Strategic Mobile Network Planning Tool for 2G/3G Regulatory Studies

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Abstract. Techno-economical studies in telecommunication networks are important and quite complicated topics. One of the major challenges is to estimate the investment in new or additional network equipment to consider a new service, or to compare two technologies in the same or different frequency band. In order to carry out this kind of analysis, a nationwide network design and dimensioning study has to be done, what requires powerful and robust algorithms with a high degree of flexibility to obtain accurate results avoiding huge amount of input data. This paper presents a strategic network planing tool which implements algorithms for 2G and 3G network dimensioning. This tool can be used by mobile network operators or regulatory authorities to develop or support techno-economic analysis in communication networks.

Keywords: GSM and UMTS design algorithms, strategic studies, network investment.

1 Introduction

Mobile telecommunication market has become one of the most relevant contributors to the nation economies in developed countries. The fast evolution from 2G Global System for Mobile Telecommunications (GSM) to 3G Universal Mobile Telecommunication System (UMTS), and the increasing demand for new data services, makes that the mobile operators have to move fast to deploy network infrastructure to cover this demand. However, an incorrect network deployment (due to an incorrect technology or frequency band selection) may derive into huge investments with non-desired results, i.e lack of coverage or capacity. To avoid this nightmare scenario, mobile network operators must carry out exhaustive strategic studies to determine which technology have to be deployed, which frequencies must be used and, of course, where the deployment should be deployed (cities, towns) and even in which area of each specific city (urban, suburban and rural) [8].

Strategic studies are hard to be carried out because they have to consider nationwide multi-service scenarios, with important differences in demography, topography and user and service profile in the different cities considered [1]. Thus,

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in order to do this kind of studies, it is mandatory to use software tools that implement algorithms for the network design and dimensioning. In this paper we present one tool and the algorithms for 2G and 3G network dimensioning, specifically implemented to support strategic and techno-economic studies in telecommunication networks. The algorithm for 2G GSM is based on the independent calculation of the cell range by propagation, using an empirical propagation model, and by traffic load, using a classical Erlang formulation based on the slotted feature of the GSM system. The algorithm for 3G is quite more evolved due to the features of the 3G UMTS access technique which requires a joint optimization of the capacity and propagation. After calculating the cell range for a single site, a procedure to estimate the number of sites (BTS or Node B) required to provide coverage to a specific area is presented, considering several types of BTS and Node B.

The rest of the paper is structured as follows. Section 2 and section 3 describes the models and methods for designing the network. Section 4 presents a study for the metropolitan area of Bilbao (Spain) and a nationwide example for the comparison among 2G GSM and 3G UMTS in the same and different frequency bands. Finally, in the last section we present some conclusions about the tool and the studies carried out with it.

2 Models and Methods for 2G-GSM Dimensioning

The objective of a network dimensioning problem is to calculate the number of network elements (Base Stations (BTS)) to be deployed in each area of a specific city (urban/suburban/rural). To calculate the number of BTS, the area covered by each one has to be obtained finding the value of the cell range of the BTS under study. To do this, we consider the following input parameters:

- A set of services S. Each service is defined by several parameters: user density in the area, individual traffic per user and binary rate of the service.
- A set of 2G-BTS, BTS. The main parameters of each BTS are: Transmission Power, Number of Sectors, Number of transceiver (TRX) per sector and cost of the BTS (C_i).
- Radio Propagation parameters P, where the fading margins, frequency bands (900 and 1800 MHz), and different propagation losses are specified.
- General parameters of the operator G, such as market share, market penetration and amount of spectrum allocated in each frequency band.

The cell range of a 2G BTS is the minimum value between the cell range by radio propagation R_P and the cell range by capacity R_T. Next we will show how these two values can be estimated for 2G networks.

2.1 Calculation of the Cell Range by Radio Propagation R_P in 2G Networks

Propagation coverage studies mainly imply two steps. The first one is to calculate the maximum allowed propagation loss in the cell, defined here as $L_{pathloss}$, and the second is to use an empirical propagation method to calculate the cell radius for this pathloss. Typical methods are the Okumura Hata COST 231 model, [2], or the Walfish Ikegami model [3].

The value of $L_{pathloss}$ is calculated using a classical link budget equation:

$$P_{Tx} + \sum G - \sum L - \sum M - L_{pathloss} = R_{Sens} \tag{1}$$

where P_{Tx} is the transmitter power, $\sum G$ is the sum of all gains, $\sum L$ is the sum of all the losses, R_{Sens} is the receiver sensitivity and finally. Note that all the parameters in Equation (1) are inputs of the system, defined in the set BTS and P, and therefore $L_{pathloss}$ can be obtained from this equation.

As it was mentioned before, the cell radius by propagation is obtained applying the $L_{pathloss}$ into an empirical propagation method. In our work we have used the 231-Okumura Hata model because it is broadly considered as the most general one in mobile networks applications [4]:

$$\begin{aligned} L_b = 46.3 + 33.9 \cdot Log(f) - 13.82 \cdot Log(h_{BTS}) - a(h_{Mobile}) \\ +(44.95 - 6.55 \cdot Log(h_{BTS})) \cdot Log(R_P) + C_m \end{aligned} \tag{2}$$

where f is the frequency in MHz, h_{BTS} is the height of the BTS in meters, h_{mobile} is the height of the mobile user in meters and R^P is the cell radius by propagation in Km. Note that $a(h_{Mobile})$ and $C(m)$ are parameters defined in the COST 231 specification. They provide the influence of the height of mobile terminal and the type of city, respectively, and they are defined as follows:

$$a(h_{Mobile}) = (1.1 \cdot Log(f) - 0.7) \cdot h_{Mobile} - (1.56 \cdot Log(f) - 0.8) \tag{3}$$

$$C_m = \begin{cases} 0dB \ for \ medium \ sized \ cities \ and \ suburban \ centres \\ 3dB \ for \ metropolitan \ centres \end{cases} \tag{4}$$

Note that if we are considering different services, the receiver sensibility may change, the propagation coverage study has to be done specifically for each service, and of course for the uplink and the downlink channels. Therefore the formulation explained above, and the value R_P, has to be applied for each service $i \in S$ and for each direction (Uplink (UL) and Downlink (DL)), obtaining a set of two vectors, containing, for each service, the cell radius by propagation, ($R_{P_{UL}}$ and $R_{P_{DL}}$):

$$\begin{aligned} \mathbf{R_{P_{DL}}} &= \{R_{P_{DL\_i}}; i = 1, \ldots, S\} \\ \mathbf{R_{P_{UL}}} &= \{R_{P_{UL\_i}}; i = 1, \ldots, S\} \end{aligned} \tag{5}$$

Cell range by propagation in the frequency band considered is the minimum value among them R_P, which is the most restrictive one.

2.2 Calculation of the Cell Range by Traffic R_T in 2G Networks

A 2G GSM network is a hard blocking system. This means that the capacity, i.e., the maximum number of users that a given BTS can support, depends directly on the amount of hardware in the BTS, [4]. Furthermore, GSM is a time division multiple access (TDMA) synchronous slotted system. Therefore the capacity required by any service can be expressed as multiple of the basic capacity unit, the slot of the TDMA frame. Following this reasoning, the process for calculating the cell range by traffic is the following:

The maximum number of available traffic channels per sector in the BTS is calculated using Equation (6):

$$N_{TCH_{Sector}} = N_{TRX_{Sector}} \cdot N_{TCH_{TRX}} \tag{6}$$

where $N_{TRX_{Sector}}$ is the number of TRX per sector and $N_{TRX_{Sector}}$ the number of traffic channels available for the cell per TRX.

With this value and using the most restrictive blocking probability Pb_i of the services $i \in S$, the maximum offered traffic A^O_{Sector} in the sector is calculated applying the inversion of the Erlang B formulation:

$$A^O_{Sector} = E_B^{-1}\left(N_{TRX_{Sector}}, Min(Pb_i)\right) \tag{7}$$

From the set of services S we can calculate the amount of traffic demanded by a single user a_{User} by means of Equation 8:

$$ad_{User} = \sum_{i=1}^{S} a_i \dot{S}lots_i \tag{8}$$

The maximum number of potential customers in the sector is calculated by the division of the total traffic supported by the sector by the individual user traffic:

$$M_{User} = \frac{A^O_{Sector}}{ad_{User}} \tag{9}$$

And finally the cell range by capacity can be estimated considering the number of sectors in the BTS and the user density:

$$R_T = \sqrt{\frac{M_{Users} \cdot N_{Sectors}}{\pi \cdot \rho_{User}}} \tag{10}$$

2.3 Estimation of the Cell Range of a Single Site

The algorithm for a single site dimensioning works as follows: for the lowest frequency band available, i.e., the best in terms of radio propagation, the values of R_T and R_P are calculated as described before. If $R_P < R_T$ the site (BTS) is considered as *propagation driven* and the cell range $R_C = R_P$. Otherwise the site is considered as *traffic driven*. In this case we need to check out whether the use of a second frequency band (if available) makes the cell range R_C to increase. In the second band, the same BTS type or another BTS type can be installed, therefore a new value of the cell range by traffic R^2_T and by propagation R^2_P have to be calculated. With the value $R^2_C = Min(R^2_T, R^2_P)$ the number of users served in the second band are obtained. These users are already served, and therefore we do not to consider them any more in the cell range calculation in the first band. Now, the R_T^1 is re-calculated. Note that $R_T^1 > R_T$ because we have removed the users in the second band. Finally we compare again R_P with R_T^1 and select the minimum one as the final cell range of the site, $R_C = Min\left(R_P, R_T^1\right)$. The complete process is depicted in Figure 1.

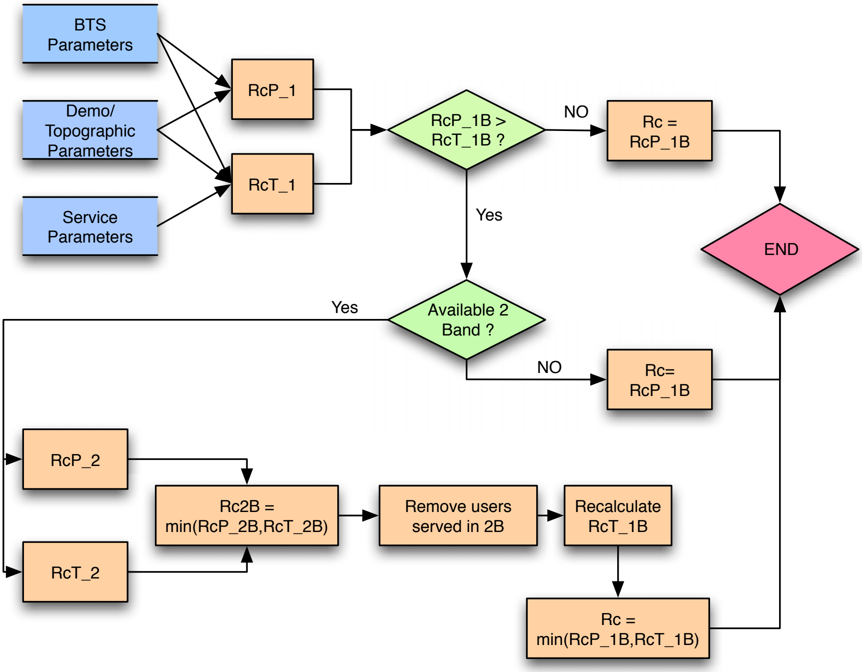

Fig. 1. GSM Single Site Dimensioning Process

2.4 Estimation of the 2G Network Deployment in a Specific Area

The algorithm for single site dimensioning is executed for each type of BTS specified in the scenario, and, in case of availability of second frequency bands, it is used for any allowed combination of BTSs in the same site. Each BTS has associated a cost factor, C_i. Let $\phi = \{\phi_1, \phi_2, \cdots, \phi_k\}$ be the K feasible solutions of BTS combinations in the area, and $C(\phi_k)$ the cost of k the solution.

The combination ϕ_k will have associated the corresponding value of the cell/site radius $R_{C_{\phi_k}}$. Therefore the area covered by the k combination, Sup_{ϕ_k} is calculated by means of the classical circle area formula. The number of sites required for providing coverage in a specific area of the district i (urban/suburban/rural) is calculated by means of Equation (11).

$$N_{Sites\ Area} = \frac{Sup_{Area}}{Sup_{\phi_l}} \tag{11}$$

If we consider that the k solution have the BTS i for the first band and the BTS j for the second band, the cost of the solution is as follows:

$$C(\phi_k) = N_{Sites\ Area} \cdot (C_i + C_j) \tag{12}$$

The algorithm selects the combination ϕ_l, which fulfils:

$$\phi_l \to C(\phi_l) = Min\left[C(\phi_k)\right]_{k=1}^{K} \tag{13}$$

3 Models and Methods for 3G-UMTS Dimensioning

Let us consider a 3G mobile network based on WCDMA technology, where the mobile operator provides a set of S services with similar parameters than the set specified in 2G-GSM. As it was defined in section 2.2, propagation coverage studies mainly imply two steps. The first one is to calculate the maximum propagation loss allowed in the cell, and the second is to use an empirical propagation method to calculate the cell radius for this path loss. In this case the difference in the receiver sensibility comes from different Eb/No values of the S services. Another point to consider is that in 3G networks, that are soft-blocking systems, the amount of users are not limited by the amount of hardware in the 3G BTS (named Node B), but by the amount of interference. The interference is measured by means of the interference margin, IM, that has to be taken into account in the link budget of the propagation studies [7].

As it was done in 2G, we obtain for 3G a set of two vectors containing, for each service, the cell radius by propagation, $(R_{P_{PUL}} and R_{P_{DL}})$.

Let us focus now on capacity studies. As it is done in propagation studies, cell radius must be calculated independently for the uplink and the downlink. The equations that determine the radius in both directions are quite similar, so we will focus on the calculation of the cell radius for the downlink case, since this is the most restrictive direction [6]. The interference margin IM determines the maximum load of the cell, η_{DL} , by means of the following relation:

$$\eta_{DL} = \frac{1}{10^{IM/10}} - 1 \tag{14}$$

The load factor of the cell, that is in fact the capacity of the cell, must be allocated to the different services, yielding the load factors of the each service $L_{Total\_DL\_i}$:

$$\eta_{DL} = \sum_{i=1}^{S} L_{Total\_DL\_i} < 1 \tag{15}$$

The number of active connections of each service Nac_{DL_i} is calculated by dividing the total load factor of each service type i over the average individual downlink load factor of the connections of the service:

$$Nac_{DL\_i} = \frac{L_{Total\_DL\_i}}{L_{DL\_i}} \tag{16}$$

where the donwlink load factor is defined by the following equation, [5]:

$$L_{DL\_i} = \frac{(Eb/No)_{DL\_i} \cdot \sigma_i}{(W/Rb_i)} \cdot [(1-\phi)+f] \tag{17}$$

where

- ϕ is the so called downlink orthogonality factor,
- Rb_i is the binary rate,
- $\sigma_i$is the activity factor of the service i,
- f is the average inter-cell interference factor, and
- W is the bandwidth of the WCDMA system.

The total offered traffic demand, A_{DL_i} in Erlang, is obtained by using the inversion of the Erlang B Loss formula. The inputs for this algorithm are the maximum number of active connections in the cell Nac_{DL_i} and the Quality of Service (QoS) of the service expressed by the blocking probability Pb_i:

$$\frac{A_{DL\_i}}{(1+f)} = E_B^{-1}\left(Pb_i, Nac_{DL\_i} \cdot (1+f)\right) \tag{18}$$

The number of users in the cell ($M_{DL\_i}^{users}$) is obtained from the division of the total offered traffic demand for service i, (A_{DL_i} in Erlang), by the individual traffic of a single user of this service, a_i:

$$M_{DL\_i}^{users} = \frac{A_{DL\_i}}{a_i} \tag{19}$$

The cell radius for each individual service is calculated as a function of the number of sectors in the node B, $N_{Sectors}$, the number of users of service i per sector, M_i^{users} and the user density, ρ_i, as follows:

$$R_{T_{DL_i}} = \sqrt{\frac{M_{DL\_i}^{Users} \cdot N_{Sectors}}{\pi \cdot \rho_i}} \tag{20}$$

Note that this process has to be done also for the uplink direction (UL). Therefore, at the end we will have obtained another set of two vectors (one for the uplink and one for the downlink), with the cell radius by capacity of each service. Note also that at the end of this entire process we will have obtained a set of four vectors, two coming from the propagation studies and two coming from traffic studies. The final cell radius R_C, will be the minimum value of all of them:

$$R_C = MIN\left[R_{P\_DL\_i}, R_{P\_UL\_i}, R_{T\_DL\_i}, R_{T\_UL\_i}\right] \tag{21}$$

This process can be usually divided into two problems:

- The *outer problem* is to find the optimum value for the interference margin IM, for balancing the cell range between propagation and capacity.
- The *inner problem* is to find the best possible allocation, given a value of the IM over the complete set of services S.

The outer problem is solved by making an iterative process to equilibrate the value of the cell radius between the resulting value calculated by propagation studies and the resulting one calculated by capacity studies. This is done by means of increasing the value of the interference margin, IM, when the cell radius by propagation is higher than by capacity or vice-versa.

For the inner problem the model applies a novel heuristic that is explained in [9] and it is summarized in the scheme of Figure 2.

The procedure of calculating the cell range is repeated for all possible Node B specified in the input parameters. Next, following a similar procedure as specified in subsection2.4, the optimum Node B configuration, in terms of investment cost, is selected for the deployment in the area.

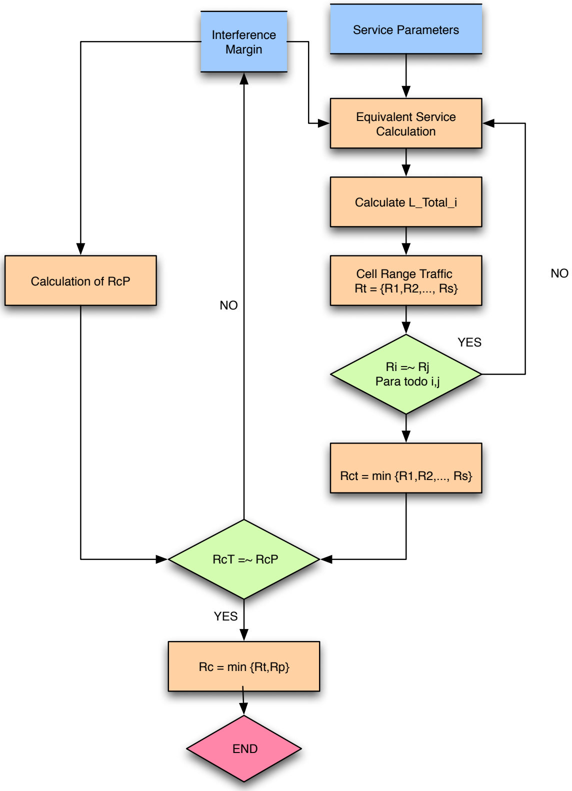

Fig. 2. UMTS Cell Range calculation algorithm

4 Experiments and Results

In order to test the performance of the algorithms and the validity of the results we propose in this article two different set of experiments will be carry out. The first set consists on calculating the network deployment in a specific city of Spain, in this case Bilbao, for both technologies, 2G-GSM and 3G-UMTS. This study allows us analyzing the results in a limited scenario. The second set consists on running the algorithms for a Spanish nationwide scenario, that is composed of 5400 districts representing 100 % of the Spanish population and 100% of the Spanish territory.

In order to make a fair comparison, we have defined the same set of services and traffic per user for 2G and 3G. Specific values are shown in Table 1, where a_U, a_S, a_R stand for the individual user traffic in urban suburban and rural respectively, and Sp is the service penetration in %. We consider that the mobile network operator has a 20% of market share.

Table 1. User service briefcase for the study

Service	Rb_i Kbps	a_U	a_S	a_R	Sp %	DR_i %
Voice	12.2	6.5	6.13	6.04	100	0
RTS	64	0.925	0.96	0.97	100	50
Streaming	64	0.465	0.26	0.22	100	80
Guaranteed Data	144	1.215	0.42	0.24	100	80
Best Effort	144	0.16	0.13	0.12	100	80
SMS	64	0.25	0.25	0.25	100	20
MMS	64	0.25	0.25	0.25	100	20

4.1 Experiments for a Single City (Bilbao)

In this experiment we consider only the metropolitan part of the city of Bilbao. It has a population of 126072 inhabitants with 31 percentage of urban area, 69 of suburban area and without rural area, because it is an important metropolis. We have performed the deployment for GSM mono-band in 900 MHz, and for GSM multi-band in 900 MHz and 1800 MHz, and UMTS 2100 MHz. The results are shown in Table 2.

Table 2. User service briefcase for the study carried out in Bilbao

Technology	Sites/Units Urban	Sites/Units Suburban	Sites/Units Rural	Cost M€
GSM 900 MHz	14/14	7/7	0	2714
GSM 900/ 1800MHz	14/14	7/7	0	2714
UMTS 2100 MHz	5/5	6/6	0	1090

Note that the results for GSM 900 MHz and GSM 900/1800 MHz are similar. This is due to the individual traffic is very low, and therefore, as the second band is only used when there is an excess of traffic in the first band, there is no need to use the second band, so in this example, the operator has free spectrum in 1800 MHz to use it or to receive incoming by hiring it to virtual mobile network operators. Note also that, despite the UMTS system is working in 2100 MHz, as Bilbao only has urban and suburban areas that are densely populated (and therefore concentrates the traffic in small extensions) this 3G system obtains better performance than 2G-GSM, in terms of number of sites and costs.

4.2 Nationwide Experiments

In this subsection we tackle a nationwide scenario. We consider the same service briefcase and frequency distribution as in the single city experiments. The results are shown in Table 3. Note that in this experiment we show global figures and we do not particularize for each area.

Table 3. Results from the nationwide scenario (Spain)

Technology	Sites/Units	Cost M€
GSM 900 MHz	15801	2921.5
GSM 900/ 1800MHz	15667/16041	2914.8
UMTS 2100 MHz	22444	3669.2

Note that in this case the GSM multi-band solution is the best one in terms of cost, since, although it has more BTS units, the reduction in the number of sites and the corresponding saving in infrastructure costs, compensates the effect. An interesting result to be analyzed is the performance of UMTS, providing a solution worse than GSM. The explanation is quite easy to understand when we analyze the results related to each area type and depending on the frequency, see Table 4.

Table 4. Comparison between UMTS 2100 MHz, and UMTS 900 MHz, for different area types

Technology	Urban	Suburban	Rural	Total
UMTS 2100	1205	958	**20281**	22444
UMTS 900	1205	425	**8191**	9821

In urban areas, where the Node B is *traffic driven*, the results in UMTS 900 and UMTS 2100 are identical. In suburban areas where sometimes the Node B is *propagation driven*, the number of Node B in UMTS 2100 is almost twice than in UMTS 900. However the main difference, and also the reason that UMTS 2100 is more expensive than GSM 900/1800, is in rural areas. Rural areas are characterized by very large low populated terrain extensions. In this areas, all Node B are *propagation driven*, and the propagation in 2100 MHz is much worse than in 900 MHz. A fair comparison between GSM and UMTS has to be done in the same frequency band. The results for this comparison are shown in Table 5.

Table 5. Comparison between the investment cost (in M€) in GSM 900 MHz, and UMTS 900 MHz, for different area types

Technology	Urban	Suburban	Rural	Total
GSM 900	317.9	135.6	2467.9	2921.5
UMTS 900	103.4	49.3	1402.7	1555.5

Note that the investment in GSM 900/1800 MHz is almost twice the investment in UMTS 900, considering only the radio access network. This comparison gives an idea of the saving in cost of using a most evolved technology, as 3G in the provision of mobile services.

5 Conclusions

This paper presents a strategic network planning tool for the estimation of the investment in mobile access networks deployments. The tool implements advanced algorithms for the dimensioning of 2G-GSM and 3G networks, under multi-service environments. This kind of tools are very valuable for mobile network operators to carry out techno-economic studies, in order to test the viability of new network investments, or to decide about the technology and frequency bands for the network deployment.

We have presented a nationwide study in Spain, where we compare 2G and 3G technologies in the same and different frequency bands. The results demonstrates that 3G-UMTS is much better than 2G in urban and suburban areas despite of the frequency band, and that only in case of rural propagation driven areas, 2G 900 MHz is better than 3G 2100 MHz. The results also show that 3G UMTS in 900 MHz is the best option despite the area. This is a very relevant result, since in Europe we are currently involved in a rearranging process to reallocate the 900 MHz spectrum.

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