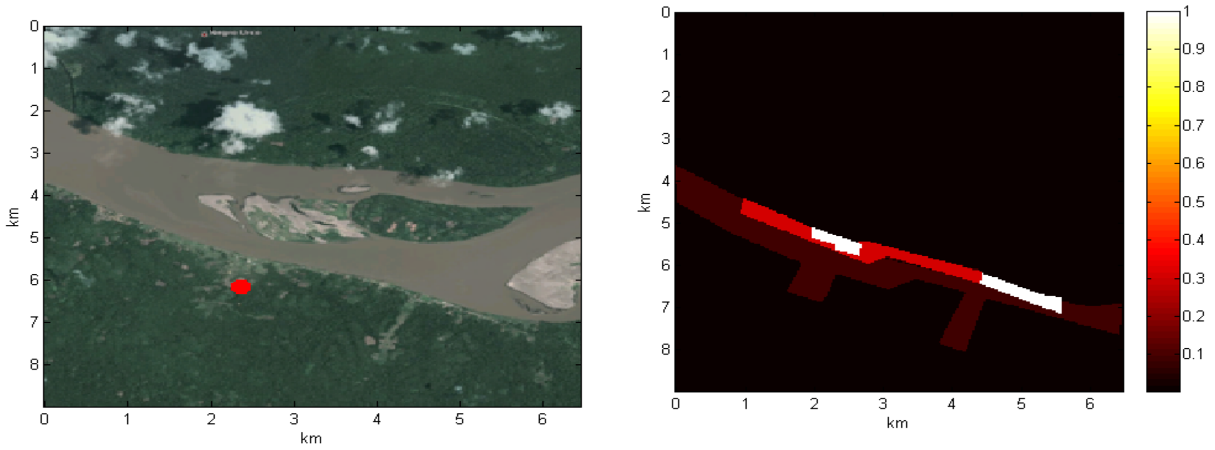
Table 4. Geographical coordinates of towers for each location where HNB for access network will be installed

Rural data and voice traffics have been characterized in previous section for rural communities. Moreover, we assume that the traffic generated is not homogeneous geographically so different areas for each location are associated to different probability of traffic generation. These probabilities are independent from the assumed traffic in 2.1, rather, they are characterize the density of houses as observed on the map, and hence, of active terminals. Figure 10 to Figure 14 show the intensity of expected traffic generation assumed for each location, as well as the position of the towers (displayed as red point). Areas with an intensity of 1 refer to maximum expected traffic generation (probability of active users), while lower intensities are referenced to this expected maximum value. As a result, different probability distributions of having active users are created for each location.



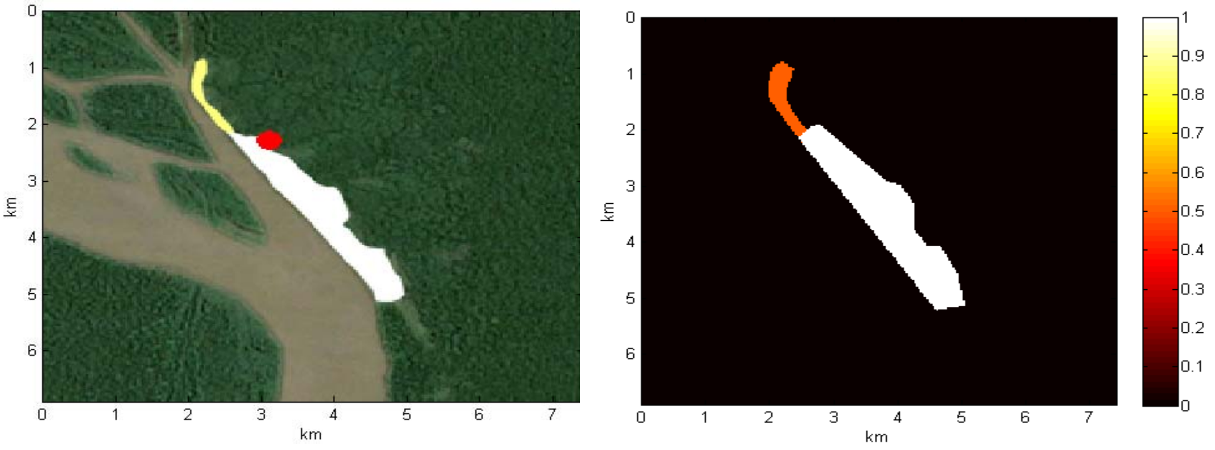
(a) Santa Clotilde location and tower position **(b) Intensity of traffic assumed**

Figure 10. Intensity of traffic generation assumed over the geographical area in Santa Clotilde, obtained from the observation of household locations on Google Earth images



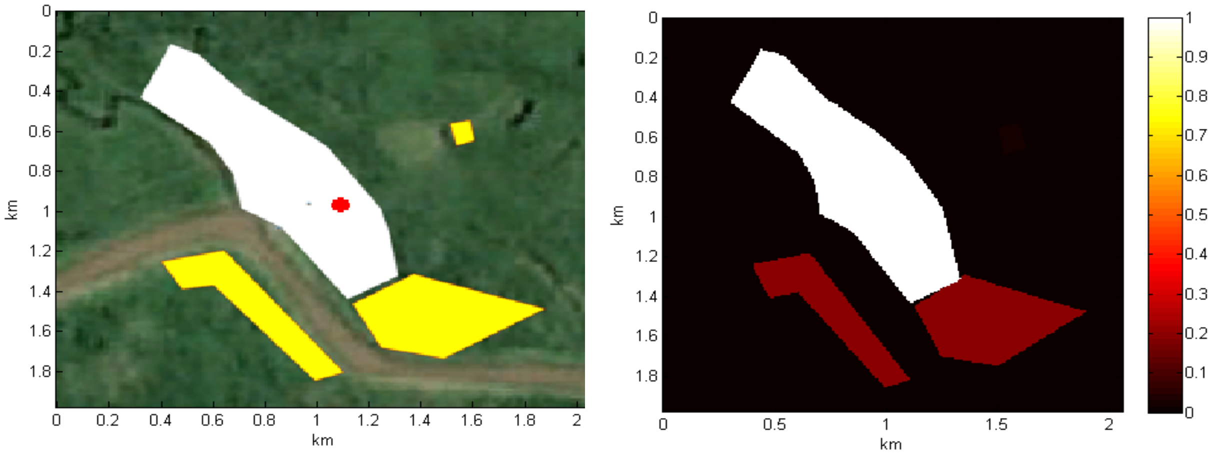
(a) Negro Urco location and tower position **(b) Intensity of traffic assumed**

Figure 11. Intensity of traffic generation assumed over the geographical area in Negro Urco, obtained from the observation of household locations on Google Earth images



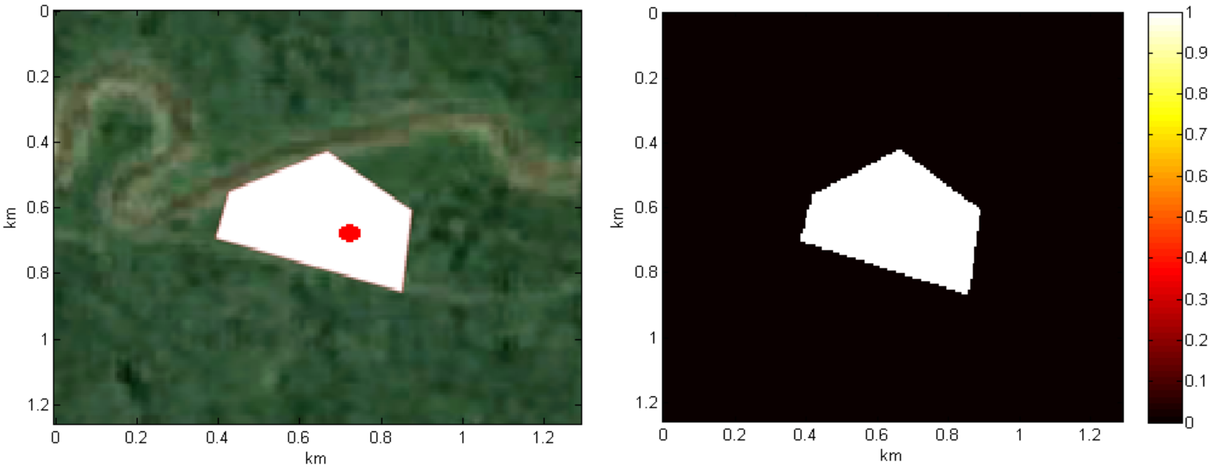
(a) Tuta Pisco location and tower position **(b) Intensity of traffic assumed**

Figure 12. Intensity of traffic generation assumed over the geographical area in Tuta Pisco. White (yellow) areas on the left plot correspond to higher (lower) density of households (identified from field observations)



(a) San Gabriel location and tower position **(b) Intensity of traffic assumed**

Figure 13. Intensity of traffic generation assumed over the geographical area in San Gabriel. White (yellow) areas on the left plot correspond to higher (lower) density of households (identified from field observations)



(a) San Juan location and tower position **(b) Intensity of traffic assumed**

Figure 14. Intensity of traffic generation assumed over the geographical area in San Juan location. White area on the left plot correspond to the location of households (identified from field observations)

Finally, the expected aggregated traffic that must be served by the network can be computed through the traffic characterization of section 2.1 and the target population who is expected to use services provided by the network:

- For Voice Traffic:
  - Symmetrical bandwidth required
  - Mobile traffic per user in rural areas is 10 mili-Erlang in busy hour,according to the model of Telefonica del Peru (section 2.1.2.3).
  - Average percentage of population with one cell phone is 53%
  - Itinerancy (% of people in transit or short periods of time stay) is assumed as 20%
- For Data Services:
  - Asymmetric per-user offered data traffic: 15 Kbps (downlink), 5 Kbps (uplink)

- Average of population with one cell phone: 53%
- Itinerancy (% of people in transit or short periods of stay): 20%

Potential market is 5% of the total population plus people in itinerancy with cell phone.

Table 5 summarizes the average aggregated voice and data traffic (according to equation (2)) offered. The network must be designed so that this traffic is accommodated with a blocking probability of 2%. Note that the backhaul requirements that will be computed in section 8 are much larger, so that they are able to accommodate instantaneous traffic peaks.

Location	**Number of inhabitants**	**Number of inhabitants + people in itinerancy**	**Average number of subscribers**	**Expected number of data users**	**Aggregated voice traffic**	**Aggregated offered data traffic [kbps]**	
						Downlink	**Uplink**
Santa Clotilde	2685	3222	1707.66	85.383	17.077 Er	1280.88	427.10
Negro Urco	263	316	167.27	8.363	1.673 Er	125.47	41.84
Tuta Pisco	287	344	182.53	9.127	1.825 Er	136.91	45.65
San Gabriel	790	948	502.44	25.122	5.024 Er	376.87	125.67
San Juan	98	118	62.33	3.116	0.623 Er	46.75	15.59

Table 5. Total number of inhabitants, target population that is expected to use wireless services and aggregated generated traffic expected in each location in year 1

3 SYSTEM ASSUMPTIONS

3.1 Adopted channel models

To model the channel in the considered rural localities given in [TUCAN3G D21], we must adopt specific and realistic channel models, according to the specific characterization of the location where the networks will be deployed.

3.1.1 Path Loss Model

ITS Irregular Terrain Model [NTIA-82-100], which also known as *Longley-Rice* model, is considered as the path los model in this document. It is a semi-empirical model which applies for frequencies between 20 MHz and 20 GHz, which is based on electromagnetic theory and statistical analyses of both terrain features and radio measurements. For a particular area, the ITS model takes into account different radio propagation conditions to compute the path loss between two terminals. These conditions are modeled statistically, where the final path loss is a value with a given level of confidence and reliability.

Path loss is computed as the sum of fixed losses, which are defined through the free space equation, and additional losses, which vary according to the time and the position of the units. The fixed losses are a function of the frequency and the distance, while the varying losses are modelled statistically by means of empirical models which take into account different physical phenomena: reflection on the ground, refraction through the atmosphere, diffraction over the obstacles and tropospheric scatter. These physical phenomena will be more or less important depending on the radio wave characteristics (frequency and polarization), the electrical characteristics of the ground (relative permittivity and conductivity), the environment physical properties (temperature, humidity, density of atmosphere, etc.) and the terrain irregularities or obstacles in the propagation path.

To compute the path losses in a particular area, we employ the Radio Mobile software [RAD]. This software works with elevation maps, obtained for example from the Space Shuttle Radar Terrain Mapping Mission [SRTM]. These elevation maps have different resolutions depending on the location and the resolution of the area of interest in TUCAN3G is about 3 arc second (90 meters). Radio Mobile allows to calculate coverage maps by giving this information in terms of field strength for each pixel in the map. It does not provide the path loss of a particular area explicitly, but resulting coverage maps can be interpreted as path loss.

To configure the propagation conditions in Radio Mobile, the inputs are:

- Base station location on the map.
- The antenna heights above the ground.
- The radiation pattern of antennas.
- Polarization of both antennas.
- Relative permittivity of the ground
- Ground conductivity.
- Surface refractivity.
- Climate.
- Variability and statistical parameters such as confidence and reliability.

The base station location (or locations), the antenna heights, the radiation pattern and the polarization of both antennas are parameters that shall be determined by the planning strategies and the particular solution adopted for the particular network. The rest of input parameters will depend on geographical area where the network will be deployed.

The atmosphere refractivity determines the amount of “bending” of the radio waves. It can be characterized through the *surface refractivity*, typically expressed in terms of N-units. This parameter depends on the atmospheric conditions (temperature, atmospheric pressure and water vapour pressure). In [ITU-R P.453-10], different values of the surface refractivity are proposed according to the geographical area. The electrical characteristics of the ground may be expressed by two parameters, the *permittivity* and the *conductivity*, and they have direct impact on the reflection of the radio wave in the ground. Permittivity and conductivity values can be found in [ITU-R P.527-3] and [ITU-R P.832-3], respectively, according to the type of ground. *Climate*, in conjunction with the surface refractivity, characterizes statistically the atmosphere in a particular location. The *variability mode* determines the statistical distributions of the parameters, depending on the topology of the network and finally, the *statistical parameters* will define the level of reliability and confidence of the model which is expressed as quantiles.

Thus, path loss is obtained from Radio Mobile software by translating the coverage maps expressed in terms of field strength into path loss. It is worth noting that this strategy implies that path loss depends on the adopted antenna patterns. Table 6 summarizes the considered input parameters to compute path losses in TUCAN3G.

Input parameter	
Frequency	Uplink: 824-849 MHz / Downlink: 869-894 MHz
Polarization	Vertical
Mode of variability	Mobile (90% of time and situations)
Surface refractivity	360 N-units
Ground conductivity	0,02 S/m
Relative ground permittivity	25
Climate	Tropical
Antenna height	Depending on the network configuration
Base station location	Depending on the network configuration

Table 6. Input parameters in Radio Mobile software to compute path loss

3.1.2 Small scale fading

The small scale fading is produced by the reflection of the radio wave in different objects, such as buildings. Each reflection takes a different path and finally the sum of these reflections, where each one has different phase and amplitudes, is received by the receiver. The small scale fading is modelled by means of a tapped-delay line profile, a model based on the COST 259 – {Rural Area} [ETSI TR 125.943], whose tapped-delay line profile is depicted in Table 7. The power of each path is time-varying and therefore, the fading can be well described by Rayleigh distributed amplitudes varying according to a classical Doppler spectrum.

Tap	Relative time (μs)	Average relative power (dB)
0	0	-5.2 (*)
1	0.042	-6.4
2	0.101	-8.4
3	0.129	-9.3
4	0.149	-10.0
5	0.245	-13.1
6	0.312	-15.3
7	0.410	-18.5
8	0.469	-20.4
9	0.528	-22.4
	Delay spread: 140 ns	
	(*) Deterministic direct path (non-fading) with Doppler frequency equal to 0,7 times the maximum Doppler spread	

Table 7. Cost 259 – {Rural Area} tapped-delay line power profile

3.1.3 Shadow fading

Shadow fading is the attenuation produced by different obstacles in the radio path. The adopted shadowing model is a lognormal random variable s (Gaussian if it is expressed in dB) with zero mean and variance $var\{s\}$:

$$f_S(\mathrm{s}) = \frac{1}{\sqrt{2\pi \cdot Var\{s\}}} \exp\left\{-\frac{s^2}{2 \cdot var\{s\}}\right\} \tag{7}$$

Longley-Rice path loss includes different attenuations due to objects that are in the radio path and therefore, adopted shadowing model only characterizes the attenuations produced by obstacles that are not taken into account in the path loss model (buildings, trees, etc). The impact of shadow fading is characterized by means of a shadow margin *SM(dB)*, which depends on the required level of confidence. In practice, a certain value of *SM*(*dB*) requires an increase of transmitted power so that the received signal strength stays above the certain value within a given level of confidence. For a *X*% level of confidence the shadow margin is given by

$$\int_{s}^{\infty} \frac{1}{\sqrt{2\pi \cdot var\{s\}}} \exp\left\{-\frac{SM^2}{2 \cdot var\{s\}}\right\} \geq X\% \tag{8}$$

For radio network planning, we assume two different levels of shadow fading: for indoor and outdoor locations. Table 8 summarizes variances and shadow margin assumptions for each type of locations with 99% confidence level.

User location	Variance (dB)	Shadow margin
Indoor	3.76	8.326 dB
Outdoor	1	2.326 dB

Table 8. Shadow margins assumed for indoor and outdoor users

3.2 Air interface assumptions

The objective of this section is to summarize the physical layer relevant aspects for Wideband Code Division Multiple Access (WCDMA) network dimensioning. Most of air interface assumptions depend on the equipment provided by ip.access, which is FDD-based (Frequency Division Duplexing) and supports Rel.99, High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA). As mentioned in [TUCAN3G D21], the main air interface assumptions of TUCAN3G are:

- Duplexing technique: FDD
- Chip Rate: 3.84 Mcps
- Channelization bandwidth: 5 MHz
- Frame length:
  - Rel-99: 10 ms
  - HSDPA and HSUPA: 10 ms or 2 ms.
- Slots per frame: 15
- Modulation scheme:
  - Rel-99: QPSK (DL) and BPSK (UL)
  - HSDPA: 16-QAM
  - HSUPA: 16-QAM

3.2.1 Codes

Direct Sequence Spread Spectrum is used in WCDMA system in order to separate transmissions in uplink and downlink and also to achieve multi-rate transmission. WCDMA uses two different types of codes: channelization codes and scrambling codes. The first are used to separate different transmissions from a single source and are responsible for changing the bandwidth of the signal. The second are used to separate different terminals or base stations and the bandwidth is kept after the scrambling operation. Figure 15 shows the spreading and the scrambling operation.

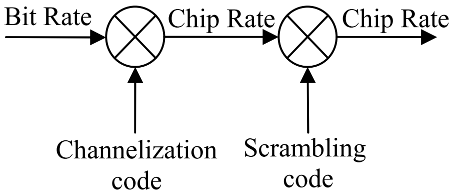


Figure 15. Scrambling and spreading in WCDMA

A further description of these WCDMA codes can be found in [TUCAN3G D21]. Table 9 summarizes the main properties and utilities of the scrambling and channelization codes.

	Channelization Codes	Scrambling Codes
Usage	**Uplink**: separation of physical data (DPDCHs and DPCCHs). **Downlink**: separation of connections to different users within one cell.	**Uplink**: separation of terminals. **Downlink**: separation of cells.
Length	4-256 chips (downlink also 512 chips)	38400 chips (*) (*) 256 chips if advanced base station receivers are used (for example, multi-user detection)
Number of codes	Maximum number of codes under one scrambling code: spreading factor (SF)	**Uplink**: Several million **Downlink**: 512
Code family	Orthogonal Variable Spreading Factor (OVSF)	Gold code (for codes of length of 38400 chips) Extended S(2) (for codes of length of 256 chips)
Spreading	Yes, increases transmission bandwidth	No, does not affect transmission bandwidth

Table 9. Funcionality of the scrambling and channelization codes [Holma00]

3.2.2 Physical channels

In [TUCAN3G D21], the frame structure and different channels (logical, transport and physical) in a WCDMA-FDD network are presented. This section provides the main assumptions of channel structure in radio network planning.

The adopted structure for dedicated physical channels is the structure provided by 3GPP specifications in the annexes of [3GPP TS 125.101] and [3GPP TS 125.104] for each type of service. Table 10 summarizes the spreading factor assumptions for each type of service of Rel.99, for both uplink and downlink. The main characteristics of physical common channels can be obtained from [Holma00] and [Laiho01].

User bit rate (service multiplexing)	Uplink SF	Downlink SF
Voice service 12.2 kbps + DCCH 3.4 kbps	64	128
Packet data 64 kbps + DCCH 3.4 kbps	16	32
Packet data 128 kbps + DCCH 3.4 kbps	8	16
Packet data 284 kbps + DCCH 3.4 kbps	4	8

Table 10. Downlink and uplink DPDCH spreading factors [Laiho01]

3.2.3 Power control procedure

In a WCDMA network, the transmitted powers by the UEs have a direct impact on the system capacity, since they increase the amount of interference in a cell. In the absence of a mechanism that controls these transmitted powers, it could happen, for example, that overpowered mobiles close to the HNB block the whole cell. This effect is known as the *near-far problem*: in the uplink, received powers from users located close to HNB are strong, whereas the received powers from remote users are too weak and cannot be detected.

Therefore, one of the most important mechanisms in a WCDMA system is the power control, which aims to mitigate the near-far problem in the uplink. This technique is also used in the downlink, but the motivation is different: if the amount of transmitted power needed to serve each user is adjusted according to the user distance to the HNB, the total transmitted power by the HNB will be lower compared to the case where all powers are equal for each user. Therefore, more users could be accommodated and the interference generated to other cells will be lowered.

Two main mechanisms are involved in the power control, which are implemented and managed by the physical layer: the fast power control and the outer-loop power control. Fast power control sets the transmitted powers to keep a target Signal to Interference plus Noise Ratio (SINR) during the connection, while the outer-loop power control adjust this target SINR according to the needs of the individual radio link and aims at a constant QoS, defined as a certain target Block Error Rate (BLER).

In addition, fast power control provides another mechanism to combat fast fading, mainly when the mobiles velocity is low and interleaving does not provide enough diversity.

It is worth noting that capacity and coverage in a WCDMA system are closely related: when the cell load is higher (high system interference), higher transmitted power is needed to meet the quality requirements. Thus, users at the cell edge may have not enough power to establish a particular service connection. This effect is known as *cell breathing*. A further description of power control procedure in WCDMA network can be found in [Holma01] and [Laiho01].

3.2.4 Synchronization and cell search procedure

Synchronization and cell search procedure are briefly described in [TUCAN3G D21]. For radio network planning, these mechanisms are important from coverage and cell range points of view, since one UE can connect to a particular HNB (or cell) through these mechanisms.

A further study of cell search and synchronization can be found in [Wang00], where it is proved that there exists a trade-off between capacity and acquisition time: it is desirable that the CPICH power be as lower as possible in order to minimize the intra-cell interference, while a lower CPICH power could mean a larger acquisition time. [Wang00] proves that a good choice for a CPICH power to have an acceptable acquisition time is allocating at least 5% of the maximum available power in the HNB. The procedure followed in allocating power for CPICH is explained in more detail at section 4.3.4. Its goal is to minimize the allocated power for pilot channel, while the whole area of interest is covered and an acceptable acquisition time is obtained.

3.3 ip.access node B specifications

This section describes those aspects of Ip.access HNB which are directly related to network planning. Two classes of Node B are considered, *E-class* and *S-class*, and both classes have the following properties:

- Services supported:
    - 12,2 kbps Adaptive Multi-Rate (AMR) voice service

    - Data services of Rel. 99 - 64/128/384 kbps.
    - Support of HSDPA to 14,4 Mbps (21 Mbps upgradable)
    - Support of HSUPA to 1,45 Mbps (5 Mbps upgradable)
- UTRAN mobility:
    - Reselection and handover to/from macro layer (two-tier deployments)
    - Reselection and handover between HNBs
    - Intra-frequency and inter-frequency reselection and handover
- Noise figure of 8 dB

Parameters that depend on the specific product class are the maximal theoretical range due to the number of chips in the firmware for the PRACH searcher, maximum number of simultaneous dedicated users, RF output power, supported UMTS bands and possibility of using external antennas. In the following sections, specific parameters depending on the class of ip.access HNB are depicted.

Despite Ip.access specifications, some possible changes in their products are considered here so that they can provide services to the areas under study, namely:

1. It is assumed that HNB S-class 16 supports the use of external antennas.
2. A HNB E-class 24 with RF output power of 24 dBm at UMTS band 2/5 is considered (it will be referred in the sequel as E-class 24*).

3.3.1 E-class HNB

The E-class Node B specifications are shown in Table 11.

	E-class 16	**E-class 24**
Simultaneous dedicated users	16	24
RF Output Power	24 / 13 dBm (*)	24 / 13 dBm (*)
UMTS bands	1, 2/5, 4	1, 2/5, 4
External antennas	Optional	Optional
Maximal theoretical range	2.4 km	2.4 km
	(*) For UMTS band 2/5 used in the TUCAN3G networks, the RF output power is 13 dBm.	

Table 11. E-class HNB specifications

3.3.2 S-class HNB

The S-class Node B specifications are shown in Table 12. All assumed support for external antenna.

	S-class 8	**S-class 16**
Simultaneous dedicated users	8	16
RF Output Power	13 dBm	20 dBm
UMTS bands	1, 2/5, 4	1, 2/5
External antennas	No	No
Maximal theoretical range	1 km	2.4 km

Table 12. S-class HNB specifications

3.4 Technical 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. Due to the low traffic expected in the rural regions in Amazon (service will mainly be limited by coverage), and the large distances between villages, we will assume that at most two HNB will be used for one location, using the two carrier frequencies Telefonica del Peru is allowed to operate. In this situation, noise-limited scenarios without intercell interference can be considered.

A noise-limited scenario is characterized by the fact that the limiting factor in the quality of a given connection is the noise and intracell interference, i.e. the interference produced by other cells is negligible. This allows simplifying the network planning procedures.

According to the features that characterize the locations, the most suitable deployments are shown in Table 13 (a subset of those defined in [TUCAN3G D21]):

Population features	Multi-HNB deployment	Traffic	Deployment aspects
Concentrated coverage area	Single HeNB with omni/directional antennas	Low traffic	- Towers up to 70 m high
Disperse coverage area	Many HeNBs in high position with omni or directional antennas	Low-to-medium traffic	- Towers up to 70 m high - Load balancing might be needed - Frequency planning is needed, if more than two HNB are deployed

Table 13. Deployments considered for Napo and Paranapura river sites

According to the locations proposed in [TUCAN3G D21], technical scenarios selected for these sites are summarized in Table 14, along with a description of why these are selected and in which situations they are expected to be appropriate The right-most column shows the tools based on Markov chain traffic modeling used to evaluate the blocking probabilities which are described in section 4.4 [Kleinrock 75]. These scenarios are selected on the basis of the previous network facilities (towers) in order to reduce installation costs and therefore, deployments with HNB/s located in the existing towers are assumed in all scenarios.

Each of these scenarios has been tested with the three types of HNBs described in section 3.3:

1. S-class 16 (16 channels, 13 dBm output power).
2. E-class 24 (24 channels, 13 dBm output power).
3. E-class 24* (24 channels, 24 dBm output power).

The HNB S-Class 8 has not been tested since the maximum theoretical range is not enough to provide coverage. Results in section 5 will elucidate the most suitable technical scenarios for each site, based on the target performance indicators shown in section 4.1.

Scenario	Number of HNB	Antenna pattern beamwidths and gain	Description	Analysis tool for voice blocking probability	Analysis tool for voice plus data blocking probability
#1	Single HNB located in high tower	Dipole Gain: 0dB	Suitable for areas where the available power is not a critical point, the amount of intracell interference is low due to small traffic and area to cover is small. Also, it is appropriated when user distribution around HNB requires omnidirectional coverage.	M/M/m/m	Two-dimensional M/M/m/m
#2	Single HNB located in high tower	Azimuth: omni Elevation: 45º (wide) Gain: 2 dB	Same as previous one, with larger coverage capability.	M/M/m/m	Two-dimensional M/M/m/m
#3	Single HNB located in high tower	Azimuth: omni Elevation: 20º (narrow) Gain: 7 dB downtilt optimised	Same as previous one, with even larger coverage capability.	M/M/m/m	Two-dimensional M/M/m/m
#4	Single HNB located in high tower	Azimuth: 180º Elevation: 20º Gain: 13 dB downtilt optimised	Antenna orientation depends on the traffic distribution in the coverage area: suitable when users are distributed within a sector of 180º. Also, appropriated when available power is critical.	M/M/m/m	Two-dimensional M/M/m/m
#5	Two HNBs located in high tower	Azimuth: 180º Elevation: 20º downtilt optimised (for each HNB)	Antenna orientation depends on the traffic distribution in the coverage area. Different frequency bands are used for each HNB. Suitable in areas with high traffic, one HNB does not provide enough circuits and the available power is critical.	2 parallel M/M/m/m	2 parallel two-dimensional M/M/m/m
#6	Two HNBs located in high tower	Azimuth: omni Elevation: 20º (narrow) Gain: 7 dB downtilt optimised	Omnidirectional antennas. Different frequency bands are used for each HNB. Suitable in areas with high traffic, one HNB does not provide enough circuits and the available power is not critical.	Two-dimensional M/M/m/m	Four-dimensional M/M/m/m

Table 14. Tested technical scenarios for proposed locations and analysis tool used for blocking probabilities (in section 4.4)

4 METHODOLOGY FOR ACCESS NETWORK PLANNING

4.1 Key performance indicators

In this framework we define the coverage, blocking and congestion probabilities as follows:

- *Coverage probability*: probability of an incoming call can be served, given a certain number of simultaneous users in the system.
- *Congestion probability*: probability that all the circuits of the HNB are occupied, i.e., the HNB could not accommodate a new call even if it is generated in a geographical position where there is radio coverage.
- *Blocking probability*: probability that a new incoming call cannot be served, i.e., percentage of generated calls that cannot be served. It encompasses coverage and congestion probabilities.

The first probability needs to be evaluated through simulations, as described in section 4.3.7. The mathematical description of the latter two probabilities can be found in section 4.4. Network performance is evaluated in terms of CPICH coverage and blocking probabilities assuming the traffic density in the busy hour. The requirements imposed to determine whether one scenario is valid or not are the following:

1. Network must be capable to cover, in the worst case, the 95% of area where the intensity of traffic generation over the geographical area is 10% higher than the maximum value.
2. Network must be capable to serve the traffic assumed in the busy hour with a blocking probability lower than 2%.

The final decision to adopt the specific scenario will depend also on the analysis described in section 7 in order to minimize the energy consumption.

4.2 Radio network planning flow chart

This section presents the steps that have been followed for radio network planning. Radio network planning starts off with the definition and characterization of parameters involved in a WCDMA network, such as path losses, channel models and specific WCDMA network parameters. Then, next step is to run the network simulator tool to obtain the required indicators that will be used to determine the performance of a particular network configuration in terms of coverage, blocking probability and energy consumption. Figure 16 shows the flow chart of the network planning procedure followed in TUCAN3G to evaluate different network configurations in each location proposed in D21.

The radio network planning can be summarized in the following points:

1. Definition and selection of different possible technical scenarios for each location (section 3.4).
2. Definition and characterization of parameters involved in radio network planning (sections 4.3.1 and 4.3.2)
3. Path loss acquisition and optimization depending on different HNB antenna configurations, i.e., different heights above the ground and downtilts (section 4.3.3).
4. CPICH coverage (section 4.3.4).
5. Capacity analysis and transmitted powers computation (section 4.3.2).
6. Blocking and congestion analysis (section 4.4).
7. Energy consumption analysis (section 7).

Steps 1-3 are necessary to characterize the physical layer network properties and parameters on which the results will rely, while steps 4-7 are the procedures to obtain different results and network performance.

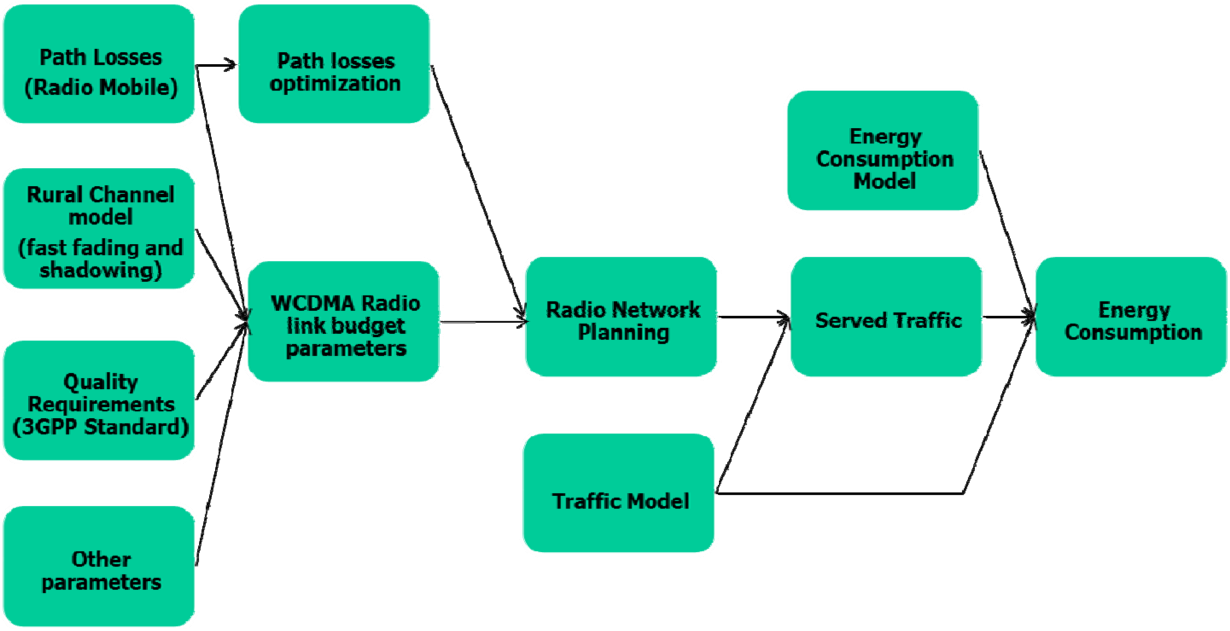


Figure 16. Radio network planning flow chart

4.3 Radio link budget

The goal of this section is to describe the main parameters of WCDMA involved in radio network planning, as well as to determine the transmitted power expressions in the uplink and the downlink depending on the network load (number of simultaneous users in the same cell). To evaluate the transmitted powers, a WCDMA network with power control in both radio link directions is assumed. Once the transmitted power expressions are obtained, the following sections focus on the last steps of radio network planning procedure described in section 4.2, giving details how to analyze the network performance through the transmitted power expressions obtained in the radio link budget.

4.3.1 Radio link budget WCDMA parameters

This section focuses on the description of the main parameters involved in the radio link budget in a WCDMA system. These parameters are needed to determine the transmitted power expressions in WCDMA network. In annex 9.1, it can be seen the different values of these parameters after their characterization and used in radio network planning.

4.3.1.1 Chip Rate (W)

Chip rate is the rate at which waveforms of WCDMA are generated. This chip rate is obtained after spreading operation.

4.3.1.2 Block Error Rate (BLER)

BLER refers to the average block error rate calculated for Transport Blocks. The system can compute this parameter with very high reliability through the Cyclic Redundancy Check (CRC). This parameter is especially important for the power control procedure since the *outer-loop power control* aims to adjust the target SINR according to a particular QoS for a particular service, which is defined in terms of BLER.

4.3.1.3 Bit rate (R)

Bit Rate is the rate of information bits, excluding overhead from higher layers, such as CRC bits, coding and DPCCH control bits. The bit rate will depend on the type of service.

4.3.1.4 Activity factor (v)

The activity factor can take values between 0 and 1 and characterizes the impact of service rate variation during the connection, resulting in an average bit rate of vR. It is important in radio network planning especially for voice service, where users seldom transmit at the same rate during the connection.

4.3.1.5 Orthogonality factor (α)

The impact of loss of orthogonality among channelization codes due to the multipath propagation conditions is characterized by means of the orthogonality factor. It can take values between 0 and 1 (α = 0 implies complete loss of orthogonality, while α = 1 corresponds to complete orthogonality). This parameter only makes sense in the downlink, where the transmissions between HNB and users at the same cell are synchronous. As mentioned previously, the orthogonality factor depends on the multipath propagation conditions and therefore, it will be characterized in radio network planning by the considered multipath channel model. In [Awoniyi03], a characterization of this parameter according to the channel tapped-delay line profile is proposed.

4.3.1.6 Spreading factor and processing gain

The spreading factor in WCDMA system is defined as the chip rate divided by the user rate. In this case, the user rate includes overhead from higher layers. The characteristic processing gain in direct sequence spread spectrum systems are typically defined as the spreading factor, but in most of WCDMA radio network planning literature the processing gain is defined as W/R, where R does not include the overhead from higher layers and channel coding.

4.3.1.7 Energy per bit over interference plus noise spectral density E_b/N_o

The energy per user bit divided by the interference plus noise spectral density is a performance indicator used in radio network planning and it is related to a certain BLER. In a WCDMA system, this parameter has different expressions depending on the direction of the link. In the uplink, it is defined for connection between user *j* and HNB *i* as

$$\left(\frac{E_b}{N_0}\right)_{ji} = \frac{W}{v_j R_j}\cdot\frac{P^r_{ji}}{P^r_i - P^r_{ji} + \sigma_i^2 + \chi_i} \tag{9}$$

where P^r_{ji} is the received power at the BS *i* from user j, σ_i^2 is the thermal noise power at the HNB *i*, P^r_i is the total received power at the HNB *i* from users located at the cell *i* and χ_i is the received interference received at HNB *i* from users connected to other cells.

In the downlink, the definition of E_b/N_0 is slightly different because the synchronized orthogonal codes reduce the interference from the same cell. Thus, it is defined in the downlink for the connection between user *j* and HNB *i* as

$$\left(\frac{E_b}{N_0}\right)_{ij} = \frac{W}{v_j R_j}\cdot\frac{P^r_{ij}}{\left(P^r_{BS_i} - \mathrm{P}^r_{ij}\right)(1-\alpha_j) + \psi_j + \sigma_j^2} \tag{10}$$

where P^r_{ij} is the received power at user *j* from BS *i* intended to serve this user, $P^r_{BS_i}$ is the total received power from BS *i* at this user, σ_j^2 is the thermal noise power at user *j* and ψ_j is the interference received at user *j* from other base stations.

These requirements will depend on the particular scenario (channel model and receiver structure) and particular network configuration (the service data rate, how the user data is mapped into the WCDMA physical channels, the channel coding, etc.).

The E_b/N_0 parameter, both for the uplink and for the downlink, is one of the most important in the radio network planning. As mentioned above, power control procedure aims to keep a target E_b/N_0 to fulfil a given target BLER and therefore, the amount of power allocated to each connection in the system will strongly depend on this target link quality indicator. In section 4.3.2, development of equations (9) and (10) is done to obtain the necessary transmitted powers both for the uplink and for the downlink depending on the cell load (intra-cell interference) and the level of inter-cell interference (which will be null according to the scenarios defined in section 3.4).

4.3.1.8 Energy per chip over total received power spectral density E_c/I_o

The energy per chip divided by the total received power spectral density is a performance indicator used typically for CPICH in downlink radio network planning. Thus, in this case the orthogonality effects are not taken into account. The expression of E_c/I_o for the CPICH is

$$\left(\frac{E_c}{I_0}\right)_{ij}^{cpich} = \frac{P_i^{cpich(r)}}{P_{BS_i}^{r} + \sigma_j^2 + \psi_j^r} \tag{11}$$

where $P_i^{cpich(\mathrm{r})}$ is the received power from CPICH at the user j. This parameter coincides with the SINR because the total received power spectral density is normalized by the chip rate. An UE can be detected one cell if the E_c/I_o for CPICH is higher than a given target value. Thus, this quality indicator parameter is relevant to determine the area covered by each cell.

4.3.1.9 Power Rise

As mentioned previously, fast power control in WCDMA adjusts the transmitted powers in the uplink and downlink to keep a fixed SINR with the objective of reducing network interference. Also, this procedure is able to compensate fast fading in the connection, which can be fairly well compensated in the case of low UE speeds.

Ideal fast fading compensation implies that terminals bear an AWGN channel (at least at a good degree of approximation) and therefore, the average E_b/N_0 needed for the required BLER is low. Consequently, the amount of power dedicated for one radio link is not constant during the connection, resulting in an average transmitted power rise. In the uplink, this effect only increases the interference received from surrounding cells because the received intra-cell powers at the BS remain the same, these being the powers which satisfy the particular target E_b/N_0. However, in the downlink, the power rise implies an increase in the amount of interference that users see from the same cell and from neighbouring cells. In [Sipila99], the impact of fast power control in the uplink is described and the power rise parameter is defined and characterized depending on the multipath conditions and UE speeds. In section 4.3.2, a mathematical definition of the power control headroom is also presented, both for the uplink and for the downlink.

4.3.1.10 Power Control Headroom

When a low-speed UE is approaching the cell edge, the UE transmission power can reach its maximum value due to fast power control procedure to compensate fast fading. Thus, a *fast fading margin* or *power control headroom* is needed in radio network planning in order to ensure that these UEs in the cell edge can be served by the network. In the downlink, this fast fading margin is needed in order to ensure that the available power in the base station is enough to compensate fast fading of all connections. This parameter is explained in further detail in [Sipila99] for the uplink. In section 4.3.2, a mathematical definition of the power rise is also presented, both for the uplink and for the downlink.

4.3.2 WCDMA power allocation

In this section, we find the expressions that describe the transmitted powers in WCDMA networks when power control is assumed, both for the uplink and for the downlink. These expressions can be obtained through the link quality requirements defined in (9) and (10), solving these equations for the required transmitted powers.

In scenarios considered in section 3.4 there is no inter-cell interference since almost all are isolated-cell deployments and the two-cell deployment uses different carriers for each cell. However, in this section the general case for power allocation in WCDMA networks is described, considering more than one cell and interference between them (denoted in the sequel as χ), since it will be useful for activities 4A2 and 4A3.

4.3.2.1 Power allocation in the uplink

In the uplink, the received signal from user *j* in the HNB *i* will be

$$P_{ji}^{r} = P_{ji} G_{i}^{bs}(\theta_{j}) G_{j}^{ms}(\theta_{i}) \frac{X_{ji}}{L_{ji}} = P_{ji} G_{ji}^{T} X_{ji}, \tag{12}$$

where P_{ji} is the transmitted power by the UE *j*, $G_j^{ms}(\theta_i)$ and $G_i^{bs}(\theta_j)$ are the UE and HNB antenna gains depending on their radiation pattern, respectively, L_{ji} denotes the path loss between this two units in the uplink and X_{ji} denotes the instantaneous multipath channel gain. We have defined the parameter $G_{ji}^{T} = G_{i}^{bs}(\theta_{j}) G_{j}^{ms}(\theta_{i}) / L_{ji}$, which denotes the effective gain between the user *j* and HNB *i*.

From the point of view of the reception of user *j*'s signal, the amount of interference power received at the HNB *i* will be the sum of all user received powers connected to the same cell, except that of the user *j*, plus the thermal noise power at the HNB, σ_i^2, and the inter-cell interference received from all users connected to the other cells. Let M_n be the total number of users connected to the cell *n* and *N* the total number of HNB in the network. Then, the SINR for the user *j* connected to the HNB *i* can be written as

$$\text{SINR}_{ji} = \frac{P_{ji} G_{ji}^{T} X_{ji}}{\sum_{m=1}^{M_i} P_{mi} G_{mi}^{T} X_{mi} - P_{ji} G_{ji}^{T} X_{ji} + \sigma_i^2 + \sum_{\substack{n=1 \\ n \neq i}}^{N} \sum_{k=1}^{M_n} P_{kn} G_{ki}^{T(n)} X_{ki}^{(n)}}. \tag{13}$$

where the $X_{ki}^{(n)}$ and $G_{ki}^{T(n)}$ denote the instantaneous gain due to fast fading and the effective gain between an user *k* connected to the cell *n* and the HNB *i*, respectively. The superscript *(n)* remarks that, despite user *k* causes interference in cell *i*, it is connected to HNB *n*.

As seen previously in section 4.3.1.7, link quality requirements are typically given in terms of energy per user bit divided by the interference plus noise spectral density, E_b/N_0 and different target E_b/N_0 to keep a particular QoS can be obtained by radio link level simulations, measurements or from technical specifications. Typically, the minimum requirements to keep a particular BLER are given for different services rates, configurations and scenarios, and they are defined in the uplink [3GPP TS 25.104] as

$$\left(\frac{E_b}{N_0}\right)_{\text{target}} \triangleq \gamma = \text{SINR} \cdot \frac{L_{chip}}{L_{inf}} = \text{SINR} \cdot \frac{W}{vR}, \tag{14}$$

where *W* is the system chip rate, *R* is the bit rate for a particular service, L_{chip} is the total number of chips per frame, L_{inf} is the number of information bits per frame and *v* is the activity factor. From equations (13) and (14), we can express the user *j* coverage condition as

$$\left(\frac{E_b}{N_0}\right)_{ji} = \frac{W}{v_j R_j}\frac{P_{ji}G_{ji}^T X_{ji}}{\sum_{m=1}^{M_i} P_{mi}G_{mi}^T X_{mi} - P_{ji}G_{ji}^T X_{ji} + \sigma_i^2 + \sum_{\substack{n=1\\ n\neq i}}^{N}\sum_{k=1}^{M_n} P_{kn} G_{ki}^{T(n)} X_{ki}^{(n)}} \geq \gamma_{ji}. \qquad (15)$$

Let P_{max}^{ms} denotes the maximum available power in the UEs. Then, the WCDMA power control in the uplink solves the following minimization problem:

$$\begin{aligned} &\underset{P_{ij}}{\text{minimize}} \quad P_{ji} \qquad i=1,\ldots,N \quad \forall j \in cell\, i \\ &\text{subject to} \quad \frac{W}{v_j R_j}\cdot\frac{P_{ji}G_{ji}^T X_{ji}}{\sum_{m=1}^{M_i} P_{mi}G_{mi}^T X_{mi} - P_{ji}G_{ji}^T X_{ji} + \sigma_i^2 + \sum_{\substack{n=1\\ i\neq n}}^{N}\sum_{k=1}^{M_n} P_{kn} G_{ki}^{T(n)} X_{ki}^{(n)}} \geq \gamma_{ji}, \qquad i=1,\ldots,N \quad \forall j \in cell\, i \qquad (16) \\ &\qquad\qquad P_{ji} \leq P_{max}^{ms}, \qquad i=1,\ldots,N \quad \forall j \in cell\, i \end{aligned}$$

Different users will be connected to one HNB or another depending on the downlink pilot coverage. To find out how the power control performs and its impact on the transmitted powers P_{ji}, it is assumed a fixed inter-cell interference in the HNB i denoted by χ_i,

$$\chi_i = \sum_{\substack{n=1\\ n\neq i}}^{N}\sum_{k=1}^{M_n} P_{kn} G_{ki}^{T(n)} X_{ki}^{(n)}, \qquad i=1,\ldots,N. \qquad (17)$$

Now, the minimization problem described in (16) can be divided into N less complex minimizations corresponding to each cell. In the optimum, if ideal power control is assumed, (16) must be fulfilled with equality and therefore we can solve the link quality restriction in (16) for each P_{ji} in the cell i and gives

$$P_{ji} = \frac{1}{G_{ji}^T}\frac{1}{X_{ji}}\frac{\sigma_i^2 + \chi_i + \sum_{m=1}^{M_i} P_{mi}G_{mi}^T X_{mi}}{1+\frac{W}{v_j R_j \gamma_{ji}}} = \frac{1}{G_{ji}^T}\frac{1}{X_{ji}}\frac{\chi_i + \sigma_i^2 + P_i}{1+\frac{W}{v_j R_j \gamma_{ji}}}, \qquad \mathrm{i}=1,\ldots,N \quad \forall j \in cell\, i, \qquad (18)$$

where P_i denotes the total received power in the HNB i and it will be

$$P_i = \sum_{m=1}^{M_i} P_{mi}G_{mi}^T X_{mi} = \sum_{m=1}^{M_i}\frac{\chi_i + \sigma_i^2 + P_i}{1+\frac{W}{v_m R_m \gamma_{mi}}}, \qquad i=1,\ldots,N. \qquad (19)$$

Solving (19) for P_i gives

$$P_i = \frac{\sum_{m=1}^{M_i}\frac{\chi_i + \sigma_i^2}{1+\frac{W}{v_m R_m \gamma_{mi}}}}{1-\sum_{m=1}^{M_i}\frac{1}{1+\frac{W}{v_m R_m \gamma_{mi}}}} = \frac{\left(\chi_i + \sigma_i^2\right)\eta_i^{ul}}{1-\eta_i^{ul}}, \qquad i=1,\ldots,N \qquad (20)$$

where η_i^{ul} is defined as the uplink intra-cell load factor:

$$\eta_i^{ul} = \sum_{m=1}^{M_i} \frac{1}{1+\dfrac{W}{v_m R_m \gamma_{mi}}}, \qquad i = 1,\ldots,N. \tag{21}$$

The intra-cell load factor defined in (21) characterizes the amount of noise rise over thermal noise plus inter-cell interference due to the interference from users connected to the same cell (intra-cell interference).

Finally, plugging (20) into (18), the transmitted power by the user j connected to the HNB i can be rewritten as

$$P_{ji} = \frac{1}{G_{ji}^T}\frac{1}{X_{ji}}\frac{1}{1+\dfrac{W}{v_j R_j \gamma_{ji}}}\frac{\sigma_i^2+\chi_i}{1-\eta_i^{ul}}, \qquad i = 1,\ldots,N \quad \forall j \in cell\, i \tag{22}$$

The transmitted power by the users is proportional to the path loss between the user and the HNB and to the inter-cell interference plus thermal noise, and inversely proportional to the antenna gains, to the instantaneous channel gain due to fast fading, to the factor which characterizes the processing gain for a particular service and to the factor $\left(1-\eta_i^{ul}\right)$.

Finally, for radio network planning, the statistics of transmitted powers during the connection are necessary. The average transmitted power of (22) for each UE in the uplink assuming ideal power control will be

$$E(\mathrm{P}_{ji}) = \bar{\mathrm{P}}_{ji} = E\left(\frac{1}{X_{ji}}\right)\cdot\frac{1}{G_{ji}^T}\frac{1}{1+\dfrac{W}{v_j R_j \gamma_{ji}}}\frac{\sigma_i^2+\chi_i}{1-\eta_i^{ul}} \tag{23}$$

where the term $E\left(1/X_{ji}\right)$ is the average power rise defined in 4.3.1.9. In addition to power rise, it is also important to characterize the variation of this transmitted power in order to determine the power control headroom, as explained in 4.3.1.10.

4.3.2.2 Power allocation in the downlink

In the downlink, the HNB i spends part of its power to serve user j. The rest of the HNB transmitted power intended to cover the other UEs and the received powers from other HNBs are perceived as interference power by user j. Hence, the link quality equation for the UE j connected to the HNB i will be

$$\left(\frac{E_b}{N_0}\right)_{ij} = \frac{W}{v_j R_j}\cdot\frac{P_{ij} G_{ij}^T X_{ij}}{\left(1-\alpha_j\right) G_{ij}^T X_{ij}\left(P_{BS_i} - P_{ij}\right) + \sigma_j^2 + \sum\limits_{\substack{n=1\\ n\neq i}}^{N} P_{BS_n} G_{nj}^T X_{nj}} \geq \gamma_{ij}, \tag{24}$$

where P_{ij} denotes the amount of transmitted power by the HNB i intended to serve the user j, $G_{ij}^T = G_i^{bs}(\theta_j) G_j^{ms}(\theta_i)/L_{ij}$ is the effective gain between the HNB i and the user j, $P_{BS_i} = P_i^{cCH} + \sum_{j=1}^{N_i} P_{ij}$ is the total transmitted power by HNB i (the summation of the powers intended to serve each user plus the total common channels power), $\sum_{\substack{n=1\\ n\neq i}}^{N} P_{BS_n} G_{nj}^T X_{nj}$ is the received interference from other HNBs at user *j* and α_j is the orthogonality factor for the downlink of user *j*. The link quality requirements, γ_{ij} , can also be obtained from measurements, simulations or from 3GPP specifications [3GPP TS 25.101].

Moreover, in the downlink planning, the common channels must be considered. For downlink common channels, such as Common Pilot Channel (CPICH), the requirements are usually given in terms of E_c/I_o [3GPP TS 25.133], where E_c is the energy per chip and I_o is the total received power spectral density at the UE, as described before in section 4.3.1.8. The link quality requirement for the CPICH must be fulfilled in any user *j* located in any position of the cell *i*, which is equivalent to say that the requirement must be satisfied in the worst case. Then,

$$\left(\frac{E_c}{I_0}\right)_{ip}^{CPICH} = \frac{P_i^{CPICH} G_{ip}^T}{P_{BS_i} G_{ip}^T + \sigma_p^2 + \psi_p} \geq \gamma_{cpich}, \tag{25}$$

where *p* denotes an user located in the worst position in the cell. The worst position in the cell will be this position where the summation $P_{BS_i} G_{ip}^T + \sigma_p^2 + \psi_p$ is the highest, where ψ_p denotes the inter-cell interference in this location. Notice in (25) that the instantaneous channel gain that characterizes the fast fading is not included in the expression and this is because it has been included in the quality requirement γ_{cpich}. Finally, notice that allocated power for CPICH is not involved in the power control procedure and therefore it does not compensate fast fading.

The requirements for the other common channels can be set in terms of relative transmitted power to the CPICH [Holma00]. Therefore, (25) can be rewritten for the set of common channels as

$$\left(\frac{E_c}{I_0}\right)_{ip}^{cCH} = \frac{P_i^{cCH} G_{ip}^T}{P_{BS_i} G_{ip}^T + \sigma_p^2 + \psi_p} \geq \gamma_{cCH}, \tag{26}$$

where P_i^{cCH} is the total transmitted power by the BS *i* for the set of common channels and γ_{cCH} denotes its quality requirement expressed in terms of E_c/I_o.

Thus, the minimization problem in the downlink for the cell *i* is

$$\begin{aligned}
&\underset{P_i^{cCH},\{P_{ij}\}}{\text{minimize}} \quad P_{BS_i} = P_i^{cCH} + \sum_{j=1}^{M_i} P_{ij} \qquad i=1,\ldots,N \quad \forall j \in cell\, i \\
&\text{subject to} \quad \frac{W}{v_j R_j} \cdot \frac{P_{ij} G_{ij}^T X_{ij}}{\left(1-\alpha_j\right)\left(P_{BS_i} - P_{ij}\right) G_{ij}^T X_{ij} + \sigma_j^2 + \sum\limits_{\substack{n=1 \\ n\neq i}}^{N} P_{BS_n} G_{nj}^T X_{nj}} \geq \gamma_{ij}, \qquad i=1,\ldots,N; \quad \forall j \in cell\, i; \\
&\qquad\qquad \frac{P_i^{cCH} G_p^T}{P_{BS_i} G_p^T + \sigma_p^2 + \psi_p} \geq \gamma_{cCH}, \qquad i=1,\ldots,N; \\
&\qquad\qquad P_i^{cCH} + \sum_{j=1}^{M_i} P_{ij} \leq P_{max}^{bs}, \qquad i=1,\ldots,N.
\end{aligned} \tag{27}$$

Assuming also a fixed inter-cell interference in each user of the cell *i* denoted by ψ_j,

$$\psi_j = \sum_{\substack{n=1 \\ n\neq i}}^{N} P_{BS_n} G_{nj}^T X_{nj}, \qquad \forall j \in cell\ \ i \tag{28}$$

the minimization problem described in (27) can be divided into N less complex minimizations corresponding to each cell. Additionally, if ideal power control is assumed, we can solve the link quality restriction in (27) for each P_{ij} in the cell i and gives

$$P_{ij} = \frac{\left(1-\alpha_j\right)P_{BS_i} + \dfrac{\sigma_j^2 + \psi_j}{G_{ij}^T X_{ij}}}{\left(1-\alpha_j\right) + \dfrac{W}{v_j R_j \gamma_{ij}}}, \qquad i = 1,\ldots,\mathrm{N}; \quad \forall j \in cell\, i. \tag{29}$$

The total transmitted power by the HNB i will be

$$P_{BS_i} = P_i^{cCH} + \sum_{m=1}^{M_i} P_{im} = P_i^{cCH} + P_{BS_i} \sum_{m=1}^{M_i} \frac{1}{1 + \dfrac{W}{v_m R_m \gamma_{im}\left(1-\alpha_m\right)}} + \sum_{m=1}^{M_i} \frac{\dfrac{\sigma_m^2 + \psi_m}{G_{im}^T X_{ij}}}{\left(1-\alpha_m\right) + \dfrac{W}{v_m R_m \gamma_{im}}}, \qquad i = 1,\ldots,N, \tag{30}$$

and solving (30) for P_{BS_i} gives

$$P_{BS_i} = \frac{P_i^{cCH} + \displaystyle\sum_{m=1}^{M_i} \frac{1}{G_{im}^T} \frac{1}{X_{im}} \frac{\sigma_m^2 + \psi_m}{\left(1-\alpha_m\right) + \dfrac{W}{v_m R_m \gamma_{im}}}}{1 - \eta_i^{dl}}, \qquad i = 1,\ldots,N, \tag{31}$$

where η_i^{dl} denotes the downlink intra-cell load factor of the cell i and it is defined as

$$\eta_i^{dl} = \sum_{m=1}^{M_i} \frac{1}{1 + \dfrac{W}{v_m R_m \gamma_{im}\left(1-\alpha_m\right)}}, \qquad i = 1,\ldots,\mathrm{N}. \tag{32}$$

Similar to the uplink, the statistics of transmitted powers by HNBs are really important for radio network planning. The average transmitted power by different HNBs will be

$$E\left(P_{BS_i}\right) = \overline{P}_{BS_i} = \frac{1}{1-\eta_i^{dl}} \left(P_i^{cCH} + E\left(\frac{1}{X}\right) \sum_{m=1}^{M_i} \frac{1}{G_{im}^T} \frac{\sigma_m^2 + \psi_m}{\left(1-\alpha_m\right) + \dfrac{W}{v_m R_m \gamma_{im}}} \right), \qquad i = 1,\ldots,N, \tag{33}$$

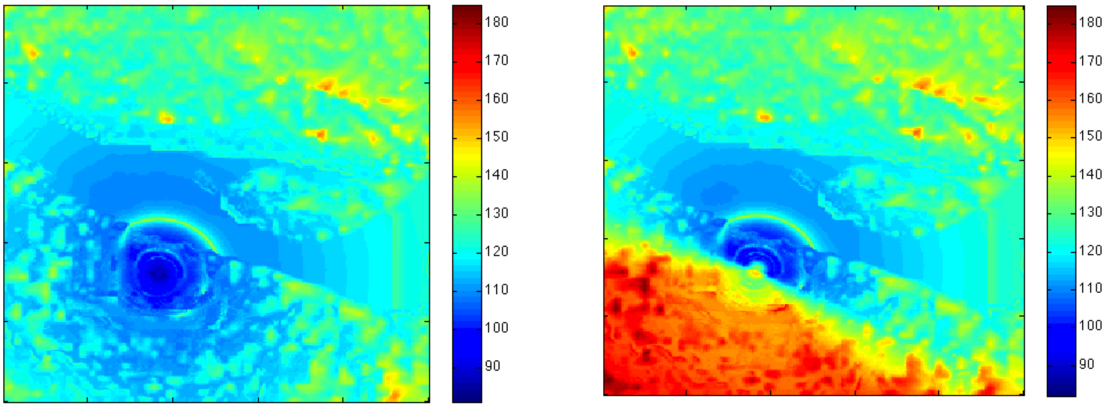
where $E(1/X)$ is the power rise for each downlink connection (we assume that multipath conditions are the same in each link). Finally, as in the uplink, a fast fading margin is needed in order to avoid that transmitted power variations might block the connection between HNB and UE. In the downlink, the fast fading margin will depend on the number of simultaneous users in the network since the same HNB is responsible for compensating fast fading through power control procedure in each connection. If we assume a power control headroom for each link, $PCH_{one\ link}$, the total power control headroom needed by the HNB in order to compensate power fluctuations can be expressed as

$$PCH_T(\mathrm{dB}) = PCH_{\text{one link}}(dB) + 10\log\left(M_i\right) \tag{34}$$

where M_i is the number of simultaneous users in the network. Notice that this way to compute the total power control headroom is quite pessimistic since we assume that all radio links can suffer fast fading at the same instant of time.

4.3.3 Path losses evaluation

Path losses of each location are obtained by Radio Mobile software. They will be different depending on the link direction (uplink and downlink) due to the terrain, operating frequency and different antenna patterns at UE and HNB. If a scenario of more than one cell is assumed, we require path losses for each cell, both for the uplink and for the downlink. Figure 17 shows as an example the path losses in dB obtained with Radio Mobile for different configurations in Negro Urco location.



(a) Isolated cell, downlink and isotropic antenna

(b) Isolated cell, downlink and antenna with azimuth beamwidth of 180°, elevation beamwidth of 20° and downtilt of 10°

Figure 17. Path losses in dB obtained for different antenna configurations in Negro Urco for a heigh above ground of 70 m

It is important to notice here that antenna pattern will have a direct impact on the obtained path loss byowing to the irregular terrain. Therefore, there will be one antenna configuration (height above ground and downtilt) that minimizes the path loss in the coverage area. Thus, a study of the impact of antenna configuration is necessary to optimize the path losses in each location and for each tested scenario. The procedure followed to evaluate this optimum antenna configuration at every place is:

1. Path loss extraction with radio mobile for each antenna configurations (different heights and downtilts).
2. Compute the 95th percentile of the path losses inside the area to cover.
3. Find the optimum configuration of HNB height and antenna downltilt that minimizes this 95th percentile.

4.3.4 Pilot coverage requirements

Downlink common channels cause interference to dedicated channels and also reduce the available power for these channels, resulting in a downlink capacity decrease. From the point of view of capacity, it is desirable that power intended for common channels to be as lower as possible subject to the CPICH quality constraint in the whole area to cover. Thus, the CPICH coverage must be fulfilled in the worst case, this is when HNB are transmitting maximum power (maximum self-interference) and the expected inter-cell interference is maximum. Obviously, if one user is able to identify one cell in the worst case, it will be able to identify the cell if the traffic load is lower, resulting in a higher coverage area. Also, notice that for the technical scenarios proposed, inter-cell interference does not exist.

For each location, as mentioned in section 2.3, intensity of traffic generation over the geographical area is assumed in order to characterize in which zones UE density will be higher (areas with many houses) or lower (areas with few houses). In section 4.1, we have defined the area to cover in the worst case as the area where the expected intensity of traffic generation is 10% higher than the maximum value. This area is limited by the maximum theoretical range (2.4 km for HNBs used). Finally, for this area we define the maximum path loss to cover as the 95th percentile, excluding in this way insignificant locations where path loss can be very high due to different physical and radio electrical reasons. Once we have the maximum path loss to cover, we can compute the minimum CPICH power (in dB) required through equation (25) as

$$P^{CPICH} = 10\log\left(\gamma_{cpich}\left(P^{bs}_{max} + \frac{\sigma_p^2 + \psi_p^{max}}{G^T_{ip}}\right)\right) + SM(dB) \qquad (35)$$

where sub-index p denotes one user located in the maximum path loss to cover (95th percentile) , ψ^{max} is the maximum inter-cell interference expected in this place depending on neighboring networks (it is 0 in the selected scenarios where no interference is expected), and SM is the shadow margin defined in 3.1.3. Multipath conditions are included in the required link quality constraint and other margins are ignored since CPICH is not considered in the power control procedures. Through the CPICH power computed in equation (35), the total power intended for downlink common channels can be determined by means of the relative transmitted powers depicted in Table 15.

	Power level relative to CPICH power
CPICH	-
P-SCH + S-SCH	-3 dB
P-CCPCH	-5 dB
PICH	-8 dB
AICH	-8 dB
S-CCPCH	-5 dB

Table 15. Downlink common channel power levels relative to CPICH power [Laiho01]

For the particular case of multi-cell scenario #5 depicted in Table 14 (two HNBs at the same tower with 180º sector antennas and 2 different carriers), the steps to determine each pilot power are practically the same as the isolated cell case described above. However, in this multi-cell network is necessary to define the area covered for each cell. For radio network planning in scenario #5, we assume a pessimistic situation, maintaining a fixed coverage area for each cell, independent from the number of simultaneous users in each cell (cell loads). The condition followed to determine whether every point (bin) within the theoretical range belong to one cell or to the other is based on the minimum downlink path loss. Moreover, soft handover is not possible between 2 cells with different operating frequencies. Also, there will be some places where path losses between a UE and HNBs are practically the same (angular limit of each sector) and in these places we always assume the worst path loss to determine the HNB which will serve the user. This decision is pessimistic as if one HNB is congested (no codes left) the UE does not try to connect to the other HNB.

For the particular case of multi-cell scenario #6 depicted in Table 14 (two HNBs at the same tower with omnidirectional antennas and 2 different carriers), the steps to determine each pilot are the same in both cells and obviously, power needed for common channels will be practically the same at each cell since the only difference between to cells are the operating frequency (same power for common channels at each cell are considered).

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Notice that the uplink is not taken into account to determine the coverage area. Usually, the cell range is limited by the uplink but due to the HNBs used in this project this is not the case since the total power available by the UEs are higher than the available power at HNB to serve a downlink connection. In macro-cells, the available power at the base stations is much higher and therefore, the network dimensioning typically is uplink-limited.

Finally, it is important to notice that in situations where antenna gains are high, path losses are low, etc. it is possible that CPICH required power is too weak to detect the cell correctly regardless of the link quality requirement. As described in section 3.2.4, a trade-off exists between acquisition time and received CPICH power strength. [Wang00] defines the minimum ratio between transmitted power for CPICH and total transmitted power by HNB of 5% to have an acceptable acquisition time. Thus, if transmitted power for CPICH required by the minimum path loss is lower than 5%, we should keep it to 5%.

4.3.5 Link quality evaluation

Once the powers of downlink common channels are determined in radio network planning, the next step is to generate different users within the coverage area and determine the necessary transmitted powers in both uplink and downlink. Equations (23) and (33) describes the average transmitted power needed depending on the cell load (number of simultaneous users in the cell) in a WCDMA system with power control. Also, these transmitted powers depend on the specific position of the users around the cell and therefore, different realizations are necessary in order to have a realistic distribution of transmitted powers by UEs and HNB for a particular cell load.

As we cited in previous sections, the transmitted powers are not fixed during the connection, but they fluctuate due to fast power control mechanism. In order to determine whether different UEs can be served by the HNB, we must test if the available power in each UE and the available power in the HNB (or HNBs) are enough to serve all users for this particular cell load and for this particular distribution of users during all connection.

Thus, one UE can be served in the uplink direction if

$$\overline{\mathrm{P}}_{ji} \cdot PCH_{ul} \cdot SM \leq P_{max}^{ms} \tag{36}$$

where $\overline{P}_{ji}$ is the average transmitted power by the UE *j* connected to HNB *i* described in (23) , PCH_{ul} is the power control headroom defined for the uplink and SM is the shadowing margin.

In the downlink, the condition is slightly different because the available power in HNB (or HNBs in the multi-cell cases) has to be capable of serving all UEs. Furthermore, we must take into account the allocated power for common channels. The coverage condition in the downlink can be expressed through equation (33) and it is

$$\frac{P_i^{cCH}}{1-\eta_i^{dl}} + \frac{E\left(\frac{1}{X}\right)\sum_{m=1}^{M_i}\frac{1}{G_{im}^T}\frac{\sigma_m^2+\psi_m}{(1-\alpha_m)+\frac{W}{v_m R_m \gamma_{im}}}}{1-\eta_i^{dl}} \cdot PCH_{dl}(M_i)\cdot SM \leq P_{max}^{bs} \tag{37}$$

where $PCH_{dl}(M_i)$ is the power control headroom in the downlink, which depends on the number of simultaneous users and P_i^{cCH} is the transmitted power for the set of common channels determined in section 4.3.4. Notice that for transmitted powers of common channels, the shadow margin has already taken into account previously and power control headroom is not needed since there is no power control for CPICH.

Conditions (36) and (37) are necessary in order to determine if there exists a non-coverage situation for a particular cell load and user distribution. We consider a non-coverage situation in the uplink if at least one UE does not have enough power to be served by the HNB and a non-coverage situation in the downlink if the HNB or at least one HNB (multi-cell case) does not have enough power to serve all users. There are other reasons for non-coverage situations which will be discussed in detail at section 4.3.7

Finally, Monte Carlo simulations are used to evaluate different situations (distributions of users around the HNB) depending on the number of simultaneous users. The procedure is as follows: for each number of simultaneous users, different realizations (random positions of users in the cell) are generated and the non-coverage situations are determined and counted for each realization. A non-coverage situation is identified when there is not enough power to serve simultaneously those users. To generate different users, we assume different intensities of traffic generation over the geographical area around the HNB, resulting more likely that user will be located in some places where there is a high density of housings. During this simulation, different blockings are counted but also transmitted powers are computed and saved for later processing. Average transmitted powers by HNB are saved without taking into account fast fading margin and shadow margin for dedicated channels.

4.3.6 Target E_b/N_o values

As mentioned previously, target link quality requirements for each service are one of the most important parameters in WCDMA network planning. For low speed mobiles, which are in TUCAN3G locations, fast power control is able to compensate fast fading fairly well and therefore, channel between HNB and UEs are practically as an AWGN channel. Thus, thanks to the fast power control, the required E_b/N_o are lower. In radio network planning, we assume that each service needs a QoS determined by a BLER of 1%. For this required BLER, we can find the quality requirements in 3GPP specifications both for the uplink [3GPP TS 25.104] and for the downlink [3GPP TS 25.101] for a AWGN channel. Table 16 summarizes these requirements defined in 3GPP specifications.

	Uplink	Downlink
Voice 12,2 kbps	8,3 dB	7,4 dB
Data 64 kbps	4,8 dB	3,98 dB
Data 128 kbps	4,5 dB	3,97 dB
Data 384 kbps	4,1 dB	3,5 dB

Table 16. Target quality requirements for an AWGN channel

The 3GPP specifications do not give a target value for 128 kbps data service, but for 144 kbps. However, it can be assumed that dedicated channels (control and data) have the same configuration in both cases and target E_b/N_o for 128 kbps data service can be expressed as

$$\left(\frac{E_b}{N_0}\right)_{128kbps} = \frac{144}{128} \cdot \left(\frac{E_b}{N_0}\right)_{144kbps}$$

In the downlink, these requirements are given in terms of the ratio of the average transmit energy per chip to the total transmit spectral density (E_c/I_{or}). These can be interpreted in terms of E_b/N_o using the following expression [Holma00]:

$$\frac{E_b}{N_0} = \frac{\frac{W}{R} \cdot \frac{E_c}{I_{or}}}{1 - \alpha + \frac{1}{I_{or} / I_{oc}}} \tag{38}$$

where I_{oc} denotes the power spectral density normalized to the chip rate of a band limited white noise source simulating interference from cells (the value of this parameters is given together with the different E_c/I_{or} values in the standard requirements). Notice that if we assume static conditions (AWGN channel), we must take the orthogonality factor is equal to 1 for the transformation from E_c/I_{or} to E_b/N_o.

4.3.7 Definition of the probability of coverage

The goal of this section is to define more precisely the probability of coverage in WCDMA networks. In equations (36) and (37) we have defined the non-coverage conditions, for the uplink and for the downlink, respectively. One user cannot be served by the network because the available powers at the UE or at the HNB are not enough, as cited in 4.3.5, but it is not the only reason. The HNB must dispose of free spreading codes for the downlink connection. The maximum number of simultaneous users limited by the number of spreading codes, or by the number of simultaneous users supported by the HNB (16 or 24 as mentioned in section 3.3) in the downlink is called *hard capacity*. On the other hand, the maximum number of users that can be served before being limited by the available power is called *soft capacity*.

Soft capacity depends on the type of service and it also depends of the specific locations of the UEs around the HNB. Notice in (23) and (33) that the maximum number of users can also be limited simply by the load factor, which does not depend on the UE distribution around the HNB, but it only depends on the type of service for each active user in the cell. This happens since being intra-cell load factor close to 1 causes that the required transmitted powers to serve one connection is infinity. The maximum number of users limited by the load factor of the cell is called *pole capacity*.

Thus, hard capacity and pole capacity can be determined easily for each type of service in the network. However, the study of soft capacity in WCDMA networks is not easy because it depends on the specific user locations. This means that for a particular number of simultaneous users, there will be situations or user distributions where the available powers at UEs and HNBs are enough to establish all service connections, while there will be user distributions where the available powers are not enough. For this reason, simulation tools are needed to evaluate capacity in 3G networks and it make sense to say that one HNB can be serve M_i simultaneous users with a certain coverage probability.

As mentioned in section 4.1, we define the probability of coverage as the probability of incoming call can be attended given a certain number of users in the system. With the simulation tool, we cannot evaluate directly this probability, but we can evaluate the probability of M_i simultaneous users can be attended by the system, both for the uplink and for the downlink through non-coverage conditions defined in 4.3.5. Now, let P_i^{cob} denotes the probability of i simultaneous users can be attended by the HNB, thus, the probability of coverage can be defined by means of Bayes' rule as

$$P_{i,i+1}^{cob} = P_{i+1}^{cob} \Big/ P_i^{cob} \tag{39}$$

In section 4.4, a further description on evaluating served traffic by the network through the coverage probabilities is given in details.

In conclusion, we have described different reasons that limit the number of active users connected in the network:

- Number of available codes in the downlink or maximum number of simultaneous users supported by HNB (hard capacity)
- The cell reaches a cell load of 1 (pole capacity)
- The available power by HNB is not enough to serve a certain distribution of users.

Finally, for the multi-cell scenario #5, everything described in this section is also valid for each cell. Notice in this two-cell deployment that, despite the number of simultaneous users supported by the HNB can increase by two, the distribution of users around these HNBs is determinant to elucidate if one cell can serve all UEs or, in contrast, this HNB cannot serve this distribution (for example, if each HNB supports 16 users, when 32 users are active in the cells, only a distribution with 16 users in each cell can be served).

The procedures followed to evaluate the blocking probabilities and the circuits associated for each scenario are described in section 4.4. In order to illustrate the concepts, Figure 18 displays the probability of i simultaneous users can be served (P_i^{cob}) for different technical scenarios in Santa Clotilde location when HNB S-class 16 is used, both for the uplink and for the downlink. Notice that, for the uplink, these probabilities are practically one, independently of the number of simultaneous users in the system and thus, the network is downlink limited. This result is expected as the available power at HNB is more stringent than the available powers at the UEs for each configuration and in each location. Note that for the downlink, scenario #3 provides the best performance in terms of coverage probabilities since it has the higher available power to serve users due to the higher antenna gain.

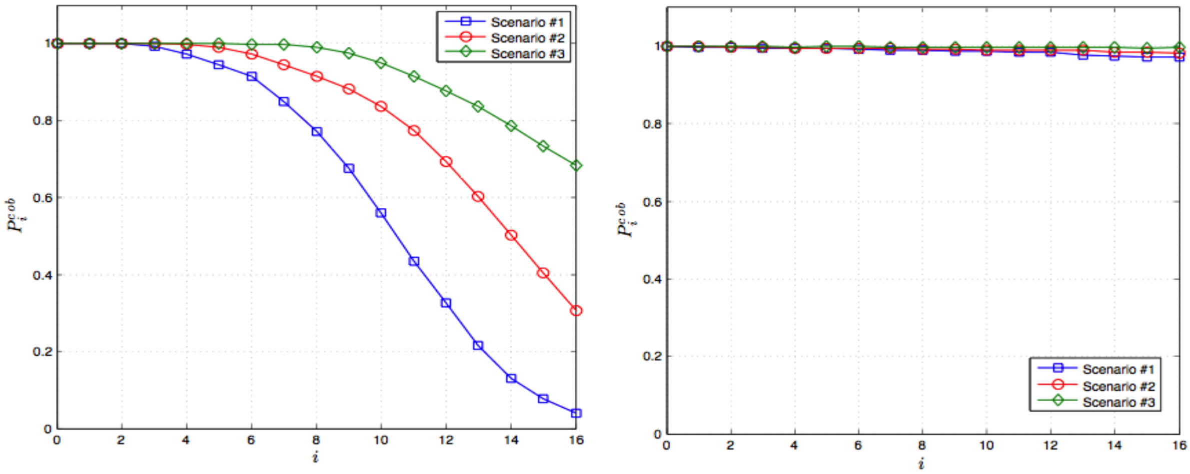


Figure 18. Downlink (left) and uplink (right) probabilities of *i* simultaneous users can be served depending on the number of simultaneous users before new incoming call for scenarios #1, #2 and #3 in Santa Clotilde location when HNB S-class 16 is used

For illustrative purposes, Figure 19 shows the downlink probabilities of *i* simultaneous users can be attended for each cell in Santa Clotilde location if scenario #5 is selected. As mentioned in section 4.4, each cell of scenario #5 can be seen as two independent networks and therefore, coverage probabilities for each cell are computed separately.

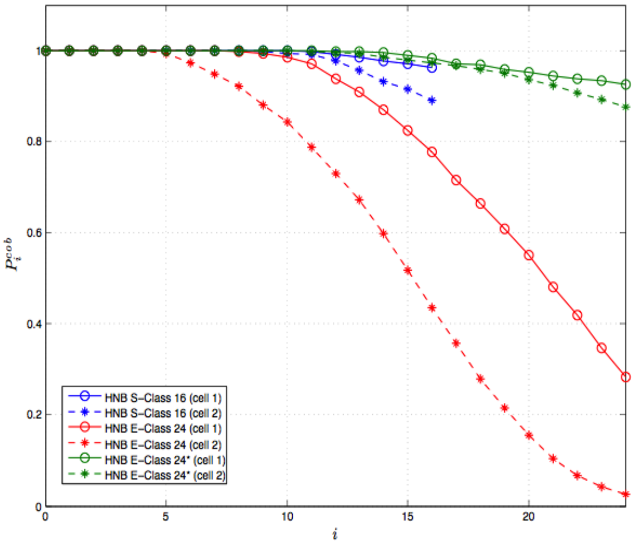


Figure 19. Downlink probabilities of *i* simultaneous users can be served depending on the number of simultaneous users before new incoming call for scenario #5 in Santa Clotilde location for different types of HNB

4.4 Queuing models, blocking and congestion probabilities

This section has the aim to provide either the analytic expressions or a method to calculate the blocking and congestion probabilities that will be used to check whether a given network dimensioning (distribution of HNB's with their corresponding powers) fulfills the minimum required quality of service. If such required minimum quality is not attained, then the network dimensioning should be reinforced by adding more HNB's, increasing their capacity, increasing their power, adjusting the antennas and radiation patterns, etc.

In conventional wireline dimensioning, a given server with N circuits will be able to provide service to a new incoming call whenever any of the circuits of the server is available. In the WCDMA case, the condition under which a call can be served is more stringent and twofold: first, the mobile terminal generating the new incoming call has to be under radio coverage (i.e., there should be enough power in the HNB to serve it); second, at least one of the circuits of the server has to be available and free.

4.4.1 Voice service

In our case, the N circuits of the server refer to the maximum number of users that the HNB can support simultaneously. This characteristic should be included within the technical specifications of the equipment at hand. Besides, in a multiHNB deployment, different HNBs are allocated different frequencies, which implies that there will be no inter-cell interference and, therefore, the analysis can be carried out using the coverage probabilities obtained without interference, i.e., on a single cell basis.

The notation used in this section is given:

- L: number of subscribers
- N: number of total available circuits of the HNB, i.e., total number of users that the HNB could serve simultaneously,
- P_i: probability of having i circuits active, i.e., i calls being served by the HNB simultaneously,
- $P_{i\to i+1}^{cob}$: probability of being able to accommodate a new incoming call when i calls are active, i.e., being served simultaneously,
- λ_v : rate of incoming calls generated by a single subscriber,
- $\lambda = L\cdot \lambda_v$: aggregated rate of incoming calls$1/\mu$: mean duration of an active call.

We will assume that the time between new incoming calls follows also an exponential distribution.

According to Bayes' rule, the probability $P_{i\to i+1}^{cob}$ can be expressed as $P_{i\to i+1}^{cob} = P_{i+1}^{cob} \big/ P_i^{cob}$, where P_i^{cob} (P_{i+1}^{cob}) is the probability that given i (i+1) calls, all of them are under radio coverage and can be served simultaneously (i.e., there is enough power) regardless the availability of circuits at the HNB. These probabilities are evaluated numerically using the principles described in section 4.3.7 in a Monte Carlo simulation test.

In this framework we define the blocking and congestion probabilities as follows:

- *Congestion probability*: probability that all the circuits of the HNB are occupied, i.e., the HNB could not accommodate a new call even if it is generated in a geographical position where there is radio coverage.
- *Blocking probability*: probability that a new incoming call cannot be served, i.e., percentage of generated calls that cannot be served.

In the following we will analyze two situations in terms of the number of subscribers for the derivation of the expressions of the blocking and congestion probabilities. In each case, the probabilities are derived using a queuing analysis based on Markov-chain model. The models are referred to as M/M/m/m, following the conventional naming that can be found in [Kleinrock 75].

4.4.1.1 M/M/m/m queuing system

This evaluation is suitable for scenarios 1 to 4 as described in Table 14.

4.4.1.1.1 Number of subscribers much higher than the number of available circuits

In this scenario, we will assume that the number of inhabitants in the cell is much higher than the number of circuits of the HNB, which means that the rate of generation of new calls is independent of the number of current active calls. Let $\lambda = L\cdot \lambda_v$ denote the aggregated rate of incoming calls for the whole set of subscribers. The continuous-time Markov chain modeling this scenario is the following:

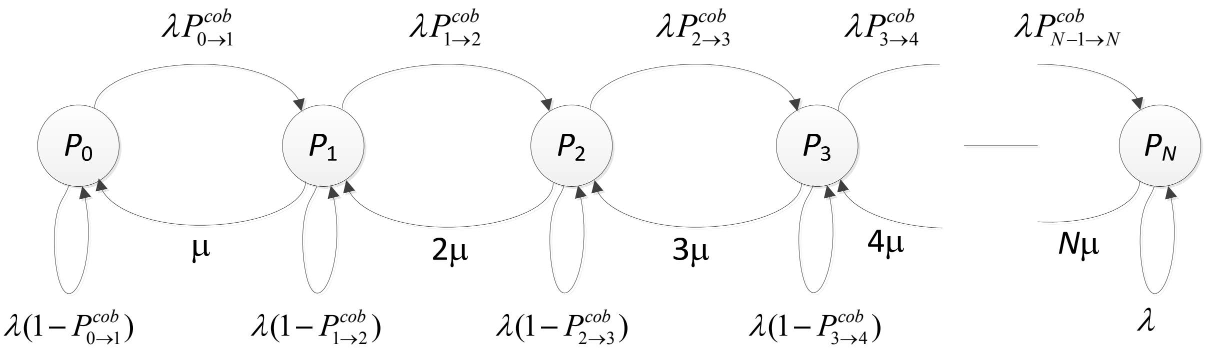


Figure 20. Markov chain characterising voice users served by a HNB of *N* circuits, assuming a large number of subscribers

The i –th state represents the situation in which i calls are being served simultaneously by the HNB, where its probability is denoted by P_i. The total offered traffic (OT) measured in Erlangs is given by

$$OT = \sum_{i=0}^{N} \lambda P_i \frac{1}{\mu} = \lambda \frac{1}{\mu} \tag{40}$$

whereas, the carried traffic (CT), in Erlangs, which only takes into account the calls that can be served (i.e., there is radio coverage and available circuits at the HNB), can be expressed as

$$CT = \sum_{i=0}^{N-1} \lambda P_i P^{cob}_{i\to i+1} \frac{1}{\mu} = \frac{\lambda}{\mu} \sum_{i=0}^{N-1} P_i P^{cob}_{i\to i+1} \tag{41}$$

The probabilities of the different states in the Markov chain can be calculated assuming that we are in a stationary regime so that, for each state, the incoming rate equals the outgoing rate:

- State 0: $P_0 \lambda P^{cob}_{0\to1} = P_1 \mu \quad \Rightarrow \quad P_1 = \frac{\lambda}{\mu} P^{cob}_{0\to1} P_o$
- State i: $P_{i-1} \lambda P^{cob}_{i-1\to i} + P_{i+1}(i+1)\mu = P_i i \mu + P_i \lambda P^{cob}_{i\to i+1} \quad \Rightarrow \quad P_{i+1} = \frac{\lambda}{(i+1)\mu} P^{cob}_{i\to i+1} P_i$
- State N: $P_{N-1} \lambda P^{cob}_{N-1\to N} = P_N N \mu \quad \Rightarrow \quad P_N = \frac{\lambda}{N\mu} P^{cob}_{N-1\to N} P_{N-1}$

According to the previous expressions:

$$P_i = P_0 \left(\frac{\lambda}{\mu}\right)^i \frac{1}{i!} \prod_{k=0}^{i-1} P^{cob}_{k\to k+1} \qquad \sum_{i=0}^{N} P_i = 1 \qquad \Rightarrow \qquad P_0 = \frac{1}{1 + \sum_{i=1}^{N} \left(\frac{\lambda}{\mu}\right)^i \frac{1}{i!} \prod_{k=0}^{i-1} P^{cob}_{k\to k+1}} \tag{42}$$

Finally, the blocking and congestion probabilities are given by

- Congestion probability:

$$P_C(N) = P_N = \frac{\left(\frac{\lambda}{\mu}\right)^N \frac{1}{N!}\prod_{k=0}^{N-1} P^{cob}_{k\rightarrow k+1}}{1+\sum_{i=1}^{N}\left(\frac{\lambda}{\mu}\right)^i \frac{1}{i!}\prod_{k=0}^{i-1} P^{cob}_{k\rightarrow k+1}} \tag{43}$$

- Blocking probability:

$$P_B(N) = \sum_{i=0}^{N-1} P_i(1-P^{cob}_{i\rightarrow i+1}) + P_N = \frac{(1-P^{cob}_{0\rightarrow 1}) + \sum_{i=1}^{N-1}(1-P^{cob}_{i\rightarrow i+1})\left(\frac{\lambda}{\mu}\right)^i \frac{1}{i!}\prod_{k=0}^{i-1} P^{cob}_{k\rightarrow k+1} + \left(\frac{\lambda}{\mu}\right)^N \frac{1}{N!}\prod_{k=0}^{N-1} P^{cob}_{k\rightarrow k+1}}{1+\sum_{i=1}^{N}\left(\frac{\lambda}{\mu}\right)^i \frac{1}{i!}\prod_{k=0}^{i-1} P^{cob}_{k\rightarrow k+1}} \tag{44}$$

4.4.1.1.2 Number of subscribers comparable to the number of available circuits

In this scenario, we will assume that the number of subscribers in the cell *L* is barely higher than the number of circuits of the HNB *N*, while *L*>*N*. The main consequence from this fact is that the rate of generation of new calls depends on the number of current active calls. Let $\lambda_o = \lambda_v$ denote the rate of generation of calls from a single subscriber. The continuous-time Markov chain modeling this scenario is shown in Figure 21.

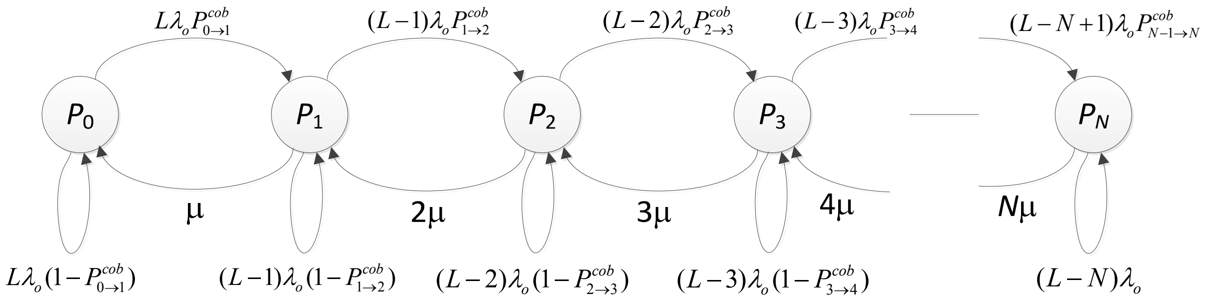


Figure 21. Markov chain characterising voice users served by a HNB of *N* circuits, assuming that the number of subscribers is comparable to *N*

As in the previous scenario, the state *i* represents the situation in which *i* calls are being served simultaneously by the HNB, where its probability is denoted by P_i.

The total offered traffic (OT) can be calculated as

$$OT = \sum_{i=0}^{N} \lambda_o (L-i) P_i \frac{1}{\mu} = \frac{\lambda_o}{\mu}(L-\overline{i}) \tag{45}$$

whereas, the carried traffic (CT), which only takes into account the calls that can be served (i.e., there is radio coverage and free circuits at the HNB), can be expressed as

$$CT = \sum_{i=0}^{N-1} \lambda_o (L-i) P_i P^{cob}_{i\rightarrow i+1} \frac{1}{\mu} = \frac{\lambda_o}{\mu}\sum_{i=0}^{N-1}(L-i) P_i P^{cob}_{i\rightarrow i+1} \tag{46}$$

The probabilities of the different states in the Markov chain can be calculated assuming that we are in a stationary regime so that, for each state, the incoming rate equals the outgoing rate:

- State 0: $P_0 L\lambda_o P^{cob}_{0\rightarrow 1} = P_1\mu \quad \Rightarrow \quad P_1 = \frac{\lambda_o}{\mu} L P^{cob}_{0\rightarrow 1} P_o$

- State i: $P_{i-1}(L-i+1)\lambda_o P^{cob}_{i-1\to i} + P_{i+1}(i+1)\mu = P_i i\mu + P_i(L-i)\lambda_o P^{cob}_{i\to i+1} \quad\Rightarrow\quad P_{i+1} = \frac{\lambda_o}{\mu}\frac{L-i}{i+1}P^{cob}_{i\to i+1}P_i$
- State N: $P_{N-1}(L-N+1)\lambda_o P^{cob}_{N-1\to N} = P_N N\mu \quad\Rightarrow\quad P_N = \frac{\lambda_o}{\mu}\frac{L-N+1}{N}P^{cob}_{N-1\to N}P_{N-1}$

According to the previous expressions:

$$P_i = P_0\left(\frac{\lambda_o}{\mu}\right)^i \frac{L!}{i!(L-i)!}\prod_{k=0}^{i-1}P^{cob}_{k\to k+1} \qquad \sum_{i=0}^{N}P_i = 1 \quad\Rightarrow\quad P_0 = \frac{1}{1+\sum_{i=1}^{N}\left(\frac{\lambda_o}{\mu}\right)^i \frac{L!}{i!(L-i)!}\prod_{k=0}^{i-1}P^{cob}_{k\to k+1}} \tag{47}$$

Finally, the blocking and congestion probabilities are given by

- Congestion probability:

$$P_C(N) = P_N = \frac{\left(\frac{\lambda_o}{\mu}\right)^N \frac{L!}{N!(L-N)!}\prod_{k=0}^{N-1}P^{cob}_{k\to k+1}}{1+\sum_{i=1}^{N}\left(\frac{\lambda_o}{\mu}\right)^i \frac{L!}{i!(L-i)!}\prod_{k=0}^{i-1}P^{cob}_{k\to k+1}} \tag{48}$$

- Blocking probability:

$$P_B(N) = \frac{\sum_{i=0}^{N-1}P_i(L-i)(1-P^{cob}_{i\to i+1}) + P_N(L-N)}{\sum_{i=0}^{N}P_i(L-i)} =$$
$$= \frac{L(1-P^{cob}_{0\to 1}) + \sum_{i=1}^{N-1}(1-P^{cob}_{i\to i+1})\left(\frac{\lambda_o}{\mu}\right)^i \frac{L!}{i!(L-i-1)!}\prod_{k=0}^{i-1}P^{cob}_{k\to k+1} + \left(\frac{\lambda_o}{\mu}\right)^N \frac{L!}{N!(L-N-1)!}\prod_{k=0}^{N-1}P^{cob}_{k\to k+1}}{L+\sum_{i=0}^{N}\left(\frac{\lambda_o}{\mu}\right)^i \frac{L!}{i!(L-i-1)!}\prod_{k=0}^{i-1}P^{cob}_{k\to k+1}} \tag{49}$$

4.4.1.2 Two parallel M/M/m/m queuing system

This is evaluation is suitable for scenario 5 as described in Table 14, where we can assume that two HNB, say *A* and *B*, give coverage to two areas with directional antennas whose radiation patterns do not overlap (an approximation in practice). Each area is generating traffic $P^{HA}\cdot\lambda$ and $P^{HB}\cdot\lambda$ respectively. Note that P^{HA} and P^{HB} are the fraction of subscribers covered by HNB *A* and *B* respectively.

Parallel independent M/M/m/m chains can be used (as those in Figure 20 and Figure 21) since there is no spill of traffic between the two coverage areas when one of the HNB is blocked. Being this the case, we are interested in both areas having the same probability of a call being blocked which implies

$$P_B^{\|}\left(N^A, N^B\right) = \max\left(P_B^A(N^A), P_B^B(N^B)\right) \tag{50}$$

where $P_B^A(N^A)$ is the blocking probability for HNB *A* when a maximum of N^A circuits are allowed (equivalently for HNB *B*) and can be computed from equations (44) or (49), which depend on the number of subscribers compared to the number of available circuits. Note that the blocking probabilities of each HNB depends on the number of circuits and the coverage probabilities.

4.4.1.3 Bidimensional M/M/m/m queuing system

This evaluation is suitable for scenario 6 as described in Table 14, where we assume that two co-located HNB with omni antennas are giving coverage to a certain population. Each UE is connected to one HNB or the other with equal probability. If one HNB cannot provide service, the traffic is spilled to the other HNB. Traffic balancing is not considered among the HNB, i.e., each user directs initially its call request to any HNB without taking into account the current load of the HNBs. In this way, we can define a bidimensional Markov chain as shown in Figure 22, where the first (second) index in each state is related with the number of active calls being attended by HNB *A* (HNB *B*):

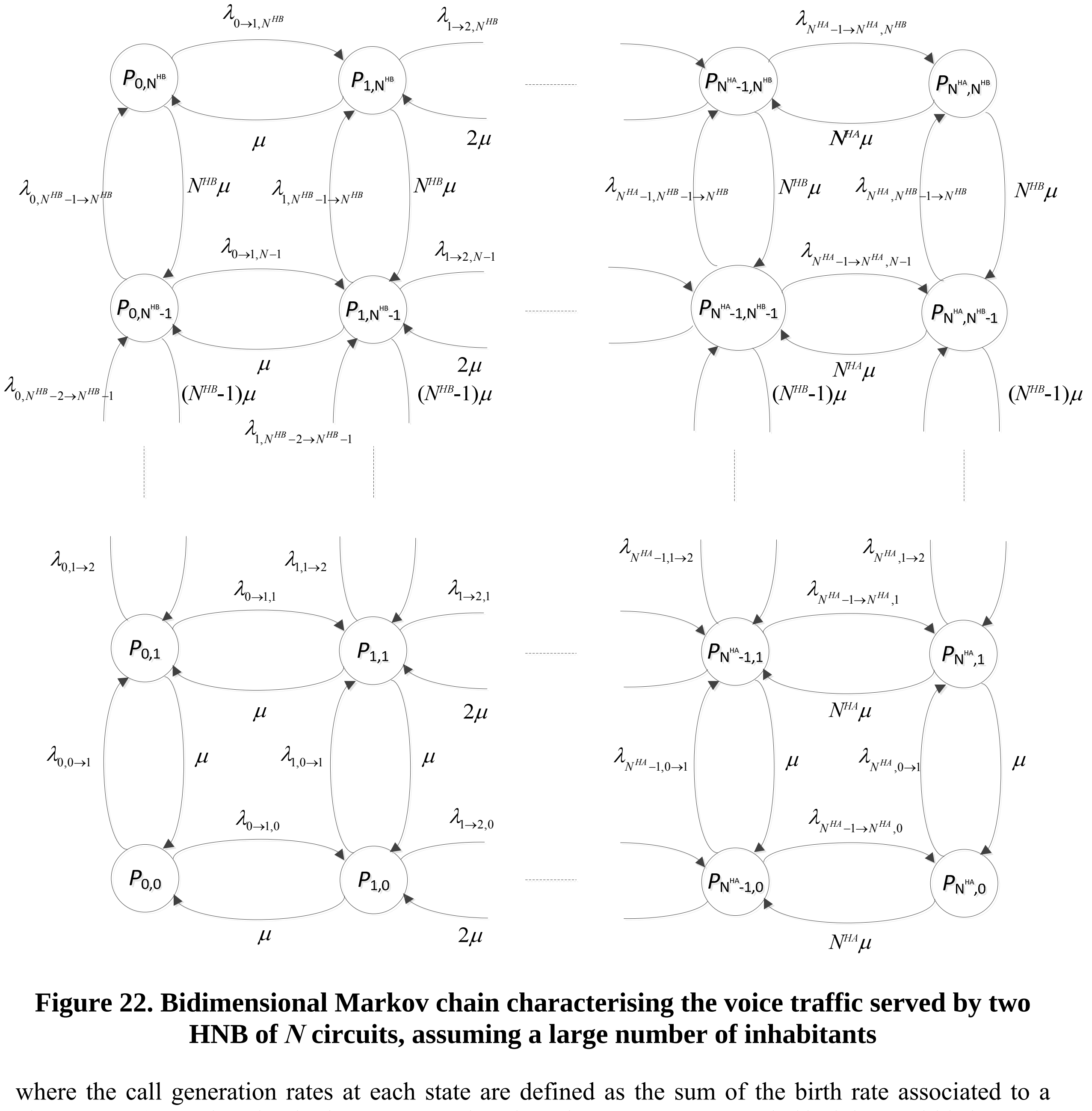


Figure 22. Bidimensional Markov chain characterising the voice traffic served by two HNB of *N* circuits, assuming a large number of inhabitants

where the call generation rates at each state are defined as the sum of the birth rate associated to a given HNB (assuming that both HNBs are placed on the same tower, one half of the total birth rate is associated to each HNB) plus the rate associated to the traffic spilled from the other HNB due to the lack of coverage:

$$\begin{aligned}
\lambda_{i\to i+1,j} &= \frac{\lambda}{2}P^{cob\,A}_{i\to i+1} + \frac{\lambda}{2}\left(1-P^{cob\,B}_{j\to j+1}\right)P^{cob\,A}_{i\to i+1} = \frac{\lambda}{2}\left(2-P^{cob\,B}_{j\to j+1}\right)P^{cob\,A}_{i\to i+1} \qquad j=0,\dots,N^B-1\\
\lambda_{i,j\to j+1} &= \frac{\lambda}{2}P^{cob\,B}_{j\to j+1} + \frac{\lambda}{2}\left(1-P^{cob\,A}_{i\to i+1}\right)P^{cob\,B}_{j\to j+1} = \frac{\lambda}{2}\left(2-P^{cob\,A}_{i\to i+1}\right)P^{cob\,B}_{j\to j+1} \qquad i=0,\dots,N^A-1
\end{aligned} \tag{51}$$

and $\lambda = L\cdot \lambda_v$ is the total birth rate for all subscribers. Note that the traffic is not spilled when one of the HNB has occupied all its circuits, which implies the following formulation for the call generation rates at $j=N^B$ and $i=N^A$

$$\begin{aligned}
\lambda_{i\to i+1,N^{HB}} &= \lambda P^{cob\,A}_{i\to i+1}\\
\lambda_{N^{HA},j\to j+1} &= \lambda P^{cob\,B}_{j\to j+1}
\end{aligned} \tag{52}$$

Note that, since the coverage area is the same, these birth rates are equal as long as the HNBs have the same available power and number of channels. The analysis of this chain is done by setting the income and outcome flows in each state as follows [Kleinrock 75]:

$$\begin{aligned}
&P_{i,j}\left(i\cdot\mu+\lambda_{i\to i+1,j}+j\cdot\mu+\lambda_{i,j\to j+1}\right)=P_{i+1,j}\left(i+1\right)\mu+P_{i-1,j}\lambda_{i-1\to i,j}+P_{i,j+1}\left(j+1\right)\mu+P_{i,j-1}\lambda_{i,j-1\to j}\\
&\qquad\qquad i=1,\dots,N^A-1\\
&\qquad\qquad j=1,\dots,N^B-1\\
&P_{0,0}\left(\lambda_{0\to 1,0}+\lambda_{0,0\to 1}\right)=P_{0,1}\mu+P_{1,0}\mu\\
&P_{i,0}\left(i\cdot\mu+\lambda_{i\to i+1,0}+\lambda_{i,0\to 1}\right)=P_{i,1}\mu+P_{i-1,0}\lambda_{i-1\to i,0}+P_{i+1,0}\left(i+1\right)\mu \qquad i=1,\dots,N^A-1\\
&P_{N^A,0}\left(\lambda_{N^A,0\to 1}+N^A\cdot\mu\right)=P_{N^A,1}\cdot\mu+P_{N^A-1,0}\lambda_{N^A-1\to N^A,0}\\
&P_{0,j}\left(\lambda_{0\to 1,j}+j\cdot\mu+\lambda_{0,j\to j+1}\right)=P_{1,j}\mu+P_{0,j-1}\lambda_{0,j-1\to j}+P_{0,j+1}\left(j+1\right)\mu \qquad j=1,\dots,N^B-1\\
&P_{0,N^B}\left(N\mu+\lambda_{0\to 1,N^B}\right)=P_{0,N^B-1}\lambda_{0,N^B-1\to N^B}+P_{1,N^B}\mu\\
&P_{i,N^B}\left(\lambda_{i\to i+1,N^B}+\left(N^B+1\right)\mu\right)=P_{i-1,N^B}\lambda_{i-1\to i,N^B}+P_{i,N^B-1}\lambda_{i,N^B-1\to N^B}+P_{i+1,N^B}\cdot\left(i+1\right)\cdot\mu\\
&\qquad\qquad i=1,\dots,N^A-1\\
&P_{N^A,N^B}\left(\left(N^A+N^B\right)\mu\right)=P_{N^A-1,N^B}\lambda_{N^A-1\to N^A,N^B}+P_{N^A,N^B-1}\lambda_{N^A,N^B-1\to N^B}\\
&P_{N^A,j}\left(\left(N^A+j\right)\cdot\mu+\lambda_{N^A,j\to j+1}\right)=P_{N^A,j+1}\left(j+1\right)\mu+P_{N^A,j-1}\lambda_{N^A,j-1\to j}+P_{N^A-1,j}\lambda_{N^A-1\to N^A,j}\\
&\qquad\qquad j=1,\dots,N^B-1
\end{aligned} \tag{53}$$

together with an additional equation required to normalize the probabilities:

$$\sum_{i=0}^{N^A}\sum_{j=0}^{N^B}P_{i,j}=1 \tag{54}$$

All these equations are linear and can be collected in the form:

$$\mathbf{\Pi p}=\mathbf{e} \tag{55}$$

where $\mathbf{\Pi}$ is a $((N+1)^2+1)\times(N+1)^2$ sparse full-column rank matrix, **p** contains all state probabilities, and $\mathbf{e}=[0\ 0\ \dots\ 0\ 1]^T$. Note that, although matrix $\mathbf{\Pi}$ is not square, (55) always admits a single solution.

Finally, the blocking and congestion probabilities are given by

- Congestion probability:

$$P_C^{2D}=P_{N^A,N^B} \tag{56}$$

- Blocking probability: will jointly depend on N^A and N^B, that is, the number of circuits allowed in each HNB

$$\begin{aligned} P_B^{2D}\left(N^A,N^B\right) = P_{N^A,N^B} + \sum_{j=0}^{N^B-1} P_{N^A,j}\left(1-P_{j\to j+1}^{cob,B}\right) + \sum_{i=0}^{N^A-1} P_{i,N^B}\left(1-P_{i\to i+1}^{cob,A}\right) + \\ + \sum_{i=0}^{N^A-1}\sum_{j=0}^{N^B-1} P_{i,j}\left(1-P_{i\to i+1}^{cob,A}\right)\left(1-P_{j\to j+1}^{cob,B}\right) \end{aligned} \tag{57}$$

It is important to mention that the state probabilities $P_{i,j}$ which appear in equations (56) and (57) depend implicitly on N^A and N^B, as for each value of the pair (N^A, N^B) a flows balance equation similar to the one shown in (55) needs to be resolved.

Overall, given a certain blocking probability (see section 4.1), we need to evaluate the minimum number of channelization codes N^A and N^B so that the backhaul requirements are minimized. A certain HNB and antenna configuration (from Table 14) is suitable for deployment if N^A and N^B are less than or equal to the number of channelization codes available at each HNB.

4.4.2 Mixed voice and data service

It is assumed that two types of users are present in the system: voice and data users. Data users are constrained to be served at 128 Kbps, according to the specifications of ip.access' HNB (see section 3.3). A total amount of N circuits is available which can be divided between voice and data, depending on the requirements or demands at a given time instant. In the WCDMA case, the condition for a voice or a data call request to be served is twofold: first, the mobile terminal generating the new incoming call has to be under radio coverage (i.e., there should be enough power in the HNB to serve it); second, at least one of the circuits of the server has to be available. Note that the first condition is related not only to pathloss but also to the intra-cell interference generated by ongoing calls.

The notation used in this section is the following:

- L_v: number of subscribers for voice services,
- L_d: number of subscribers for data services,
- N: number of total available circuits of the HNB, i.e., number of total users that the HNB could serve simultaneously,
- $P_{i,j}$: probability of having i voice circuits and j data circuits active, i.e., $i + j$ calls being served by the HNB simultaneously,
- $P_{i\to i+1,j}^{cob}$: probability of being able to accommodate a new incoming voice call request when i voice calls and j data calls are active, i.e., being served simultaneously,
- $P_{i,j\to j+1}^{cob}$: probability of being able to accommodate a new incoming data call request when j data calls and i voice calls are active, i.e., being served simultaneously,
- λ_v : rate of incoming voice calls generated by a single subscriber,
- λ_d : rate of incoming data calls generated by a single subscriber,
- $\lambda_V = L_v \cdot \lambda_v$: aggregated rate of incoming voice calls,
- $\lambda_D = L_d \cdot \lambda_d$: aggregated rate of incoming data packets,
- $1/\mu_v$: mean duration of an active voice call (we will assume that the duration of each active call follows an exponential distribution),
- $1/\mu_d$: mean duration of an active data call (see equation (6)).

We will assume that the arrival times of voice calls and data packets are independent and that the time between consecutive arrivals also follows an exponential distribution characterized by the rate of generation of the incoming calls. We will also assume that the number of subscribers in the cell is much higher than the number of circuits of the HNB, which means that the rate of generation of new calls is independent of the number of current active calls.

Let us adopt N=16 circuits available for traffic delivery, being the spreading factors used 16 (for data traffic), 128 (for voice traffic) and 256 (for common channels). For data traffic, it is clear that a maximum of 15 codes of length 16 can be used so that common channels can be accommodated.

According to Bayes' rule, the probabilities $P^{cob}_{i\to i+1,j}$ can be expressed as $P^{cob}_{i\to i+1,j} = P^{cob}_{i+1,j} \big/ P^{cob}_{i,j}$, where $P^{cob}_{i,j}$ is the probability that given i voice calls and j data calls, all of them are under radio coverage and can be served simultaneously (i.e., there is enough power at the HNB to serve all). Likewise, the probabilities $P^{cob}_{i,j\to j+1}$ can be expressed as $P^{cob}_{i,j\to j+1} = P^{cob}_{i,j+1} \big/ P^{cob}_{i,j}$. These probabilities are evaluated numerically using the principles described in section 4.3.7 in a Monte Carlo simulation test.

In this framework we define the blocking and congestion probabilities separately for voice and data calls.

4.4.2.1 2D M/M/m/m queuing system

This evaluation is suitable for scenarios 1 to 4 as described in Table 14. Having this in mind, the continuous-time Markov chain modeling this scenario is shown in Figure 23. Note that the two dimensions are associated to voice channels occupied (in the horizontal display) and data channels occupied (in the vertical display). Again, state $P_{0,N}$ cannot exist if only N-1 data circuits can be accommodated.

Unfortunately the values of the state probabilities $P_{i,j}$ cannot be obtained in closed form. Rather we need to adopt the theory of stationary continuous Markov chains to assess that the probability of reaching any state can be computed from the probability of the neighbor states and the transition rates. We need to equation input and output flows in each state [Kleinrock 75]. In this way it is possible to write down the following relationships:

$$\begin{aligned}
&P_{i,j}\left(i\cdot\mu_v + \lambda_V P^{cob}_{i\to i+1,j} + j\cdot\mu_d + \lambda_D P^{cob}_{i,j\to j+1}\right) = \\
&\qquad = P_{i+1,j}\left(i+1\right)\mu_v + P_{i-1,j}\lambda_V P^{cob}_{i-1\to i,j} + P_{i,j+1}\left(j+1\right)\mu_d + P_{i,j-1}\lambda_D P^{cob}_{i,j-1\to j} && i=1,\ldots,N-2 \quad j=1,\ldots,N-i-1 \\
&P_{0,j}\left(\lambda_V P^{cob}_{0\to 1,j} + j\cdot\mu_d + \lambda_D P^{cob}_{0,j\to j+1}\right) = P_{1,j}\mu_v + P_{0,j-1}\lambda_D P^{cob}_{0,j-1\to j} + P_{0,j+1}\left(j+1\right)\mu_d && j=1,\ldots,N-2 \\
&P_{i,0}\left(i\cdot\mu_v + \lambda_V P^{cob}_{i\to i+1,0} + \lambda_D P^{cob}_{i,0\to 1}\right) = P_{i,1}\mu_d + P_{i-1,0}\lambda_V P^{cob}_{i-1\to i,0} + P_{i+1,0}\left(i+1\right)\mu_v && i=1,\ldots,N-1 \\
&P_{i,N-i}\left(i\cdot\mu_v + (N-i)\mu_d\right) = P_{i,N-i-1}\lambda_D P^{cob}_{i,N-i-1\to N-i} + P_{i-1,N-i}\lambda_V P^{cob}_{i-1\to i,N-i} && i=1,\ldots,N-1 \\
&P_{0,0}\left(\lambda_V P^{cob}_{0\to 1,0} + \lambda_D P^{cob}_{0,0\to 1}\right) = P_{0,1}\mu_d + P_{1,0}\mu_v \\
&P_{N,0}N\cdot\mu_v = P_{N-1,0}\lambda_V P^{cob}_{N-1\to N,0} \\
&P_{0,N-1}\left(\left(N-1\right)\mu_d + \lambda_V P^{cob}_{0\to 1,N-1}\right) = P_{0,N-2}\lambda_D P^{cob}_{0,N-2\to N-1} + P_{1,N-1}\mu_v
\end{aligned}$$

Also, we need an additional equation to normalize the probabilities:

$$\sum_{j=0}^{N-1} P_{0,j} + \sum_{i=1}^{N}\sum_{j=0}^{N-i} P_{i,j} = 1$$

All these equations are linear and can be collected in the form:

$$\mathbf{\Pi p} = \mathbf{e} \tag{58}$$

where $\mathbf{\Pi}$ is a $((N^2+3N)/2+1)\times(N^2+3N)/2$ sparse full-column rank matrix, **p** contains all state probabilities, and $\mathbf{e} = [0\ 0\ \ldots\ 0\ 1]^T$. Note that, although matrix $\mathbf{\Pi}$ is not square, the previous set of equations always admits a single solution.

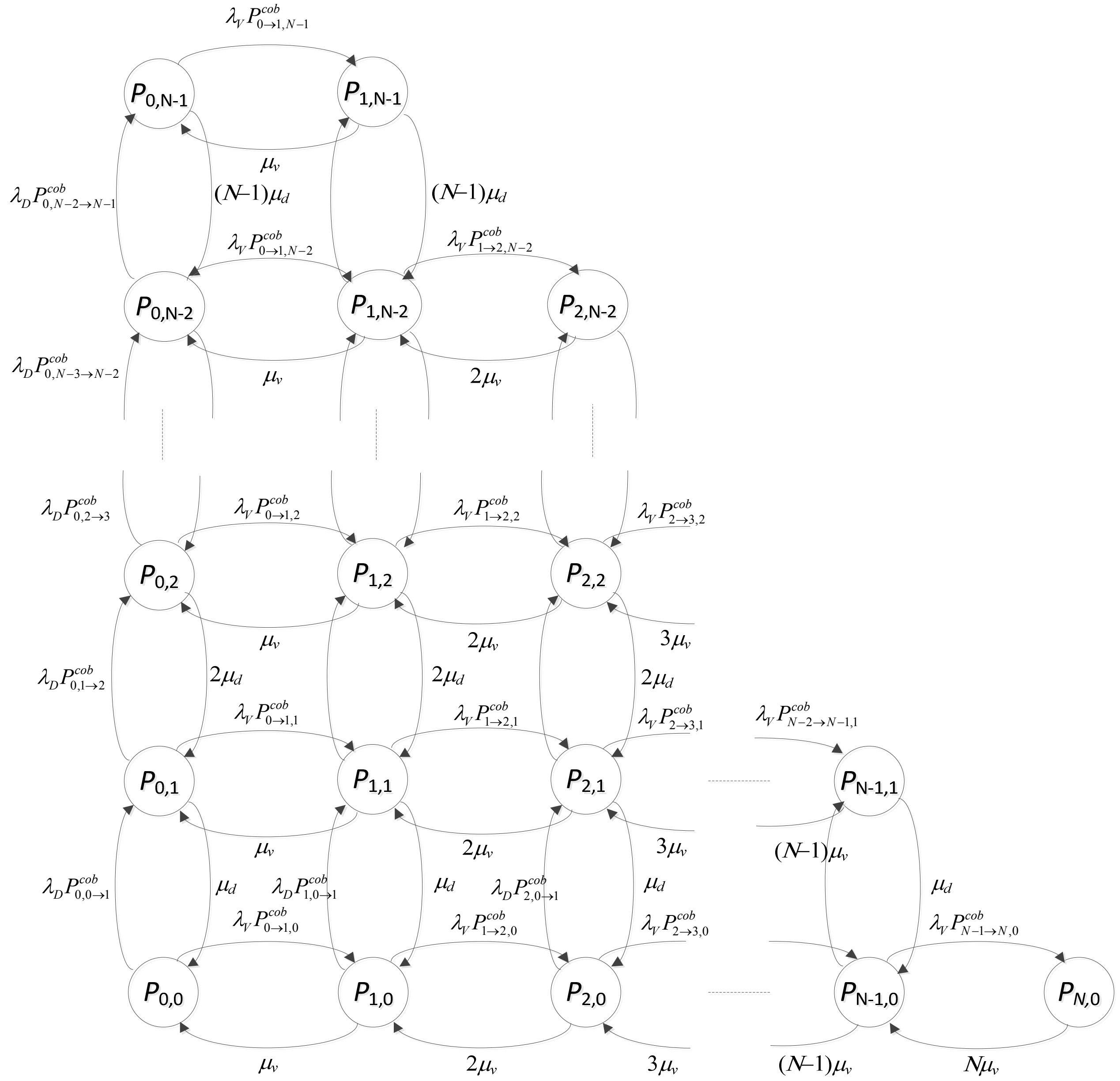


Figure 23. Markov chain characterising mixed voice and data users served by a HNB of N circuits, assuming a large number of subscribers

In the definition of blocking probabilities, we incorporate the parameters N_v and N_d. N_v (N_d) is the maximum number of simultaneous voice (data) calls that can be served. Taking this into account, a new incoming voice (data) call will be served whenever the current number of voice (data) calls being served is lower than N_v (N_d) and the total number of calls being served is lower than N (N-1). The objective of this work is to determine the minimum number of voice (N_v) and data (N_d) circuits that are needed to guarantee a given blocking probability. Depending on their relative values, we may encounter situations as those presented in Figure 24. Note that in the sloppy border $N_d + N_v = N$, being N the total number of codes available at the HNB. The plot on the left (right) represents the case where $N_d + N_v < N$ ($N_d + N_v > N$). The top-right corner (denoted as (N_v*, N_d*)) represents the state generating the largest voice plus data bitrate (note the larger bitrate per channel associated data channels as compared to voice channels).

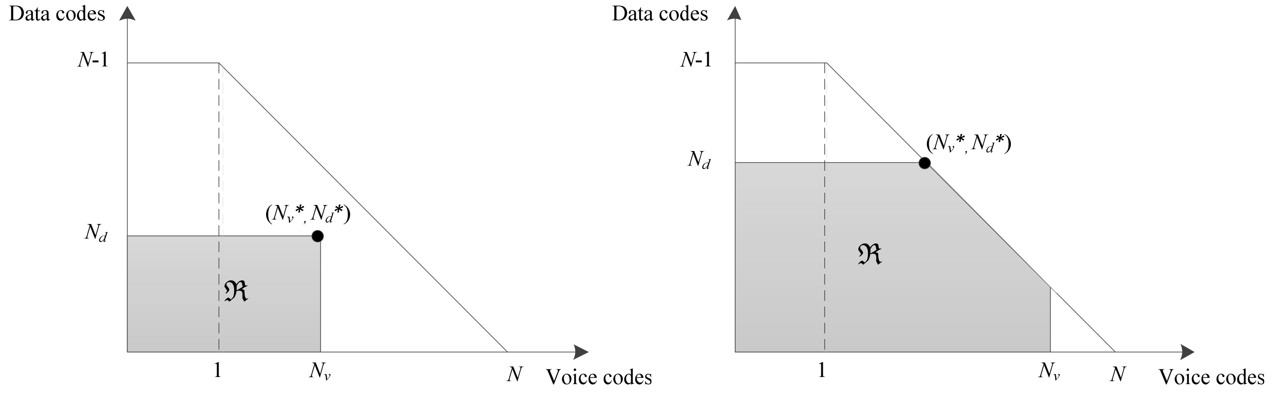


Figure 24. Examples of regions $\Re(N_v, N_d)$ from the bidimensional Markov chain (in Figure 23) used to capture the number of codes needed to set the blocking probability at a given value. The top-right corner (denoted as (N_v^*, N_d^*)) represents the state generating the largest voice plus data bitrate

According to Figure 23 and Figure 24, we define the blocking and congestion probabilities as follows:

- *Congestion probability for voice*: probability that all the circuits of the HNB are occupied, i.e., the HNB could not accommodate a new call even if it is generated in a geographical position where there is radio coverage

  $$P_{C,v}\left(N_v,N_d\right)=\sum_{i=0}^{N-N_v} P_{N_v,i}+\sum_{i=0}^{N_d+N_v-N-1} P_{N-N_d+i,N_d-i} \qquad (59)$$

  It should be noted that the second term in the summation only appears as a consequence of the slope in the region $\Re$ (see Figure 24), that is, only if $N_d + N_v > N$.

- *Congestion probability for data*: probability that all the circuits of the HNB are occupied, i.e., the HNB could not accommodate a new data call even if it is generated in a geographical position where there is radio coverage

  $$P_{C,d}\left(N_v,N_d\right)=\sum_{i=0}^{N-N_d} P_{i,N_d}+\sum_{i=1}^{N_d+N_v-N} P_{N-N_d+i,N_d-i} \qquad (60)$$

  It should be noted that the second term in the summation only appears as a consequence of the slope in the region $\Re$ (see Figure 24), that is, only if $N_d + N_v > N$.

- *Blocking probability for voice*: probability that a new incoming voice call cannot be served. It is given by

  $$P_{B,v}\left(N_v,N_d\right)=P_{C,v}\left(N_v,N_d\right)+\sum_{i=0}^{N-N_d-1} P_{i,N_d}\left(1-P_{i\to i+1,N_d}^{cob}\right)+\sum_{(i,j)\in\Re} P_{i,j}\left(N_v,N_d\right)\left(1-P_{i\to i+1,j}^{cob}\right) \qquad (61)$$

  where region $\Re(n_v,n_d)$ is the convex subset of states in Figure 23 defined by $0 \leq n_v < N_v$, $0 \leq n_d < N_d$ and $n_v + n_d < N$ (note that the northern, northeastern and eastern borders are not included in the region). Figure 24 illustrates the concept.

- *Blocking probability for data*: probability that a new incoming data call cannot be served. It is given by

$$P_{B,d}\left(N_v,N_d\right)=P_{C,d}\left(N_v,N_d\right)+\sum_{i=0}^{N-N_v-1}P_{N_v,i}\left(1-P^{cob}_{N_v,i\to i+1}\right)+\sum_{(i,j)\in\Re}P_{i,j}\left(N_v,N_d\right)\left(1-P^{cob}_{i,j\to j+1}\right) \tag{62}$$

where the region $\Re(n_v,n_d)$ is defined above.

Equations (61) and (62) are used in section 6 to determine the number of required codes for a target blocking probability. A certain HNB and antenna configuration (from those in Table 14) is suitable for deployment if N_v and N_d are less than or equal to the number of channelization codes available.

It is important to mention that the probabilities in equations (59) to (62) depend implicitly on N_v and N_d, as for each value of the pair (N_v, N_d). For each possible pair (N_v, N_d) the flows balance set of equations that has to be solved to find the state probabilities is that obtained from (58) by keeping only the equations corresponding to states (i ,j) such that $0\le i\le N_v$, $0\le j\le N_v$, and $0\le i+j\le N$. The other equations have to be skipped. In addition, those flows whose origins were in the states that are kept in the new set of equations and that were directed towards states that have been skipped, have to be eliminated in the new set of equations.

Once all N^2 possible regions $\Re$ have been tested, those fitting the target blocking probabilities for voice and data (see section 4.1) are kept. For each of those regions, the backhaul required is computed as sum of the contribution of the N_v* voice channels plus the contribution from the N_d* data channels of the top-right corner of the region (the state generating the highest bitrate demands). Among all regions kept, we decide the one with the lowest bandwidth demands.

4.4.2.2 Parallel 2D M/M/m/m queuing system

This evaluation is suitable for scenario 5 as described in Table 14, where we can assume that two HNB', say *HA* and *HB*, give coverage to two areas with directional antennas whose radiation patterns do not overlap (an approximation in practice). Each area is generating traffic $P^A\cdot\lambda_V$, $P^A\cdot\lambda_D$ and $P^B\cdot\lambda_V$, $P^B\cdot\lambda_D$ respectively. Note that P^A and P^B are the fraction of subscribers covered by HNB *A* and *B* respectively.

Parallel independent 2D M/M/m/n chains can be used (as those shown in Figure 23) since there is no traffic spill between the two coverage areas when one of the HNB is blocked. When this is the case, we are interested in both areas having the same probability of a call being blocked which implies

$$\begin{aligned}P^{\|}_{B,v}\left(N^A_v,N^A_d,N^B_v,N^B_d\right)&=\max\left(P^A_{B,v}\left(N^A_v,N^A_d\right),P^B_{B,v}\left(N^B_v,N^B_d\right)\right)\\P^{\|}_{B,d}\left(N^A_v,N^A_d,N^B_v,N^B_d\right)&=\max\left(P^A_{B,d}\left(N^A_v,N^A_d\right),P^B_{B,d}\left(N^B_v,N^B_d\right)\right)\end{aligned} \tag{63}$$

where $P^A_{B,v}\left(N^A_v,N^A_d\right)$ has been defined in section 4.4.2.1 (likewise for all other probabilities). Note that the blocking probabilities of each HNB differ in the number of circuits but also on the coverage probabilities included in equations (44) and (49). Overall, given a target blocking probabilities for voice and data, we need to determine the minimum number of channelization codes N_v and N_d that jointly match the target blocking probabilities, so that the backhaul requirement is minimized. A certain HNB and antenna configuration (from Table 14) is suitable for deployment if N_v and N_d are less than or equal to the number of channelization codes available.

4.4.2.3 4D M/M/m/m queuing system

This evaluation is suitable for scenario 6 as described in Table 14. Having this in mind, the analysis tool is a 4D M/M/m/m Markov chain that can be analyzed using the principle of flows balance as in previous cases. The flows among states are depicted in Figure 25, where the indexes of the states are defined as: i_A and i_B, refer to the number of voice calls being served simultaneously at HNB *A* and *B* respectively, while j_A and j_B denote the number of data connections being served simultaneously at HNB *A* and *B*, respectively.

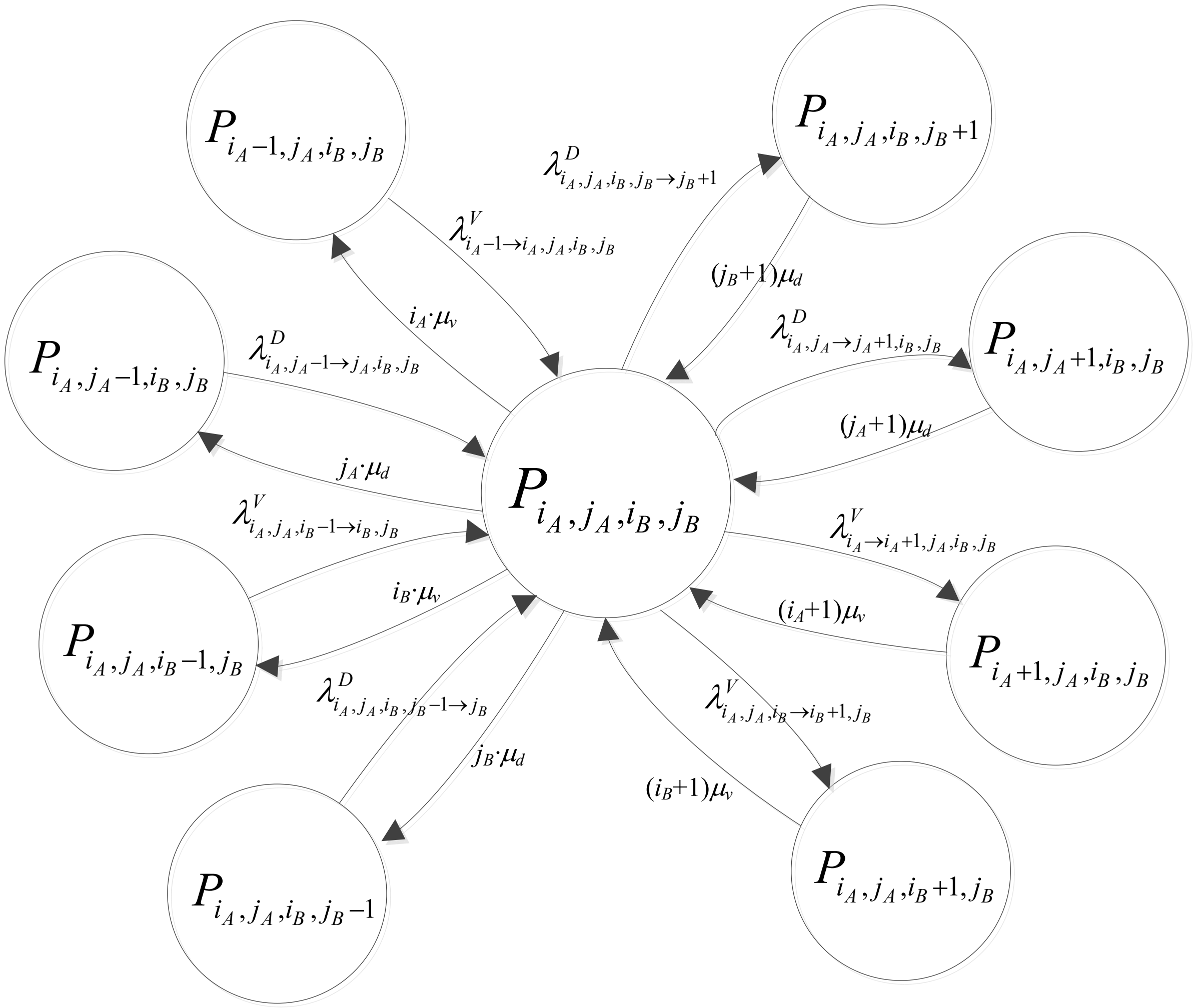


Figure 25. Links among the states of a 4D Markov chain characterising mixed voice and data users served by two colocated HNB with omnidirectional antennas

The expressions for the birth rates can be derived in a straightforward way from those in 4.4.1.3 assuming that voice and data traffic spill between HNBs are possible. It is expressed as:

$$\begin{aligned}
\lambda^{V}_{i_A\to i_A+1,j_A,i_B,j_B} &= \frac{\lambda_V}{2}\left(2-P^{cob\,B}_{i_B\to i_B+1,j_B}\right)P^{cob\,A}_{i_A\to i_A+1,j_A} && \left(i_B<N_v^B \text{ and } i_B+j_B<N\right) \text{ and } \left(i_A<N_v^A \text{ and } i_A+j_A<N\right)\\
\lambda^{V}_{i_A,j_A,i_B\to i_B+1,j_B} &= \frac{\lambda_V}{2}\left(2-P^{cob\,A}_{i_A\to i_A+1,j_A}\right)P^{cob\,B}_{i_B\to i_B+1,j_B} && \left(i_A<N_v^A \text{ and } i_A+j_A<N\right) \text{ and } \left(i_B<N_v^B \text{ and } i_B+j_B<N\right)\\
\lambda^{D}_{i_A,j_A\to j_A+1,i_B,j_B} &= \frac{\lambda_D}{2}\left(2-P^{cob\,B}_{i_B,j_B\to j_B+1}\right)P^{cob\,A}_{i_A,j_A\to j_A+1} && \left(j_B<N_d^B \text{ and } i_B+j_B<N\right) \text{ and } \left(j_A<N_d^A \text{ and } i_A+j_A<N\right)\\
\lambda^{D}_{i_A,j_A,i_B,j_B\to j_B+1} &= \frac{\lambda_D}{2}\left(2-P^{cob\,A}_{i_A,j_A\to j_A+1}\right)P^{cob\,B}_{i_B,j_B\to j_B+1} && \left(j_A<N_d^A \text{ and } i_A+j_A<N\right) \text{ and } \left(j_B<N_d^B \text{ and } i_B+j_B<N\right)
\end{aligned} \tag{64}$$

At the border region the birth rates are defined with the condition of a HNB not being able to accept new calls:

$$\begin{aligned}
\lambda^{V}_{i_A\to i_A+1,j_A,i_B,j_B} &= \lambda_V P^{cob\,A}_{i_A\to i_A+1,j_A} && \left(i_B = N_v^B \ \text{ or } \ i_B + j_B = N\right) \text{ and } \left(i_A < N_v^A \ \text{ and } \ i_A + j_A < N\right)\\
\lambda^{V}_{i_A,j_A,i_B\to i_B+1,j_B} &= \lambda_V P^{cob\,B}_{i_B\to i_B+1,j_B} && \left(i_A = N_v^A \ \text{ or } \ i_A + j_A = N\right) \text{ and } \left(i_B < N_v^B \ \text{ and } \ i_B + j_B < N\right)\\
\lambda^{D}_{i_A,j_A\to j_A+1,i_B,j_B} &= \lambda_D P^{cob\,A}_{i_A,j_A\to j_A+1} && \left(j_B = N_d^B \ \text{ or } \ i_B + j_B = N\right) \text{ and } \left(j_A < N_d^A \ \text{ and } \ i_A + j_A < N\right)\\
\lambda^{D}_{i_A,j_A,i_B,j_B\to j_B+1} &= \lambda_D P^{cob\,B}_{i_B,j_B\to j_B+1} && \left(j_A = N_d^A \ \text{ or } \ i_A + j_A = N\right) \text{ and } \left(j_B < N_d^B \ \text{ and } \ i_B + j_B < N\right)
\end{aligned} \tag{65}$$

As usual, the equilibrium equations for flows at each state can be collected in a linear set of equations:

$$\mathbf{\Pi p} = \mathbf{e} \tag{66}$$

where now $\mathbf{\Pi}$ is a $(((N^2 + 3N)/2)^2 + 1) \times ((N^2 + 3N)/2)^2$ sparse full-column rank matrix, **p** contains all state probabilities, and $\mathbf{e} = [0\ 0\ \ldots\ 0\ 1]^T$.

The definition of the congestion and blocking probabilities is as follows:

- *Congestion probability for voice*: probability that none of the HNBs can accommodate new voice calls even if it is generated in a geographical position with radio coverage. This is the situation in the region
$$\Re_v\left(i_A,i_B,j_A,j_B\right) = \left\{i_A,i_B,j_A,j_B \middle| \left(i_A = N_v^A \ \text{ or } \ i_A + j_A = N\right) \text{ and } \left(i_B = N_v^B \ \text{ or } \ i_B + j_B = N\right)\right\} \tag{67}$$
$$P_{C,v}\left(N_v^A, N_d^A, N_v^B, N_d^B\right) = \sum_{\{i_A,i_B,j_A,j_B\}\in\Re_v} P_{i_A,j_A,i_B,j_B}$$
- *Congestion probability for data*: probability that none of the HNBs can accommodate new data packet connections even if it is generated in a geographical position with radio coverage coverage. This is the situation when
$$\Re_d\left(i_A,i_B,j_A,j_B\right) = \left\{i_A,i_B,j_A,j_B \middle| \left(j_A = N_d^A \ \text{ or } \ i_A + j_A = N\right) \text{ and } \left(j_B = N_d^B \ \text{ or } \ i_B + j_B = N\right)\right\} \tag{68}$$
$$P_{C,d}\left(N_v^A, N_d^A, N_v^B, N_d^B\right) = \sum_{\{i_A,i_B,j_A,j_B\}\in\Re_d} P_{i_A,j_A,i_B,j_B}$$
- *Blocking probability for voice*: probability that a new incoming voice call cannot be served. It is given by the probability of congestion plus the probability of an unsuccessful voice call due to the lack of coverage for states not belonging to region $\Re_v\left(i_A,i_B,j_A,j_B\right)$ (defined in (67)):

$$\begin{aligned}
P_{B,v}\left(N_v^A, N_d^A, N_v^B, N_d^B\right) &= P_{C,v}\left(N_v^A, N_d^A, N_v^B, N_d^B\right) + \sum_{\{i_A,i_B,j_A,j_B\}\notin\Re_v} P_{i_A,j_A,i_B,j_B}\left(1 - P^{cob\ A,B}\left(i_A,i_B,j_A,j_B\right)\right) =\\
&= P_{C,v}\left(N_v^A, N_d^A, N_v^B, N_d^B\right) + \sum_{\{i_A,i_B,j_A,j_B\}\in\Re_v^{AB}} P_{i_A,j_A,i_B,j_B}\left(1 - P^{cob\ A}_{i_A\to i_A+1,i_B,j_A,j_B}\right)\left(1 - P^{cob\ \mathrm{B}}_{i_A,i_B\to i_B+1,j_A,j_B}\right) +\\
&+ \sum_{\{i_A,i_B,j_A,j_B\}\in\Re_v^{A}} P_{i_A,j_A,i_B,j_B}\left(1 - P^{cob\ A}_{i_A\to i_A+1,i_B,j_A,j_B}\right) + \sum_{\{i_A,i_B,j_A,j_B\}\in\Re_v^{B}} P_{i_A,j_A,i_B,j_B}\left(1 - P^{cob\ \mathrm{B}}_{i_A,i_B\to i_B+1,j_A,j_B}\right)
\end{aligned}$$

where

$$\Re_v^{AB}\left(i_A,i_B,j_A,j_B\right) = \left\{i_A,i_B,j_A,j_B \middle| \left(i_A < N_v^A \ \text{ and } \ i_A + j_A < N\right) \text{ and } \left(i_B < N_v^B \ \text{ and } \ i_B + j_B < N\right)\right\}$$

denotes the inner states for the voice services, and correspond to those states with two outgoing voice flows (see Figure 25),

$$\Re_v^{A}\left(i_A,i_B,j_A,j_B\right) = \left\{i_A,i_B,j_A,j_B \middle| \left(i_A < N_v^A \ \text{ and } \ i_A + j_A < N\right) \text{ and } \left(i_B = N_v^B \ \text{ or } \ i_B + j_B = N\right)\right\}$$

denotes the states with increasing i_A and one departing voice flow (see Figure 25), and

$$\Re_v^{B}\left(i_A,i_B,j_A,j_B\right) = \left\{i_A,i_B,j_A,j_B \middle| \left(i_B < N_v^B\right) \text{ and } \left(i_A = N_v^A \ \text{ or } \ i_A + j_A = N\right)\right\}$$

$$\Re_v^B\left(i_A,i_B,j_A,j_B\right)=\left\{i_A,i_B,j_A,j_B\middle|\left(i_B<N_v^B \text{ and } i_B+j_B<N\right) \text{ and } \left(i_A=N_v^A \text{ or } i_A+j_A=N\right)\right\}$$

denotes the states with increasing i_B and one departing voice flow (see Figure 25).

- *Blocking probability for data*: probability that a new incoming data packet connection cannot be served. It is given by the probability of congestion plus the probability of an unsuccessful data packet connection due to the lack of coverage for states not belonging to region $\Re_d\left(i_A,i_B,j_A,j_B\right)$ (defined in (68)):

$$\begin{aligned}P_{B,d}\left(N_v^A,N_d^A,N_v^B,N_d^B\right)&=P_{C,d}\left(N_v^A,N_d^A,N_v^B,N_d^B\right)+\sum_{\{i_A,i_B,j_A,j_B\}\notin\Re_d}P_{i_A,j_A,i_B,j_B}\left(1-P^{cob\ A,B}\left(i_A,i_B,j_A,j_B\right)\right)=\\&=P_{C,d}\left(N_v^A,N_d^A,N_v^B,N_d^B\right)+\sum_{\{i_A,i_B,j_A,j_B\}\in\Re_d^{AB}}P_{i_A,j_A,i_B,j_B}\left(1-P^{cob\ A}_{i_A,i_B,j_A\to j_A+1,j_B}\right)\left(1-P^{cob\ \mathrm{B}}_{i_A,i_B,j_A,j_B\to j_B+1}\right)+\\&+\sum_{\{i_A,i_B,j_A,j_B\}\in\Re_d^{A}}P_{i_A,j_A,i_B,j_B}\left(1-P^{cob\ A}_{i_A,i_B,j_A\to j_A+1,j_B}\right)+\sum_{\{i_A,i_B,j_A,j_B\}\in\Re_d^{B}}P_{i_A,j_A,i_B,j_B}\left(1-P^{cob\ \mathrm{B}}_{i_A,i_B,j_A,j_B\to j_B+1}\right)\end{aligned}$$

where

$$\Re_d^{AB}\left(i_A,i_B,j_A,j_B\right)=\left\{i_A,i_B,j_A,j_B\middle|\left(j_A<N_d^A \text{ and } i_A+j_A<N\right) \text{ and } \left(j_B<N_d^B \text{ and } i_B+j_B<N\right)\right\}$$

denotes the inner states for the data services, and correspond to those states with two departing data flows (see Figure 25),

$$\Re_d^A\left(i_A,i_B,j_A,j_B\right)=\left\{i_A,i_B,j_A,j_B\middle|\left(j_A<N_d^A \text{ and } i_A+j_A<N\right) \text{ and } \left(j_B=N_d^B \text{ or } i_B+j_B=N\right)\right\}$$

denotes the states with increasing j_A and one departing data flow (see Figure 25), and

$$\Re_d^B\left(i_A,i_B,j_A,j_B\right)=\left\{i_A,i_B,j_A,j_B\middle|\left(j_B<N_d^B \text{ and } i_B+j_B<N\right) \text{ and } \left(j_A=N_d^A \text{ or } i_A+j_A=N\right)\right\}$$

denotes the states with increasing j_B and one departing data flow (see Figure 25).

5 NETWORK PLANNING RESULTS

The objective of this section is to present the network performance for each scenario depicted in Table 14 and for each location considered in TUCAN3G where the network will be deployed. Network performance is evaluated in terms of CPICH coverage and blocking probabilities as mentioned in section 4.1.

First, traffic density assumption over the geographical area in each location is described. As mentioned previously, heterogeneous density of users around the HNB is assumed in order to characterize those places where is more likely that a user tries to establish one connection to the cell. This distribution depends practically on the density of housings in the zone. Once the traffic distribution over the area is defined, we can evaluate the necessary power for CPICH and the rest of common channels to cover the whole area of interest, as detailed in 4.3.4. The rest of HNB power that has not been allocated to common channels may be available for dedicated channels, i.e., to serve different users. In this step, some scenarios may not be valid due to, for example, all the available power is needed to transport common channels and no power is left for dedicated channels, which typically happens for low power HNBs.

Then, blocking and congestion probabilities are computed according to the expressions described in 4.4 assuming only voice users (12.2 kbps AMR). The maximum required blocking probability for considering the valid performance of a particular scenario is 2%, as mentioned in 4.1. These probabilities are evaluated for each case described in 4.4:

- Case A: number of inhabitants is much higher than the number of available circuits (codes).
- Case B: number of inhabitants not much higher than the number of available circuits.

Then, blocking and congestion probabilities are computed when mixed voice and FTP traffic is assumed, following the guidelines of section 4.4.2. To avoid showing excessive results, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2.

5.1 Napo river region

Locations in Napo river region are: Santa Clotilde, Negro Urco and Tuta Pisco. The following sections show the results for each location.

5.1.1 Santa Clotilde

In Santa Clotilde, scenarios #1, #2, #3, #4, #5 and #6 depicted in Table 14 are tested. Scenario #4 is not possible to test in this location since the traffic distribution around the HNB implies omnidirectional coverage. Table 4 and Figure 10 show the location and tower coordinates and the intensity of traffic generation assumed over the geographical area, respectively. In Figure 26, two cells of scenario #5 are identified by means of the minimum path loss criteria described in 4.3.4. Notice that the resulting coverage areas depend on the orientations of each antenna and these orientations are selected in such a way that each cell covers the approximately the same density of traffic assumed over the area. Notice that Figure 26 does not depict the coverage area for each cell, but in which cell one user will try to establish a connection depending on its position by following the minimum path loss criteria described in 4.3.4. Non-coloured area represents the zone outside the range of HNBs.

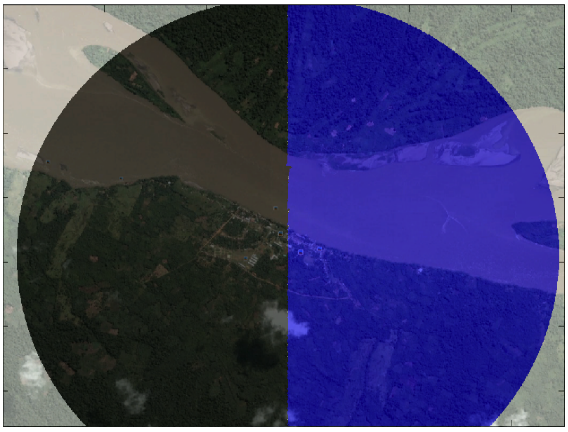


Figure 26. Identification of each cell (not necessarily showing coverage areas) in scenario #5 – blue: cell 1; black: cell 2 – Santa Clotilde

5.1.1.1 Antenna configuration

Table 17 summarizes the best antenna configuration (height and downtilt) depending on the selected scenario of Table 14. The best configuration is selected as the one that minimizes the 95th percentile of path loss of the area to cover, as mentioned in section 4.3.3. The different 95th percentiles of path loss obtained depending on the particular scenario are displayed in annex 9.2.

	Height	Downtilt
Scenario #1	70 m	-
Scenario #2	70 m	-
Scenario #3	70 m	10º
Scenario #4	-	-
Scenario #5	Cell 1: 70 m Cell 2: 70 m	Cell 1: 10º Cell 2: 10º
Scenario #6	Cell 1: 70 m Cell 2: 70 m	Cell 1: 10º Cell 2: 10º

Table 17. Optimum antenna configurations (Santa Clotilde)

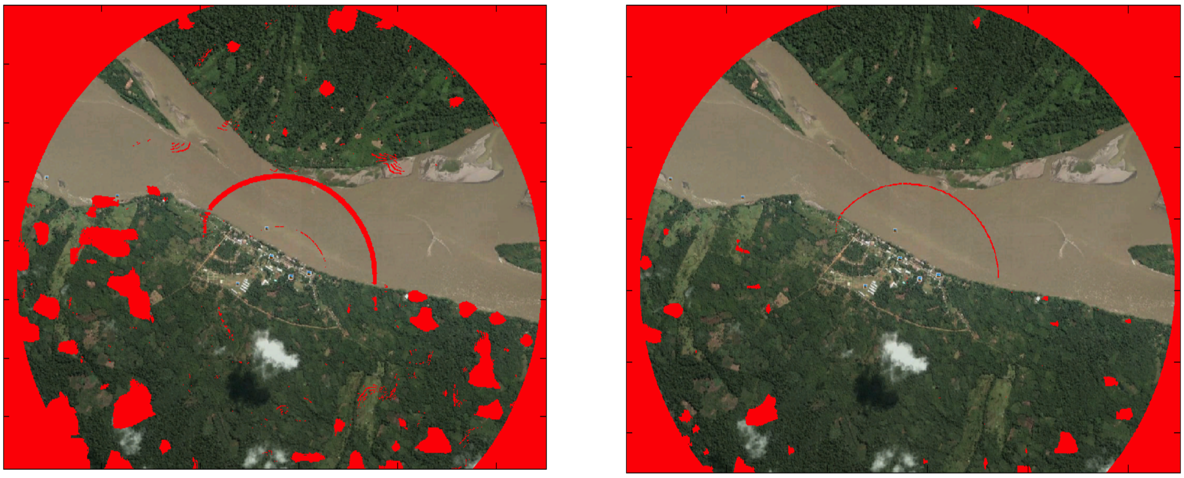
5.1.1.2 CPICH coverage

Results obtained for CPICH coverage evaluation described in section 4.3.4 are detailed in Table 18. This table shows the total transmitted powers for common channels needed to cover the area defined in section 4.1 in the worst case and the available power for dedicated channels. It can be seen that the HNB E-Class 24 does not have enough power in scenarios #1 and #2 and therefore, the available power for dedicated channels is zero. However, antenna gains in scenarios #3,#5 and #6 are higher and thus, HNB E-Class 24 can cover the whole area and provide power to serve users. Notice in Table 11 and Table 12 that HNB E-Class 24* has higher available power to serve users after CPICH planning. Finally, it can be seen that scenarios with higher antenna gains (#3 and #5) provide better performance (lower power for common channels and higher power for dedicated channels). For the particular case of scenario #6, power for common channels is equal at all HNBs since both must cover the same area.

Thus, the available power for dedicated channels after common channels planning determines the capacity of the network to serve users in the downlink and therefore, the results obtained are clearly related to the capacity results showed in section 5.1.1.3. Finally, in order to illustrate how the type of HNB and the scenario impacts on the covered area, different coverage maps are plotted in Figure 27 for different situations. Notice that the covered area would be the same in all scenarios as long as the resulting power for common channels were more than 13% of the total available power at HNB.

HNB	Scenario	Percentage of area covered (%)	Maximum path loss including shadow margin (dB)	TX power for common channels (dBm)	Available power for dedicated channels (dBm)	P_i^{cCH} / P_{max}^{bs} (%)
S-Class 16	#1	95	131.4263	16.1691	17.6796	41.3914
	#2	95	131.4263	14.3820	18.6077	27.4285
	#3	95	133.5263	11.9863	19.2532	15.7992
	#5	98.7492	138.3990 (sector 1) 138.3990 (sector 2)	11.1394 (sector 1) 11.1394 (sector 2)	20.5308 (sector 1) 20.5308 (sector 2)	13.0000 (sector 1) 13.0000 (sector 2)
	#6	95 (cell 1) 95 (cell 2)	133.5263 (cell 1) 133.5263 (cell 2)	11.9863 (cell 1) 11.9863 (cell 2)	19.2532 (cell 1) 19.2532 (cell 2)	15.7992 (cell 1) 15.7992 (cell 2)
E-Class 24	#1	95	131.4263	15.8597	0	193.1832
	#2	95	131.4263	13.9062	0	123.2026
	#3	95	133.5263	11.1237	8.4508	64.9180
	#5	96.3927	131.3990 (sector 1) 134.7763 (sector 2)	4.1394 (sector 1) 6.8220 (sector 2)	12.3952 (sector 1) 11.8018 (sector 2)	13.0000 (sector 1) 24.1100 (sector 2)
	#6	95 (cell 1) 95 (cell 2)	133.5263 (cell 1) 133.5263 (cell 2)	11.1237 (cell 1) 11.1237 (cell 2)	8.4508 (cell 1) 8.4508 (cell 2)	64.9180 (cell 1) 64.9180 (cell 2)
E-Class 24*	#1	95	131.4263	16.6994	23.1053	18.6184
	#2	95	131.4263	15.1593	23.3922	13.0597
	#3	97.2424	136.3990	15.1394	23.3952	13.0000
	#5	99.7636	142.3990 (sector 1) 142.3990 (sector 2)	15.1394 (sector 1) 15.1394 (sector 2)	23.3952 (sector 1) 23.3952 (sector 2)	13.0000 (sector 1) 13.0000 (sector 2)
	#6	97.2 (cell 1) 97.2 (cell 2)	136.3990 (cell 1) 136.3990 (cell 2)	15.1394 (cell 1) 15.1394 (cell 2)	23.3952 (cell 1) 23.3952 (cell 2)	13.0000 (cell 1) 13.0000 (cell 2)

Table 18. CPICH coverage results (Santa Clotilde)



(a) Scenario #1 and HNB S-class 16 **(b) Scenario #5 and HNB E-class 24***

Figure 27. Coverage areas for two scenarios and HNB type (Santa Clotilde)

5.1.1.3 Blocking and congestion probabilities

In section 5.1.1.3.1, blocking and congestion probabilities are evaluated when only voice traffic is assumed, while section 5.1.1.3.2 is devoted to analyse mixed traffic.

5.1.1.3.1 Voice Traffic

Congestion and blocking probabilities for the downlink obtained for each configuration in Santa Clotilde are presented in Table 19: situations where the target blocking probability (2%) is fulfilled are depicted in green, while situations where it is not fulfilled are depicted in red. It can be seen that both cases for traffic model (case A and case B) gives practically the same results in isolated-cell scenarios since the number of inhabitants is high in Santa Clotilde. In multi-cell scenarios, only case A traffic model is assumed to compute blocking and congestion probabilities, as it is the most pessimistic. Also, notice that HNB E-class 24 provides a blocking probability of 1 in scenarios #1 and #2 due to the lack of available power for dedicated channels as proved in 5.1.1.2.

Empty cells for certain scenarios in Table 19, Table 20, Table 23, Table 24, Table 27, Table 28, Table 31, Table 32, Table 35 and Table 36 indicate that case B has not been evaluated.

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	0,0392	0,0379	0,3231	0,3205
	#2	0,1191	0,1162	0,2514	0,2479
	#3	0,1778	0,1740	0,2226	0,2186
	#5	0,0151		0,0226	
	#6	0,0003		0,0013	
E-Class 24	#1	0	0	1	1
	#2	0	0	1	1
	#3	0	0	0,4838	0,4822
	#5	1,27E-06		0,0566	
	#6	2,52E-16		0,1415	
E-Class 24*	#1	0,0037	0,0034	0,1138	0,1114
	#2	0,0122	0,0111	0,0638	0,0617
	#3	0,0173	0,0159	0,0482	0,0462
	#5	3,34E-05		0,0019	
	#6	3,49E-10		2,64E-05	

Table 19. Blocking and congestion probabilities for the downlink (Santa Clotilde)

As seen in previous sections, the blocking and congestion probabilities depend on the coverage probabilities. Notice that in all single-cell scenarios, if HNB E-Class 24 is used, congestion probabilities are zero since it is not possible to serve the maximum number of simultaneous users (coverage probabilities are low due to HNB E-Class 24 does not have enough power). If HNB E-Class 24* or HNB S-Class 16 are used, the blocking probabilities for single-cell scenarios are higher than 2%. Congestion probabilities for these cases are near to 2% which means that capacity is limited practically by the maximum number of simultaneous users that the HNB can serve. Scenario #5 does not provide blocking probabilities less than 2% even though multi-cell deployment doubles the number of available codes and the available power in DL comparing with the isolated-cell scenarios. However, scenario #6 provides congestion probabilities less than 2% if HNB S-Class 16 or HNB E-Class 24* are used. This happens because in scenario #5, although the antenna gains are higher at each cell, a new user can only be served by one HNB (the coverage areas are not overlapped); while in scenario #6, if one HNB cannot provide service, the traffic is spilled to the other. In localities where the performance is limited by hard capacity, and not by available power at HNBs, scenario #6 always provides lower blocking probabilities.

Finally, Table 20 shows the blocking and congestion probabilities for the UL. Results obtained for HNB E-Class 24 and HNB E-Class 24* are the same since the limitation in the UL is associated to the available power at the UE and to the maximum number of codes at HNBs. It can be seen that UL for all scenarios has a better performance. Notice that the blocking and congestion probabilities are practically the same in all scenarios when any HNB is used. This means that coverage probabilities are practically always one, independently of the number of simultaneous users and therefore, the capacity of the UL is basically limited by the maximum number of simultaneous users supported by HNBs.

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	0,2070	0,2030	0,2089	0,2046
	#2	0,2073	0,2033	0,2086	0,2043
	#3	0,2080	0,2040	0,2083	0,2040
	#5	0,0167		0,0168	
	#6	0,0004		0,0004	
E-Class 24 and E-class 24*	#1	0,0240	0,0221	0,0263	0,02427
	#2	0,0241	0,0222	0,0257	0,0237
	#3	0,0242	0,0222	0,0249	0,0229
	#5	3,8E-05		8,05E-05	
	#6	4,38E-10		6,72E-08	

Table 20. Blocking and congestion probabilities for the uplink (Santa Clotilde)

5.1.1.3.2 Mixed voice and data traffic

Mixed voice and data traffic results have not been included. Rather, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2. Notice that the power allocation for common channels is not depend on the type of UE services and therefore, the available power in the downlink will be the same both for the case of only voice users and the case of mixed voice and data users.

5.1.2 Negro Urco

In Negro Urco, all scenarios depicted in Table 14 are tested to evaluate the network performance. Scenario #4 is possible to test in this location since the traffic distribution around the HNB is concentrated within a sector of 180º. Table 4 and Figure 11 shows the location and tower coordinates and the intensity of traffic generation assumed over the geographical area, respectively. In Figure 28, two cells of scenario #5 are identified by means of the minimum path loss criteria described in 4.3.4. Notice that the resulting cells depend on the orientations of each antenna and these orientations are selected in such a way that each cell covers the approximately the same density of traffic assumed over the area.

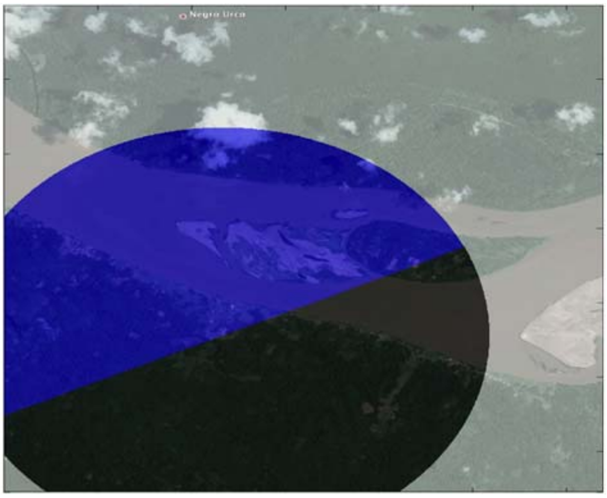


Figure 28. Identification of each cell (not necessarily showing coverage areas) in scenario #5 – blue: cell 1; black: cell 2 – Negro Urco

5.1.2.1 Antenna configuration

Table 21 summarizes the best antenna configuration (height and downtilt) depending on the selected scenario of Table 14. The different 95th percentiles of path loss obtained depending on the particular scenario can be seen in annex 9.2.2.

	Height	Downtilt
Scenario #1	70 m	-
Scenario #2	70 m	-
Scenario #3	70 m	10º
Scenario #4	70 m	10º
Scenario #5	Sector 1: 70 m Sector 2: 70 m	Sector 1: 10º Sector 2: 10º
Scenario #6	Cell 1: 70 m Cell 2: 70 m	Cell 1: 10º Cell 2: 10º

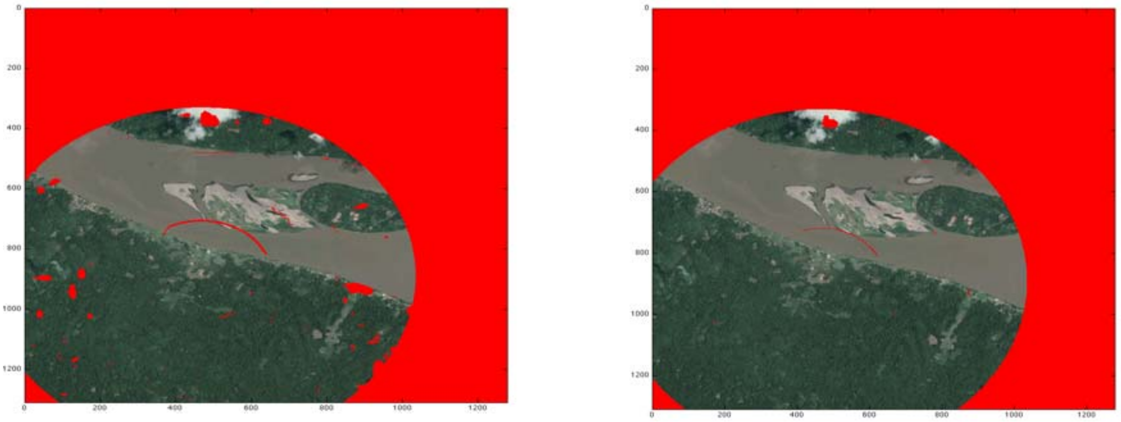
Table 21. Optimum antenna configurations (Negro Urco)

5.1.2.2 CPICH coverage

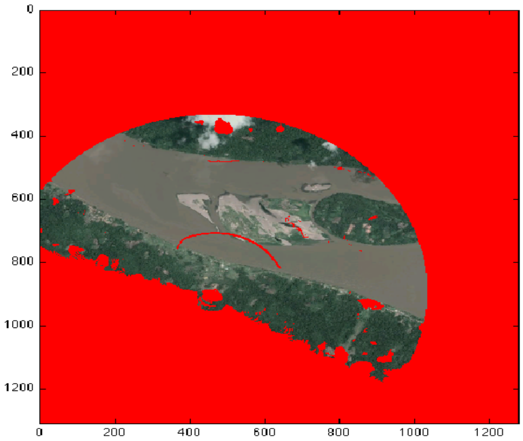
Table 22 summarize the CPICH coverage results for different scenarios in Negro Urco. It can be seen that, when E-Class 24 is used, only scenarios #4 and #5 are valid since these provide enough power for dedicated channels. On the other hand, all configurations when HNB S-Class 16 and HNB E-Class 24* provide enough power for users. Finally, in order to illustrate how the type of HNB and the scenario impacts on the covered area, different coverage maps are plotted in Figure 29 for different percentages of covered area, which depends on the specific HNB type and the selected scenario.

HNB	Scenario	Percentage of area covered (%)	Maximum path loss including shadow margin (dB)	TX power for common channels (dBm)	Available power for dedicated channels (dBm)	P_i^{cCH} / P_{max}^{bs} (%)
S-Class 16	#1	95	134.6554	19.1979	12.2696	83.1357
	#2	95	134.6554	17.3052	16.6495	53.7673
	#3	95	136.6562	14.5828	18.5293	28.7261
	#4	96.9973	138.3990	11.1394	19.3952	13
	#5	97.7511	138.3990 (sector 1) 138.5263 (sector 2)	11.1394 (sector 1) 11.2323 (sector 2)	19.3952 (sector 1) 19.3952 (sector 2)	13.0000 (sector 1) 13.2810 (sector 2)
	#6	95 (cell 1) 95 (cell 2)	136.6562 (cell 1) 136.6562 (cell 2)	14.5828 (cell 1) 14.5828 (cell 2)	18.5293 (cell 1) 18.5293 (cell 2)	28.7261 (cell 1) 28.7261 (cell 2)
E-Class 24	#1	95	134.6554	19.0466	0	402.4003
	#2	95	134.6554	17.0690	0	255.2096
	#3	95	136.6562	14.1296	0	129.7063
	#4	95	136.6562	8.4708	11.1128	35.2434
	#5	97.6409	131.3990 (sector 1) 138.5263 (sector 2)	4.1394 (sector 1) 10.1848 (sector 2)	12.3952 (sector 1) 9.7854 (sector 2)	13.0000 (sector 1) 52.2975 (sector 2)
	#6	95 (cell 1) 95 (cell 2)	136.6562 (cell 1) 136.6562 (cell 2)	14.1296 (cell 1) 14.1296 (cell 2)	0 (cell 1) 0 (cell 2)	129.7063 (cell 1) 129.7063 (cell 2)
E-Class 24*	#1	95	134.6554	19.4700	22.1133	35.2371
	#2	95	134.6554	17.7191	22.8334	23.5454
	#3	95	136.6562	15.3278	23.3663	13.5763
	#4	99.6394	142.3990	15.1394	23.3952	13
	#5	99.8673	142.3990 (sector 1) 142.3990 (sector 2)	15.1394 (sector 1) 15.1394 (sector 2)	23.3952 (sector 1) 23.3952 (sector 2)	13.0000 (sector 1) 13.0000 (sector 2)
	#6	95 (cell 1) 95 (cell 2)	136.6562 (cell 1) 136.6562 (cell 2)	15.3278 (cell 1) 15.3278 (cell 2)	23.3663 (cell 1) 23.3663 (cell 2)	13.5763 (cell 1) 13.5763 (cell 2)

Table 22. CPICH coverage results (Negro Urco)



(a) **Scenario #1 and HNB S-class 16** (b) **Scenario #5 and HNB E-class 24***



(c) **Scenario #4 and HNB S-class 16**

Figure 29. Coverage areas for three scenarios and HNB types (Negro Urco)

5.1.2.3 Blocking and congestion probabilities

5.1.2.3.1 Voice Traffic

Congestion and blocking probabilities obtained for each configuration in Negro Urco are presented in Table 23 and Table 24. It can be seen that HNB E-class 24 provides a blocking probability of 1 in scenarios #1, #2,#3 and #6 because there is no power available for dedicated channels after CPICH planning.

Notice that in all scenarios, the congestion probabilities are very low. This happens since the number of inhabitants in Negro Urco is low and therefore, the aggregated traffic to be served by the network is small. However, blocking probabilities are high in many cases which means that network performance is practically limited by the available power at HNB. Scenarios that fulfil the requirements for the DL are scenarios #4, #5 and #6 if HNB S-Class 16 is used, and scenarios #3, #4 and #6 when HNB E-Class 24* is used (scenarios with higher antenna gains and HNBs with higher available power). For the UL all scenarios, except the scenario #1 which has a lower antenna gain at HNB, provides a blocking probability less than 2% and notice that blocking and congestion probabilities are practically the same in valid scenarios since the network performance is limited by the hard capacity in the UL. Blocking and congestion probabilities for the UL are expected to be always lower than DL since the coverage probabilities are always higher (each UL connection has always more available power than the DL). As a consequence, UL results are irrelevant from the selected configuration.

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	0	0	0,2916	0,2906
	#2	7,63E-15	3,66E-15	0,1375	0,1361
	#3	3,98E-13	1,91E-13	0,0317	0,0307
	#4	5,23E-12	2,51E-12	0,0006	0,0005
	#5	2,5E-15		0,0006	
	#6	0		7,81E-05	-
E-Class 24	#1	0	0	1	1
	#2	0	0	1	1
	#3	0	0	1	1
	#4	0	0	0,0598	0,0585
	#5	9,35E-27		0,0453	
	#6	0	0	1	1
E-Class 24*	#1	0	0	0,0541	0,0529
	#2	2,1E-23	3,75E-24	0,0147	0,0140
	#3	3,66E-22	6,52E-23	0,0007	0,0007
	#4	3,35E-21	5,97E-22	7,54E-05	6,62E-05
	#5	3,07E-26		2,96E-05	
	#6	0		1,91E-09	

Table 23. Blocking and congestion probabilities for the downlink (Negro Urco)

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	1.82E-11	8.76E-12	0.0253	0.0253
	#2	3.06E-11	1.47E-11	1.46E-06	1.13E-06
	#3	3.37E-11	1.62E-11	3.37E-11	1.48E-11
	#4	3.37E-11	1.62E-11	3.37E-11	1.48E-11
	#5	2.62E-15		2.62E-15	
	#6	0		0	
E-Class 24 and E-Class 24*	#1	1.94E-20	3.45E-21	0.0241	0.0241
	#2	4.49E-20	8E-21	1.46E-06	1.13E-06
	#3	6.96E-20	1.24E-20	3.37E-16	1.33E-16
	#4	6.95E-20	1.24E-20	4.13E-06	3.83E-06
	#5	3.12E-26		3.12E-26	
	#6	0		0	

Table 24. Blocking and congestion probabilities for the uplink (Negro Urco)

5.1.2.3.2 Mixed voice and data traffic

Mixed voice and data traffic results have not been included. Rather, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2.

5.1.3 Tuta Pisco

In Tuta Pisco, scenarios #1, #2 and #3 and #6 from Table 14 are tested in order to evaluate the network performance. Scenario #4 is not contemplated since the traffic distribution around the HNB implies the usage of omni-directional antennas. As can be seen at Figure 12, traffic intensity on the geographical area implies that scenario #5 is not useful. Table 4 and Figure 12 show the location, tower coordinates and the intensity of traffic assumed over the area.

5.1.3.1 Antenna configuration

Table 25 summarizes the best antenna configuration (height and downtilt) depending on the selected scenario of Table 14. The different 95th percentiles of path loss obtained depending on the particular scenario can be seen in annex in section 9.

	Height	Downtilt
Scenario #1	50 m	-
Scenario #2	50 m	-
Scenario #3	50 m	10º
Scenario #6	50 m (cell 1) 50 m (cell 2)	10º (cell 1) 10º (cell 2)

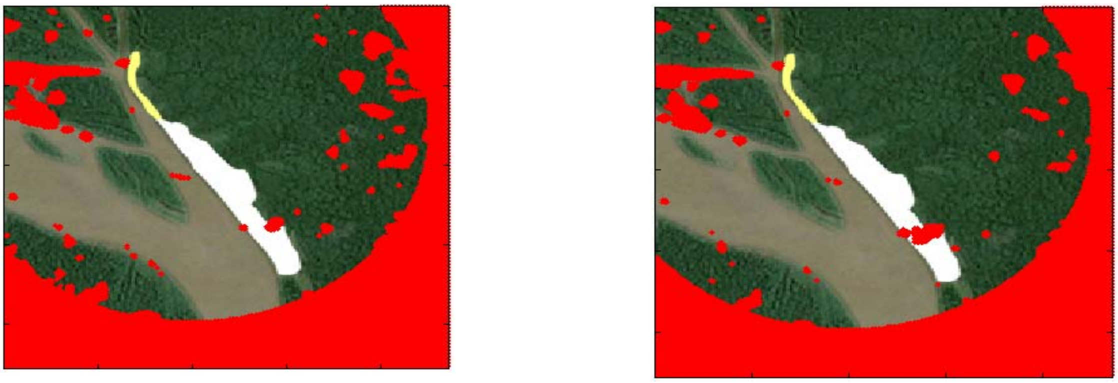
Table 25. Optimum antenna configurations (Tuta Pisco)

5.1.3.2 CPICH coverage

Table 26 summarizes the CPICH coverage results for different scenarios in Tuta Pisco. It can be seen that, when E-Class 24 is used, only scenario #3 and #6 are valid since these provide enough power for dedicated channels. On the other hand, all configurations when HNB S-Class 16 and HNB E-Class 24* provide enough power to serve users. Coverage maps are plotted in Figure 30 for different percentages of covered area, which depends on the specific HNB used and the selected scenario.

HNB	Scenario	Percentage of area covered (%)	Maximum path loss including shadow margin (dB)	TX power for common channels (dBm)	Available power for dedicated channels (dBm)	P_i^{cCH} / P_{max}^{bs} (%)
S-Class 16	#1	95	131.7289	16.4464	17.4725	44.1209
	#2	95	131.7289	14.4464	18.5831	29.1506
	#3	98.9	132.3990	11.1394	19.3952	13
	#6	98.9 (cell 1) 98.9 (cell 2)	132.3990 (cell 1) 132.3990 (cell 2)	11.1394 (cell 1) 11.1394 (cell 2)	19.3952 (cell 1) 19.3952 (cell 2)	13 (cell 1) 13 (cell 2)
E-Class 24	#1	95	131.7289	16.1568	0	206.8629
	#2	95	131.7289	14.2003	0	131.8339
	#3	95	128.8385	6.8750	11.7849	24.4063
	#6	95 (cell 1) 95 (cell 2)	128.8385 (cell 1) 128.8385 (cell 2)	6.8750 (cell 1) 6.8750 (cell 2)	11.7849 (cell 1) 11.7849 (cell 2)	24.4063 (cell 1) 24.4063 (cell 2)
E-Class 24*	#1	95	131.7289	16.9458	23.0469	19.7050
	#2	95	131.7289	15.3815	23.3578	13.7453
	#3	100	136.3990	15.1394	23.3952	13
	#6	100 (cell 1) 100 (cell 2)	136.3990 (cell 1) 136.3990 (cell 2)	15.1394 (cell 1) 15.1394 (cell 2)	23.3952 (cell 1) 23.3952 (cell 2)	13 (cell 1) 13 (cell 2)

Table 26. CPICH coverage results (Tuta Pisco)



(a) Scenario #3 and HNB S-class 16 **(b) Scenario #1 and HNB E-class 24***

Figure 30. Coverage area for two scenarios and HNB types (Tuta Pisco)

5.1.3.3 Blocking and congestion probabilities

5.1.3.3.1 Voice Traffic

Congestion and blocking probabilities obtained for each configuration in Tuta Pisco are presented in Table 27 and Table 28. It can be seen that HNB E-class 24 provides a blocking probability of 1 in scenarios #1, #2 because there is not power available for dedicated channels after CPICH planning.

Notice that in all scenarios, the congestion probabilities are very low. This happens since the number of inhabitants in Tuta Pisco is low and therefore, the aggregated traffic to serve by the network is small. Scenarios that fulfil the requirements for the DL are scenarios #3 and #6 for HNB S-Class 16 and scenarios #1, #2, #3 and #6 for HNB E-Class 24*. HNB E-Class 24 does not have enough power to provide blocking probabilities less than 2% in any scenario.

Finally, blocking and congestion probabilities are lower for UL than for DL since the coverage probabilities are always higher (each UL connection has always more available power than the DL). Therefore, UL results are irrelevant in the choice of a particular configuration and HNB for each location. Notice that for the UL, all scenarios are valid regardless of HNB used.

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	6,26E-15	3,2E-15	0,0825	0,0811
	#2	8,33E-14	4,27E-14	0,0278	0,0269
	#3	4,94E-12	2,53E-12	0,0027	0,0025
	#6	3,06E-16		5,51E-08	
E-Class 24	#1	0	0	1	1
	#2	0	0	1	1
	#3	0	0	0,2247	0,2232
	#6	0		0,0253	
E-Class 24*	#1	0	0	0,0059	0,0056
	#2	2,43E-22	5,05E-23	0,0007	0,0006
	#3	5,47E-21	1,13E-21	0,0002	0,0002
	#6	0		6,48E-11	

Table 27. Blocking and congestion probabilities for the downlink (Tuta Pisco)

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	1,16E-10	5,97E-11	0,0003	0,0003
	#2	1,16E-10	5,96E-11	0,0001	0,0001
	#3	1,17E-10	6E-11	1,17E-10	5,53E-11
	#6	1,49E-16		1,49E-16	
E-Class 24 and E-Class 24*	#1	4,7E-19	9,76E-20	0,0003	0,0003
	#2	4,82E-19	1E-19	0,0001	0,0001
	#3	4,86E-19	1,01E-19	4,86E-19	8,85E-20
	#6	0		0	

Table 28. Blocking and congestion probabilities for the uplink (Tuta Pisco)

5.1.3.3.2 Mixed voice and data traffic

Mixed voice and data traffic results have not been included. Rather, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2.

5.2 *Paranapura river region*

Selected locations in Paranapura river region are San Gabriel and San Juan. The following sections show the results for each location in this region.

5.2.1 San Gabriel

In San Gabriel, scenarios #1, #2, #3, #5 and #6 depicted in Table 14 are tested in order to evaluate the network performance. Scenario #4 is not a suitable solution to test in this location since the traffic distribution around the HNB implies an omnidirectional coverage. Table 4 and Figure 13 show the location and tower coordinates and the intensity of traffic generation assumed over the geographical area, respectively. In Figure 31, two cells of scenario #5 are identified by means of the minimum path loss criteria described in 4.3.4. Notice that the resulting cells depend on the orientations of each antenna and these orientations are selected in such a way that each cell covers the approximately the same density of expected traffic over the area.

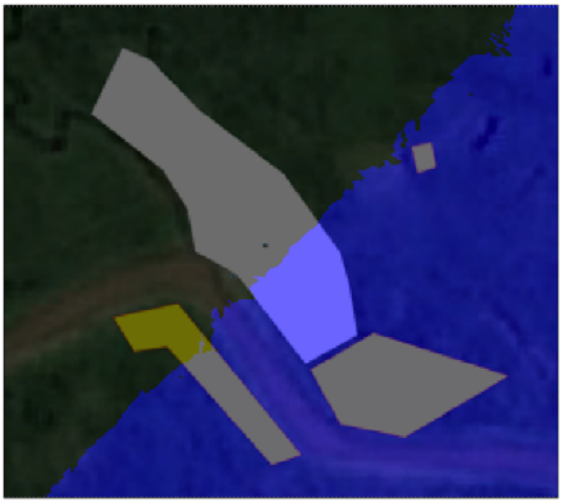


Figure 31. Identification of each cell in scenario #5 – blue: cell 1; black: cell 2 – San Gabriel

5.2.1.1 Antenna configuration

Table 29 summarizes the best antenna configuration (height and downtilt) depending on the selected scenario of Table 14. The different 95th percentiles of path loss obtained depending on the particular scenario can be seen in annex 9.2.3.

	Height	Downtilt
Scenario #1	30 m	-
Scenario #2	30 m	-
Scenario #3	30 m	10º
Scenario #4	-	-
Scenario #5	Sector 1: 40 m Sector 2: 20 m	Sector 1: 10º Sector 2: 10º
Scenario #6	30 m (cell 1) 30 m (cell 2)	10º (cell 1) 10º (cell 2)

Table 29. Optimum antenna configurations (San Gabriel)

5.2.1.2 CPICH coverage

Table 30 summarize the CPICH coverage results for different scenarios in San Gabriel. It can be seen that all scenarios are valid for each type of HNB since the available power to cover the worst path loss is enough. Moreover, the final power allocated by common channels is the minimum required power for an acceptable acquisition time (13% of total radiated power of HNB or equivalently a CPICH power of 5% of total radiated power of HNB). It happens because the covered area is small and resulting worth path loss to cover is low. Different coverage maps are plotted in Figure 32 for different percentages of covered area, which depends on the specific HNB and the selected scenario.

HNB	Scenario	Percentage of area covered (%)	Maximum path loss including shadow margin (dB)	TX power for common channels (dBm)	Available power for dedicated channels (dBm)	P_i^{cCH} / P_{max}^{bs} (%)
S-Class 16	#1	99.9764	125.3990	11.1394	19.3952	13
	#2	100	127.3990	11.1394	19.3952	13
	#3	99.7	132.3990	11.1394	19.3952	13
	#5	100	138.3990 (sector 1) 138.3990 (sector 2)	11.1394 (sector 1) 11.1394 (sector 2)	19.3952 (sector 1) 19.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	99.7 (cell 1) 99.7 (cell 2)	132.3990 (cell 1) 132.3990 (cell 2)	11.1394 (cell 1) 11.1394 (cell 2)	19.3952 (cell 1) 19.3952 (cell 2)	13 (cell 1) 13 (cell 2)
E-Class 24	#1	99.1577	118.3990	4.1394	12.3952	13
	#2	99.6772	120.3990	4.1394	12.3952	13
	#3	99.2	125.3990	4.1394	12.3952	13
	#5	99.3781	131.3990 (sector 1) 131.3990 (sector 2)	4.1394 (sector 1) 4.1394 (sector 2)	12.3952 (sector 1) 12.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	99.2 (cell 1) 99.2 (cell 2)	125.3990 (cell 1) 125.3990 (cell 2)	4.1394 (cell 1) 4.1394 (cell 2)	12.3952 (cell 1) 12.3952 (cell 2)	13 (cell 1) 13 (cell 2)
E-Class 24*	#1	100	129.3990	15.1394	23.3952	13
	#2	100	131.3990	15.1394	23.3952	13
	#3	100	136.3990	15.1394	23.3952	13
	#5	100	142.3990 (sector 1) 142.3990 (sector 2)	15.1394 (sector 1) 15.1394 (sector 2)	23.3952 (sector 1) 23.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	100 (cell 1) 100 (cell 2)	136.3990 (cell 1) 136.3990 (cell 2)	15.1394 (cell 1) 15.1394 (cell 2)	23.3952 (cell 1) 23.3952 (cell 2)	13 (cell 1) 13 (cell 2)

Table 30. CPICH coverage results (San Gabriel)

(a) Scenario #1 and HNB S-class 16 **(b) Scenario #1 and HNB E-class 24**

Figure 32. Coverage areas for two scenarios and and HNB types (San Gabriel)

5.2.1.3 Blocking and congestion probabilities

5.2.1.3.1 Voice Traffic

Congestion and blocking probabilities obtained for each configuration in San Gabriel are presented in Table 31 and Table 32. It can be seen that all configurations provide blocking probabilities lower than 2% for each type of HNB. Notice that despite scenario #3 uses a higher antenna gain, scenarios #1 and

#2 may provide better performance if HNB S-Class 16 or HNB E-Class 24* are used. It happens because antennas with wide elevation beamwidth may provide overall better power budget in this coverage area. Best scenario may also depend on the specific HNB because coverage area is different if power for common channels is fixed as the 13% of total radiated power.

For the UL, blocking probabilities are always lower than blocking probabilities in the DL and furthermore, these coincide with congestion probabilities in all scenarios since in the UL, network performance is totally limited by the number of available channelization codes.

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	5,04E-05	4,06E-05	0,0002	0,0001
	#2	5,14E-05	4,14E-05	6,84E-05	5,56E-05
	#3	5,09E-05	4,1E-05	0,0001	0,0001
	#5	5,17E-08		1,37E-06	
	#6	6,79E-16		4,75E-12	
E-Class 24	#1	1,09E-13	6,36E-14	0,0183	0,0174
	#2	3,03E-12	1,78E-12	0,0047	0,0043
	#3	1,34E-10	7,85E-11	0,0007	0,0006
	#5	7,74E-15		1,77E-06	
	#6	5,47E-17		2,3E-10	
E-Class 24*	#1	6,94E-10	4,07E-10	2,68E-07	2,22E-07
	#2	7,09E-10	4,16E-10	1,13E-09	6,98E-10
	#3	6,46E-10	3,79E-10	4,89E-05	4,53E-05
	#5	7,54E-15		9,45E-14	
	#6	0		0	

Table 31. Blocking and congestion probabilities for the downlink (San Gabriel)

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	5,18E-05	4,18E-05	5,18E-05	4,08E-05
	#2	5,18E-05	4,18E-05	5,18E-05	4,08E-05
	#3	5,18E-05	4,18E-05	5,18E-05	4,08E-05
	#5	5,18E-08		5,18E-08	
	#6	7,02E-16		7,02E-16	
E-Class 24 and E-Class 24*	#1	7,1E-10	4,17E-10	7,1E-10	4,01E-10
	#2	7,1E-10	4,17E-10	7,1E-10	4,01E-10
	#3	7,1E-10	4,17E-10	7,1E-10	4,01E-10
	#5	8,24E-15		8,24E-15	
	#6	5,18E-17		5,18E-17	

Table 32. Blocking and congestion probabilities for the uplink (San Gabriel)

5.2.1.3.2 Mixed voice and data traffic

Mixed voice and data traffic results have not been included. Rather, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2.

5.2.2 San Juan

In San Gabriel, scenarios #1, #2, #3, #5 and #6 depicted in Table 14 are tested in order to evaluate the network performance. Scenario #4 is not possible to test in this location since the traffic distribution around the HNB implies omnidirectional coverage. Table 4 and Figure 14 shows the location and tower coordinates and the intensity of traffic generation assumed over the geographical area, respectively. In Figure 33, two cells of scenario #5 are identified by means of the minimum path loss criteria described in 4.3.4. Notice that the resulting cells depend on the orientations of each antenna and these orientations are selected in such a way that each cell covers the approximately the same density of expected traffic over the area.

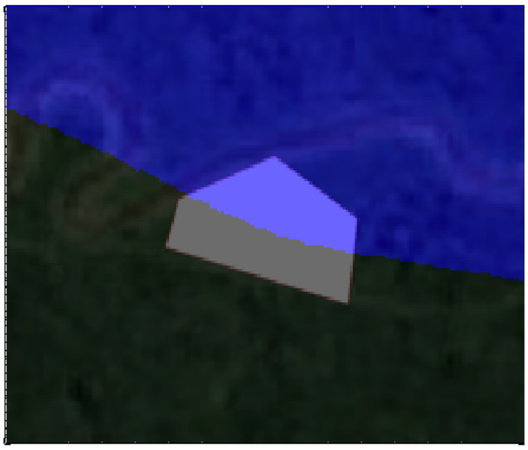


Figure 33. Identification of each cell in scenario #5 – blue: cell 1; black: cell 2 – San Juan

5.2.2.1 *Antenna configuration*

Table 33 summarizes the best antenna configuration (height and downtilt) depending on the selected scenario of Table 14. The different 95th percentiles of path loss obtained depending on the particular scenario can be seen in annex 9.2.5.

	Height	**Downtilt**
Scenario #1	20 m	-
Scenario #2	20 m	-
Scenario #3	20 m	10º
Scenario #4	-	-
Scenario #5	Sector 1: 20 m Sector 2: 20 m	Sector 1: 20º Sector 2: 10º
Scenario #6	20 m (cell 1) 20 m (cell 2)	10º (cell 1) 10º (cell 2)

Table 33. Optimum antenna configurations (San Juan)

5.2.2.2 *CPICH coverage*

Table 34 summarize the CPICH coverage results for different scenarios in San Juan. It can be seen that all scenarios are valid for each type of HNB since the available power to cover the worst path loss is enough. Moreover, the power allocated by common channels is the minimum required power for an acceptable acquisition time (13% of total radiated power of HNB or equivalently a CPICH power of 5% of total radiated power of HNB). It happens because the covered area is small and resulting worst path loss to cover is low. Also, notice that for all scenarios the whole area is covered (100%).

HNB	Scenario	Percentage of area covered (%)	Maximum path loss including shadow margin (dB)	TX power for common channels (dBm)	Available power for dedicated channels (dBm)	P_i^{cCH} / P_{max}^{bs} (%)
S-Class 16	#1	100	125.3990	11.1394	19.3952	13
	#2	100	127.3990	11.1394	19.3952	13
	#3	100	132.3990	11.1394	19.3952	13
	#5	100	138.3990 (sector 1) 138.3990 (sector 2)	11.1394 (sector 1) 11.1394 (sector 2)	19.3952 (sector 1) 19.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	100 (cell 1) 100 (cell 2)	132.3990 (cell 1) 132.3990 (cell 2)	11.1394 (cell 1) 11.1394 (cell 2)	19.3952 (cell 1) 19.3952 (cell 2)	13 (cell 1) 13 (cell 2)
E-Class 24	#1	100	118.3990	4.1394	12.3952	13
	#2	100	120.3990	4.1394	12.3952	13
	#3	100	125.3990	4.1394	12.3952	13
	#5	100	131.1990 (sector 1) 131.1990 (sector 2)	4.1394 (sector 1) 4.1394 (sector 2)	12.3952 (sector 1) 12.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	100 (cell 1) 100 (cell 2)	125.3990 (cell 1) 125.3990 (cell 2)	4.1394 (cell 1) 4.1394 (cell 2)	12.3952 (cell 1) 12.3952 (cell 2)	13 (cell 1) 13 (cell 2)
E-Class 24*	#1	100	129.3990	15.1394	23.3952	13
	#2	100	131.3990	15.1394	23.3952	13
	#3	100	136.3990	15.1394	23.3952	13
	#5	100	142.3990 (sector 1) 142.3990 (sector 2)	15.1394 (sector 1) 15.1394 (sector 2)	23.3952 (sector 1) 23.3952 (sector 2)	13 (sector 1) 13 (sector 2)
	#6	100 (cell 1) 100 (cell 2)	136.3990 (cell 1) 136.3990 (cell 2)	15.1394 (cell 1) 15.1394 (cell 2)	23.3952 (cell 1) 23.3952 (cell 2)	13 (cell 1) 13 (cell 2)

Table 34. CPICH coverage results (San Juan)

5.2.2.3 Blocking and congestion probabilities

5.2.2.3.1 Voice Traffic

Congestion and blocking probabilities obtained for each configuration in San Juan are presented in Table 35 and Table 36. All configurations yield blocking below 2% for each type of HNB.

Congestion probabilities coincide with blocking probabilities practically in all scenarios using any HNB since the network performance is limited by the number of available channelization codes at HNB. Notice that despite scenario #3 uses a higher antenna gain, scenarios #1 and #2 may provide better performance. It happens because antennas with wide elevation beamwidth may provide overall improved link budget in this coverage area. In the UL, all single-cell scenarios provide the same results regardless of the used HNB type.

HNB	**Scenario**	**Congestion Probability**		**Blocking Probability**	
		Case A	**Case B**	**Case A**	**Case B**
S-Class 16	#1	1,33E-17	1,62E-18	1,33E-17	1,22E-18
	#2	1,33E-17	1,62E-18	1,33E-17	1,22E-18
	#3	1,33E-17	1,62E-18	3,93E-15	1,27E-15
	#5	6,68E-22		6,68E-22	
	#6	0		0	
E-Class 24 (13 dBm)	#1	1,02E-29	6,1E-32	2,78E-26	9,11E-28
	#2	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#3	7,65E-30	4,58E-32	3,99E-08	2,96E-08
	#5	3,06E-36		4,9E-17	
	#6	0		0	
E-Class 24 (24 dBm)	#1	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#2	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#3	1,02E-29	6,11E-32	8,73E-28	1,93E-29
	#5	3,14E-36		3,14E-36	
	#6	0		0	

Table 35. Blocking and congestion probabilities for the downlink (San Juan)

HNB	Scenario	Congestion Probability		Blocking Probability	
		Case A	Case B	Case A	Case B
S-Class 16	#1	1,33E-17	1,62E-18	1,33E-17	1,22E-18
	#2	1,33E-17	1,62E-18	1,33E-17	1,22E-18
	#3	1,33E-17	1,62E-18	1,33E-17	1,22E-18
	#5	6,68E-22		6,68E-22	
	#6	0		0	
E-Class 24*	#1	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#2	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#3	1,02E-29	6,11E-32	1,02E-29	3,8E-32
	#5	3,14E-36		3,14E-36	
	#6	0		0	

Table 36. Blocking and congestion probabilities for the uplink (San Juan)

5.2.2.3.2 Mixed voice and data traffic

Mixed voice and data traffic results have not been included. Rather, the dimensioning of voice and data circuits as well as the evaluation of the required backhaul are displayed in section 6.2.

6 EVALUATION OF BACKHAUL REQUIREMENTS

This section evaluates the backhaul bandwidth demanded by the access network in the busy hour, according to the population distribution and traffic demands as it was analysed in and section 2.1. In accordance to previous sections, voice-only service is studied first and then mixed voice and data services.

6.1 Backhaul required for voice traffic

The voice traffic generated in each location is obtained as described in section 2.3. The number of voice circuits N_v for the traffic at the peak hour and a blocking probability of 2% is obtained numerically according to what is described in section 4.4.1. As the voice traffic is symmetric we adopt the highest among DL and UL in the peak hour. Results for each location are given in the following tables. 25+25 kbps of backhaul for each voice connection would be used for UL+DL.

6.1.1 Ideal case (unit coverage probability)

Here it is assumed that all coverage probabilities are one, independent on the traffic density or available transmitted power. These results may be used as a reference of performance if larger power at the HNB were available. Table 37 to Table 41 show the required backhaul when unit coverage probabilities are supposed for each location and year. Those situations where the target blocking probability cannot be achieved are marked with dash symbol ‘-‘.

Table 37 shows that the network can only satisfy the requirements in the first year in Santa Clotilde. Only multi-cell scenarios can fulfill the requirements and it can be seen that any HNB can provide enough circuits to serve users. From the second year and on, the number of available channelization codes at HNBs is not enough to serve the expected increase in the voice traffic.

For the other localities, the performance requirements can be fulfilled during first five years (assuming ideal coverage probabilities), any HNB class can provide enough number of voice circuits, with the exception of San Gabriel, where only HNB E-Class 24 and HNB E-Class 24* can offer enough channelization codes to serve voice users in single-cell scenarios from the second year and on.

Table 38 shows the minimum number of voice codes needed in Negro Urco to serve the increasing expected voice traffic during five years. It can be seen that any HNB can provide enough number of circuits for all scenarios. Table 39 summarizes the minimum number of circuits required in Tuta Pisco, where any HNB has enough channelization codes to serve voice users regardless of the chosen scenario. The number of voice circuits required in San Gabriel can be seen in Table 40 and, as mentioned above, all HNBs have enough codes to serve the expected voice traffic if multi-cell scenario is assumed; while only HNB E-Class 24 and HNB E-Class 24* can provide enough circuits for single-cell scenarios. Finally, Table 41 shows the minimum number of required circuits in San Juan and in this case, all scenarios using any HNB are capable to serve the expected voice traffic along the five years.

Year	Scenario	Number of required circuits	Blocking probability	Backhaul required (Kbps)
Year 1	#1,#2,#3,#4	-	-	-
	#5	14 (sector 1) 16 (sector 2)	0,0167	750
	#6	25	0,0164	625
Year 2	#1,#2,#3,#4	-	-	-
	#5	-	-	-
	#6	-	-	-
Year 3	#1,#2,#3,#4	-	-	-
	#5	-	-	-
	#6	-	-	-
Year 4	#1,#2,#3,#4	-	-	-
	#5	-	-	-
	#6	-	-	-
Year 5	#1,#2,#3,#4	-	-	-
	#5	-	-	-
	#6	-	-	-

Table 37. Number of required codes and resulting block probabilities for the uplink and downlink when ideal coverage is assumed (Santa Clotilde)

Year	Scenario	Number of required circuits	Blocking probability	Backhaul required (Kbps)
Year 1	#1,#2,#3,#4	6	0,0057	150
	#5	4 (sector 1) 4 (sector 2)	0,0104	200
	#6	6	0,0057	150
Year 2	#1,#2,#3,#4	10	0,0131	250
	#5	7 (sector 1) 6 (sector 2)	0,0181	325
	#6	10	0,0131	250
Year 3	#1,#2,#3,#4	10	0,0169	250
	#5	7 (sector 1) 7 (sector 2)	0,0117	350
	#6	10	0,0169	250
Year 4	#1,#2,#3,#4	10	0,0187	250
	#5	7 (sector 1) 7 (sector 2)	0,0128	350
	#6	10	0,0187	250
Year 5	#1,#2,#3,#4	11	0,0095	275
	#5	7 (sector 1) 7 (sector 2)	0,0139	350
	#6	11	0,0095	275

Table 38. Number of required codes and resulting block probabilities for the uplink and downlink when ideal coverage is assumed (Negro Urco)

Year	Scenario	Number of required circuits	Blocking probability	Backhaul required (Kbps)
Year 1	#1,#2,#3,#4	6	0,0083	150
	#6	6	0,0083	150
Year 1 Year 2	#1,#2,#3,#4	11	0,0095	275
	#6	11	0,0095	275
Year 2	#1,#2,#3,#4	11	0,0126	275
	#6	11	0,0126	275
Year 3	#1,#2,#3,#4	11	0,0140	275
	#6	11	0,0140	275
Year 4	#1,#2,#3,#4	11	0,0157	275
	#6	11	0,0157	275

Table 39. Number of required codes and resulting block probabilities for the uplink and downlink when ideal coverage is assumed (Tuta Pisco)

Year	Scenario	Number of required circuits	Blocking probability	Backhaul required (Kbps)
Year 1	#1,#2,#3,#4	10	0,0188	250
	#5	6 (sector 1) 7 (sector 2)	0,0176	325
	#6	10	0,0188	250
Year 2	#1,#2,#3,#4	22	0,0128	550
	#5	12 (sector 1) 14 (sector 2)	0,0169	650
	#6	22	0,0128	550
Year 3	#1,#2,#3,#4	22	0,0188	550
	#5	12 (sector 1) 15 (sector 2)	0,0166	600
	#6	22	0,0188	550
Year 4	#1,#2,#3,#4	23	0,0140	575
	#5	12 (sector 1) 15 (sector 2)	0,0186	675
	#6	23	0,0140	575
Year 5	#1,#2,#3,#4	23	0,0165	575
	#5	13 (sector 1) 15 (sector 2)	0,0162	700
	#6	23	0,0165	575

Table 40. Number of required codes and resulting block probabilities for the uplink and downlink when ideal coverage is assumed (San Gabriel)

Year	Scenario	Number of required circuits	Blocking probability	Backhaul required (Kbps)
Year 0	#1,#2,#3,#4	4	0,0034	100
	#5	3 (sector 1) 3 (sector 2)	0,0043	150
	#6	4	0,0034	100
Year 1	#1,#2,#3,#4	6	0,0069	150
	#5	4 (sector 1) 4 (sector 2)	0,0120	200
	#6	6	0,0069	150
Year 2	#1,#2,#3,#4	6	0,0084	150
	#5	4 (sector 1) 4 (sector 2)	0,0140	200
	#6	6	0,0084	150
Year 3	#1,#2,#3,#4	6	0,0092	150
	#5	4 (sector 1) 4 (sector 2)	0,0149	200
	#6	6	0,0092	150
Year 4	#1,#2,#3,#4	6	0,0099	150
	#5	4 (sector 1) 4 (sector 2)	0,0158	200
	#6	6	0,0099	150

Table 41. Number of required codes and resulting block probabilities for the uplink and downlink when ideal coverage is assumed (San Juan)

6.1.2 Realistic evaluation

Actual results are displayed here, assuming the three types of ip.access HNBs, and simulated (adopting the models in 4.3.7 and hence lower than 1) coverage probabilities that take into consideration the intracell interference. Those situations where the target blocking probability cannot be achieved are marked with dash symbol ‘-‘.

6.1.2.1 Santa Clotilde

Table 42 and Table 43 summarize the minimum number of voice circuits required to serve the voice traffic expected in Santa Clotilde during the first five years. In Table 42 it can be seen that only scenario #6 can satisfy the target blocking probability if HNB E-Class 16 is used, while scenario #5 and scenario #6 can fulfill the requirements with HNB E-Class 24* is use. Obviously, as given in section 6.1.1, starting from the second year, there is no available HNB type with enough codes to serve the expected voice traffic.

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	-	-	-	-	-
	#6	25	0,0164	25	0,0183	625
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	14 (sector 1) 16 (sector 2)	0,0166	14 (sector 1) 16 (sector 2)	0,0178	750
	#6	25	0,0164	25	0,0167	625

Table 42 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Santa Clotilde) – Year 1

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-

Table 43 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Santa Clotilde) – Year 2 to year 5

6.1.2.2 Negro Urco

Table 44, Table 45, Table 46, Table 47 and Table 48 summarize the minimum number of voice circuits required to serve the voice traffic in Negro Urco during the first five years. During the first year, it can be seen that scenarios #4, #5 and #6 can fulfill the requirements if HNB S-Class 16 is used, while if HNB E-Class 24* is used, the requirements are satisfied by scenarios #2, #3, #4, #5 and #6. From the second year, only scenario #6 can fulfill the target blocking probability if HNB S-Class is assumed, and scenarios #4, #5 and #6 with the HNB E-Class 24* is used. Due to the rise in voice traffic starting from the second year, scenario #4, which has the antenna with higher gain, is the only isolated-cell scenario capable to serve this expected traffic.

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	6	0,0057	6	0,0059	150
	#5	4 (sector 1) 4 (sector 2)	0,0104	4 (sector 1) 4 (sector 2)	0,0104	200
	#6	6	0,0057	6	0,0060	150
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	6	0,0057	6	0,0179	150
	#3	6	0,0057	6	0,0060	150
	#4	6	0,0057	6	0,0057	150
	#5	4 (sector 1) 4 (sector 2)	0,0104	4 (sector 1) 4 (sector 2)	0,0104	200
	#6	6	0,0057	6	0,0057	150

Table 44 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Negro Urco) – Year 1

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	10	0,0131	10	0,01997	250
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	10	0,0131	10	0,0171	250
	#5	7 (sector 1) 6 (sector 2)	0,0182	7 (sector 1) 6 (sector 2)	0,0186	325
	#6	10	0,0131	10	0,0131	250

Table 45 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Negro Urco) – Year 2

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	10	0,0169	11	0,0158	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	10	0,0169	11	0,0135	275
	#5	7 (Sector 1) 7 (Sector 2)	0,0117	7 (Sector 1) 7 (Sector 2)	0,0117	350
	#6	10	0,0169	10	0,0169	250

Table 46 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Negro Urco) – Year 3

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	10	0,0187	11	0,0172	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	10	0,0187	11	0,0148	275
	#5	7 (Sector 1) 7 (Sector 2)	0,0127	7 (Sector 1) 7 (Sector 2)	0,0127	350
	#6	10	0,0187	10	0,0187	250

Table 47 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Negro Urco) – Year 4

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	11	0,0095	11	0,0188	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	11	0,0096	11	0,0162	275
	#5	7 (Sector 1) 7 (Sector 2)	0,0139	7 (Sector 1) 7 (Sector 2)	0,0139	350
	#6	11	0,0095	11	0,0096	275

Table 48 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Negro Urco) – Year 5

6.1.2.3 Tuta Pisco

Table 49, Table 50, Table 51, Table 52 and Table 53 show the minimum number of voice circuits required to serve the expected voice traffic in Tuta Pisco during the first five years. During first year scenarios #3 and #6 can fulfill the requirements with HNB S-Class 16, while all scenarios can satisfy the required blocking probability with HNB E-Class 24. From the second year, only scenario #6 can fulfill the target blocking probability with HNB S-Class, and scenarios #3 and #6 with HNB E-Class 24*.

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	6	0,0083	6	0,0097	150
	#6	6	0,0083	6	0,0083	150
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	6	0,0086	6	0,0121	150
	#2	6	0,0084	6	0,0085	150
	#3	6	0,0083	6	0,0083	150
	#6	6	0,0083	6	0,0083	150

Table 49 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Tuta Pisco) – Year 1

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	11	0,0095	11	0,0098	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	11	0,0095	12	0,0168	300
	#6	11	0,0095	11	0,0095	275

Table 50 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Tuta Pisco) – Year 2

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	11	0,0126	11	0,0130	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	11	0,0126	13	0,0184	325
	#6	11	0,0126	11	0,0126	275

Table 51 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Tuta Pisco) – Year 3

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	11	0,0140	11	0,0145	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	11	0,0140	13	0,0197	325
	#6	11	0,0140	11	0,0141	275

Table 52 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Tuta Pisco) – Year 4

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	11	0,0157	11	0,0162	275
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#6	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	11	0,0157	15	0,0199	375
	#6	11	0,0157	11	0,0157	275

Table 53 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (Tuta Pisco) – Year 5

6.1.2.4 San Gabriel

Table 54, Table 55, Table 56, Table 57 and Table 58 show the minimum required number of voice circuits to serve the expected voice traffic in San Gabriel during the first five years. During the first year all HNB have enough channelization codes to serve the expected voice users using any scenario. From the second year, multi-cell scenarios (#5 and #6) satisfy the target blocking probability regardless of the HNB type. However, only HNB E-Class 24* has enough codes and available power to serve the expected voice traffic satisfying the requirements for any isolated-cell scenario.

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	10	0,0188	10	0,0189	250
	#2	10	0,0188	10	0,0189	250
	#3	10	0,0188	10	0,0189	250
	#5	6 (sector 1) 7 (sector 2)	0,0176	6 (sector 1) 7 (sector 2)	0,0176	325
	#6	10	0,0188	10	0,0189	250
E-Class 24	#1	10	0,0188	12	0,0194	300
	#2	10	0,0188	11	0,0111	275
	#3	10	0,0188	10	0,0190	250
	#5	6 (sector 1) 7 (sector 2)	0,0179	6 (sector 1) 7 (sector 2)	0,0179	325
	#6	10	0,0188	10	0,0188	250
E-Class 24*	#1	10	0,0188	10	0,0188	250
	#2	10	0,0188	10	0,0188	250
	#3	10	0,0188	10	0,0189	250
	#5	6 (sector 1) 7 (sector 2)	0,0176	6 (sector 1) 7 (sector 2)	0,0176	325
	#6	10	0,0188	10	0,0188	250

Table 54 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Gabriel) – Year 1

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 14 (sector 2)	0,0169	12 (sector 1) 14 (sector 2)	0,0169	650
	#6	22	0,0128	22	0,0128	550
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 14 (sector 2)	0,0173	12 (sector 1) 14 (sector 2)	0,0173	650
	#6	22	0,0128	22	0,0130	550
E-Class 24*	#1	22	0,0128	22	0,0132	550
	#2	22	0,0128	22	0,0128	550
	#3	22	0,0128	22	0,0167	550
	#5	12 (sector 1) 14 (sector 2)	0,0169	12 (sector 1) 14 (sector 2)	0,0169	650
	#6	22	0,0128	22	0,0128	550

Table 55 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Gabriel) – Year 2

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	0,0167	12 (sector 1) 15 (sector 2)	0,0168	675
	#6	22	0,0188	22	0,0188	550
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	0,0161	12 (sector 1) 15 (sector 2)	0,0163	675
	#6	22	0,0188	22	0,0189	550
E-Class 24*	#1	22	0,0188	22	0,0192	550
	#2	22	0,0188	22	0,0188	550
	#3	22	0,0188	23	0,016	575
	#5	12 (sector 1) 15 (sector 2)	0,0167	12 (sector 1) 15 (sector 2)	0,0167	675
	#6	22	0,0188	22	0,0188	550

Table 56 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Gabriel) – Year 3

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	0,0186	12 (sector 1) 15 (sector 2)	0,0187	675
	#6	23	0,0140	23	0,0141	575
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	0,0180	12 (sector 1) 15 (sector 2)	0,0182	675
	#6	23	0,0140	23	0,0142	575
E-Class 24*	#1	23	0,0140	23	0,0146	575
	#2	23	0,0140	23	0,0141	575
	#3	23	0,0140	23	0,0187	575
	#5	12 (sector 1) 15 (sector 2)	0,0186	12 (sector 1) 15 (sector 2)	0,0186	675
	#6	23	0,0140	23	0,0141	575

Table 57 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Gabriel) – Year 4

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	13 (sector 1) 15 (sector 2)	0,0162	13 (sector 1) 15 (sector 2)	0,0162	700
	#6	23	0,0165	23	0,0165	575
E-Class 24	#1	-	-	-	-	-
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#5	13 (sector 1) 15 (sector 2)	0,0166	13 (sector 1) 15 (sector 2)	0,0169	700
	#6	23	0,0165	23	0,0167	575
E-Class 24*	#1	23	0,0165	23	0,0171	575
	#2	23	0,0165	23	0,0165	575
	#3	23	0,0165	24	0,0155	600
	#5	13 (sector 1) 15 (sector 2)	0,0162	13 (sector 1) 15 (sector 2)	0,0162	700
	#6	23	0,0165	23	0,0165	575

Table 58 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Gabriel) – Year 5

6.1.2.5 San Juan

Table 59, Table 60, Table 61, Table 62 and Table 63 show the minimum required number of voice circuits to serve the expected voice traffic in San Juan during the first five years. Along the first five years, all HNB types have enough channelization codes and available power to serve the expected voice users using any scenario.

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probabilit y	
S-Class 16	#1	4	0,0034	4	0,0034	100
	#2	4	0,0034	4	0,0034	100
	#3	4	0,0034	4	0,0034	100
	#5	3 (sector 1) 3 (sector 2)	0,0043	3 (sector 1) 3 (sector 2)	0,0043	150
	#6	4	0,0034	4	0,0034	100
E-Class 24	#1	4	0,0034	4	0,0034	100
	#2	4	0,0034	4	0,0034	100
	#3	4	0,0034	4	0,0034	100
	#5	3 (sector 1) 3 (sector 2)	0,0043	3 (sector 1) 3 (sector 2)	0,0043	150
	#6	4	0,0034	4	0,0034	100
E-Class 24*	#1	4	0,0034	4	0,0034	100
	#2	4	0,0034	4	0,0034	100
	#3	4	0,0034	4	0,0034	100
	#5	3 (sector 1) 3 (sector 2)	0,0043	3 (sector 1) 3 (sector 2)	0,0043	150
	#6	4	0,0034	4	0,0034	100

Table 59 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Juan) – Year 1

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	6	0,0069	6	0,0069	150
	#2	6	0,0069	6	0,0069	150
	#3	6	0,0069	6	0,0069	150
	#5	4 (sector 1) 4 (sector 2)	0,0120	4 (sector 1) 4 (sector 2)	0,0120	200
	#6	6	0,0069	6	0,0069	150
E-Class 24	#1	6	0,0069	6	0,0069	150
	#2	6	0,0069	6	0,0069	150
	#3	6	0,0069	6	0,0069	150
	#5	4 (sector 1) 4 (sector 2)	0,0120	4 (sector 1) 4 (sector 2)	0,0120	200
	#6	6	0,0069	6	0,0069	150
E-Class 24*	#1	6	0,0069	6	0,0069	150
	#2	6	0,0069	6	0,0069	150
	#3	6	0,0069	6	0,0069	150
	#5	4 (sector 1) 4 (sector 2)	0,0084	4 (sector 1) 4 (sector 2)	0,0084	200
	#6	6	0,0069	6	0,0069	150

Table 60 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Juan) – Year 2

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	6	0,0084	6	0,0084	150
	#2	6	0,0084	6	0,0084	150
	#3	6	0,0084	6	0,0084	150
	#5	4 (sector 1) 4 (sector 2)	0,0140	4 (sector 1) 4 (sector 2)	0,0140	200
	#6	6	0,0084	6	0,0084	150
E-Class 24	#1	6	0,0084	6	0,0084	150
	#2	6	0,0084	6	0,0084	150
	#3	6	0,0084	6	0,0084	150
	#5	4 (sector 1) 4 (sector 2)	0,0140	4 (sector 1) 4 (sector 2)	0,0140	200
	#6	6	0,0084	6	0,0084	150
E-Class 24*	#1	6	0,0084	6	0,0084	150
	#2	6	0,0084	6	0,0084	150
	#3	6	0,0084	6	0,0084	150
	#5	4 (sector 1) 4 (sector 2)	0,0140	4 (sector 1) 4 (sector 2)	0,0140	200
	#6	6	0,0084	6	0,0084	150

Table 61 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Juan) – Year 3

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	6	0,0092	6	0,0092	150
	#2	6	0,0092	6	0,0092	150
	#3	6	0,0092	6	0,0092	150
	#5	4 (sector 1) 4 (sector 2)	0,0149	4 (sector 1) 4 (sector 2)	0,0149	200
	#6	6	0,0092	6	0,0092	150
E-Class 24	#1	6	0,0092	6	0,0092	150
	#2	6	0,0092	6	0,0092	150
	#3	6	0,0092	6	0,0092	150
	#5	4 (sector 1) 4 (sector 2)	0,0149	4 (sector 1) 4 (sector 2)	0,0149	200
	#6	6	0,0092	6	0,0092	150
E-Class 24*	#1	6	0,0092	6	0,0092	150
	#2	6	0,0092	6	0,0092	150
	#3	6	0,0092	6	0,0092	150
	#5	4 (sector 1) 4 (sector 2)	0,0149	4 (sector 1) 4 (sector 2)	0,0149	200
	#6	6	0,0092	6	0,0092	150

Table 62 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Juan) – Year 4

HNB	Scenario	Uplink		Downlink		Backhaul required (Kbps)
		Number of required circuits	Blocking probability	Number of required circuits	Blocking probability	
S-Class 16	#1	6	0,0099	6	0,0099	150
	#2	6	0,0099	6	0,0099	150
	#3	6	0,0099	6	0,0099	150
	#5	4 (sector 1) 4 (sector 2)	0,0158	4 (sector 1) 4 (sector 2)	0,0158	200
	#6	6	0,0099	6	0,0099	150
E-Class 24	#1	6	0,0099	6	0,0099	150
	#2	6	0,0099	6	0,0099	150
	#3	6	0,0099	6	0,0099	150
	#5	4 (sector 1) 4 (sector 2)	0,0158	4 (sector 1) 4 (sector 2)	0,0158	200
	#6	6	0,0099	6	0,0099	150
E-Class 24*	#1	6	0,0099	6	0,0099	150
	#2	6	0,0099	6	0,0099	150
	#3	6	0,0099	6	0,0099	150
	#5	4 (sector 1) 4 (sector 2)	0,0158	4 (sector 1) 4 (sector 2)	0,0158	200
	#6	6	0,0099	6	0,0099	150

Table 63 . Number of required codes and resulting block probabilities for the uplink and downlink when only voice users are assumed (San Juan) – Year 5

6.2 Backhaul required for mixed voice and data traffic

The voice and data traffics generated in each location are obtained as described in section 2.3. For the evaluation of the number of channels associated to voice traffic (N_v) and data traffic (N_d) that fit a certain blocking probability, we follow this methodology:

1. Adopt a HNB type + antenna configuration providing the grade of service required, both for voice and data.
2. Evaluate the number of channelization codes required to meet the blocking probability for voice and data traffic (for UL and DL), call it N_v and N_d respectively, according to the guidelines of section 4.4.2.
3. Evaluate the voice plus data traffic for these channels. For voice channels assume 25 kbps of backhaul. For data traffic, assume 128 kbps for both UL and DL, plus additional overhead due to signalling of 20%.

For the mixed voice and data case we cannot define a peak hour (notice that traffic in Figure 4 and Figure 8 peak at different hours). By analysing the traffic through the day, three peak hours can be identified where both voice and data traffic are larger than the rest. The required number of circuits has been evaluated on each hour. For voice, the required number of circuits (the same for the UL and DL since symmetric design) will be the maximum number of required circuits among the three hours both for the UL and for the DL. The number of required data circuits will be the maximum number of required circuits among the three most loaded hours, differentiating between UL and DL (asymmetry is assumed for data traffic). The required dimension of backhaul will be the maximum among the three hours, differentiating between UL and DL. Notice that the dimension of backhaul is not determined by the resulting total number of circuits for voice and data traffic since it may happen that the maximum number of voice circuits and maximum number of data circuits are required in different hours. Therefore, despite access network must have enough codes, not all will be used at the same time.

6.2.1 Ideal case (unit coverage probability)

Here it is assumed that all coverage probabilities are one, independently on the traffic density or available power. Results are a reference of performance if larger power at the HNB were available. Table 64 to Table 69 show the required backhaul when unit coverage probabilities are supposed for each location and year. Those situations where the target blocking probability cannot be achieved are marked with dash symbol '-'.

Table 64 shows that the expected voice and data traffic in Sta Clotilde cannot be served with the desired blocking probability using any of the scenarios after the second year, confirming what has already been seen in section 6.1.1 when only voice traffic is assumed. This is why an analysis for data-only traffic is shown in Table 65, assuming that the existing GSM network could serve all voice traffic. This study is not repeated for the other localities. Notice that all HNBs provide enough channelisation codes and available power using any scenario considering only data users are assumed.

When voice and data users are assumed, the blocking probability depends on the number of maximum simultaneous users supported by the HNB if N_v plus N_d is higher than this number of maximum users, although coverage probabilities are always one. This happens because the congestion probability will be higher for HNBs with lower number of maximum users. Therefore, in those places and years where N_v plus N_d is higher than the maximum number of simultaneous users supported by any of HNBs, we must distinguish different cases.

Table 66 and Table 67 summarize the number of required voice and data circuits in Negro Urco and Tuta Pisco considering the ideal coverage probabilities. It can be seen that the expected traffic is low enough for all HNBs to fulfill the requirements in any scenario. Table 68 shows the required voice and data circuits in San Gabriel. In this location, It is expected that HNB S-Class 16 does not have enough codes to serve the expected traffic starting from the second year with the assumption of isolated-cell scenario. Starting from the third year, other type of HNBs either do not have enough codes in the same type of scenarios. Finally, Table 69 shows the required number of required voice and data circuits in San Juan. It can be seen that the expected traffic is low enough for all HNBs to fulfill the requirements in any scenario.

Year	**HNB**	**Scenario**	**Uplink**			**Downlink**		
			Number of required circuits (VOICE)	**Number of required circuits (DATA)**	**Backhaul required (kbps)**	**Number of required circuits (VOICE)**	**Number of required circuits (DATA)**	**Backhaul required (kbps)**
Year 1 Year 2	S-Class 16	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	25	4	1239,4	25	7	1675,2
	E-Class 24 and E-Class 24*	#1.#2,#3,#4	-	-	-	-	-	-
		#5	14 (sector 1) 16 (sector 2)	3 (sector 1) 3 (sector 2)	1671,6	14 (sector 1) 16 (sector 2)	5 (sector 1) 5 (sector 2)	2236
		#6	25	4	1239,4	25	7	1700,2
Year 3	All HNBs	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	-	-	-	-	-	-
Year 4	All HNBs	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	-	-	-	-	-	-
Year 5	All HNBs	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	-	-	-	-	-	-
Year 1	All HNBs	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	-	-	-	-	-	-

Table 64. Number of required codes for the uplink and downlink when voice and data users are assumed and ideal coverage (Santa Clotilde)

Year	**Scenario**	**Uplink**			**Downlink**		
		Number of required circuits (DATA)	**Blocking Probability**	**Backhaul required (kbps)**	**Number of required circuits (DATA)**	**Blocking Probability**	**Backhaul required (kbps)**
Year 1	#1.#2,#3,#4	4	0,0146	614,4	7	0,0173	1075,2
	#5	3 (sector 1) 3 (sector 2)	0,0160	921,6	5 (sector 1) 5 (sector 2)	0,0172	1536
	#6	4	0,0146	614,4	7	0,0173	1075,2
Year 2	#1.#2,#3,#4	7	0,0152	1075.2	14	0,0164	2150.4
	#5	5 (sector 1) 5 (sector 2)	0,0155	1536	8 (sector 1) 10 (sector 2)	0,0170	2764,8
	#6	7	0,0152	1075.2	14	0,0164	2150.4
Year 3	#1.#2,#3,#4	7	0,0187	1075.2	15	0,0120	2304
	#5	5 (sector 1) 5 (sector 2)	0,0183	1536	9 (sector 1) 10 (sector 2)	0,0127	2918,4
	#6	7	0,0187	1075.2	15	0,0120	2304
Year 4	#1.#2,#3,#4	8	0,0074	1228,8	15	0,0137	2304
	#5	5 (sector 1) 5 (sector 2)	0,0196	1536	9 (sector 1) 10 (sector 2)	0,0141	2918,4
	#6	8	0,0074	1228,8	15	0,0137	2304
Year 5	#1.#2,#3,#4	8	0,0082	1228,8	15	0,0156	2304
	#5	5 (sector 1) 6 (sector 2)	0,0090	1689,6	9 (sector 1) 10 (sector 2)	0,0157	2918,4
	#6	8	0,0082	1228,8	15	0,0156	2304

Table 65. Number of required codes for the uplink and downlink when only data users are assumed and ideal coverage (Santa Clotilde)

Year	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
Year 1	#1.#2,#3,#4	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
Year 2	#1.#2,#3,#4	10	3	685,8	10	4	864,4
	#5	7 (sector 1) 6 (sector 2)	2 (sector 1) 2 (sector 2)	939,4	7 (sector 1) 6 (sector 2)	3 (sector 1) 3 (sector 2)	1246,6
	#6	10	3	685,8	10	4	864,4
Year 3	#1.#2,#3,#4	10	3	710,8	10	4	864,4
	#5	7 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	964,4	7 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1271,6
	#6	10	3	710,8	10	4	864,4
Year 4	#1.#2,#3,#4	10	3	710,8	10	4	864,4
	#5	7 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	964,4	7 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1271,6
	#6	10	3	710,8	10	4	864,4
Year 5	#1.#2,#3,#4	11	3	735,8	11	4	889,4
	#5	7 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	964,4	7 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1271,6
	#6	11	3	735.8	11	4	889,4

Table 66. Number of required codes for the uplink and downlink when voice and data users are assumed and ideal coverage (Negro Urco)

Year	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
Year 1	#1.#2,#3,#4	6	2	457,2	6	3	610,8
	#6	6	2	457,2	6	3	610,8
Year 1 Year 2	#1.#2,#3,#4	11	3	735,8	11	4	889,4
	#6	11	3	735,8	11	4	889,4
Year 2	#1.#2,#3,#4	11	3	735,8	11	4	889,4
	#6	11	3	735,8	11	4	889,4
Year 3	#1.#2,#3,#4	11	3	735,8	11	4	889,4
	#6	11	3	735,8	11	4	889,4
Year 4	#1.#2,#3,#4	11	3	735,8	11	4	889,4
	#6	11	3	735,8	11	4	889,4

Table 67. Number of required codes for the uplink and downlink when voice and data users are assumed and ideal coverage (Tuta Pisco)

Year	**HNB**	**Scenario**	**Uplink**			**Downlink**		
			Number of required circuits (VOICE)	**Number of required circuits (DATA)**	**Backhaul required (kbps)**	**Number of required circuits (VOICE)**	**Number of required circuits (DATA)**	**Backhaul required (kbps)**
Year 1	All HNBs	#1.#2,#3,#4	10	3	710,8	10	4	864,4
		#5	6 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	939,4	6 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1246,6
		#6	10	3	710,8	10	4	864,4
Year 2 Year 3	S-Class 16	#1.#2,#3,#4	-	-	-	-	-	-
		#5	12 (sector 1) 14 (sector 2)	3 (sector 1) 3 (sector 2)	1546,6	12 (sector 1) 14 (sector 2)	4 (sector 1) 5 (sector 2)	1957,4
		#6	22	4	1164,4	22	7	1575,2
	E-Class 24 and E-Class 24*	#1.#2,#3,#4	22	4	1114,4	22	7	1500,2
		#5	12 (sector 1) 14 (sector 2)	3 (sector 1) 3 (sector 2)	1571,6	12 (sector 1) 14 (sector 2)	4 (sector 1) 5 (sector 2)	1982,4
		#6	22	4	1164,4	22	7	1575,2
Year 4 Year 5	S-Class 16	#1.#2,#3,#4	-	-	-	-	-	-
		#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1546,6	12 (sector 1) 15 (sector 2)	4 (sector 1) 5 (sector 2)	1957,4
		#6	22	4	1164,4	22	7	1600,2
	E-Class 24 and E-Class 24*	#1.#2,#3,#4	-	-	-	-	-	-
		#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	4 (sector 1) 5 (sector 2)	2057,4
		#6	22	4	1164,4	22	7	1600,2
Year 1 Year 2	S-Class 16	#1.#2,#3,#4	-	-	-	-	-	-
		#5	12 (sector 1) 16 (sector 2)	3 (sector 1) 3 (sector 2)	1546,6	12 (sector 1) 16 (sector 2)	4 (sector 1) 6 (sector 2)	2086
		#6	23	4	1189,4	23	7	1600,2
	E-Class 24 and E-Class 24*	#1.#2,#3,#4	-	-	-	-	-	-
		#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	4 (sector 1) 5 (sector 2)	2057,4
		#6	23	4	1189,4	23	7	1600,2
Year 3	S-Class 16	#1.#2,#3,#4	-	-	-	-	-	-
		#5	-	-	-	-	-	-
		#6	23	4	1189,4	23	7	1625,2
	E-Class 24 and E-Class 24*	#1.#2,#3,#4	-	-	-	-	-	-
		#5	13 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1621,6	13 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
		#6	23	4	1189,4	23	7	1625,2

Table 68. Number of required codes for the uplink and downlink when voice and data users are assumed and ideal coverage (San Gabriel)

Year	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
Year 1	#1.#2,#3,#4	4	2	407.2	4	2	407.2
	#5	3 (sector 1) 3 (sector 2)	1 (sector 1) 1 (sector 2)	457,2	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	764,4
	#6	4	2	407.2	4	2	407.2
Year 2	#1.#2,#3,#4	6	2	457.2	6	3	610.8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610.8
Year 3	#1.#2,#3,#4	6	2	457.2	6	3	610.8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610.8
Year 4	#1.#2,#3,#4	6	2	457.2	6	3	610.8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610.8
Year 5	#1.#2,#3,#4	6	2	457.2	6	3	610.8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610.8

Table 69. Number of required codes for the uplink and downlink when voice and data users are assumed and ideal coverage (San Juan)

6.2.2 Realistic evaluation

Results with more realistic assumptions are displayed here, assuming the three types of ip.access HNBs, and simulated (adopting the models in 4.3.7 and hence lower than 1) coverage probabilities. Those situations where the target blocking probability cannot be achieved are marked with dashed symbol '-'. In all cases, results are shown in years 0 through 5, in different tables.

6.2.2.1 Santa Clotilde

Table 70 shows the required number of voice and data circuits in the first year. If we assume realistic coverage probabilities, scenario #6 fulfils the requirements with HNB S-Class 16 is used, while scenarios #5 and #6 satisfy the requirements with HNB E-Class 24. From the second year, it has been seen as any HNB does not have enough channelization codes to serve the expected voice traffic.

Thus, Table 71, Table 72, Table 73, Table 74 and Table 75 display the case of data-only traffic as none of the studied scenarios studied is able to accommodate mixed voice and data with the required blocking probability. It is certain that that the existing GSM network run by Telefonica del Peru could serve all voice traffic. In the first year, HNB S-Class 16 has enough codes and available power to satisfy the requirements for scenarios #5 and #6 are assumed. On the other hand, HNB E-Class 24 has enough codes and available power to satisfy the requirements for scenario #6, while and HNB E-Class 24* has enough codes and available power to satisfy the requirements for scenarios #3,#5 and #6 are assumed. Starting from the second year, only scenario #5 with HNB S-Class 16 and scenarios #5 and #6 for the HNB E-Class 24* can fulfil the requirements.

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	30	4	1239,4	30	8	1828,8
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	14 (sector 1) 17 (sector 2)	3 (sector 1) 3 (sector 2)	1671,6	14 (sector 1) 17 (sector 2)	5 (sector 1) 7 (sector 2)	2568,2
	#6	25	4	1239,4	25	8	1828,8

Table 70 . Number of required codes for the uplink and downlink when voice and data users are assumed (Santa Clotilde) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)	Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	3 (sector 1) 3 (sector 2)	0,0160	921,6	5 (sector 1) 6 (sector 2)	0,0123	1689,6
	#6	4	0.0146	614.4	7	0.0187	1075.2
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	4	0,0146	614,4	10	0,0197	1536
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	4	0,0147	614,4	10	0,0196	1536
	#5	3 (sector 1) 3 (sector 2)	0,0160	921,6	5 (sector 1) 5 (sector 2)	0,0182	1536
	#6	4	0.0146	614.4	7	0.0176	1075.2

Table 71 . Number of required codes for the uplink and downlink when only data users are assumed (Santa Clotilde) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)	Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	7	0,0152	1075,2	15	0,0153	2304
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	5 (sector 1) 5 (sector 2)	0,0155	1536	9 (sector 1) 11 (sector 1)	0,0155	3072
	#6	7	0,0152	1075,2	14	0,0188	2150,4

Table 72 . Number of required codes for the uplink and downlink when only data users are assumed (Santa Clotilde) – Year 2

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)	Number of required circuits (DATA)	Blocking probability	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	7	0,0187	1075,2	15	0,0198	2304
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	5 (sector 1) 5 (sector 2)	0,0183	1536	9 (sector 1) 11 (sector 1)	0,0177	3072
	#6	7	0,0187	1075,2	15	0,0146	2304

Table 73 . Number of required codes for the uplink and downlink when only data users are assumed (Santa Clotilde) – Year 3

HNB	**Scenario**	**Uplink**			**Downlink**		
		Number of required circuits (DATA)	**Blocking probability**	**Backhaul required (kbps)**	**Number of required circuits (DATA)**	**Blocking probability**	**Backhaul required (kbps)**
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	8	0,0074	1228,8	16	0,0147	2457,6
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	5 (sector 1) 5 (sector 2)	0,0196	1536	9 (sector 1) 11 (sector 1)	0,0187	3072
	#6	8	0,0074	1228,8	15	0,0165	2304

Table 74 . Number of required codes for the uplink and downlink when only data users are assumed (Santa Clotilde) – Year 4

HNB	**Scenario**	**Uplink**			**Downlink**		
		Number of required circuits (DATA)	**Blocking probability**	**Backhaul required (kbps)**	**Number of required circuits (DATA)**	**Blocking probability**	**Backhaul required (kbps)**
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	8	0,0082	1228,8	16	0,0163	2457,6
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	5 (sector 1) 6 (sector 2)	0,0090	1689,6	9 (sector 1) 11 (sector 1)	0,0198	3072
	#6	8	0,0082	1228,8	15	0,0185	2304

Table 75 . Number of required codes for the uplink and downlink when only data users are assumed (Santa Clotilde) – Year 5

6.2.2.2 Negro Urco

Table 76, Table 77, Table 78, Table 79 and Table 80 show the minimum number of voice and data circuits required to serve the expected traffic in Negro Urco during the first five years. In the first year, HNB S-Class 16 has enough circuits and available power if scenario #6 is assumed and HNB E-Class 24* has enough circuits and available power if scenarios #5 and #6 are assumed. From second year and on, only HNB E-Class 24* can satisfy the requirements if scenario #6 is assumed.

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8

Table 76 . Number of required codes for the uplink and downlink when voice and data users are assumed (Negro Urco) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	10	3	685,8	10	4	864,4

Table 77 . Number of required codes for the uplink and downlink when voice and data users are assumed (Negro Urco) – Year 2

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 78 . Number of required codes for the uplink and downlink when voice and data users are assumed (Negro Urco) – Year 3

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 79 . Number of required codes for the uplink and downlink when voice and data users are assumed (Negro Urco) – Year 4

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#4	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 80 . Number of required codes for the uplink and downlink when voice and data users are assumed (Negro Urco) – Year 5

6.2.2.3 Tuta Pisco

Table 81, Table 82, Table 83, Table 84 and Table 85 show the minimum number of voice and data circuits required to serve the expected traffic in Tuta Pisco during the first five years. In the first year, HNB S-Class 16 has enough circuits and available power if scenario #6 is assumed and HNB E-Class 24* has enough circuits and available power if scenarios #3 and #6 are assumed. Starting from the second year, only scenario #6 can be used for both HNBs.

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	6	2	457,2	6	4	764,4
	#6	6	2	457,2	6	3	610,8

Table 81 . Number of required codes for the uplink and downlink when voice and data users are assumed (Tuta Pisco) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	12	3	760,8	12	4	914,4
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 82 . Number of required codes for the uplink and downlink when voice and data users are assumed (Tuta Pisco) – Year 2

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	12	3	760,8	12	4	914,4
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 83 . Number of required codes for the uplink and downlink when voice and data users are assumed (Tuta Pisco) – Year 3

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	13	3	760,8	12	4	939,4
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 84 . Number of required codes for the uplink and downlink when voice and data users are assumed (Tuta Pisco) – Year 4

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	13	3	760,8	13	4	939,4
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	-	-	-	-	-	-
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#6	11	3	735,8	11	4	889,4

Table 85 . Number of required codes for the uplink and downlink when voice and data users are assumed (Tuta Pisco) – Year 5

6.2.2.4 San Gabriel

Table 86, Table 87, Table 88, Table 89 and Table 90 show the minimum number of voice and data circuits required to serve the expected traffic in San Gabriel during the first five years. In the first year, HNB S-Class 16 and HNB E-Class 24* have enough circuits and available power if any scenario is assumed, while HNB E-Class 24 has enough circuits and available power if scenarios #3, #5 and #6 are assumed. From second year, only scenario #6 can be used for both HNBs. it can be seen that due to the high expected traffic in this locality, only multi-cell scenarios can fulfill the requirements for 5 years: scenario #5 if HNB E-Class 24 or HNB E-Class 24* is used and scenario #6 for any HNB.

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	10	3	710,8	10	4	864,4
	#2	10	3	710,8	10	4	864,4
	#3	10	3	710,8	10	4	864,4
	#5	6 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	939,4	6 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1246,6
	#6	10	3	710,8	10	4	864,4
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	11	3	735,8	11	5	1043
	#5	6 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	939,4	6 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1246,6
	#6	10	3	710,8	10	4	864,4
E-Class 24*	#1	10	3	710,8	10	4	864,4
	#2	10	3	710,8	10	4	864,4
	#3	10	3	710,8	10	4	864,4
	#5	6 (sector 1) 7 (sector 2)	2 (sector 1) 2 (sector 2)	939,4	6 (sector 1) 7 (sector 2)	3 (sector 1) 3 (sector 2)	1246,6
	#6	10	3	710,8	10	4	864,4

Table 86 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Gabriel) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 14 (sector 2)	3 (sector 1) 3 (sector 2)	1546,6	12 (sector 1) 14 (sector 2)	5 (sector 1) 5 (sector 2)	2086
	#6	22	4	1164,4	22	7	1575,2
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 14 (sector 2)	3 (sector 1) 3 (sector 2)	1571,6	26	5 (sector 1) 5 (sector 2)	2161
	#6	22	4	1164,4	22	7	1600,2
E-Class 24*	#1	-	-	-	-	-	-
	#2	22	4	1114,4	22	7	1500,2
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 14 (sector 2)	3 (sector 1) 3 (sector 2)	1571,6	26	5 (sector 1) 4 (sector 2)	1982,4
	#6	22	4	1164,4	22	7	1575,2

Table 87 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Gabriel) – Year 2

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1546,6	12 (sector 1) 15 (sector 2)	5 (sector 1) 6 (sector 2)	2214,6
	#6	22	4	1164,4	22	7	1600,2
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
	#6	23	4	1164,4	23	7	1625,2
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
	#6	22	4	1164,4	22	7	1600,2

Table 88 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Gabriel) – Year 3

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	23	4	1189,4	23	7	1600,2
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
	#6	24	4	1189,4	24	7	1625,2
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	12 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1596,6	12 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
	#6	23	4	1189,4	23	7	1600,2

Table 89 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Gabriel) – Year 4

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	-	-	-	-	-	-
	#6	23	4	1189,4	23	7	1625,2
E-Class 24	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	13 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1621,6	13 (sector 1) 15 (sector 2)	5 (sector 1) 5 (sector 2)	2186
	#6	24	4	1189,4	24	7	1625,2
E-Class 24*	#1	-	-	-	-	-	-
	#2	-	-	-	-	-	-
	#3	-	-	-	-	-	-
	#5	13 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	1621,6	13 (sector 1) 15 (sector 2)	3 (sector 1) 3 (sector 2)	2186
	#6	23	4	1189,4	23	7	1625,2

Table 90 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Gabriel) – Year 5

6.2.2.5 San Juan

Table 91, Table 92, Table 93, Table 94 and Table 95 show the minimum number of voice and data circuits required to serve the expected traffic in San Juan during the first five years. Due to the traffic expected in this locality is low (few inhabitants), all HNBs have enough codes and available power for five years to serve all data and voice users for any scenario.

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	4	2	407,2	4	2	407,2
	#2	4	2	407,2	4	2	407,2
	#3	4	2	407,2	4	2	407,2
	#5	3 (sector 1) 3 (sector 2)	1 (sector 1) 1 (sector 2)	457,2	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	764,4
	#6	4	2	407,2	4	2	407,2
E-Class 24	#1	4	2	407,2	4	2	407,2
	#2	4	2	407,2	4	2	407,2
	#3	4	2	407,2	4	2	407,2
	#5	3 (sector 1) 3 (sector 2)	1 (sector 1) 1 (sector 2)	457,2	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	764,4
	#6	4	2	407,2	4	2	407,2
E-Class 24*	#1	4	2	407,2	4	2	407,2
	#2	4	2	407,2	4	2	407,2
	#3	4	2	407,2	4	2	407,2
	#5	3 (sector 1) 3 (sector 2)	1 (sector 1) 1 (sector 2)	457,2	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	764,4
	#6	4	2	407,2	4	2	407,2

Table 91 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Juan) – Year 1

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24*	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	3 (sector 1) 3 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8

Table 92 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Juan) – Year 2

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24*	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610,8

Table 93 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Juan) – Year 3

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24*	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610,8

Table 94 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Juan) – Year 4

HNB	Scenario	Uplink			Downlink		
		Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)	Number of required circuits (VOICE)	Number of required circuits (DATA)	Backhaul required (kbps)
S-Class 16	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457,2	6	3	610,8
E-Class 24*	#1	6	2	457,2	6	3	610,8
	#2	6	2	457,2	6	3	610,8
	#3	6	2	457,2	6	3	610,8
	#5	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4	4 (sector 1) 4 (sector 2)	2 (sector 1) 2 (sector 2)	814,4
	#6	6	2	457.2	6	3	610,8

Table 95 . Number of required codes for the uplink and downlink when voice and data users are assumed (San Juan) – Year 5

7 ENERGY PROVISION FOR HNB

7.1 Power consumption models of HNB

EARTH project provides a power consumption model for various types of LTE Base Stations in [EARTH-D23]. The model is useful for quantifying the energy losses of different BS components: antenna interface, power amplifier, radio frequency transceiver, baseband interface, AC/DC power supply, cooling and main supply. Thus, the power consumed by a base station is modeled as a function of the radiated power by [EARTH-D23]:

$$P_{in} = \begin{cases} N_{TRX}\left(P_0 + \Delta_p P_{RF}\right) & 0 < P_{RF} \le P_{\max} \\ N_{TRX} P_{sleep} & P_{RF} = 0 \end{cases} \tag{69}$$

where P_{max} is the maximum RF output power, P_0 is the linear model parameter to represent power consumption at zero RF output power, Δ_p is the slope of the load depending on the radiated power, N_{TRX} denotes the number of transmitter and receivers present at the base station and finally, P_{sleep} denotes the power consumed in the sleep mode. These parameters depend on the type of base station. For example Table 96 presents these values for Macro-, Micro-, Pico- y Femto- base stations.

BS type	N_{TRX}	P_{max} (W)	P_0 (W)	Δ_p	P_{sleep} (W)
Macro	6	20 (43 dBm)	130	4.7	75
Micro	2	6.3 (38 dBm)	56	2.6	39
Pico	2	0.13 (21 dBm)	6.8	4	4.3
Femto	2	0.05 (17 dBm)	4.8	8	2.9

Table 96. Power model parameters for different BS types

Figure 34 presents the consumed power in terms of dBW by the different BSs considered in Table 96 as a function of the RF output power. We can observe that the differences in consumed power at low/medium transmitted power and at full-load of the BSs are up to 2.3 dB, 0.9 dB, 0.31 dB, and 0.22 dB for macro-, micro-, pico- and femto-BS, respectively. Moreover the savings in consumed power at the BS when in sleep mode with respect to the active mode are around of 2 dB.

7.2 Radiated power evaluation

The objectives of this section are to analyse the radiated power by the HNB, or HNBs in multi-cell scenario, and to determine the expression of total radiated energy per day by HNBs. This radiated energy will be used on energy unit dimensioning.

First, we can obtain the distribution of transmitted powers by HNBs through the simulation tool. For different number of simultaneous users, a different transmitted power distribution can be obtained. We are interested in the average transmitted powers to evaluate the radiated power and therefore, the power control headroom and shadowing margin are not taken into account.

Figure 35 shows the average transmitted power for each number of simultaneous voice users when the scenario #2 and scenario #3 are assumed for Negro Urco location and HNB S-class 16 are used. It can be seen that if a configuration with a higher antenna gain is used, the average transmitted power by the HNB is lower.

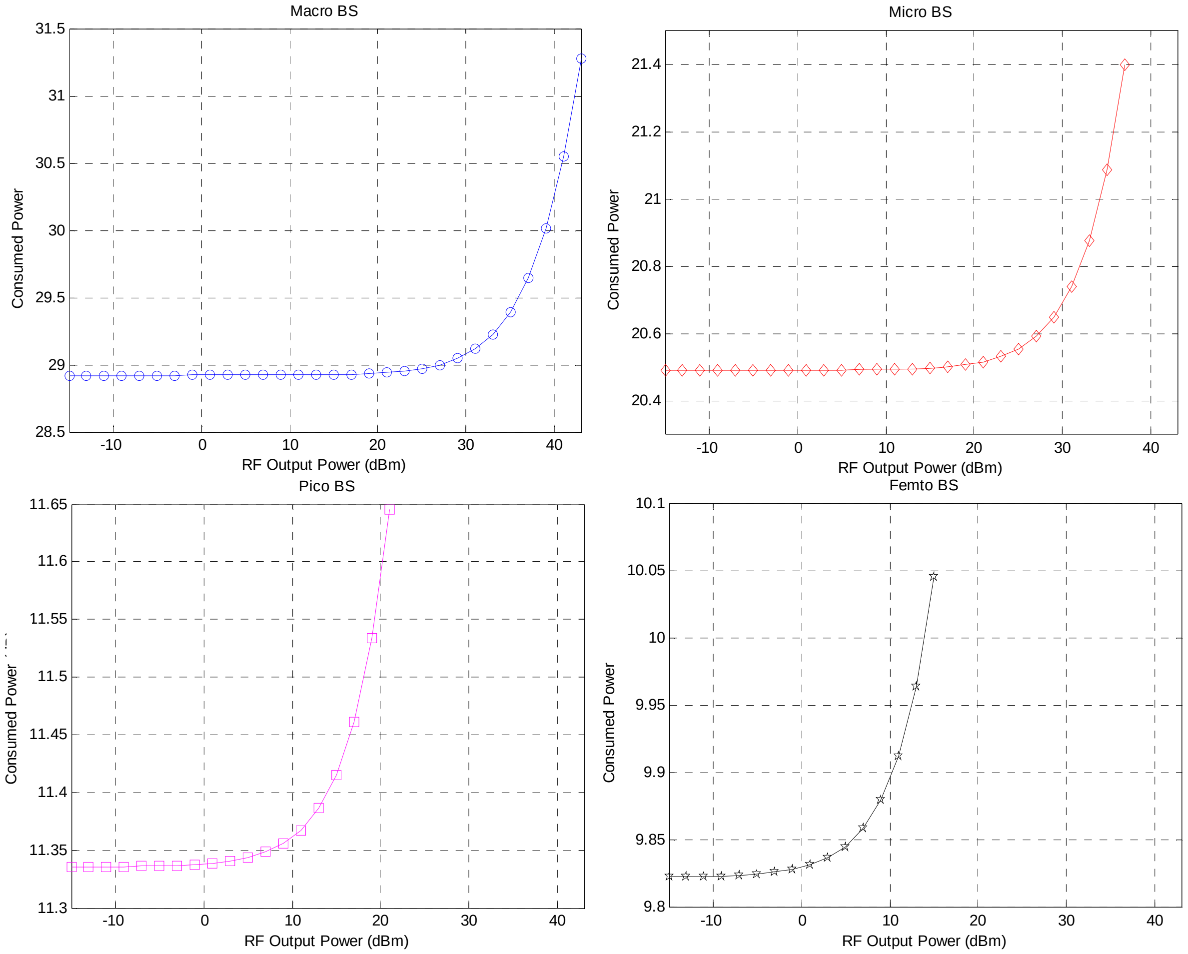


Figure 34. Total consumed power (dBW) as a function of the RF output power (dBm). Top-left: Macro BS, Top-right: Micro BS, Bottom-left: Pico BS and Bottom-right: Femto-BS

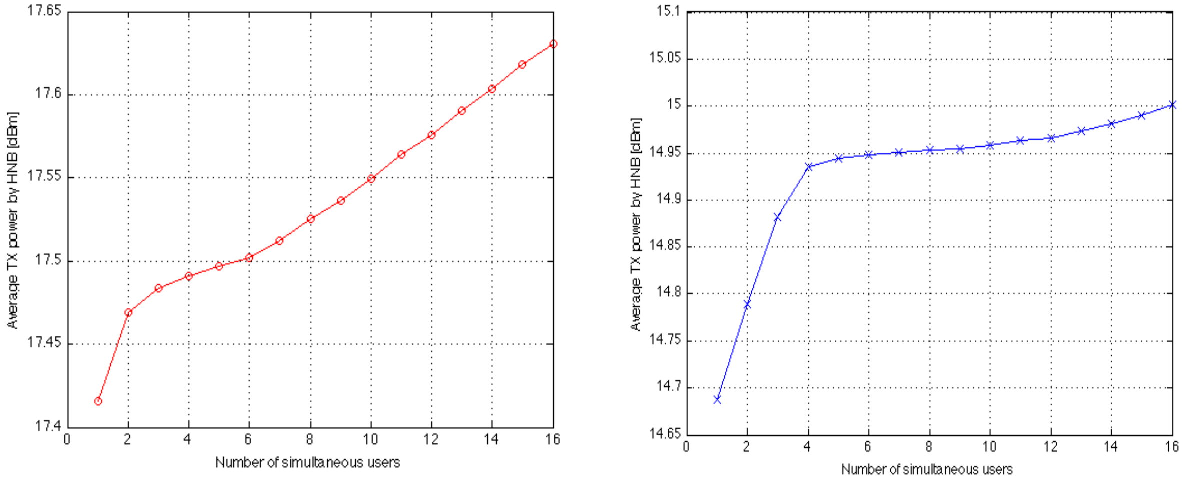


Figure 35. Average radiated powers (dBm) depending on the number of simultaneous voice users in Negro Urco and HNB S-class 16. Scenarios #2 (left) and #3 (right).

Figure 36 shows the probability density function of the radiated power for the scenario #2 when there are 6 simultaneous users on the network.

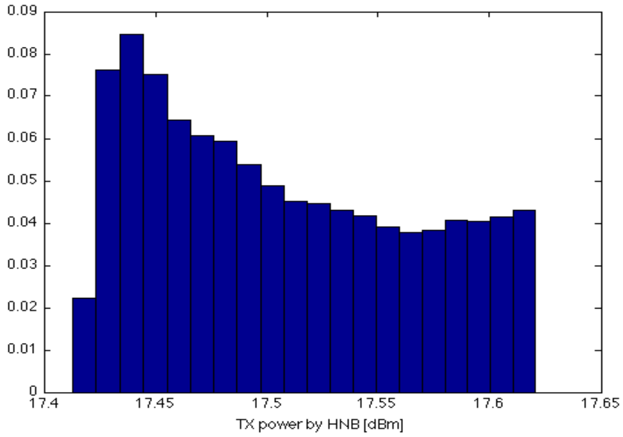


Figure 36. Probability density function of the radiated power (dBm) conditioned to the number of simultaneous users is equal to 6. Scenario #2 in Negro Urco, HNB S-class 16

Notice that the density function of the radiated power conditioned to the number of simultaneous users is not taken into account the variation of traffic density per hour along the day, but only depends on the traffic density assumptions on the geographical area. In following sections, the traffic variation along the day is important and it must be considered for energy unit dimensioning.

First, let $f\left(P_R | i\right)$ denotes the density function of the radiated power conditioned to i number of channels (or simultaneous users). This density function is depicted in Figure 36 for 6 simultaneous users. Let $p\left(i | h\right)$ denote the probability of the number of simultaneous users being *i,* for a certain hour h of the day. This last probability is the probability of state i in the Markov chain described in 4.4, for particular density traffic, λ/μ, which depends on the specific hour of the day (different traffic densities along the day are characterized in section 2.1).

Through different traffic densities per hour along the day and through the coverage probabilities defined in 4.3.7, we can compute all the probabilities of being i simultaneous users for each particular hour. Then, the density function of the total radiated power conditioned to a particular hour of the day can be expressed as

$$f(P_R \mid h) = \sum_{i=1}^{I} f(P_R \mid i) p(i \mid h) \tag{70}$$

where I denotes the maximum number of simultaneous channels supported by the network, as obtained from the target blocking probability, and specified in section 6 for each location, scenario and HNB type. Finally, we compute the average radiated energy by the HNB along the day. Let $\overline{P_R}(h)$ denote the average radiated power by the HNB depending on the hour of the day:

$$\overline{P}_R(h) = \int P_R \cdot f(P_R \mid h) \cdot dP_R \tag{71}$$

and the average radiated energy by the HNB along the day in $W{\cdot}h$ will be given by

$$L = \sum_{h=0}^{23} \overline{P}_R(h) \tag{72}$$

7.3 Dimensioning of energy units

7.3.1 General evaluation methodology

For the energy units dimensioning we follow the methodology explained in [Rendon11]. The total energy that the solar panels have to generate is (in Watts·hour, *Wh*)

$$E_{SP} = L\left(1+\eta_G\right) f_c \tag{73}$$

where L is the total energy required by the systems, η_G denotes the losses due to the inefficiency of the solar cells (around 10%) and f_c is a correction factor (f_c=1.3) introduced as the solar cells have to generate energy for the system and for the batteries that are accumulating the energy.

The number of solar panels depends on the solar radiation in the place of interest and nominal power (P_{nom}) of the solar cells. The nominal power is obtained assuming that solar radiation si 1000 Wh/m^2:

$$n_{SP} = \frac{L\left(1+\eta_G\right) f_c}{P_{nom}\frac{G_{dm}}{1000}} \tag{74}$$

where G_{dm} is taken as the average daily solar radiation during the worst month of the year (for example in the Loreto region in Peru, where solar radiation is 4270 Wh/m^2).

The capacity of the batteries (in *Wh*) should be enough to provide electrical energy to the system to be up to N_{da} days without any charging procedure. Therefore the capacity of the batteries must satisfy,

$$C_B = L\left(1+\eta_G\right)\frac{N_{da}}{P_{d\max}} \tag{75}$$

where P_{dmax} is a parameter to impose that a battery should have at least 20% of its maximum capacity (P_{dmax}=0.8). The number of required batteries becomes

$$n_B = \frac{C_B}{C_1} \tag{76}$$

where C_1 is the capacity of a single battery which is obtained from the product data sheet ($Ah \times V$).

7.3.2 Application to TUCAN3G sites

In order to dimension the energy units we have selected the same type of batteries and solar cells as a reference, which are currently used in the WiFi long distance network [TUCAN3G-D21]

- Battery: Ritar (12 V, 100 Ah C_1 = 1200 Ah×V)
- Solar cell: Solar World (P_{nom} = 85 W per panel)

The number of solar panels and batteries will be obtained from equations (74) and (76), respectively, assuming N_{da}=3 days without any battery charging, as the worst case. The total power consumed by the HNB is calculated taking into account the radiated power along the day obtained in section 7.2 and the power consumption model presented in (69), section 7.1. We have selected the *femtocell model* and *picocell model* in Table 96 to estimate the consumed power of the HNB selected in TUCAN3G.

Table 97 and Table 98 present the number of solar panels and batteries required by a single-HNB or two-HNB installation in case the HNBs were working 24h a day and using all the transmitted power (HNB S-Class 16: 20 dBm, HNB E-Class 24: 13 dBm and HNB E-Class 24*: 24 dBm). The total number of required energy units can be obtained from tables, rounded up to the nearest integer. Energy units are expressed in rational numbers in tables in order to be able to compare the different energy consumption according to the specific scenario and selected HNB types.

HNB type	Femtocell Power consumption model		Picocell Power consumption model	
	Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	1.0591	0.9240	1.3616	1.1880
E-Class 24	0.9379	0.8183	1.30	1.1344
E-Class 24*	1.2878	0.8183	1.4760	1.2878

Table 97. Dimensioning of single-HNB installation transmitting 24h at maximum power

HNB type	Femtocell Power consumption model		Picocell Power consumption model	
	Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	2.1182	1.8480	2.7232	2.3760
E-Class 24	1.8758	1.6366	2.60	2.2688
E-Class 24*	2.5756	1.6366	2.952	2.5756

Table 98. Dimensioning of two-HNB installation transmitting 24h at maximum power

In general, HNBs are not always using all the transmitted power, and varies according to the traffic demands. Consequently, the assumption of full power transmission 24h per day is rather pessimistic. Therefore, we have evaluated the probability density function of the transmitted power per HNB on each hour according to the guidelines of section 7.2, and we have calculated the required total energy per each type of HNB in average.

In the following sections the energy dimensioning for all locations is shown, using these assumptions. For completeness, all scenarios have been evaluated. It is understood that the given values have to be rounded up to determine the number of solar panels and batteries in every scenario and location.

7.3.2.1 Dimensioning for voice traffic

This section shows the results obtained from the energy unit dimensioning for each locality, assuming that the radiated power by the HNB varies along the day according to the daily profile of voice traffic, which is given in section 2.1.1. Through equations in section 7.2, the average radiated energy by the HNB type along the day is computed for each valid scenario/HNB obtained during the backhaul dimensioning in section 6.1.2. Then, through this average radiated energy along the day, energy units are dimensioned as mentioned in section 7.3.

7.3.2.1.1 Santa Clotilde

Table 99, Table 100, Table 101, Table 102 and Table 103 show the dimensioning of energy units for Santa Clotilde during the first five years assuming only voice users. Those situations where the target blocking probability cannot be achieved are marked with dash symbol ‘x‘. As seen in 6.1.2.1, starting from the second year, there is no HNB to provide enough codes to serve the expected voice traffic using any scenario. Notice that E-Class 24* consumes more energy than S-Class 16 in the first year for scenario #6. It happens because the power allocated by common channels is higher when E-Class 24* as it is mentioned in Table 18. Energy consumption for scenario #5 is lower than for scenario #6 since selected antennas have higher gain in scenario #5 and therefore, the power intended to serve users and for common channels is less.

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8624	1,6249	2,5954	2,2644
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9169	1,6724	2,6227	2,2882
	#6	1,9179	1,6733	2,6232	2,2887

Table 99. Energy dimensioning when voice traffic is assumed (Santa Clotilde) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×

Table 100. Energy dimensioning when voice traffic is assumed (Santa Clotilde) – Year 2

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×

Table 101. Energy dimensioning when voice traffic is assumed (Santa Clotilde) – Year 3

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×

Table 102. Energy dimensioning when voice traffic is assumed (Santa Clotilde) – Year 4

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×

Table 103. Energy dimensioning when voice traffic is assumed (Santa Clotilde) – Year 5

7.3.2.1.2 Negro Urco

Table 104, Table 105, Table 106, Table 107 and Table 108 shows the dimensioning of energy units for Negro Urco during the first five years assuming only voice users. Notice that energy consumption is lower if scenario #4 is assumed since it uses antennas with high gain. Obviously, multi-cell scenarios consume more energy than isolated-cell scenarios.

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9281	0,8098	1,2962	1,1309
	#5	1,8567	1,6200	2,5926	2,2620
	#6	1,9098	1,6663	2,6191	2,2851
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	1,0040	0,8760	1,3341	1,1640
	#3	0,9634	0,8406	1,3138	1,1463
	#4	0,9584	0,8362	1,3113	1,1441
	#5	1,9166	1,6722	2,6225	2,2881
	#6	1,9262	1,6806	2,6273	2,2923

Table 104. Energy dimensioning when voice traffic is assumed (Negro Urco) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9107	1,6671	2.6196	2,2855
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9593	0,8370	1,3118	1,1445
	#5	1,9174	1,6729	2,6229	2,2885
	#6	1,9274	1,6816	2,6279	2,2928

Table 105. Energy dimensioning when voice traffic is assumed (Negro Urco) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9108	1,6671	2,6196	2,2856
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9594	0,8370	1,3118	1,1445
	#5	1,9175	1,6730	2,6230	2,2885
	#6	1,9275	1,6817	2,6280	2,2929

Table 106. Energy dimensioning when voice traffic is assumed (Negro Urco) – Year 3

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9108	1,6671	2,6196	2,2856
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9594	0,8371	1,3118	1,1445
	#5	1,9175	1,6730	2,6230	2,2885
	#6	1,9276	1,6817	2,6280	2,2929

Table 107. Energy dimensioning when voice traffic is assumed (Negro Urco) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9109	1,6672	2,6197	2,2856
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9594	0,8371	1,3118	1,1445
	#5	1,9176	1,6730	2,6230	2,2885
	#6	1,9276	1,6818	2,6280	2,2929

Table 108. Energy dimensioning when voice traffic is assumed (Negro Urco) – Year 5

7.3.2.1.3 Tuta Pisco

Table 109, Table 110, Table 111, Table 112 and Table 113 shows the dimensioning of energy units for Tuta Pisco during the first five years assuming only voice users.

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9346	0,8154	1,2994	1,1337
	#6	1,8689	1,6306	2,5987	2,2673
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	0,9854	0,8598	1,3248	1,1559
	#2	0,9618	0,8391	1,3130	1,1456
	#3	0,9586	0,8364	1,3114	1,1442
	#6	1,9166	1,6722	2,6226	2,2881

Table 109. Energy dimensioning when voice traffic is assumed (Tuta Pisco) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8695	1,6311	2,5990	2,2676
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9598	0,8374	1,3120	1,1447
	#6	1,9177	1,6731	2,6231	2,2886

Table 110. Energy dimensioning when voice traffic is assumed (Tuta Pisco) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8696	1,6312	2,5990	2,2676
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9599	0,8374	1,3120	1,1447
	#6	1,9178	1,6732	2,6231	2,2886

Table 111. Energy dimensioning when voice traffic is assumed (Tuta Pisco) – Year 3

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8696	1,6312	2,5990	2,2676
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9599	0,8375	1,3121	1,1447
	#6	1,9178	1,6732	2,6231	2,2886

Table 112. Energy dimensioning when voice traffic is assumed (Tuta Pisco) – Year 4

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8696	1,6312	2,5990	2,2676
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9599	0,8375	1,3121	1,1448
	#6	1,9178	1,6733	2,6231	2,2886

Table 113. Energy dimensioning when voice traffic is assumed (Tuta Pisco) – Year 5

7.3.2.1.4 San Gabriel

Table 114, Table 115, Table 116, Table 117 and Table 118 shows the dimensioning of energy units for San Gabriel during the first five years assuming only voice users.

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,9279	0,8096	1,2961	1,1308
	#2	0,9278	0,8095	1,2960	1,1307
	#3	0,9278	0,8094	1,2960	1,1307
	#5	1,8552	1,6186	2,5918	2,2613
	#6	1,8553	1,6187	2,5919	2,2613
E-Class 24	#1	0,9119	0,7956	1,2881	1,1238
	#2	0,9119	0,7956	1,2880	1,1238
	#3	0,9118	0,7955	1,2880	1,1238
	#5	1,8235	1,5909	2,5760	2,2475
	#6	1,8235	1,5910	2,5760	2,2475
E-Class 24*	#1	0,9580	0,8358	1,3111	1,1439
	#2	0,9579	0,8357	1,3111	1,1439
	#3	0,9579	0,8358	1,3111	1,1439
	#5	1,9151	1,6709	2,6218	2,2875
	#6	1,9153	1,6710	2,6219	2,2875

Table 114. Energy dimensioning when voice traffic is assumed (San Gabriel) – Year 1

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8556	1,6190	2,5920	2,2615
	#6	1,8557	1,6191	2,5921	2,2615
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8235	1,5910	2,5760	2,2475
	#6	1,8237	1,5911	2,5761	2,2476
E-Class 24*	#1	0,9592	0,8369	1,3117	1,1444
	#2	0,9590	0,8367	1,3116	1,1444
	#3	0,9590	0,8367	1,3116	1,1444
	#5	1,9160	1,6717	2,6222	2,2878
	#6	1,9163	1,6719	2,6224	2,2880

Table 115. Energy dimensioning when voice traffic is assumed (San Gabriel) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_{B}	*Solar panels* n_{SP}	*Batteries* n_{B}
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8556	1,6190	2,5921	2,2615
	#6	1,8558	1,6191	2,5921	2,2616
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8235	1,5910	2,5760	2,2475
	#6	1,8237	1,5911	2,5761	2,2476
E-Class 24*	#1	0,9593	0,8370	1,3118	1,1445
	#2	0,9591	0,8368	1,3117	1,1444
	#3	0,9591	0,8368	1,3117	1,1444
	#5	1,9161	1,6717	2,6223	2,2879
	#6	1,9164	1,6720	2,6224	2,2880

Table 116. Energy dimensioning when voice traffic is assumed (San Gabriel) – Year 3

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_{B}	*Solar panels* n_{SP}	*Batteries* n_{B}
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8557	1,6190	2,5921	2,2615
	#6	1,8558	1,6191	2,5921	2,2616
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8236	1,5910	2,5760	2,2475
	#6	1,8237	1,5911	2,5761	2,2476
E-Class 24*	#1	0,9594	0,8370	1,3118	1,1445
	#2	0,9591	0,8368	1,3117	1,1444
	#3	0,9592	0,8369	1,3117	1,1444
	#5	1,9161	1,6718	2,6223	2,2879
	#6	1,9164	1,6720	2,6224	2,2880

Table 117. Energy dimensioning when voice traffic is assumed (San Gabriel) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8557	1,6190	2,5921	2,2615
	#6	1,8558	1,6191	2,5921	2,2616
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	1,8236	1,5910	2,5760	2,2475
	#6	1,8237	1,5911	2,5761	2,2476
E-Class 24*	#1	0,9594	0,8371	1,3118	1,1445
	#2	0,9592	0,8369	1,3117	1,1444
	#3	0,9592	0,8369	1,3117	1,1444
	#5	1,9162	1,6718	2,6223	2,2879
	#6	1,9165	1,6721	2,6225	2,2880

Table 118. Energy dimensioning when voice traffic is assumed (San Gabriel) – Year 5

7.3.2.1.5 San Juan

Table 119, Table 120, Table 121, Table 122 and Table 123 show the dimensioning of energy units for Tuta Pisco during the first five years assuming only voice users.

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92753	0,80925	1,29588	1,13062
	#2	0,92753	0,80925	1,29588	1,13062
	#3	0,92755	0,80926	1,29589	1,13063
	#5	1,85504	1,61848	2,59175	2,26124
	#6	1,85508	1,61851	2,59177	2,26125
E-Class 24	#1	0,91171	0,79545	1,28797	1,12372
	#2	0,91171	0,79544	1,28797	1,12372
	#3	0,91172	0,79545	1,28797	1,12373
	#5	1,82341	1,59089	2,57594	2,24744
	#6	1,82343	1,59090	2,57594	2,24745
E-Class 24*	#1	0,95741	0,83532	1,31082	1,14366
	#2	0,95741	0,83531	1,31082	1,14366
	#3	0,95743	0,83533	1,31083	1,14367
	#5	1,91478	1,67060	2,62162	2,28730
	#6	1,91481	1,67062	2,62163	2,28731

Table 119. Energy dimensioning when voice traffic is assumed (San Juan) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92756	0,80927	1,29590	1,13064
	#2	0,92756	0,80927	1,29589	1,13064
	#3	0,92758	0,80929	1,29591	1,13065
	#5	1,85507	1,61850	2,59176	2,26125
	#6	1,85511	1,61853	2,59178	2,26127
E-Class 24	#1	0,91172	0,79545	1,28797	1,12373
	#2	0,91172	0,79545	1,28797	1,12373
	#3	0,91173	0,79546	1,28798	1,12373
	#5	1,82342	1,59089	2,57594	2,24745
	#6	1,82344	1,59091	2,57595	2,24745
E-Class 24*	#1	0,95748	0,83538	1,31086	1,14369
	#2	0,95748	0,83538	1,31085	1,14369
	#3	0,95750	0,83540	1,31087	1,14370
	#5	1,91484	1,67065	2,62165	2,28733
	#6	1,91488	1,67069	2,62167	2,28734

Table 120. Energy dimensioning when voice traffic is assumed (San Juan) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92756	0,80928	1,29590	1,13064
	#2	0,92756	0,80927	1,29589	1,13064
	#3	0,92758	0,80930	1,29591	1,13065
	#5	1,85507	1,61850	2,59176	2,26125
	#6	1,85511	1,61854	2,59178	2,26127
E-Class 24	#1	0,91172	0,79545	1,28797	1,12373
	#2	0,91172	0,79545	1,28797	1,12373
	#3	0,91173	0,79546	1,28798	1,12373
	#5	1,82342	1,59089	2,57594	2,24745
	#6	1,82344	1,59091	2,57595	2,24745
E-Class 24*	#1	0,95749	0,83539	1,31086	1,14369
	#2	0,95748	0,83538	1,31086	1,14369
	#3	0,95751	0,83540	1,31087	1,14370
	#5	1,91485	1,67066	2,62165	2,28733
	#6	1,91489	1,67069	2,62167	2,28735

Table 121. Energy dimensioning when voice traffic is assumed (San Juan) – Year 3

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92756	0,80928	1,29590	1,13064
	#2	0,92756	0,80927	1,29590	1,13064
	#3	0,92759	0,80930	1,29591	1,13065
	#5	1,85507	1,61850	2,59176	2,26125
	#6	1,85511	1,61854	2,59178	2,26127
E-Class 24	#1	0,91172	0,79545	1,28797	1,12373
	#2	0,91172	0,79545	1,28797	1,12373
	#3	0,91173	0,79546	1,28798	1,12373
	#5	1,82342	1,59089	2,57594	2,24745
	#6	1,82344	1,59091	2,57595	2,24745
E-Class 24*	#1	0,95749	0,83539	1,31086	1,14369
	#2	0,95749	0,83538	1,31086	1,14369
	#3	0,95751	0,83541	1,31087	1,14370
	#5	1,91485	1,67066	2,62165	2,28733
	#6	1,91489	1,67069	2,62167	2,28735

Table 122. Energy dimensioning when voice traffic is assumed (San Juan) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92757	0,80928	1,29590	1,13064
	#2	0,92756	0,80928	1,29590	1,13064
	#3	0,92759	0,80930	1,29591	1,13065
	#5	1,85507	1,61851	2,59177	2,26125
	#6	1,85511	1,61854	2,59178	2,26127
E-Class 24	#1	0,91172	0,79545	1,28797	1,12373
	#2	0,91172	0,79545	1,28797	1,12373
	#3	0,91173	0,79546	1,28798	1,12373
	#5	1,82342	1,59089	2,57594	2,24745
	#6	1,82344	1,59091	2,57595	2,24745
E-Class 24*	#1	0,95749	0,83539	1,31086	1,14369
	#2	0,95749	0,83539	1,31086	1,14369
	#3	0,95751	0,83541	1,31087	1,14370
	#5	1,91485	1,67066	2,62165	2,28733
	#6	1,91489	1,67070	2,62167	2,28735

Table 123. Energy dimensioning when voice traffic is assumed (San Juan) – Year 5

7.3.2.2 Dimensioning for mixed voice and data traffic

This section shows the results obtained in the dimensioning of energy units for each locality, assuming that the radiated power by the HNB varies along the day according to the daily profile of voice and data traffic given in sections 2.1.1 and 2.1.2. Through equations in section 7.2, the average radiated energy by the HNB along the day is computed for each valid scenario/HNB obtained during the backhaul dimensioning in section 6.1.2. Then, through this average radiated energy along the day, the dimensioning of energy units is done as mentioned in section 7.3.

7.3.2.2.1 Santa Clotilde

Table 124 shows the dimensioning of energy units for Santa Clotilde in the first year assuming voice and data users. As seen in 6.2.2, from second year there is no HNB that can satisfy the requirements if mixed traffic is assumed. Thereforem, Table 125, Table 126, Table 127, Table 128 and Table 129 show the dimensioning of energy units for Santa Clotilde during the first five years assuming only data users.

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8645	1,6267	2,5965	2,2654
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9203	1,6754	2,6244	2,2897
	#6	1,9221	1,6770	2,6253	2,2905

Table 124. Energy dimensioning when mixed traffic is assumed (Santa Clotilde) – Year 1

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8575	1,6206	2,5930	2,2623
	#6	1,8588	1,6218	2,5936	2,2629
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8412	1,6064	2,5848	2,2552
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9625	0,8397	1,3133	1,1459
	#5	1,9201	1,6752	2,6243	2,2896
	#6	1,9221	1,6770	2,6253	2,2905

Table 125. Energy dimensioning when only data traffic is assumed (Santa Clotilde) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8614	1,6241	2,5949	2,2640
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9248	1,6794	2,6266	2,2917
	#6	1,9276	1,6817	2,6280	2,2929

Table 126. Energy dimensioning when only data traffic is assumed (Santa Clotilde) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8616	1,6242	2,5950	2,2641
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9252	1,6797	2,6268	2,2919
	#6	1,9280	1,6822	2,6283	2,2931

Table 127. Energy dimensioning when only data traffic is assumed (Santa Clotilde) – Year 3

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8617	1,6243	2,5951	2,2642
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9254	1,6799	2,6269	2,2919
	#6	1,9282	1,6823	2,6283	2,2932

Table 128. Energy dimensioning when only data traffic is assumed (Santa Clotilde) – Year 4

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8618	1,6244	2,5951	2,2642
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9256	1,6800	2,6270	2,2920
	#6	1,9284	1,6825	2,6284	2,2933

Table 129. Energy dimensioning when only data traffic is assumed (Santa Clotilde) – Year 5

7.3.2.2.2 Negro Urco

Table 130, Table 131, Table 132, Table 133 and Table 134 show the dimensioning of energy units for Negro Urco during the first five years assuming voice and data users. Notice that the energy consumption when mixed traffic is assumed is slightly higher than only voice traffic is assumed (section 7.3.2.1.2) because of the rise in transmitted power to serve data users (power for common channels is the same).

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9118	1,6680	2,6201	2,2860
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	0,9596	0,8373	1,3119	1,1446
	#5	1,9189	1,6742	2,6237	2,2891
	#6	1,9291	1,6831	2,6288	2,2936

Table 130. Energy dimensioning when mixed traffic is assumed (Negro Urco) – Year 1

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9313	1,6850	2,6299	2,2945

Table 131. Energy dimensioning when mixed traffic is assumed (Negro Urco) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9315	1,6852	2,6300	2,2946

Table 132. Energy dimensioning when mixed traffic is assumed (Negro Urco) – Year 3

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9315	1,6852	2,6300	2,2946

Table 133. Energy dimensioning when mixed traffic is assumed (Negro Urco) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#4	×	×	×	×
	#5	×	×	×	×
	#6	1,9316	1,6853	2,6300	2,2946

Table 134. Energy dimensioning when mixed traffic is assumed (Negro Urco) – Year 5

7.3.2.2.3 Tuta Pisco

Table 135, Table 136, Table 137, Table 138 and Table 139 show the dimensioning of energy units for Tuta Pisco during the first five years assuming voice and data users.

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8703	1,6318	2,5994	2,2679
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9600	0,8376	1,3121	1,1448
	#6	1,9190	1,6743	2,6237	2,2891

Table 135. Energy dimensioning when mixed traffic is assumed (Tuta Pisco) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8714	1,6327	2,5999	2,2684
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,9210	1,6760	2,6247	2,2900

Table 136. Energy dimensioning when mixed traffic is assumed (Tuta Pisco) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8715	1,6328	2,6000	2,2684
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,9211	1,6761	2,6248	2,2901

Table 137. Energy dimensioning when mixed traffic is assumed (Tuta Pisco) – Year 3

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8715	1,6328	2,6000	2,2684
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,9212	1,6762	2,6248	2,2901

Table 138. Energy dimensioning when mixed traffic is assumed (Tuta Pisco) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,8715	1,6329	2,6000	2,2684
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	×	×	×	×
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#6	1,9212	1,6762	2,6248	2,2901

Table 139. Energy dimensioning when mixed traffic is assumed (Tuta Pisco) – Year 5

7.3.2.2.4 San Gabriel

Table 140, Table 141, Table 142, Table 143 and Table 144 show the dimensioning of energy units for San Gabriel during the first five years assuming voice and data users.

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,9284	0,8100	1,2963	1,1310
	#2	0,9283	0,8099	1,2963	1,1310
	#3	0,9282	0,8098	1,2962	1,1309
	#5	1,8558	1,6191	2,5921	2,2616
	#6	1,8559	1,6192	2,5922	2,2616
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	0,9119	0,7956	1,2881	1,1238
	#5	1,8236	1,5910	2,5760	2,2475
	#6	1,8237	1,5911	2,5761	2,2476
E-Class 24*	#1	0,9591	0,8368	1,3117	1,1444
	#2	0,9589	0,8366	1,3116	1,1443
	#3	0,9590	0,8367	1,3116	1,1443
	#5	1,9164	1,6720	2,6224	2,2880
	#6	1,9167	1,6722	2,6226	2,2881

Table 140. Energy dimensioning when mixed traffic is assumed (San Gabriel) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8567	1,6199	2,5926	2,2620
	#6	1,8569	1,6201	2,5927	2,2621
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8238	1,5912	2,5761	2,2476
	#6	1,8240	1,5914	2,5762	2,2477
E-Class 24*	#1	×	×	×	×
	#2	0,9618	0,8392	1,3130	1,1456
	#3	×	×	×	×
	#5	1,9186	1,6739	2,6235	2,2890
	#6	1,9191	1,6743	2,6238	2,2892

Table 141. Energy dimensioning when mixed traffic is assumed (San Gabriel) – Year 2

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8568	1,6200	2,5926	2,2620
	#6	1,8570	1,6202	2,5927	2,2621
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8238	1,5912	2,5761	2,2476
	#6	1,8240	1,5914	2,5763	2,2477
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9188	1,6741	2,6236	2,2891
	#6	1,9193	1,6745	2,6239	2,2893

Table 142. Energy dimensioning when mixed traffic is assumed (San Gabriel) – Year 3

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8570	1,6202	2,5928	2,2621
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8238	1,5912	2,5761	2,2476
	#6	1,8241	1,5914	2,5763	2,2477
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9189	1,6742	2,6237	2,2891
	#6	1,9194	1,6746	2,6239	2,2893

Table 143. Energy dimensioning when mixed traffic is assumed (San Gabriel) – Year 4

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	×	×	×	×
	#6	1,8571	1,6203	2,5928	2,2621
E-Class 24	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,8238	1,5912	2,5761	2,2476
	#6	1,8241	1,5915	2,5763	2,2477
E-Class 24*	#1	×	×	×	×
	#2	×	×	×	×
	#3	×	×	×	×
	#5	1,9190	1,6743	2,6237	2,2891
	#6	1,9195	1,6747	2,6240	2,2893

Table 144. Energy dimensioning when mixed traffic is assumed (San Gabriel) – Year 5

7.3.2.2.5 San Juan

Table 145, Table 146, Table 147, Table 148 and Table 149 show the dimensioning of energy units for San Juan during the first five years assuming voice and data users.

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_{B}	*Solar panels* n_{SP}	*Batteries* n_{B}
S-Class 16	#1	0,92768	0,80938	1,29595	1,13069
	#2	0,92767	0,80937	1,29595	1,13069
	#3	0,92772	0,80941	1,29597	1,13071
	#5	1,85532	1,61872	2,59189	2,26136
	#6	1,85538	1,61878	2,59192	2,26139
E-Class 24	#1	0,91175	0,79548	1,28799	1,12374
	#2	0,91174	0,79547	1,28799	1,12374
	#3	0,91176	0,79549	1,28800	1,12375
	#5	1,82348	1,59094	2,57597	2,24747
	#6	1,82351	1,59097	2,57598	2,24748
E-Class 24*	#1	0,95777	0,83563	1,31100	1,14382
	#2	0,95777	0,83563	1,31100	1,14381
	#3	0,95781	0,83567	1,31102	1,14383
	#5	1,91545	1,67118	2,62195	2,28759
	#6	1,91551	1,67123	2,62198	2,28762

Table 145. Energy dimensioning when mixed traffic is assumed (San Juan) – Year 1

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_{B}	*Solar panels* n_{SP}	*Batteries* n_{B}
S-Class 16	#1	0,92776	0,80945	1,29599	1,13072
	#2	0,92775	0,80944	1,29599	1,13072
	#3	0,92780	0,80949	1,29602	1,13074
	#5	1,85538	1,61878	2,59192	2,26139
	#6	1,85546	1,61885	2,59196	2,26142
E-Class 24	#1	0,91177	0,79549	1,28800	1,12375
	#2	0,91176	0,79549	1,28799	1,12374
	#3	0,91178	0,79551	1,28801	1,12375
	#5	1,82349	1,59095	2,57597	2,24748
	#6	1,82353	1,59099	2,57599	2,24749
E-Class 24*	#1	0,95796	0,83580	1,31110	1,14390
	#2	0,95795	0,83579	1,31109	1,14390
	#3	0,95801	0,83584	1,31112	1,14392
	#5	1,91561	1,67133	2,62204	2,28766
	#6	1,91568	1,67139	2,62207	2,28769

Table 146. Energy dimensioning when mixed traffic is assumed (San Juan) – Year 2

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92776	0,80945	1,29600	1,13073
	#2	0,92776	0,80945	1,29599	1,13072
	#3	0,92781	0,80949	1,29602	1,13075
	#5	1,85539	1,61878	2,59192	2,26139
	#6	1,85547	1,61885	2,59196	2,26143
E-Class 24	#1	0,91177	0,79549	1,28800	1,12375
	#2	0,91176	0,79549	1,28799	1,12374
	#3	0,91178	0,79551	1,28801	1,12375
	#5	1,82349	1,59095	2,57598	2,24748
	#6	1,82353	1,59099	2,57599	2,24749
E-Class 24*	#1	0,95798	0,83581	1,31110	1,14391
	#2	0,95797	0,83581	1,31110	1,14390
	#3	0,95803	0,83586	1,31113	1,14393
	#5	1,91563	1,67134	2,62204	2,28767
	#6	1,91570	1,67140	2,62208	2,28770

Table 147. Energy dimensioning when mixed traffic is assumed (San Juan) – Year 3

HNB	Scenario	Femtocell power consumption		Picocell power consumption	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92777	0,80945	1,29600	1,13073
	#2	0,92776	0,80945	1,29599	1,13072
	#3	0,92781	0,80949	1,29602	1,13075
	#5	1,85539	1,61878	2,59193	2,26139
	#6	1,85547	1,61885	2,59196	2,26143
E-Class 24	#1	0,91177	0,79550	1,28800	1,12375
	#2	0,91176	0,79549	1,28800	1,12374
	#3	0,91178	0,79551	1,28801	1,12376
	#5	1,82349	1,59095	2,57598	2,24748
	#6	1,82353	1,59099	2,57600	2,24749
E-Class 24*	#1	0,95798	0,83582	1,31111	1,14391
	#2	0,95798	0,83581	1,31110	1,14391
	#3	0,95804	0,83586	1,31113	1,14393
	#5	1,91563	1,67134	2,62204	2,28767
	#6	1,91570	1,67140	2,62208	2,28770

Table 148. Energy dimensioning when mixed traffic is assumed (San Juan) – Year 4

HNB	**Scenario**	**Femtocell power consumption**		**Picocell power consumption**	
		Solar panels n_{SP}	*Batteries* n_B	*Solar panels* n_{SP}	*Batteries* n_B
S-Class 16	#1	0,92777	0,80946	1,29600	1,13073
	#2	0,92776	0,80945	1,29600	1,13073
	#3	0,92782	0,80950	1,29602	1,13075
	#5	1,85539	1,61879	2,59193	2,26139
	#6	1,85547	1,61886	2,59197	2,26143
E-Class 24	#1	0,91177	0,79550	1,28800	1,12375
	#2	0,91176	0,79549	1,28800	1,12375
	#3	0,91179	0,79551	1,28801	1,12376
	#5	1,82349	1,59095	2,57598	2,24748
	#6	1,82353	1,59099	2,57600	2,24749
E-Class 24*	#1	0,95799	0,83582	1,31111	1,14391
	#2	0,95798	0,83582	1,31111	1,14391
	#3	0,95804	0,83587	1,31114	1,14393
	#5	1,91564	1,67135	2,62205	2,28767
	#6	1,91571	1,67141	2,62208	2,28770

Table 149. Energy dimensioning when mixed traffic is assumed (San Juan) – Year 5

8 CONCLUSIONS AND RECOMMENDATIONS

An evaluation of the traffic requirements in the target communities in Napo river and Paranapura river have generated the following recommendations for the access network, in terms of HNB deployment, backhaul requirements and energy units.

The possible configurations, HNB (or HNBs) and scenarios fulfilling the blocking probability requirements imposed by TUCAN3G are presented in the following sections for each target communities during the first five years. For each valid configuration, we can read out:

1. The required backhaul in terms of kbps (both for the uplink and for the downlink)
2. The required numbers of solar panel and battery units. HNB S-Class 16 and HNB E-Class 24* can be considered as *pico* model, where HNB E-Class 24 is assumed as *femto model* with respect to the maximum radiated power by HNB according to given description in Table 96.

In order to select one configuration for each community on each year, we propose the following hierarchy of criteria:

1. For each year, choose the scenario, which supposes a minimum number of HNBs, giving preference to those ones that use HNB S-Class 16 or E-Class 24 (as off-the-shelf products).
2. If several solutions are still valid, choose the one requiring the least backhaul bandwidth.
3. If more than one scenario requires the same backhaul, then choose the scenario with lower energy consumption.
4. If more than one scenario still survives, choose the one with the lowest cost.
5. Whenever no scenario using HNB S-Class 16 or E-Class 24 cannot provide service for a particular year, chose HNB E-Class 24*.
6. Finally, if the scenario and/or HNB has to be changed starting from the second year, this scenrio and/or HNB for the second year will also be selected for the first year.

Other factors have not been taken into account.

8.1 Solutions for each location

8.1.1 Santa Clotilde

For the particular case of voice and data traffic, applying the criteria and by reading out the Table 150, our recommendation is (marked by grey shading on table):

- Choose scenario #6 using HNBs S-Class 16 during the first year.
- As seen in previously sections, from second year there is no possible configuration to serve the expected voice and data traffic simultaneously with the HNB at hand.

	Scenario	**HNB type**	**Backhaul DL [Kbps]**	**Backhaul UL [Kbps]**	**Solar panels units**	**Battery units**
Year 1	#5	E-Class 24*	1671,6	2568,2	2,6244	2,2897
	#6	E-Class 16	1828,8	1239,4	2,5965	2,2654
		E-Class 24*	1828,8	1239,4	2,6253	2,2905
Year 2	×	×	×	×	×	×
Year 3	×	×	×	×	×	×
Year 4	×	×	×	×	×	×
Year 5	×	×	×	×	×	×

Table 150. Preferred deployment for voice and data coverage over a five years period (Santa Clotilde)

For the particular case of data-only traffic, applying the criteria and by reading the Table 151, our recommendation is (marked by grey shading on table):

- Choose scenario #6 using HNBs S-Class 16 for the five years.

	Scenario	HNB type	Backhaul DL [Kbps]	Backhaul UL [Kbps]	Solar panels	Battery units
Year 1	#3	E-Class 24*	1536	614,4	1,3133	1,1459
	#5	S-Class 16	1689,6	921,6	2,5930	2,2623
		E-Class 24*	1536	921,6	2,6243	2,2896
	#6	S-Class 16	1075,2	614,4	2,5936	2,2629
		E-Class 24	1536	614,4	1,8412	1,6064
		E-Class 24*	1075,2	614,4	2,6253	2,2905
Year 2	#5	E-Class 24*	3072	1536	2,6266	2,2917
	#6	S-Class 16	2304	1075,2	2,5949	2,2640
		E-Class 24*	2150,4	1075,2	2,6280	2,2929
Year 3	#5	E-Class 24*	3072	1536	2,6268	2,2919
	#6	S-Class 16	2304	1075,2	2,5950	2,2641
		E-Class 24*	2304	1075,2	2,6283	2,2931
Year 4	#5	E-Class 24*	3072	1536	2,6269	2,2919
	#6	S-Class 16	2457,6	1228,8	2,5951	2,2642
		E-Class 24*	2304	1228,2	2,6283	2,2932
Year 5	#5	E-Class 24*	3072	1689,6	2,6270	2,2920
	#6	S-Class 16	2457,6	1228,8	2,5951	2,2642
		E-Class 24*	2304	1228,2	2,6284	2,2933

Table 151. Preferred deployment for data-only coverage over a five years period (Santa Clotilde)

8.1.2 Negro Urco

Applying the criteria, and by reading the Table 152, our recommendation is (marked by grey shading on table):

- Choose scenario #6 using HNBs E-Class 24* for the five years.

	Scenario	HNB type	Backhaul DL [Kbps]	Backhaul UL [Kbps]	Solar panels units	Battery units
Year 1	#4	E-Class 24*	610,8	457,2	1,3119	1,1446
	#5	E-Class 24*	814,4	814,4	2,6237	2,2891
	#6	S-Class 16	610,8	457,2	2,6201	2,2860
		E-Class 24*	610,8	457,2	2,6288	2,2936
Year 2	#6	E-Class 24*	864,4	685,8	2,6299	2,2945
Year 3	#6	E-Class 24*	889,4	735,8	2,6300	2,2946
Year 4	#6	E-Class 24*	889,4	735,8	2,6300	2,2946
Year 5	#6	E-Class 24*	889,4	735,8	2,6300	2,2946

Table 152. Preferred deployment for voice and data coverage over a five years period (Negro Urco)

8.1.3 Tuta Pisco

Applying the criteria, and by reading the Table 153, our recommendation is (marked by grey shading on table):

- Choose scenario #6 using HNBs S-Class 16 for the five years.

	Scenario	HNB type	Backhaul DL [Kbps]	Backhaul UL [Kbps]	Solar panels units	Battery units
Year 1	#3	E-Class 24*	764,4	457,2	1,3121	1,1448
	#6	S-Class 16	610,8	457,2	2,5994	2,2679
		E-Class 24*	610,8	457,2	2,6237	2,2891
Year 2	#6	S-Class 16	914,4	760,8	2,5999	2,2684
		E-Class 24*	889,4	735,8	2,6247	2,2900
Year 3	#6	S-Class 16	914,4	760,8	2,6000	2,2684
		E-Class 24*	889,4	735,8	2,6248	2,2901
Year 4	#6	S-Class 16	939,4	760,8	2,6000	2,2684
		E-Class 24*	889,4	735,8	2,6248	2,2901
Year 5	#6	S-Class 16	939,4	760,8	2,6000	2,2684
		E-Class 24*	889,4	735,8	2,6248	2,2901

Table 153. Preferred deployment for voice and data coverage over a five years period (Tuta Pisco)

8.1.4 San Gabriel

Applying the criteria, and by reading the Table 154, our recommendation is (marked by grey shading on table):

- From first to fourth year, choose scenario #6 using HNBs S-Class 16.
- During fifth year, choose scenario #6 using HNBs E-Class 24.

	Scenario	HNB type	Backhaul DL [Kbps]	Backhaul UL [Kbps]	Solar panels units	Battery units
Year 1	#1	S-Class 16	864,4	710,8	1,2963	1,1310
		E-Class 24*	864,4	710,8	1,3117	1,1444
	#2	S-Class 16	864,4	710,8	1,2963	1,1310
		E-Class 24*	864,4	710,8	1,3116	1,1443
	#3	S-Class 16	864,4	710,8	1,2962	1,1309
		E-Class 24	1043	735,8	0,9119	0,7956
		E-Class 24*	864,4	710,8	1,3116	1,1443
	#5	S-Class 16	1246,6	939,4	2,5921	2,2616
		E-Class 24	1246,6	939,4	1,8236	1,5910
		E-Class 24*	1246,6	939,4	2,6224	2,2880
	#6	S-Class 16	864,4	710,8	2,5922	2,2616
		E-Class 24	864,4	710,8	1,8237	1,5911
		E-Class 24*	864,4	710,8	2,6226	2,2881
Year 2	#2	E-Class 24*	1500,2	1114,4	1,3130	1,1456
	#5	S-Class 16	2086	1546,6	2,5926	2,2620
		E-Class 24	2161	1571,6	1,8238	1,5912
		E-Class 24*	1982,4	1571,6	2,6235	2,2890
	#6	S-Class 16	1575,2	1164,4	2,5927	2,2621
		E-Class 24	1600,2	1164,4	1,8240	1,5914
		E-Class 24*	1575,2	1164,4	2,6238	2,2892

Year 3	#5	S-Class 16	2214,6	1546,6	2,5926	2,2620
		E-Class 24	2186	1596,6	1,8238	1,5912
		E-Class 24*	2186	1596,6	2,6236	2,2891
	#6	S-Class 16	1600,2	1164,4	2,5927	2,2621
		E-Class 24	1625,2	1164,4	1,8240	1,5914
		E-Class 24*	1600,2	1164,4	2,6239	2,2893
Year 4	#5	E-Class 24	2186	1596,6	1,8238	1,5912
		E-Class 24*	2186	1596,6	2,6237	2,2891
	#6	S-Class 16	1600,2	1189,4	2,5928	2,2621
		E-Class 24	1625,2	1189,4	1,8241	1,5914
		E-Class 24*	1600,2	1189,4	2,6239	2,2893
Year 5	#5	E-Class 24	2186	1621,6	1,8238	1,5912
		E-Class 24*	2186	1621,6	2,6237	2,2891
	#6	S-Class 16	1625,2	1189,4	2,5928	2,2621
		E-Class 24	1625,2	1189,4	1,8241	1,5915
		E-Class 24*	1625,2	1189,4	2,6240	2,2893

Table 154. Preferred deployment for voice and data coverage over a five years period (San Gabriel)

8.1.5 San Juan

Applying the criteria, and by reading the Table 155, our recommendation is (marked by grey shading on table):

- Choose scenario #2 using HNBs E-Class 24 during the five years.

	Scenario	HNB type	Backhaul DL [Kbps]	Backhaul UL [Kbps]	Solar panels units	Battery units
Year 1	#1	E-Class 16	407,2	407,2	1,29595	1,13069
		E-Class 24	407,2	407,2	0,91175	0,79548
		E-Class 24*	407,2	407,2	1,31100	1,14382
	#2	E-Class 16	407,2	407,2	1,29595	1,13069
		E-Class 24	407,2	407,2	0,91174	0,79547
		E-Class 24*	407,2	407,2	1,31100	1,14381
	#3	E-Class 16	407,2	407,2	1,29597	1,13071
		E-Class 24	407,2	407,2	0,91176	0,79549
		E-Class 24*	407,2	407,2	1,31102	1,14383
	#5	E-Class 16	764,4	457,2	2,59189	2,26136
		E-Class 24	764,4	457,2	1,82348	1,59094
		E-Class 24*	764,4	457,2	2,62195	2,28759
	#6	E-Class 16	407,2	407,2	2,59192	2,26139
		E-Class 24	407,2	407,2	1,82351	1,59097
		E-Class 24*	407,2	407,2	2,62198	2,28762
Year 2	#1	E-Class 16	610,8	457,2	1,29599	1,13072
		E-Class 24	610,8	457,2	0,91177	0,79549
		E-Class 24*	610,8	457,2	1,31110	1,14390
	#2	E-Class 16	610,8	457,2	1,29599	1,13072
		E-Class 24	610,8	457,2	0,91176	0,79549
		E-Class 24*	610,8	457,2	1,31109	1,14390
	#3	E-Class 16	610,8	457,2	1,29602	1,13074
		E-Class 24	610,8	457,2	0,91178	0,79551
		E-Class 24*	610,8	457,2	1,31112	1,14392
	#5	E-Class 16	814,4	814,4	2,59192	2,26139
		E-Class 24	814,4	814,4	1,82349	1,59095

		E-Class 24*	814,4	814,4	2,62204	2,28766
	#6	E-Class 16	610,8	457,2	2,59196	2,26142
		E-Class 24	610,8	457,2	1,82353	1,59099
		E-Class 24*	610,8	457,2	2,62207	2,28769
Year 3	#1	E-Class 16	610,8	457,2	1,29600	1,13073
		E-Class 24	610,8	457,2	0,91177	0,79549
		E-Class 24*	610,8	457,2	1,31110	1,14391
	#2	E-Class 16	610,8	457,2	1,29599	1,13072
		E-Class 24	610,8	457,2	0,91176	0,79549
		E-Class 24*	610,8	457,2	1,31110	1,14390
	#3	E-Class 16	610,8	457,2	1,29602	1,13075
		E-Class 24	610,8	457,2	0,91178	0,79551
		E-Class 24*	610,8	457,2	1,31113	1,14393
	#5	E-Class 16	814,4	814,4	2,59192	2,26139
		E-Class 24	814,4	814,4	1,82349	1,59095
		E-Class 24*	814,4	814,4	2,62204	2,28767
	#6	E-Class 16	610,8	457,2	2,59196	2,26143
		E-Class 24	610,8	457,2	1,82353	1,59099
		E-Class 24*	610,8	457,2	2,62208	2,28770
Year 4	#1	E-Class 16	610,8	457,2	1,29600	1,13073
		E-Class 24	610,8	457,2	0,91177	0,79550
		E-Class 24*	610,8	457,2	1,31111	1,14391
	#2	E-Class 16	610,8	457,2	1,29599	1,13072
		E-Class 24	610,8	457,2	0,91176	0,79549
		E-Class 24*	610,8	457,2	1,31110	1,14391
	#3	E-Class 16	610,8	457,2	1,29602	1,13075
		E-Class 24	610,8	457,2	0,91178	0,79551
		E-Class 24*	610,8	457,2	1,31113	1,14393
	#5	E-Class 16	814,4	814,4	2,59192	2,26139
		E-Class 24	814,4	814,4	1,82349	1,59095
		E-Class 24*	814,4	814,4	2,62204	2,28767
	#6	E-Class 16	610,8	457,2	2,59196	2,26143
		E-Class 24	610,8	457,2	1,82353	1,59099
		E-Class 24*	610,8	457,2	2,62208	2,28770
Year 5	#1	E-Class 16	610,8	457,2	1,29600	1,13073
		E-Class 24	610,8	457,2	0,91177	0,79550
		E-Class 24*	610,8	457,2	1,31111	1,14391
	#2	E-Class 16	610,8	457,2	1,29600	1,13073
		E-Class 24	610,8	457,2	0,91176	0,79549
		E-Class 24*	610,8	457,2	1,31111	1,14391
	#3	E-Class 16	610,8	457,2	1,29602	1,13075
		E-Class 24	610,8	457,2	0,91179	0,79551
		E-Class 24*	610,8	457,2	1,31114	1,14393
	#5	E-Class 16	814,4	814,4	2,59193	2,26139
		E-Class 24	814,4	814,4	1,82349	1,59095
		E-Class 24*	814,4	814,4	2,62205	2,28767
	#6	E-Class 16	610,8	457,2	2,59197	2,26143
		E-Class 24	610,8	457,2	1,82353	1,59099
		E-Class 24*	610,8	457,2	2,62208	2,28770

Table 155. Preferred deployment for voice and data coverage over a five years period (San Juan)

8.2 Recommendations to WP5

The following table shows the requirements for DL and UL traffic for all locations over the period of 5 years.

	Location	**Backhaul DL [Kbps]**	**Backhaul UL [Kbps]**
Year 1	Santa Clotilde (*mixed traffic assumed*)	1828,8	1239,4
	Santa Clotilde (*only data traffic assumed*)	1075,2	614,4
	Negro Urco	610,8	457,2
	Tuta Pisco	610,8	457,2
	San Gabriel	864,4	710,8
	San Juan	407,2	407,2
Year 2	Santa Clotilde (*only data traffic assumed*)	2304	1075,2
	Negro Urco	864,4	685,8
	Tuta Pisco	914,4	760,8
	San Gabriel	1575,2	1164,4
	San Juan	610,8	457,2
Year 3	Santa Clotilde (*only data traffic assumed*)	2304	1075,2
	Negro Urco	889,4	735,8
	Tuta Pisco	914,4	760,8
	San Gabriel	1600,2	1164,4
	San Juan	610,8	457,2
Year 4	Santa Clotilde (*only data traffic assumed*)	2457,6	1228,8
	Negro Urco	889,4	735,8
	Tuta Pisco	939,4	760,8
	San Gabriel	1600,2	1189,4
	San Juan	610,8	457,2
Year 5	Santa Clotilde (*only data traffic assumed*)	2457,6	1228,8
	Negro Urco	889,4	735,8
	Tuta Pisco	939,4	760,8
	San Gabriel	1625,2	1189,4
	San Juan	610,8	457,2

Table 156. Backhaul required bandwidth (kbps) for each location over a five years period

8.3 Recommendations to WP6

Table 157 shows the required HNB, antennas and energy units for all locations over the period of 5 years. As mentioned in section 7.3.2, the required numbers of solar panels and batteries have been obtained for particular values of nominal power of solar cells ($P_{nom} = 85\ W$) and capacity of batteries ($C = 1200\ Ah\times V$), respectively. The decision of these elements is arbitrary. In fact, other reference batteries and solar cells may be taken depending on the cost. If this is the case, the required number of solar panels and batteries can be easily recomputed applying the equations in (77):

$$\#SolarPanels(P_{nom}) = \left\lceil SP \cdot \frac{P_{nom}[W]}{85} \right\rceil$$
$$\#Batteries(C) = \left\lceil B \cdot \frac{C[Ah \times V]}{1200} \right\rceil \tag{77}$$

where $\lceil x \rceil$ denotes a function that rounds x up to the nearest integer, and SP and B can be read out from Table 158.

Locality		**HNB/s**	**Antenna Configuration**	**Solar panels units**	**Battery units**
Santa Clotilde (*mixed traffic assumed*)		Two HNBs S-Class 16	Two antennas: - Azimuth BW: 360º - Elevation BW: 20º - Gain: 7 dB - Height: 70 m - Downtilt: 10º	3	3
Santa Clotilde (*only data traffic assumed*)		Two HNBs S-Class 16	Two antennas: - Azimuth BW: 360º - Elevation BW: 20º - Gain: 7 dB - Height: 70 m - Downtilt: 10º	3	3
Negro Urco		Two HNBs E-Class 24*	Two antennas: - Azimuth BW: 360º - Elevation BW: 20º - Gain: 7 dB - Height: 70 m - Downtilt: 10º	3	3
Tuta Pisco		Two HNBs S-Class 16	Two antennas: - Azimuth BW: 360º - Elevation BW: 20º - Gain: 7 dB - Height: 50 m - Downtilt: 10º	3	3
San Gabriel	Years 1 to 4	One HNBs S-Class 16	One antenna: - Azimuth BW: 360º - Elevation BW: 20º - Gain: 7 dB - Height: 30 m - Downtilt: 10º	3	3
	Year 5	One HNBs S-Class 24		2	2
San Juan		One HNBs E-Class 24	One antenna: - Azimuth BW: 360º - Elevation BW: 45º - Gain: 2 dB - Height: 20 m - Downtilt: -	1	1

Table 157. Required equipment and configuration for each location over the period of 5 years. P_{nom} = 85 *W* for solar cells and *C* = 1200 *Ah*×*V* for the capacity of batteries have been assumed

	Location	*SP*	*B*
Year 1	Santa Clotilde (*mixed traffic assumed*)	2,5965	2,2654
	Santa Clotilde (*only data traffic assumed*)	2,5936	2,2629
	Negro Urco	2,6201	2,2860
	Tuta Pisco	2,5994	2,2679
	San Gabriel	2,5922	2,2616
	San Juan	0,9117	0,7955
Year 2	Santa Clotilde (*only data traffic assumed*)	2,5949	2,2640
	Negro Urco	2,6299	2,2945
	Tuta Pisco	2,5927	2,2621
	San Gabriel	2,5927	2,2621
	San Juan	0,9118	0,7955
Year 3	Santa Clotilde (*only data traffic assumed*)	2,5950	2,2641
	Negro Urco	2,6300	2,2946
	Tuta Pisco	2,6000	2,2684
	San Gabriel	2,5927	2,2621
	San Juan	0,9118	0,7955
Year 4	Santa Clotilde (*only data traffic assumed*)	2,5951	2,2642
	Negro Urco	2,6300	2,2946
	Tuta Pisco	2,6000	2,2684
	San Gabriel	2,5928	2,2621
	San Juan	1,8241	1,5915
Year 5	Santa Clotilde (*only data traffic assumed*)	2,5951	2,2642
	Negro Urco	2,6300	2,2946
	Tuta Pisco	2,6000	2,2684
	San Gabriel	0,9118	0,7955
	San Juan	0,9118	0,7955

Table 158. *SP* and *B* values for each location over a period of 5 years

9 ANNEX

9.1 Values of link budget parameters

Table X depicts the values of the different radio link budget parameters after their characterization. These values are used to obtain the different results in radio network planning.

Parameter	Value
Operating frequency	824-849 MHz (uplink) 869-894 MHz (downlink)
Chip Rate	3.84 MHz
Service Rate	12.2 kbps (voice service) 128 kbps (data service)
Activity Factor	0.67 (voice service) 1 (data service)
Power Rise	1.6 dB
Shadowing Margin	8.326 dB (indoor) 2.326 dB (outdoor)
Power Control Headroom	2 dB (uplink) 2 dB + 10log M (downlink) (*)
Orthogonality factor	0.65
Link quality requirements for DPCH (E_b/N_o)	Uplink: 8.3 dB (voice service) 4.5 dB (data service) Downlink: 7.4 dB (voice service) 3.97 dB (data service)
Link quality requirements for CPICH (E_c/I_o)	-17 dB
HNB antenna gain	0 dB (scenario #1) 2 dB (scenario #2) 7 dB (scenario #3) 13 dB (scenarios #4 and #5)
UE antenna gain	0 dB (voice service) 2 dB (data service)
HNB Noise Figure	8 dB
UE Noise Figure	6 dB
Downlink spreading factor	128 (voice service) 16 (data service)
Maximum number of simultaneous users supported by HNB	16 (HNB S-class 16) 24 (HNB E-class 24) 24 (HNB E-class 24*)
Maximum available power at HNB	20 dBm (HNB S-class 16) 24 dBm (HNB E-class 24) 24 dBm (HNB E-class 24*)
Maximum available power at UEs	21 dBm (voice service) 24 dBm (data service)
UE body losses	3 dB (voice service) 0 dB (data service)
HNB additional losses	1 dB
(*) M: number of simultaneous users	

Table 159. Values assumed for link budget parameters

9.2 Path loss optimisation results

This section summarizes the different 95th percentiles of path loss in the required covered area in each location and for each configuration described in Table 14.

9.2.1 Santa Clotilde

Height/downtilt	10º	20º	30º	40º
20 m	145,98	162,55	176,95	187.35
30 m	141.95	158,00	172,55	183,10
40 m	138,65	154,11	168,85	179,55
50 m	135,60	150,40	165,28	176,15
60 m	133,15	147.30	162,30	173,35
70 m	131,20	144,50	159,70	170,95

Table 160. Percentile 95th of path losses (dB) obtained for different heights and downtilts. Scenarios #3 and #6, Santa Clotilde.

Height	Pathloss (dB)
20 m	143,40
30 m	139,54
40 m	136,40
50 m	133,44
60 m	131,00
70 m	129,10

Table 161. Percentile 95th of path losses (dB) obtained for different heights. Scenarios #1 and #2, Santa Clotilde.

	Cell 1				Cell 2			
Height/downtilt	10º	20º	30º	40º	10º	20º	30º	40º
20 m	140,75	156,85	171,40	181.95	149,40	166,05	180,43	190,80
30 m	136,25	151,65	166,39	177,10	145,65	161,75	176,30	186,85
40 m	132,50	147,25	162,15	173,05	142,10	157,65	172,35	183,05
50 m	129,50	143,60	158,68	169,72	138,94	154,00	168,83	179,65
60 m	127,55	141,08	156,20	167,40	135,65	150,11	165,10	176,10
70 m	126,95	139,62	154,95	166,35	133,13	146,90	162,05	173,20

Table 162. Percentile 95th of path losses (dB) obtained in multi-cell deployment for different heights and downtilts. Scenario #5, Santa Clotilde.

9.2.2 Negro Urco

Height/downtilt	10º	20º	30º	40º
20 m	149,50	166,39	180,70	191,03
30 m	145,75	162,20	176,65	187,10
40 m	142,85	158,85	173,40	184
50 m	140,00	155,55	170,25	180,95
60 m	137,55	152,65	167,45	178,30
70 m	134,33	149,05	163,95	174,90

Table 163. Percentile 95th of path losses (dB) obtained for different heights and downtilts. Scenarios #3,#4 and #6, Negro Urco

Height	Pathloss (dB)
20 m	146,85
30 m	143,20
40 m	140,40
50 m	137,70
60 m	135,35
70 m	132,33

Table 164. Percentile 95th of path losses (dB) obtained for different heights. Scenarios #1 and #2, Negro Urco

	Cell 1				Cell 2			
Height/downtilt	10º	20º	30º	40º	10º	20º	30º	40º
20 m	132,4	149,04	163,40	173,80	150,81	167,60	181,95	192,30
30 m	129,45	145,44	159,95	170,55	147,45	163,80	178,29	188,75
40 m	127,35	142,15	157,00	167,90	144,17	160,10	174,70	185,30
50 m	124,70	139,00	154,05	165,10	141,70	157,20	171,90	182,60
60 m	122,65	136,10	151,35	162,60	138,90	153,97	168,80	179,65
70 m	121,40	133,90	149,40	160,90	136,85	151,45	166,45	177,40

Table 165. Percentile 95th of path losses (dB) obtained in multi-cell deployment for different heights and downtilts. Scenario #5, Negro Urco

9.2.3 Tuta Pisco

Height/downtilt	10º	20º	30º	40º
20 m	139.45	156.35	170.70	181.00
30 m	136.20	152.50	167.00	177.45
40 m	133.80	149.60	164.20	174.85
50 m	131.65	146.85	161.60	172.40

Table 166. Percentile 95th of path losses (dB) obtained for different heights and downtilts. Scenarios #3 and #6, Tuta Pisco

Height	Pathloss (dB)
20 m	136.80
30 m	133.70
40 m	131.50
50 m	129.40

Table 167. Percentile 95th of path losses (dB) obtained for different heights. Scenarios #1 and #2, Tuta Pisco

9.2.4 San Gabriel

Height/downtilt	10º	20º	30º	40º
20 m	100,25	115,90	130,52	141,15
30 m	95,20	108,95	123,95	135,00
40 m	97,90	106,69	122,24	134,25
50 m	100,90	106,82	122,10	134,25
60 m	105,90	108,40	122,75	135,00

Table 168. Percentile 95th of path losses (dB) obtained for different heights and downtilts. Scenarios #3 and #6, San Gabriel

Height	Pathloss (dB)
20 m	97,75
30 m	93,10
40 m	94,40
50 m	94,95
60 m	95,85

Table 169. Percentile 95th of path losses (dB) obtained for different heights. Scenarios #1 and #2, San Gabriel

	Cell 1				Cell 2			
Height/downtilt	10º	20º	30º	40º	10º	20º	30º	40º
20 m	101,25	117,00	131,65	142,25	93,25	108,25	122,95	133,70
30 m	95,75	109,70	124,70	135,75	94,10	105,55	120,95	132,60
40 m	95,15	105,25	120,50	132,10	99,80	108,40	123,90	135,95
50 m	99,95	106,15	121,22	133,35	101,90	107,65	122,95	135,05
60 m	104,60	105,92	119,65	132,02	106,55	110,33	124,88	137,13

Table 170. Percentile 95th of path losses (dB) obtained in multi-cell deployment for different heights and downtilts. . Scenario #5, San Gabriel

9.2.5 San Juan

Height/downtilt	10º	20º	30º	40º
20 m	104,98	113,20	128,25	140,43
30 m	119,10	111,30	124,70	138,30
40 m	128,66	119,30	124,45	137,20
50 m	134,22	127,73	121,40	130,63
60 m	136,15	133,26	124,83	129,05

Table 171. Percentile 95th of path losses (dB) obtained for different heights and downtilts. Scenarios #3 and #6, San Juan

Height	Pathloss (dB)
20 m	100,90
30 m	103,09
40 m	102,81
50 m	102,46
60 m	101,7431

Table 172. Percentile 95th of path losses (dB) obtained for different heights. Scenarios #1 and #2, San Juan

	Cell 1				Cell 2			
Height/downtilt	10º	20º	30º	40º	10º	20º	30º	40º
20 m	106,55	105,76	120,98	134,33	104,66	114,25	130,00	141,88
30 m	121,80	112,08	124,62	138,96	114,43	110,75	124,70	137,95
40 m	129,99	122,95	116,68	128,46	126,50	114,60	125,58	139,08
50 m	134,98	129,46	121,47	129,35	132,74	124,45	121,25	131,85
60 m	136,56	134,69	127,47	124,26	135,35	131,15	120,20	130,4

Table 173. Percentile 95th of path losses (dB) obtained in multi-cell deployment for different heights and downtilts. Scenario #5, San Juan