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# Assessment of spectrum value: application to sub-1GHz frequency bands

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## Keywords

Techno-economic model, digital dividend, second digital dividend, LTE

## Abstract

This paper is focused on the impact in network operator costs of new sub-1GHz spectrum bands, which will be soon available to provide mobile broadband services. To analyse these effects a techno-economic model has been used to evaluate the maximum inter-site distance and therefore the cheapest network. The results achieved show the different value of the sub 1GHz bands depending on the spectrum holding of the operator.

## 1 Introduction

The growing demand of mobile broadband is creating a very difficult situation that has to be faced by mobile operators and regulatory bodies. The massive adoption of smartphones, Over-The-Top services and mobile broadband subscriptions are behind of an almost exponential increase of mobile data traffic that mobile networks must carry. Mobile operators can still manage this volume of data, but previsions show that, if forecast are fulfilled, networks will collapse unless operators undertake important changes in their networks [1].

In addition, everyone is aware of the importance of reaching a wide broadband coverage because it could significantly contribute to the economic development and social welfare of a country. Therefore, ensuring that operators have access to enough spectrum resources to provide fast broadband services has become a priority for many regulators.

Mobile network capacity is directly related to the amount of spectrum available; therefore increasing this amount by licensing new bands is a way to increase the whole network capacity. In this way, the European Radio Spectrum Policy Program pointed out the need of identify, at least, 1,200 MHz for mobile services. This paper is focused on the sub 1 GHz frequency bands that have been allocated recently or they will be allocated in the near future.

The allocation and licensing of a new spectrum band for mobile services, the 800 MHz band, has taken place in a process known as digital dividend. The digital switchover has released large amounts of spectrum due to the higher efficiency of digital television compared to analogue standards. As a result, regulators have decided to attribute the spectrum between 790-862 MHz to mobile broadband.

This spectrum band has been highly valued by mobile operators because of its good propagation characteristics that allow them both to improve its coverage easily and to provide better services.

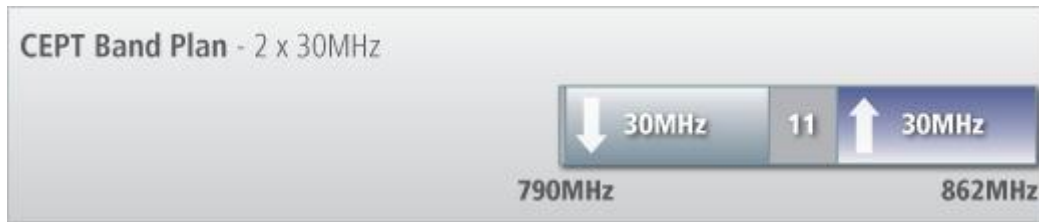


Figure 1. Spectrum configuration for the 800 MHz band in Europe. Source: CEPT.

Because of that, a process is going forward in Europe generating high expectation regarding a potential allocation of new sub1 GHz spectrum, which has been called “the second digital dividend”, and consists in the attribution of the 700 MHz band (694-790 MHz) to mobile services.

Despite the fact that the *World Radiocommunication Conference (WRC)* is scheduled to take place in November 2015, several countries have already expressed their intentions to assign this spectrum to telecom operators, since it is expected that the 700 MHz frequency band will be then allocated to mobile. Indeed, in Germany the auction of this band is taking place at the time of writing. Finland and Sweden have indicated that they will release this band before January 1<sup>st</sup> and April 2017 respectively. The French regulator has planned an auction for this year and indicated that this spectrum will be released before April 2016. Holland will try to clear this band before 2017 and United Kingdom has published that they will do so before 2022.

The purpose of this paper is to analyse the economic impact of this new spectrum band in mobile operators’ network costs. Having more spectrum allows mobile operators to deploy fewer sites because of enhanced capacity per site, and that savings should be related to the prices that they will pay in auctions for the spectrum licenses. This topic has been already studied in [2] but only comparing the cost using the 900 MHz band and 1800 MHz band. Other approach has been used in [3] but it is applied to the case of Italy. In this paper a general methodology is developed that can be applied to different countries.

This paper is structured as follows. Section 2 explains the techno-economic model that has been used to calculate network costs under a specific demand assumption taking into account the available spectrum holding. Section 3 explains the methodology and data employed to forecast the demand, the geotypes under study and the spectrum holdings used. Section 4 explains the results obtained for the two cases studied, the digital dividend and the second digital dividend.

## 2 Techno-economic Model

In this section, the model used to obtain the results is described. This model analyses the network capacity for different spectrum holdings (spectrum bands and bandwidth) and the effect in the cost that an operator has to face in order to ensure the same services to its users. The next figure shows the flow chart of the model developed.

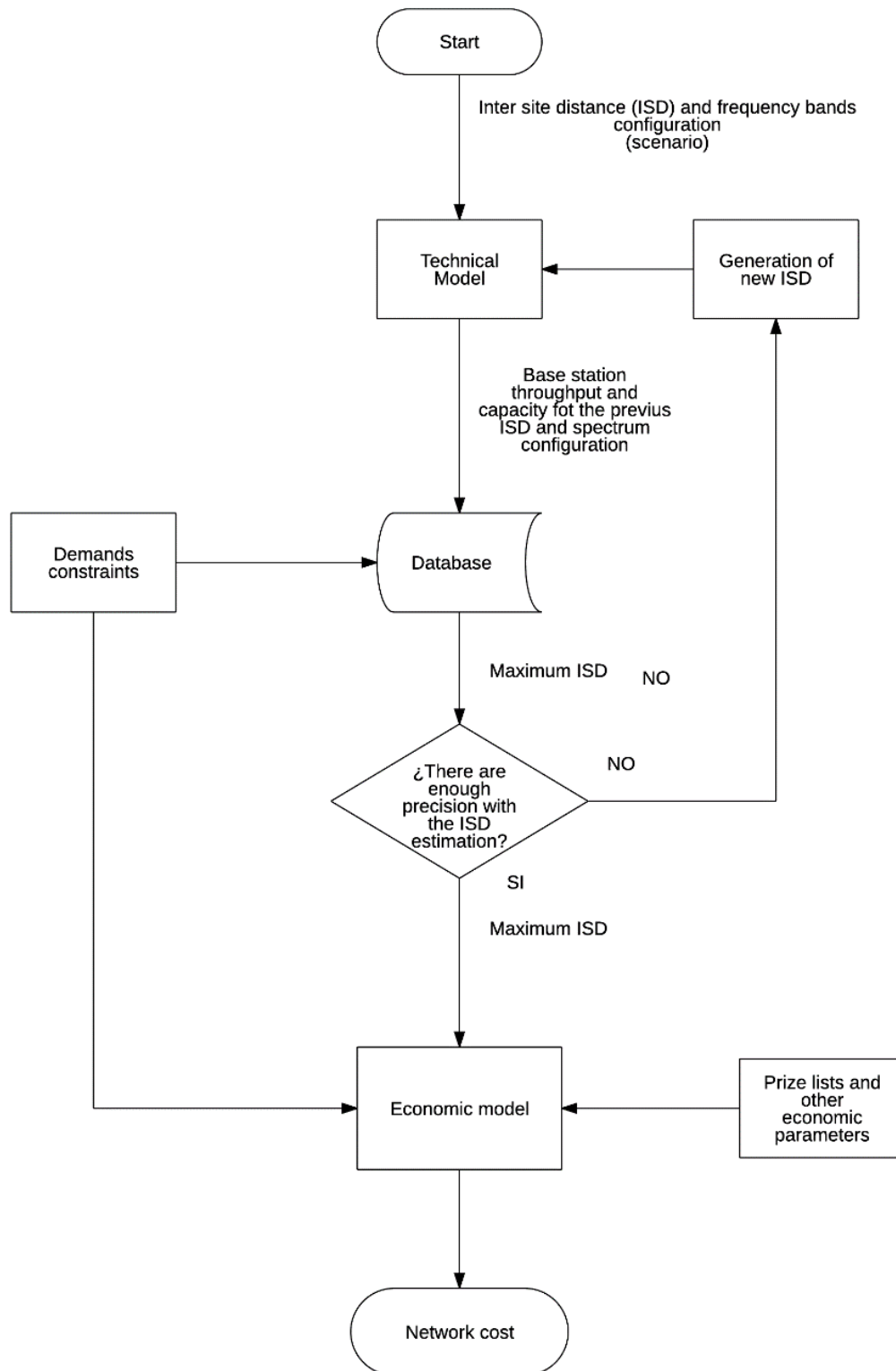


Figure 2. Flow chart of the techno-economic model

Two different parts compose this model: a technical model and an economic model.

The technical model consists in a LTE simulator implemented in Matlab. This simulator allows us to obtain information about the system throughput and capacity for different inter-site distances and spectrum holdings.

The results of every simulation are stored in a database that will be consulted to obtain the maximum inter-site distance for any specific demand condition.

The economic model uses these data, inter-site distance and demand conditions, to calculate the number of network elements, as base stations, links, etc., which are needed to provide the service. Then the minimum investment (CAPEX, CAPital Expenditures) and the Operational Expenses of the network (OPEX) are calculated using a table with the prices of the different assets.

As it can be seen in the flow chart, the technical model ignores the traffic demand conditions but it simulates different scenarios that are processed and from which the required radius for any combination of variables input can be obtained.

## 2.1 Technical model

The aim of this model is to obtain the volume of mobile traffic that a base station can handle for an inter-site distance and a spectrum configuration. To develop this model we have used the System Level LTE Simulator of the *Technische Universität Wien* [4] as a start and we have implemented all the necessary modules for our purposes.

The model implemented is focused on downlink throughput ignoring uplink because the first one is the bottleneck in mobile networks due to the asymmetry between the quantity of downloaded and uploaded data.

### 2.1.1 Parameters used in simulations

The next table shows the parameters used in the Matlab simulations.

Name	Value
Number of base stations	2 rings (19 base stations)
Number of sectors	3 sectors per site
Number of users per sector	10
User distribution in the sector	Uniform
Shadow fading model	Claussen
Fast fading model	ExtPedB (pedestrian 5 km/h)
Simulation length	150 TTI
Scheduler	Proportional Fair
Number of TX antenna	2
Number of RX antenna	2
MIMO	CLSM
TX Power	4.6dBm/Hz
Noise figure	9 dB

Thermal noise	-174 dBm/Hz
Map resolution	Radius/25 * Radius/25
Traffic model	Full Buffer

Table 1. Technical parameters used in the simulations

### 2.1.2 Propagation Model

The propagation model used in the simulations has been used in a public consult of Ofcom. It has been defined by the ERC (*European Radiocommunications Committee*)<sup>1</sup> and implemented in the SEAMCAT <sup>2</sup> project. This model is based on a modified Okumura-Hata model and allows us to distinguish between three scenarios: propagation in an urban scenario, propagation in a suburban scenario and propagation in a rural scenario.

## 2.2 Dimensioning

### 2.2.1 Radio access network

Once we have carried out all the computer simulations it is necessary to process this data to obtain the maximum inter-site distance able to satisfy the demand conditions. We have adopted the methodology explained in [5] and used by the UIT [6]. This methodology consists in two independent analyses, one focused on the capacity and the other on the throughput of a cell. The final result is the most restrictive.

We have considered other alternatives like the methodology used by Ofcom in [7] but it does not fit as well as the methodology used does.

#### 2.2.1.1 Throughput limitation

For each inter-site distance we calculate the maximum number of user per sector that the base station is able to provide the service granting a minimum throughput.

$$N^{\circ} \text{ user/sector} = \frac{\text{Sector throughput} * \text{Sector load}}{\frac{\text{Target throughput}}{\text{over} - \text{subscription factor}}}$$

Equation 1. Number of users per sector according to the target throughput.

In addition, for each inter-site distance we can calculate the base station radius and therefore the size of the regular hexagon that represents the coverage of a sector. Using this data we can obtain the maximum density of users that can be served for each inter-site distance.

#### 2.2.1.2 Capacity limitation

For each inter-site distance we calculate the maximum number of users per sector that the base station is able to provide to the service granting a monthly data cap.

<sup>1</sup> ERC Report 68, "Monte-Carlo Radio Simulation Methodology for the use in sharing and compatibility studies between different radio services or systems"

<sup>2</sup> "SEAMCAT implementation of Extended Hata and Extended Hata SRD models" [http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation\\_v2.pdf](http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v2.pdf)

$$N^{\circ} \text{ users/sector} = \frac{\text{Sector throughput(Mbps)} * 3600 * \text{Sector load}}{8192 * \frac{\text{User datacap(GB)}}{30} * \% \text{ Busy Hour}}$$

Equation 2. Number of users per sector according to the data cap.

As in the previous constraint we transform the number of users per sector into a density of users using the inter-site distance.

#### 2.2.1.3 Parameters used

We have used the following parameters in order to calculate the densities.

Name	Value	Reference
Sector throughput	From simulations	
% of traffic during the busy hour	15%	[5] [8]
Sector load	85%	[9] [10]
Over-subscription factor (peak to average ratio)	1:20	[5] [11]

Table 2. Technical parameters used to calculate the capacity and throughput constraint.

#### 2.2.1.4 Coverage limitation

In addition to the throughput and capacity restrictions we have taken into account another constraint: the coverage limitation. This constraint can be relevant in rural areas where user density is low so the cell radius could be too large otherwise.

We have used a tool developed in [12] which allows us to obtain the maximum coverage radius for a specific demand condition.

	700 MHz	800 MHz	1800 MHz
Dense urban & urban	2,44 km	2,2 km	1,05 km
Suburban	4,63 km	4,27 km	2,38 km
Rural	23,93 km	22,57 km	14,13 km

Table 3. Maximum coverage radios.

As we can show, the rural scenario has really good propagation characteristics so we obtain a very long range. We have to point out that, in practice, it is really difficult to find scenarios that meet these characteristics while the orography often imposes constraints. Anyway, in this study we are going to use the data shown in the previous table.

The parameters used to obtain the radius are shown in the next table.

Parameter	Value
Antenna height (Urban and Suburban scenarios)	20
Antenna height (Rural scenario)	45
Receptor height	1.5
Edge user throughput	1 Mbps
Neighbour cell load	85 %
Coverage probability	90%
Edge coverage probability	75%

Table 4. Technical parameters used to obtain the coverage constraint.

### 2.2.2 Backhaul network

Part of the dimensioning is performed to obtain the maximum inter-site distance needed to meet the demand conditions. Once we know this distance and the total area under study, the calculation of the number of base stations needed to cover this area is direct.

To calculate the area covered by a three-sector base station is considered the ideal case where this coverage area consists in three hexagons, one per sector.

For dimensioning the backhaul network a geometrical model has been used. This model allows us to estimate the number of network elements and the kilometres of infrastructure needed. To obtain these data, the model assumes that the study area is a square that can be divided in so many regions as aggregation levels. Thus, and considering the topology used, the distances between the individual devices can be calculated, i.e. the length of the links. Furthermore, as the distances calculated are measured in a straight line, what is almost impossible in a real deployment, we have used a non-linear factor that represents the presence of obstacles, which prevent straight point-to-point links to be deployed.

This process is performed iteratively, starting with the lowest level of aggregation (base station) and ascending to the highest level (core router) to obtain the equipment and infrastructure needed for each level of aggregation.

## 2.3 Economic Model

The economic model is a costs model that allows us to obtain the different costs associated with the deployment of LTE with a given inter-site distance. Specifically, in this study we will focus on capital costs (Expenditures Capital (CAPEX)) and Operational Expenditures (OPEX)) over a period of 10 years considering multiple frequency bands.

### 2.3.1 CAPEX

Capital Expenditures encompass all investments in equipment and infrastructure made by a company whose useful life is longer than one taxable year. In our study, CAPEX is composed of all expenses related to:

- Acquisition of equipment: base stations, backhaul and core network.

- Deploy of own infrastructure: sites, optic fibre, microwave links.
- Acquisition of spectrum licenses.

### 2.3.2 OPEX

Operational Expenditures encompass all those costs necessary for the usual development of the company and the acquisition of goods with less than one year lifespan. Within operating costs can be distinguished two types of costs depending on the nature of their origin: maintenance costs and other business costs. Maintenance costs include all those costs necessary to provide the services offered by the company. On the other hand, business-related costs include costs, such as marketing costs, personnel, etc. This division has been made since in this study only the costs associated directly to network maintenance costs will be considered (network-driven costs) and while other costs that could be added and are the same in all scenarios can only cause distortion in the data.

These operational costs are usually defined as a percentage of its acquisition cost (CAPEX). This percentage will be higher or lower depending on the asset and reflects the amount of money needed to perform its configuration, maintenance and operation.

### 2.3.3 Total costs

Before identifying and cataloguing the major costs incurred by an operator to provide such services, the unit costs of each equipment, infrastructure deployed and maintenance activity of the company have been estimated. To set this unit cost we have used information from different sources such as other techno-economic studies, public and private published data from manufacturers and operators and data from national regulatory authorities. In addition, as our study is long-term, it has been necessary to consider the evolution of these prices over the study period because there are significant differences in their evolution. The price of equipment has a downward trend over the years as a result of economies of scale and market maturity while installation costs of infrastructure are a growing trend due to inflation and the increase in the price of labour.

Once the required amount of elements and its unitary cost is calculated, the CAPEX and OPEX values can be obtained according to the following expressions.

$$CAPEX^i = \sum_j M_j^i c_j^c (1 + P_j^c)^{i-1}$$

$$OPEX^i = \sum_j M_j^i o_j^o (1 + P_j^o)^{i-1}$$

*Equation 3. CAPEX and OPEX calculation.*

j: amount of assets during the year i.

$M_j$ : amounts of elements j acquire in year i.

$C^c$ : Acquisition unitary cost of element j.

$C^o$ : Operational unitary cost of element j.

$P^c$ : annual trend of acquisition cost of element  $j$ .

$P^o$ : annual trend of operational cost of element  $j$ .

As the acquired assets have more than a year of life it is necessary to obtain the CAPEX annualized to be aware of how much it costs us to provide the service every year, splitting up the investment that has been done and how much it costs each year. This will need not only to divide the CAPEX of the asset into several cash flows but also to take into account the cost of capital over those years. This cost of capital, which is known as the discount rate or Weighted Average cost of Capital (WACC), is considered 15%.

$$CAPEX \text{ annualized}^i = \sum_j \frac{\sum_{k=\max\{i-LF_j+1;1\}}^i CAPEX_j^k \cdot (1 + WACC)}{LF_j}$$

Finally, to take into account the time value of money, CAPEX and OPEX are updated at present by the following expressions:

$$CAPEX_{\text{annualized actual}} = \sum_{i=1}^n \frac{CAPEX \text{ annualized}^i}{(1 + WACC^i)}$$

$$OPEX \text{ actual} = \sum_{i=1}^n \frac{OPEX^i}{(1 + WACC^i)}$$

Where  $n$  is the number of years of the study.

### 3 Scenarios

#### 3.1 Demand forecast

The traffic carried by mobile networks is growing exponentially, but the great uncertainty about future products and services causes to be very complicated to make predictions about their evolution due to the large number of variables involved.

In regard to this study we need to calculate the evolution of the traffic carried by the LTE networks in order to be able to make the dimensioning of these networks. To face this complex problem it has been divided into three more specific and simple forecasts that, combined, provide us the desired data. These provisions are:

- The evolution of mobile broadband subscriptions
- The evolution of LTE penetration
- The evolution of the amount of data generated by one smartphone

The division of the initial prediction in three simple projections allows us to tackle this task but also causes a diversion of some variable that may impact on the results. This effect is especially important in the evolution of LTE penetration since it is a value that starts near zero and therefore can be small variations from double to drastically reduce the final forecast. The next variable with ability to impact on results would be the evolution of traffic generated by a smartphone, as the exponential growth shows.

### 3.1.1 Evolution of mobile broadband subscriptions

To make this forecast the data provided by the European Union related to the fulfilment of the Digital Agenda for Europe has been used as a starting point.

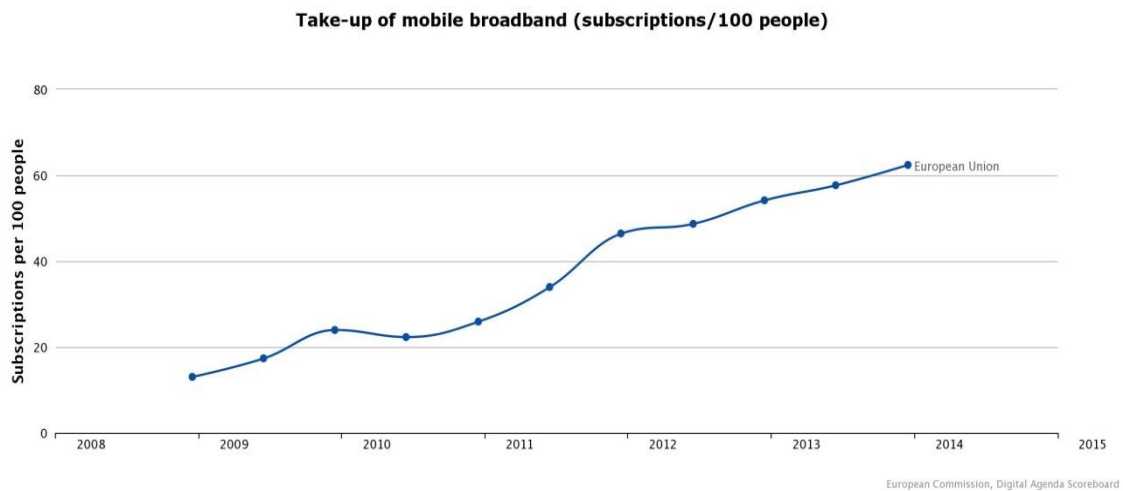


Figure 3. Historical data about take-up of mobile broadband. Source: the scoreboard of the digital agenda for Europe

The latest reports from which these data are available are from December 2013 and indicate that there are, in average, 62.4 mobile broadband subscriptions per 100 inhabitants in the European Union.

To make the forecast on the evolution of the number of lines, data from other studies already undertaken have been used. We have specifically used the expected growth in [13] where the period of study is divided into two distinct sections: from 2012-2020 and 2020-2030. In the first period (2012-2020) it has been a CAGR of 14%, obtaining in 2020 a penetration of 118 lines per 100 inhabitants. In the following period a lower growth, namely a CAGR of 3% is assumed until 2030 so we get an insight into 2024 of 135 lines per 100 inhabitants and finally in 2030, there will be 159 lines per 100 inhabitants. This lower growth is explained by saturation of the market of wireless broadband because of their maturity.

### 3.1.2 The evolution of LTE penetration

To calculate the penetration of LTE we have used various methods such as the logistic curve and function Gompertz but the data did not suit to any realistic scenario so we decided to calculate the forecast using a different methodology. For the final forecast, we have used data and forecasts made by GSMA. The evolution of similar technologies, in our case the 3G technologies, has been extended from that forecasts.

Data from GSMA has been chosen for this forecast because they come from the operators themselves, which are a reliable source of information. In addition, these data are specifically from Europe while many others analyse the evolution of LTE globally, making complex to extract specific data on the evolution of Europe.

### 3.1.3 The evolution of the amount of data generated by one smartphone

After a deep analysis, comparing information from various sources and watching the large discrepancies between the data used and the results of the forecasts obtained, it has been

decided to conduct our own study of the evolution of the demand focusing in Europe, which is detailed below.

We have used data from Ericsson [14] for the calculation of the amount of information generated by a Smartphone. This decision was based on the same criteria than the LTE penetration case; it is one of the most specific data exclusively from Europe that is available. According to the report, the data traffic generated by a mobile user is shown in the next table.

2013	2019
800MB	2.8 GB

Table 5. Traffic generated by a user. Source: [14]

These data have also been contrasted with data from the Cisco Visual Networking Index [15]

From the above data a forecast of data consumption by users was performed. The study examines the economic impact of having certain frequency bands for a period of 10 years. It is this long period that does not allow us to model the growth of traffic in a simple way so it is necessary to distinguish their evolution in different chronological phases, each with different characteristics. This same methodology was used in Ofcom's report [16] in which the study period has been divided into two different phases: before 2020 and after 2020.

Regarding the growth characteristics it has been assumed that in the first stage traffic grows very quickly, almost exponentially since both historical and all predictions consulted suggest so [15] [17] [18] [19] [20] [21].

In the second phase it has been assumed that the growth rate will fall due to market maturity and the limitation in time of use of mobile applications<sup>3</sup>.

The results of our prediction are shown in the next table:

Year	2013	2018	2020	2024
MB/month	800	2.800	3.575	5.829

Table 6. Results from our forecast.

These results are similar to the data used by Ofcom in [13], specifically they resemble the scenario of high demand.

### 3.2 Geotypes

In this study, four different geotypes have been distinguished depending on the population density. Furthermore, this geotypes have different propagation characteristics as noted in the section 2.1.2. The population density and the propagation model configuration are shown in the following table:

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<sup>3</sup> The amount of data generated by a Smartphone is currently growing almost exponentially as it is increasing both the amount of data they transmit applications as the number of hours used. It is this last factor that can ensure that it is impossible to continue to increase indefinitely.

Geotype	Population density	Propagation model
Dense Urban	25.000	Urban
Urban	10.000	Urban
Suburban	1.000	Suburban
Rural	50	Rural

Table 7. Geotypes used in the analysis.

### 3.3 Spectrum scenarios

The different spectrum scenarios and the criteria for its choice are explained below.

First, we have to point out that we will analyse the costs of the network for an operator with a 30% of market share.

Nowadays a European telecommunication operator has usually acquired spectrum on multiple frequency bands: 900 MHz, 1,800 MHz, 2,100 MHz and 2,600 MHz. However, we cannot assume that the operator can deploy LTE in all these frequency bands since it has to provide service with the older technologies because of the user equipment and of commercial reasons.

The 900 MHz band is currently being used by GSM, the second mobile generation, and until the digital dividend spectrum was released it was the lowest frequency band so it was used to provide mobile telephony because of its good propagation characteristics. In addition, GSM is also deployed in 1,800 MHz band to meet the capacity requirements in densely populated areas as well as UMTS and HSPA. On the other hand, UMTS and HSPA are mainly deployed in 2,100 MHz band to provide broadband services.

Therefore, for this study, it has been assumed that operators have 20 MHz of bandwidth in the 2,600 MHz band to deploy LTE. In addition, it has been assumed that they have 10 MHz in 1,800 MHz band to deploy LTE despite they provide services with other technologies in the same 20 MHz band. These assumptions are based in the most used bands to deploy LTE worldwide provided by GSA [22].

In order to analyse the savings generated by the allocation of new frequency bands to mobile broadband is necessary compare the deployment cost in the new spectrum scenarios with the previous situations. For the digital dividend, the spectrum holding explained above has been used as base case (blue bars figure-left) and the new scenario adds the 800 MHz band (orange bars figure-left). For the second digital dividend the base case has the 800, 1,800 and 2,600 frequency bands (blue bars figure-right) and the new scenario adds the 700 MHz band (orange bars figure-right).

The next figures shown the spectrum holdings used to analyse the economic impact of the first and second digital dividend.

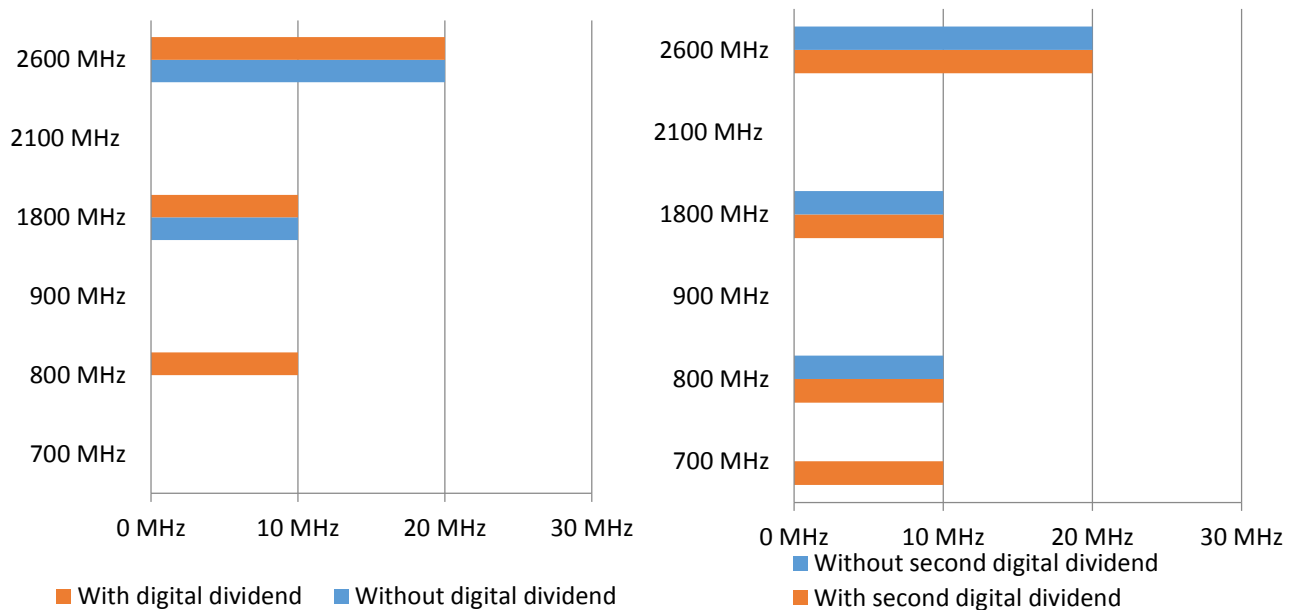


Figure 4. Spectrum bands used to evaluate the impact of the digital dividend and the second digital dividend

## 4 Results

With the spectrum holding and the demand assumptions detailed in section 3 and the methodology explained in section 2, the cell radii have been calculated for each year, geotype and scenario. Once the radius has been calculated, the economic model provides us the estimation of network costs for each scenario.

For each scenario two different analyses have been made. An initial analysis in which the price of spectrum (licenses and fees) is taking into account, which will be used to assess the differences in network costs. Then, a second analysis including spectrum costs has been made in order to provide a more wide vision and evaluate differences between the values of both bands. The spectrum costs for the 700 MHz band have been supposed equal to the 800 MHz band to allow an easy comparison. The spectrum costs have been obtained from the Spanish case, auction and taxes. These data have been normalized and are shown in the next table.

Geotype	Digital dividend savings		Second digital dividend savings	
	Without spectrum costs	With spectrum costs	Without spectrum costs	With spectrum costs
Dense Urban	19,84%	-4,78%	10,12%	-15,33%
Urban	30,52%	12,48%	10,80%	-11,30%
Suburban	38,49%	27,24%	9,63%	-6,57%
Rural	28,19%	15,21%	10,14%	6,98%

Table 8. Results obtained

The results achieved show that the 800 MHz band is able to provide significant savings to mobile operators because of its good propagation characteristics. The scenario without spectrum costs shows us the reason behind the high prices paid by operators in the auctions; for instance in Spain mobile operators paid about 500 million euros for 2x10 MHz despite having strong coverage obligations<sup>4</sup>. If we analyse the source of these savings we found that the extended coverage is the main reason because rural and suburban scenarios were coverage limited instead of capacity limited at least during the first years.

The results with spectrum costs show us that all geotypes are profitable except for dense urban as we could expect because in other case operators would not have paid so much for the spectrum. In this densely urban geotype other bands such as the 3.5 GHz band may be more appropriate but this scenario reflects the high-density areas inside big cities so its impact in the total costs is very low. The other geotypes show us relevant savings because of the great impact of extended coverage that justify the amounts paid in the auction.

The results achieved related to the second digital dividend are quite different. We have obtained that the 700 MHz bands generates less savings than the digital dividend if the operator has spectrum in 800 MHz band. It can be noticed that this band is able to provide big savings but if we include spectrum costs we have an over cost rather than a saving except in the rural geotype that is always profitable because of the good propagation characteristics of sub 1 GHz spectrum.

## 5 Conclusions

The conclusion with the data related to the first and the second digital dividend is that 700 MHz band should be less valued than the 800 MHz band for operators with spectrum in the 800 MHz band. This result should affect to the prices paid by operators for this spectrum in the auctions or the coverage obligations associated to spectrum by regulators. On the other hand operators that could not achieved spectrum in 800 MHz band have an important chance because of the opportunity cost of this spectrum for them is much higher than for their competitors. For these operators the savings would be similar to the first digital dividend savings.

Finally the authors have to point out other aspects which are out of the scope of this paper but they could have effects in the auctions.

Firstly, the methodology used allows us to change the radius and the number of base stations every year. In practice, contracts for renting a site are long-time contracts so an operator cannot modify the architecture of its network easily. Depending on the actual network architecture an operator can be more or less interested in this spectrum. For instance an operator with GSM deployed in 900 MHz could be more interested than an operator whose network is optimized to operate with only 1,800, 2,100 and 2,600 frequency bands. In this context an operator could be forced to acquire more spectrum because it cannot densify its network or because changing this architecture has an over cost that we are not including.

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<sup>4</sup> In Spain they have to cover at least the 90% of population entities sized under 5,000 inhabitants with a network able to provide 30 Mbps.

Secondly, there are other reasons apart from technical reasons taken into account in this paper to acquire this spectrum such as commercial reasons or granting a better user experience because of a better in-building reception.

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