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Conference Paper

Valuation of spectrum for mobile broadband services: Engineering value versus willingness to pay

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Valuation of spectrum for mobile broadband services - Engineering value versus willingness to pay

Abstract

Radio spectrum is a vital asset and resource for mobile network operators. With spectrum in the 800 and 900 MHz bands coverage can be provided with fewer base station sites compared to higher frequency bands like 2.1 and 2.6 GHz. With more spectrum, i.e. wider bandwidth, operators can offer higher capacity and data rates. Larger bandwidths means that capacity can be provided with fewer base station sites, i.e. with lower cost. Operators that acquire more spectrum in existing or new bands can re-use existing sites for capacity build out. Engineering value is one way to estimate the marginal value of spectrum. The calculation of engineering value is based on comparison of different network deployment options using different amounts of spectrum. This paper compare estimates of engineering value of spectrum with prices paid at a number of spectrum auctions, with a focus on Sweden. A main finding is that estimated engineering value of spectrum is much higher than prices operators have paid at spectrum auctions during the last couple of years. The analysis also includes a discussion of drivers that determine the willingness to pay for spectrum.

JEL codes: O14, K23, M11

Keywords: Radio spectrum, mobile communications, spectrum valuation, spectrum allocation, mobile broadband, marginal value of spectrum, engineering value

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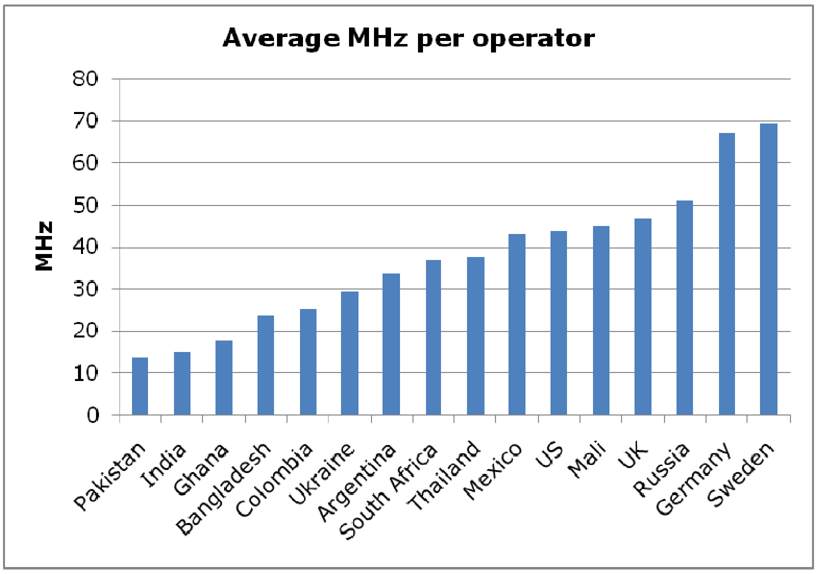
1. Introduction

Spectrum allocation

The European Commission has launched a Digital Agenda which aims to provide “fast” broadband with speeds above 30 Mbps for all Europeans by 2020 and “ultra-fast” broadband with speeds above 100 Mbps for 50 percent of all European households by 2020. Given that it is significantly more expensive to deploy fiber access networks compared to mobile networks mobile communication is set to be instrumental in fulfilling the Digital Agenda. The expansion of mobile data makes spectrum to a key asset in the deployment of 4G (LTE) through spectrum in the 800 MHz-band (digital dividend) as well as in the 2.6 GHz-band. Moreover, the significance of spectrum will be reinforced by the introduction of spectrum aggregation when LTE Advanced will be available. The allocation of spectrum is therefore of immense importance motivating National Regulators to use auctions as a mechanism to determine the allocation of spectrum enabling market participants to set the market price on spectrum.

The take-off for mobile broadband through dongles and smartphones underscores the essential role spectrum plays for mobile operators, as it enables operators to provide coverage and capacity in their mobile networks. However, the conditions for the operators varies considerable as operators in Pakistan and India in average have access to just around 2 x 15 MHz while operators in Germany and Sweden in average have access to 2 x 70 MHz.

Figure 1 Average MHz per operator (downlink)[2]



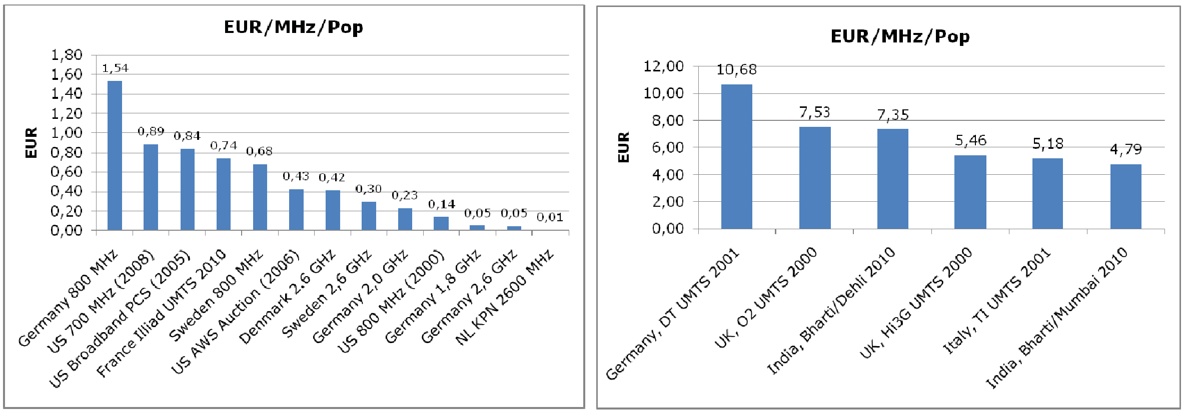
Source: NRAs, Operator reports, authors’ calculations

[2] The calculation is based on the total amount of spectrum operators have in the different countries, and then calculated as a market share weighted average per country.

Price for spectrum

The enhanced role for spectrum turns spectrum allocation into decisive events for mobile operators. One estimate for the marginal value of spectrum for operators could be derived from auction prices paid by operators. The outcome of recent spectrum auctions show that operators in Germany paid EUR 1.54 per MHz/pop for spectrum in the 800 MHz band, and the Swedish operators in average paid EUR 0.68 per MHz/pop for the 800 MHz band, while prices for spectrum in the 2.6 GHz band reached EUR 0.30 per MHz/pop in Sweden, EUR 0.05 in Germany and just 0.01 in the Netherlands. Interestingly enough, prices paid at the Indian 3G auction in 2010 for spectrum in the main two cities are not far off from prices paid at the 3G auctions in the year 2000-2001.

Figure 2 Prices paid per MHz/Pop in spectrum auctions and for 3G licenses in India and Europe



Source: NRAs, authors' calculations

Paper objective and research question

The objective with this paper is to analyze the marginal value of spectrum. The analysis takes the outcome from recent spectrum auctions in Sweden as a point of departure for the valuation. This is complemented with an examination of spectrum holdings for the Swedish mobile operators, and an assessment of the intrinsic properties of spectrum which altogether determine the conditions for network deployment. The analysis is also complemented with an international comparison of auction prices on spectrum.

The paper makes the assumption that auction prices are an expression for what operators are prepared to pay for spectrum. This allows us to make the assumption that it is the marginal value of spectrum. Subsequently, we are analyzing what it means in terms of engineering value, which in this case is explored in terms of network deployment.

Key concepts in the analysis are the marginal value of spectrum which is a construct covering the engineering and strategic value of spectrum, and the willingness to pay, which could be regarded as an outcome from spectrum auctions and thereby an expression of the value of spectrum. This facilitates the paper to explore potential gaps between the willingness to pay for spectrum and the marginal value of spectrum. The willingness to pay depends on the available frequency allocation options and the freedom of action for mobile network operators. The calculation of engineering value of spectrum is based on comparison of different network deployment options using different amounts of spectrum. Hence, the general research question for the paper is:

What do the paid levels for spectrum imply for the marginal value of spectrum and willingness to pay?

Given that a number of factors have an impact on the final price operators pay for spectrum the aim with this paper is to make a contribution to the ongoing discussion of spectrum, and give some input to the understanding of operators view on the value of spectrum and their willingness to pay for spectrum. The paper is also set to give input to the analysis of operators' strategy of their current business and positioning for the future development. Moreover, the examination of the market valuation will enable the reader to relate to the theoretical discussion on spectrum and its valuation in a market with massively growing data volumes. Key aspects in the analysis are:

- To identify factors for competitive advantage in relation to spectrum; impact on production cost depending upon amount of spectrum
- To analyze ranges of engineering and strategic value of spectrum
- Identify factors that determine the willingness to pay for spectrum
- To explore potential deviation of estimated value and the willingness to pay for spectrum

2. Methodology

In this section we describe the work flow and the different steps in the analysis. Unlike our previous contributions on spectrum valuation, e.g. to the ITS Conferences in Tokyo and Copenhagen 2010 (Mölleryd, Markendahl and Mäkitalo) and (Mölleryd, Markendahl, Mäkitalo and Werding), we do not model and analyze mobile broadband networks at any specific markets. In this paper we identify drivers for willingness to pay for spectrum, collect empirical data on spectrum allocation cases and analyze these cases in terms of various drivers.

The first step in the analysis is to identify key technical factors and network performance parameters related to the amount of spectrum of individual operators. Capacity, coverage and data rate are linked network costs for varying amounts of spectrum using cost structure analysis methods presented in the PhD theses by Johansson (2007) and Markendahl (2011). The engineering value of spectrum is related to network costs using the approach developed by Marks et.al. (1996). Using this approach the value of spectrum is derived from the additional cost or cost saving depending upon if operators are allocated spectrum or not, and how much spectrum that are allocated.

In addition to the cost related aspects we also discuss other factors like market position of mobile operators due to offered data rate and time to market. For example, the data rate depends on the amount of spectrum, the use of carrier or band aggregation and on the level of cooperation between operators (Mölleryd, Markendahl and Mäkitalo, 2010) and (Markendahl, 2011).

Next, we present empirical data on spectrum allocation of different bands in Sweden. The amount and price of spectrum is presented using the metric “price per MHz normalized with the population” (EUR/MHz/pop). We also presents “stories” about the spectrum allocation processes indicating how operators “behave” including spectrum auction for the 800 MHz band, re-allocation of the 900 MHz band and some cases of appeals.

The core of the analysis is to calculate the engineering value of spectrum using alternative deployment scenarios and to compare these numbers with prices paid at the auctions for the 800 MHz and 2.6 GHz bands. Next the technical factors are linked to how operators have acted and identify the driving forces. The drivers are discussed using the spectrum allocation situations in Sweden 2008 and 2011 respectively. The drivers are identified and analyzed based on the “situation” (market position and spectrum allocation) for different mobile operators.

Finally, we discuss two types of implications of the presented analysis. The first aspect is the financial situation for different operators. The other aspect is the overall role of the amount of spectrum using “Cooper’s law” where increase of radio capacity is linked to the site density, improvement of technology, frequency division and available bandwidth (pp: 65, Webb, 2007).

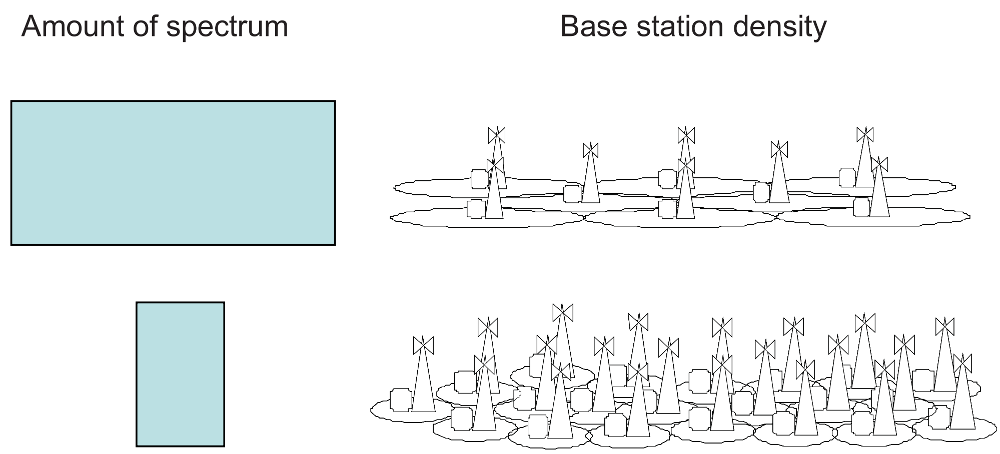
3. Dimensions of spectrum value

In this section we discuss various types of benefits and ”values” associated with spectrum and control of different amounts of bandwidth as seen from a mobile operator perspective. This includes capacity, coverage and data rate and the interrelations with network costs. The evolution of cost for radio equipment, basic cost structure and system complexity is also discussed. We also highlight the importance of data rates for the marketing message of mobile operators and different ways to increase the system bandwidth (and hence the data rate).

Coverage, capacity and cost

Capacity can be increased by replacing existing radio equipment with more efficient systems, by adding more radio equipment to existing base stations sites (using additional spectrum) or by deployment of new base stations (using existing spectrum). Operators that are unable to obtain additional spectrum are forced to deploy more base stations. Compared to competitors which can add more spectrum and re-use existing base stations sites these operators will face a large increase in network investments, see figure 3.

Figure 3 Illustration of base station density satisfying the same user demand (capacity) in the area, comparing “high” level of allocated spectrum and “lower” level of allocated spectrum. The picture is from a presentation by Markendahl, Mäkitalo, Mölleryd at the COST-TERRA workshop in Brussels, June 2011.



The basic relation between network costs, capacity demand, bandwidth, service area is derived by Zander (1997). For a specific amount of spectrum and for a specific radio access technology it can be formulated as
“the deployment of N times more capacity requires N times more base stations”.

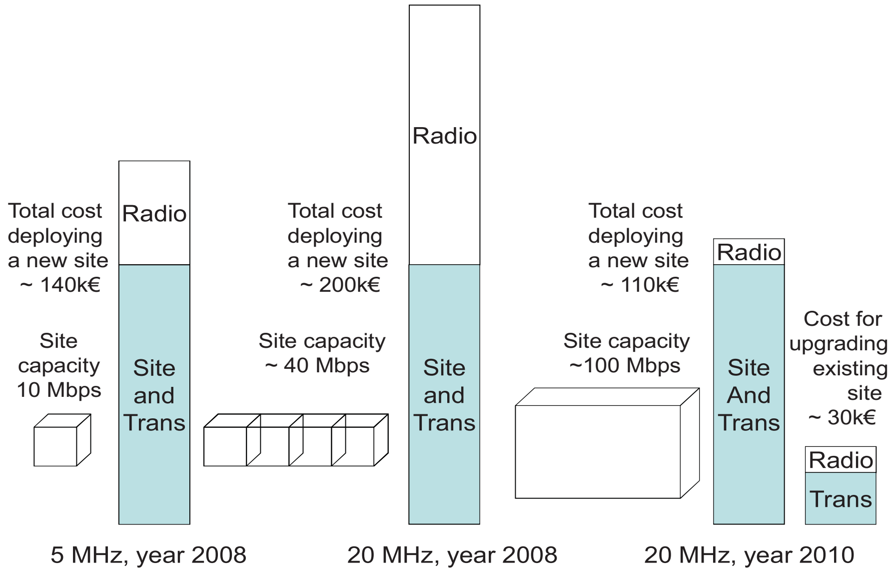
The type of frequency band is also essential as lower frequency bands like 800 and 900 MHz provide better coverage compared to the 2.1 and 2.6 GHz bands. Hence, the value of 800 MHz can be expressed as the additional cost if the capacity and coverage would be provided by deployment of networks with higher bands e.g. 2.6 GHz, see examples in (Mölleryd, Markendahl, Mäkitalo, 2010).

Cost and cost structure

The intense competition among network and radio equipment manufactures has pushed down prices during the last couple of years. This enables operators to replace existing radio equipment with new equipment (LTE) for only EUR 10K per base station. This is an approximation of the market price supported by statements by Telia and Ericsson. The first indication of these price levels was found 2009 when Telenor signed an agreement with Huawei for the replacement of approximately 6000 base stations for EUR 63 million[3]. The cost-capacity ratio has improved more than 20 times in just a few years, see figure 4. The most recent base station equipment supports multi-standard solutions, e.g. GSM, WCDMA and LTE[4], further improving the cost efficiency.

It is, however, not the cost of the radio equipment that is the key issue. As illustrated in figure 4 the dominating component in the cost structure of radio access networks is cost associated with the base station sites. This includes costs for towers or masts, non-telecom equipment, power, installation, and site lease. The capacity is related to the amount of radio equipment, but the main cost driver is the amount of new sites that needs to be deployed. More spectrum means that operators can re-use existing sites and hence exploit previous infrastructure investments. This is also a key aspect when network sharing between operators is used.

Figure 4 Site capacity and deployment costs, based on assumptions of 3 sector sites and cell average spectral efficiency of 0.7 bps per Hz (using HSPA year 2008) and 1.7 bps per Hz (using LTE year 2010).



Source: Authors' calculations (Markendahl, 2011)

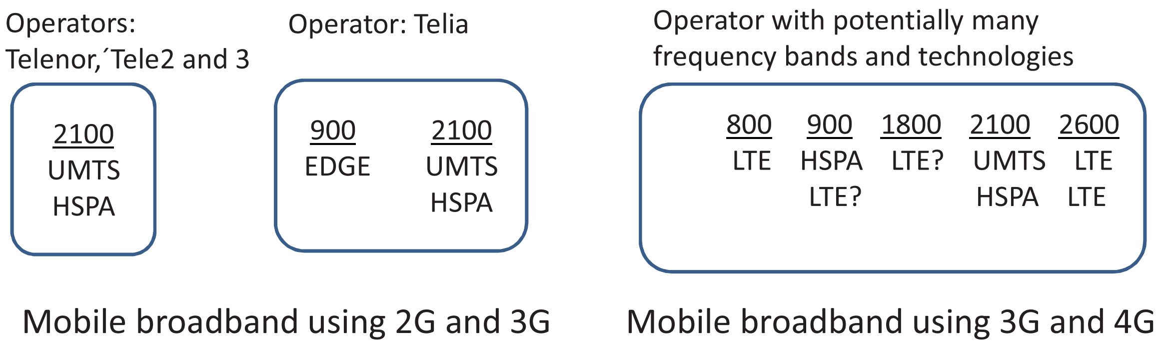
[3] Source: http://www.telenor.com/en/news-and-media/press-releases/2009/telenor-to-replace-its-infrastructure-for-mobile-services-in-norway

[4] An example (NSN): http://www.nokiasiemensnetworks.com/portfolio/products/mobile-broadband/single-ran-advanced/flexi-multiradio-10-base-station

System complexity

Compared to the situation when mobile voice services was launched we are now faced with a situation where operators for one service need to consider many radio access technologies and many frequency bands. GSM voice services initially used the 900 MHz band, later in combination with the 1800 MHz band. This can be compared to mobile broad band services where multiple frequency bands and technologies are used, see figure 5. This multitude of bands and technologies will have an impact on the complexity of both the network and the user equipment. However, the current multi-standard base stations support GSM, UMTS and LTE operating at different frequency bands.

Figure 5 Illustration of multitudes of technologies and frequency bands



Data rates - technically

Both the peak and average data rates depend on both the system bandwidth (MHz) and the spectral efficiency of the used radio access technology. The spectral efficiency (expressed as bps per Hz) depends on the signal strength, usually a function of the distance to the base station and (if indoor) wall penetration losses. Operators with higher system bandwidth than competitors can claim that they are able to offer higher data rates. Technically, higher bandwidth influences the user experience in two ways:

1. Higher peak data rates can be provided.
2. More users can be served at a given data rate when the network is loaded.

The peak data rate can be achieved very close to the base station assuming that the user is alone in the cell and is thereby not forced to share the capacity. The peak data rate is often used by operators in their marketing. The average cell data rate is what users "should expect" taking into account an "average location" and multiple users in the cell. The technology development with introduction of LTE and aggregation of carrier or bands has changed the rules of the game. We will come back to this, but first we will make some observations regarding the importance of data rates for mobile operators.

Data rates – observations from operator marketing

Network performance in terms of data rates and coverage are considered to be very important by the operators. This can be observed from statements made by operators in their marketing. All operators claim to offer the best broadband access services. See some examples below from the operator web sites in December 2010 as described in (Markendahl, 2011).

- *"The fastest Mobile Broadband in Sweden - according to information retrieved from Bredbandskollen.se, November 25, 2010" (Telenor)*[5]
- *"Today the best Mobile Broadband in Sweden was nominated and the winner is Tele2. This means that you can do web surfing at higher speeds with Tele2 compared to any other operator."* [6]
- *"We have the fastest 4G network in Stockholm."(Tele2)* [7] *"For the fourth year in a row the magazine "Mobil" did nominate our Mobile Broadband to be the best in Sweden" (3 (HI3G) Sweden)* [8]*"*
- *4G. The fastest Mobile Broadband in the world for just 15 € per month until the Easter holiday, ordinary price 60€ per month." (Telia)*
- *"Today 8 million of Sweden's population have coverage with Turbo3G+" (Telia)*

These statements about data rates for 3G networks are used in marketing although the measured differences in various tests are negligible. The operators use similar type of radio access technology, the same system bandwidth and in many cases share networks. Hence, operators have so far had difficulties to offer different bit rates. This situation will change when carrier and band aggregation is introduced. This will be discussed in the following subsection

The mobile operators in Sweden continue to use data rates in their marketing. Telia, Telenor and Tele 2 offer 4G service with data rates up to 80 Mbps. Just in time for the summer vacation advertisements from Telia say that:

"4G is now deployed in the Stockholm archipelago and at the Swedish west coast"

In May 2011 Telenor and 3 (HI3G) announced that the peak data rate for 3G mobile broadband has increased from 16 Mbps to 32 Mbps. This is achieved by carrier aggregation, where 2 of the 5 MHz WCDMA carriers are used in combination. Operator 3 (HI3G) markets the service this way:

"We offer twice the speed but we still offer the lowest price in Sweden"

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[5] The "Bredbandskollen" service measures the connection speed at which a user's web browser can send and receive data, as an indication of real connection speed, see also www.netnod.se/other/valueadd/bbk

[6] http://www.tele2.se/mobilt-bredband/bast-i-test.html

[7] http://www.tele2.se/mobilt-bredband/4g.html

[8] http://www.tre.se/Privat/Mobilt-bredband/DataSubscriptionListPage/

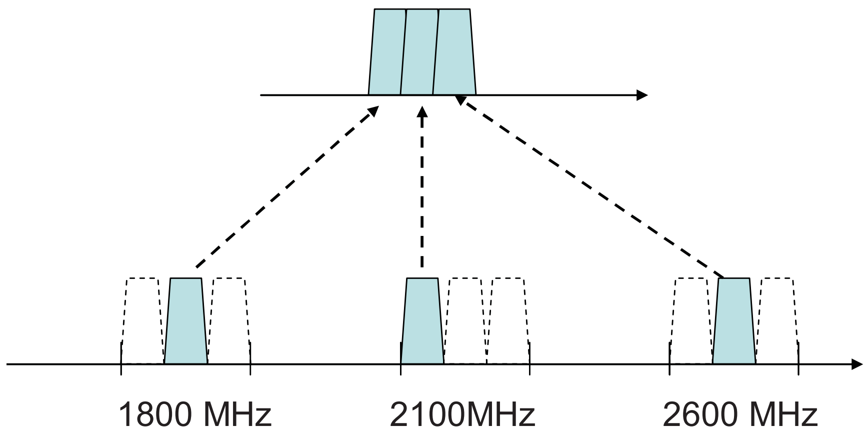
Data rates – what can be expected in the future

The technology development with the introduction of LTE and LTE-advanced aggregation of carrier or bands will change the market position of mobile operators depending on how much spectrum the different operators can use in different bands. In the next two sections these differences for Swedish operators will be described and analysed.

For 3G with a single 5 MHz carrier and with the same release of WCDMA or HSPA the very same bit rates could be offered provided a similar network deployment. Regardless of the total amount of spectrum the bit rate performance depends on what can be achieved for a single 5 MHz carrier. LTE supports system bandwidth from 1.4 MHz up to 20 MHz. Hence, operators with different amounts of spectrum will be able to provide different peak data rates.

Moreover, with band aggregation higher system bandwidths and data rates can be offered. Hence, operators with spectrum bands suitable for aggregation will have an advantage. In figure 6 an example is shown where an operator combines the 1.8 GHz, 2.1 GHz and 2.6 GHz bands. This means that operators that share networks will be able to combine their spectrum resources and hence have a competitive advantage compared to operators running their own networks.

Figure 6 Illustration of band aggregation combining 1800, 2100 and 2600 MHz bands resulting in higher system bandwidth



4. Empirical data – spectrum allocation in Sweden

In this section we present "stories" from spectrum allocation in Sweden including the 2.6 GHz auction in 2008, the renewal and re-allocation process of the 900 MHz licenses 2009-2011, the 800 MHz auction in 2011 and the renewal and upcoming auction of the 1800 MHz band. First, the operators and joint ventures for network deployment and operation are described.

Mobile operators and joint ventures in Sweden

The Swedish operators entered network sharing arrangements in 2001 in order to fulfill the 3G coverage obligations, and also driven by the fact that TeliaSonera did not obtain a 3G license. This paved the way for the formation of Svenska UMTS Nät (Sunab) by TeliaSonera and Tele2, and 3GIS founded by Telenor and HI3G.

In 2009 Tele2 and Telenor decided to establish a common network company Net4Mobility in order to deploy a common GSM and LTE network. Interestingly enough, both Telenor and Tele2 continued network sharing, but with new partners. Tele2 and Telenor used Net4Mobility as the vehicle in the 800 MHz auction. This reduced the potential number of buyers and thereby lowered the price for spectrum in the 800 MHz-band.

Figure 7 Network sharing companies in Sweden

About the 2.6 GHz band

In the following, we present empirical data on spectrum allocation of different bands in Sweden. The amount and price of spectrum is presented by using the metric "price per MHz normalized with the population" (EUR/MHz/pop). We also presents "stories" about the spectrum allocation processes indicating how operators "behave" including spectrum auction for the 800 MHz band, refarming of the 900 MHz band and some cases of appeals.

PTS held an auction for LTE spectrum in the 2.6 GHz band in 2008 where 2 x 70 MHz for FDD and 50 MHz for TDD were allocated. The auction resulted in prices with a range of EUR 0.32 to 0.35 per MHz/pop.

Table 1 Outcome of the auction 2008 of spectrum in 2.6 GHz

Block	MHz	Licencees	Price EURm	EUR/MHz /Pop
FDD 1-4	2 x 20	Tele2	60,9	0,32
FDD 5-6	2 x 10	HI3G	33,0	0,35
FDD 7-10	2 x 20	TeliaSonera	62,5	0,33
FDD 11-14	2 x 20	Telenor	59,2	0,32
TDD	50	Intel	17,7	0,04

Source: PTS, authors' calculations

Sweden – allocation of 900 MHz spectrum

The Swedish Post and Telecom Agency (PTS) decided to renew the operators' 900 MHz licenses in March 2009 based on a common application from the operators including HI3G, which previously only had spectrum for 3G, and was allocated 5 MHz. The allocation decision was based on the presumption that existing licensees has the right to maintain as the spectrum holder of the allocated spectrum, rather than allocated through the auction mechanism, as the demand of spectrum was in line with the available spectrum.

However, PTS decision was appealed to the Administrative Court by Nordisk Mobiltelefon International AB[9] arguing that the allocation of 900 MHz spectrum should be done in a transparent process providing new entrants with the possibility to participate. The appeal started a process that was stretched out over two years enabling the existing GSM operators (TeliaSonera, Tele2 and Telenor) to maintain its service while prohibiting HI3G to get access to the 900 MHz spectrum.

Table 2 The "legal" process for allocation of 900 MHz in Sweden

Date	Subject
November 2008	Application from the operators: TeliaSonera, Telenor, Tele2, HI3G for renewed 900 MHz licenses in combination of reallocation of spectrum in order to facilitate a new entrant HI3G
March 2009	PTS decided to allocate 900 MHz spectrum in accordance with the application
March 2009	Nordisk Mobiltelefon International (NMI) appealed the decision to the Administrative

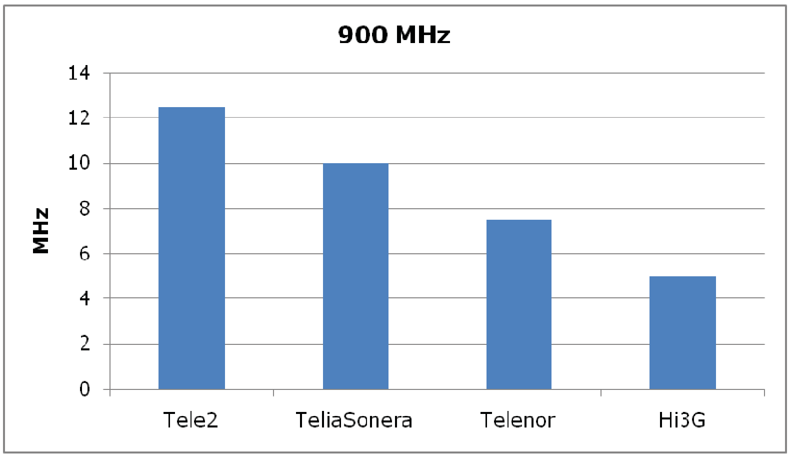
[9] Nordisk Mobiltelefon International AB is a very small Swedish company that was part of the establishment of a 450 MHz operator in the Nordics which went in to receivership in early 2009, and subsequently taken over by Access Industries. Nordisk Mobiltelefon International AB a 450 MHz license in Ireland through Wirefree Communications but there is no network in operation.

	Court
April 2009	NMI was denied the right to appeal by the Administrative Court
April 2009	NMI appealed the decision to the Administrative Court of Appeal
July 2010	The Administrative Court of Appeal decided that NMI had the right to appeal
H2 2010	The Administrative Court consider the appeal
February 2011	NMI made a deal with Net4Mobility (Tele2 and Telenor) through an investment company as an intermediary
February 2011	NMI requested the Administrative Court to withdraw the appeal
May 2011	PTS decision from March 2009 had legal force a

Source: PTS, the Administrative Court, and the Administrative Court of Appeals

The appeal process was terminated when Net4Mobility made an agreement with Nordisk Mobiltelefon International through an intermediary. This paved the way for PTS decision to get legal force, which had an impact on Tele2's and Telenor's bidding strategy for the auction of 800 MHz, which took place in March 2011. The allocation of 900 MHz spectrum is shown in figure 8.

Figure 8 Distribution of spectrum in 900 MHz



Source: PTS

800 MHz auction

Given the legal uncertainty regarding the allocation of 900 MHz it was not directly linked to the allocation of 800 MHz spectrum. The limited amount of available spectrum in the 800 MHz band with a total of 2 x 30 MHz, divided into 5 MHz slots, motivated PTS to impose a spectrum cap of 10 MHz in the auction that took place in March 2011. Moreover, the lowest block, FDD1, which is adjacent to the spectrum band used for terrestrial TV the licensee is obliged to take necessary measures in order to avoid interference with broadcasting of terrestrial TV. Moreover, the FDD 6 block was combined with a broadband deployment coverage requirement stipulating that EUR 33m of the winning bid should be used to deploy coverage at individuals households identified by PTS. Moreover, the minimum bid was EUR 16m per 5 MHz block. The auction resulted in that the licensees paid from EUR 18.3m up to EUR 52m for a 5 MHz block.

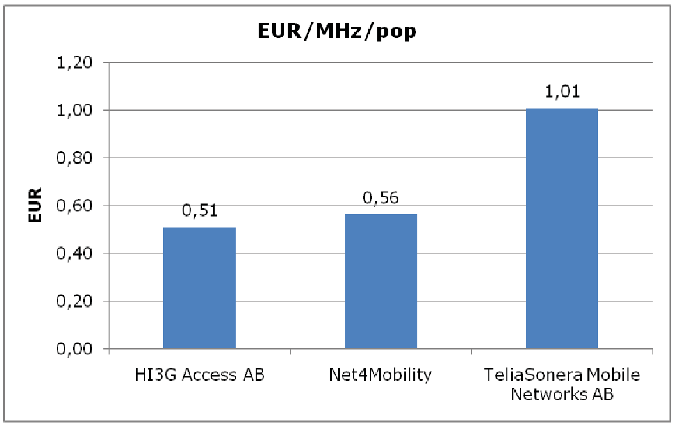
Table 3 Outcome of the auction 800 MHz spectrum

Block	Downlink	MHz	Licencees	Winning bid MEUR	EUR/MHz /Pop
FDD 1	791-796	2x5	HI3G Access	18,3	0,39
FDD 2	796-801	2x5	HI3G Access	29,6	0,63
FDD 3	801-806	2x5	TeliaSonera	42,9	0,91
FDD 4	806-811	2x5	TeliaSonera	52,0	1,11
FDD 5	811-816	2x5	Net4Mobility	46,7	0,99
FDD 6	816-821	2x5	Net4Mobility	38,8	0,83

Source: PTS, authors' calculations

By deducting the investment commitment of EUR 33m from the winning bid that Net4Mobility made the prices paid by HI3G, TeliaSonera and Net4Mobility are in the range EUR 0.51 to EUR 1.01.

Figure 9 Price per MHz and population,



Source: PTS and authors' calculations

Altogether, the obvious question is why the result ended as it did, and why TeliaSonera paid almost the double amount compared to HI3G?

Firstly, the lowest block requires that the licensee take action in order to avoid interference with terrestrial TV. This requires special arrangements for the radio access network, like inserting filters and vertical antennas. Secondly, the last block requires that the licensee provide special solutions in rural areas in order to establish coverage to specific households that PTS identifies. This implies that block 2, 3, 4 and 5 were not combined with any specific obligations. The auction was completed after five days generating a total of EUR 233m.

Sweden – allocation of 1800 MHz

Although the 1800 MHz band is not sharing the same coverage characteristics as the sub-1 GHz band it could be used as a capacity overlay to 900 MHz, and in the longer run as an attractive expansion band for LTE. PTS decided in February 2010 to renew the existing licenses, but only with half of the existing spectrum in order to release spectrum that could be sold in an auction. PTS decision was appealed to the Administrative Court. But in May 2011 the Administrative Court of Appeal closed the case after it was withdrawn which resulted in that PTS decision has legal force paving the way for an auction in the latter part of 2011.

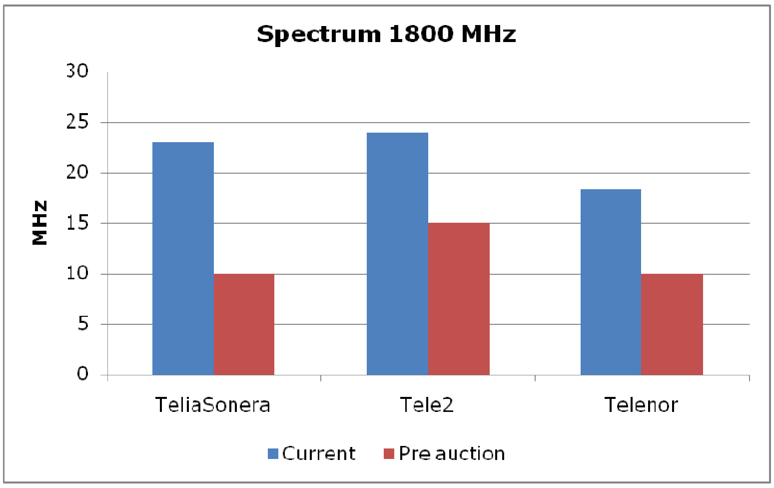
Table 4 The process of allocation of 1800 MHz spectrum

Date	Subject
February 2010	PTS decided to renew licenses but with less spectrum
March 2010	Decision appealed to the Administrative Court of Appeals
October 2010	Administrative Court of Appeal decided not to overrule PTS decision
October 2010	Decision appealed to the Administrative Court of Appeal
May 2011	Administrative Court of Appeal withdrew the case
H2 2011	Auction planned

Source: PTS, the Administrative Court

The current holdings of spectrum are that TeliaSonera, Tele2 and Telenor have 23 MHz, 24 MHz and 18.4 MHz respectively. The explanation behind Tele2 large holding is that it has taken over a company that has an 1800 license. The auction will consist of seven blocks of 5 MHz, altogether 2 x 35 MHz. Moreover, 2 x 5 MHz will be unlicensed which will create opportunities for example indoor solutions by new service providers.

Figure 10 Spectrum holding in 1800 MHz



Source: PTS

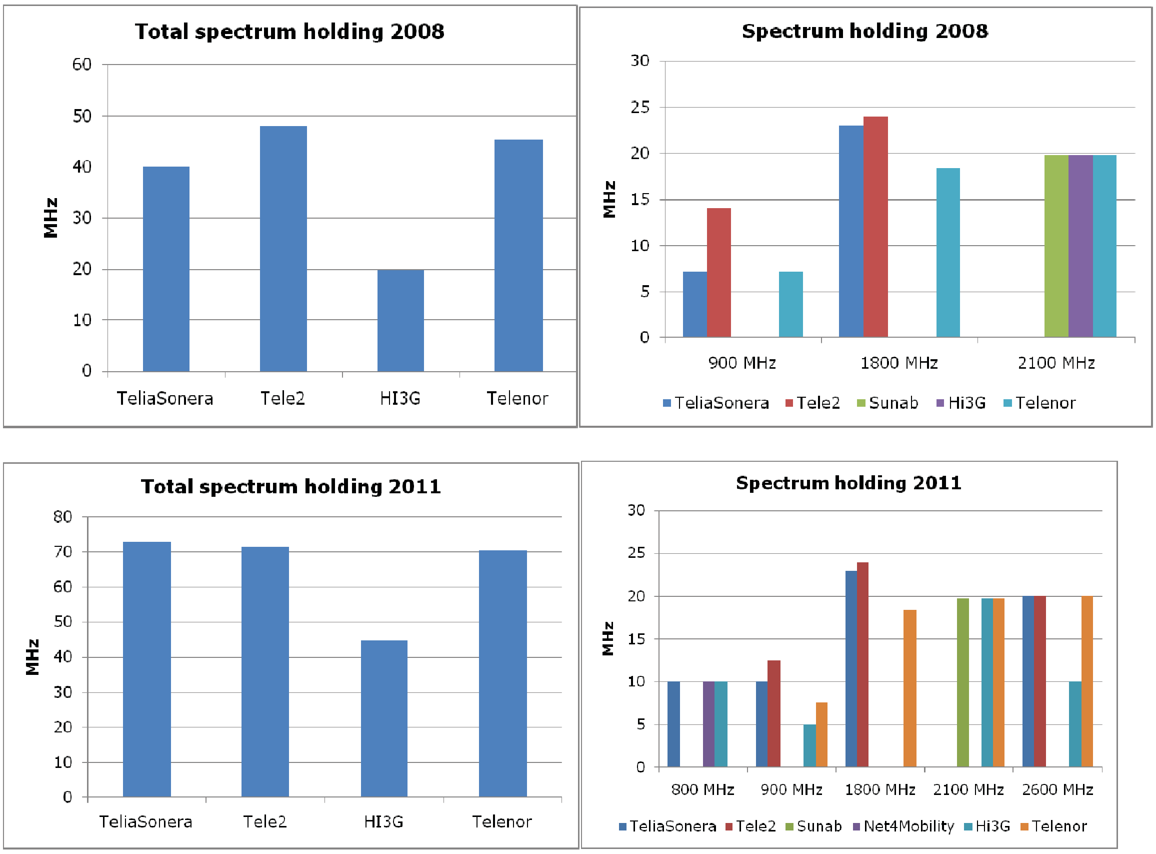
5. Analysis

The analysis in this section considers the spectrum allocation in Sweden with focus on the situation before the 2.6 GHz and 800 MHz auctions, i.e. 2008, and after these auctions, i.e. 2011. The analysis is made per operator considering network deployment options, engineering value, auction prices, the relative amount of spectrum compared to others and strategy aspects for each operator.

Summary of spectrum allocation

The amount of spectrum in different bands for the Swedish operators in 2008 and 2011 are presented in Figure 11. The Swedish operators, TeliaSonera, Tele2 and Telenor have around 2 x 70 MHz each, while HI3G have 2 x 45 MHz. During the period 2008 to 2011 the Swedish operators in total have captured 107 MHz of additional spectrum. TeliaSonera has obtained 32.8 MHz, HI3G 25 MHz, Telenor 23.3 MHz and Tele2 23.5 MHz.

Figure 11 Spectrum holding for Swedish operators years 2008 and 2011, Total bandwidth and distributed over different bands



Source: PTS

Engineering value versus auction price

Deployment options

The engineering value of spectrum is calculated as the cost savings provided that the spectrum band was acquired. Hence, a comparison is made requiring "some other" network deployment option(s) that could be used assuming that the spectrum band of interest was not acquired.

When it comes to the 2.6 GHz band to be used for LTE mobile broadband services one option is to use the 2.1 GHz band and 3G technology in order to provide additional capacity. This means a denser 3G network and that at least two times more sites needs to be deployed in order to double the capacity. Taking into account the higher spectral efficiency of LTE compared to HSPA an even denser network needs to be deployed. In our calculation we assume four times denser network in the capacity limited areas. For Hi3G with 10 MHz of 2.6 GHz spectrum twice the number of sites is needed in order to offer the same capacity as the operators with 20 MHz of spectrum.

For wide area coverage of mobile broadband using the 800 MHz band we have two options to be used for the comparison: 1) to build a denser 3G network using the 2.1 GHz band and 2) to allocate part of the 900 MHz band for mobile broadband services. A 2.1 GHz network offering the same capacity would need at least four times the number of sites in order to provide the same coverage as an 800 MHz network. This needs to be agreed with the network sharing partner, see discussion in the section "Company strategy aspects" below.

When the 900 MHz band is used for mobile broad band existing 2G and 3G sites could be re-used. The existing site grid would be sufficient to provide coverage. However, no operator would be able to allocate 10 MHz needed in order to provide the same capacity and data rates as in the case with the 10 MHz in the 800 MHz band. Hi3G just have 5 MHz and the other operators use the 900 MHz band for GSM voice services. For comparison we can assume that 5 MHz will be used implying twice the site density in order to provide the same capacity.

Estimated engineering value

The basis for estimating the value of spectrum is to apply the principal of engineering value, which according to Sweet (2002), is determined by the cost savings in the infrastructure of an operator's network obtained by having access to additional spectrum. The approach is in line with Marks et al (1996) which define the marginal value of spectrum as the value of output forgone when frequencies are used for a particular use rather than the next best alternative. The nine cases listed in table 5 are recent spectrum allocation cases in Sweden, and where the calculation is based on a geotype classification of Sweden in Urban, which covers 1% of the country and 29% of the population, Suburban which covers 27% of the country and 59% of the population and Rural which represents 73% of the geographical area and 12% of the population.

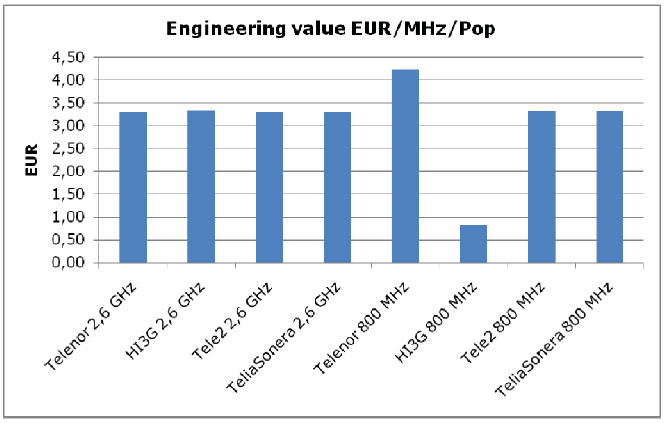
Table 5 Estimation of engineering value for nine Swedish cases

Operator	Case	Basis for engineering value	Engineering value EURm	MHz	EUR/MHz/ pop	More sites
Telenor	Value of 20 MHz in 2600 MHz	Denser 2100 MHz network	618	20	3,3	2,6
HI3G	Value of 10 MHz in 2600 MHz (to have 20 MHz rather than 10 MHz)	Denser 2600 MHz network	314	10	3,3	2,0
Tele2	Value of 20 MHz in 2600 MHz	Denser 2100 MHz network	618	20	3,3	2,4
TeliaSonera	Value of 20 MHz in 2600 MHz	Denser 2100 MHz network	618	20	3,3	2,4
Telenor	Value of 10 MHz in 800 MHz	Denser 2100 MHz network	397	10	4,2	3,4
HI3G	Value of 10 MHz in 800 MHz	900 MHz network and denser 2100 MHz network	78	10	0,8	1,7
Tele2	Value of 10 MHz in 800 MHz	Denser 2100 MHz network	312	10	3,3	3,4
TeliaSonera	Value of 10 MHz in 800 MHz	Denser 2100 MHz network	312	10	3,3	3,4

Source: PTS, authors' calculations

The estimated capex levels for sites in the different geotypes urban, suburban and rural are EUR 0.04m, EUR 0.089 and EUR 0.11m respectively. The cell radius is from 0.6 km up to 12 km depending upon frequency band and geotype. The spectral efficiency is assumed to be 1 bps/Hz for HSPA and 1.5 bps/Hz for LTE.[10] The table show the operator and case for current spectrum and the basis for calculating the engineering value. The last column indicates how many more sites the alternative spectrum requires in order to generate an equal amount of capacity as the base case. The estimated engineering value is in the range from EUR 0.8 to EUR 4.2 per MHz/pop, as illustrated in figure 12.

Figure 12 Engineering value EUR per MHz and population for nine Swedish cases



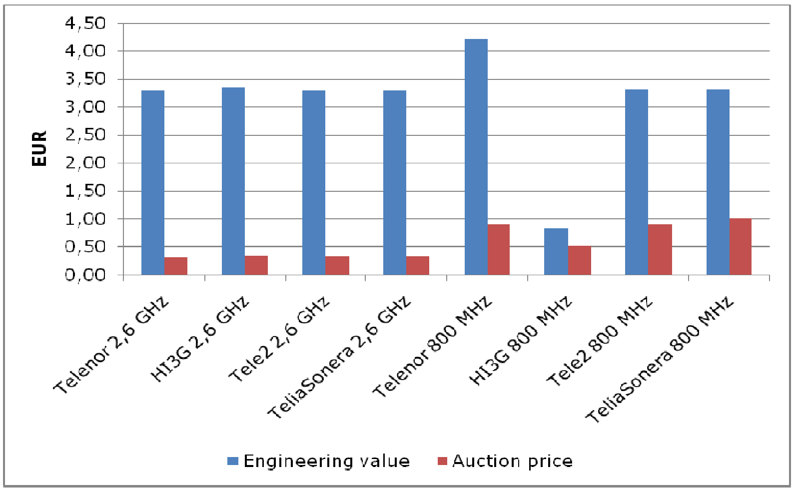
Source: authors' calculations

[10] The basis for geotypes and cell radius are based on an LRIC model developed by Analysys Mason concerning for a generic mobile operator in Sweden, see http://www.pts.se/upload/Remisser/2011/Telefoni/10-8320-pts-mobil-lric-final-model.zip

Comparison with auctions prices

The analysis of engineering value of spectrum is based on the alternative use of spectrum and is a way to capture the marginal value of spectrum which also could be stated as the project value. But auction prices are what operators actually have paid for spectrum, which besides the project value also incorporates market power value and option value.[11] The following figure presents the engineering value and auction prices expressed as EUR/MHz/pop.

Figure 13 Comparison between engineering value and auction prices



Source: PTS, authors' calculations

In order to explain to the deviation between the engineering value and auction prices, which is a factor from 1.5 up to 10, three arguments could be highlighted:

1. The value of spectrum that are derived from spectrum auctions depends, according to Beard et al. (2011), critically on allocation choices, like for example rules to exclude incumbents or formal spectrum caps. This implies that auction prices only partly reflect the underlying value of spectrum.
2. The transition from the regime of control and command to spectrum trading has only partly taken place. This limits the competition on spectrum and thereby prices on spectrum auctions.
3. Operators' valuation of spectrum and thereby the willingness to pay for spectrum are influenced by network strategy where network sharing and potential spectrum sharing contribute to hold down auction prices on spectrum.

Comparing the engineering value for the Swedish case with prices that operators paid for 3G - licences in Germany, UK and Italy around the year 2000, which were in the range of EUR 5 up to EUR 10 per MHz/pop as shown in figure 2, show that the calculated value is considerable lower.

[11] http://www.acma.gov.au/webwr/_assets/main/lib310867/ifc12-09_final_opportunity_cost_pricing_of_spectrum.pdf

Although the 3G prices were seen as outrageous they are in line with prices that have been paid at recent auctions for 3G spectrum in Mumbai and Delhi.

Altogether, the analysis of the engineering value gives an input to the valuation of the marginal value of spectrum. The deviation between auction prices, which could be seen as the level of operators willingness to pay for spectrum, and the estimated engineering value indicate that the auction prices for the Swedish case does not truly reflect the marginal value of spectrum as the calculation of the engineering value of spectrum suggests. Moreover, there is not yet a functioning market for spectrum as spectrum trading is limited and the restrictions on the usage is also giving limitations. This is also the case with spectrum caps which safeguard that spectrum is not concentrated to one player in order to maintain an efficient competition on the end user market.

Company strategy aspects

Impact of network sharing agreements

As described above one network deployment option used for estimating the engineering value of spectrum is to deploy a denser 3G network. This can be used for the comparison but in real life we need to consider the impact of network sharing agreements. Deployment of a denser 3G network require that both partners have the same interest, e.g. that none of the partners would have acquired spectrum in the 2.6 GHz or 800 MHz bands.

TeliaSonera

During the last decade TeliaSonera has offered mobile broadband services using a shared network together with Tele2. Studies of network sharing and interviews indicate that operators have not been able to develop independent network expansion strategies (Markendahl, 2011).

Since TeliaSonera does not have any own 3G license, a strong driver to acquire spectrum in the 2.6 GHz and 800 MHz bands would be the ability to fully control bands for mobile broadband access services. This is evident from the 2.6 GHz and 800 MHz auctions and that TeliaSonera did not want to share LTE networks with the 3G sharing partner Tele2.

We can make some observations from the 800 MHz auction. TeliaSonera paid significantly more than its competitors, and the strategy indicates that the operator was prepared to pay the most to secure block 4. From the outcome of the auction it is possible to derive the conclusion that TeliaSonera was prepared to pay significantly more in order to take the middle part of the available spectrum. This implies that TeliaSonera controls a key asset and as spectrum is tradable it will not be possible to establish a 20 MHz carrier with continuous spectrum in 800 MHz without involving TeliaSonera. This implies a considerable higher strategic valuation.

Tele2

Tele2 has traditionally been perceived as a low price operator using very cost-efficient network deployment. The establishment of the joint venture Net4Mobility together with Telenor indicate that Tele2 see a lot of benefits with network sharing. These benefits must be seen as more important than the drawbacks due to less independence. Although Tele2 is characterised as cost-efficient company it has the same amount of spectrum and also can offer the same data rates. In addition, the cooperation with Telenor offers a possibility to access even more spectrum.

Telenor

Telenor is more or less in the same position as Tele2 with substantial assets in the form of spectrum and also sharing agreements. In addition 3G network enhancements made together with Hi3G can be exploited, e.g. “the fastest 3G” offering 32 Mbps.

Hi3G

Hi3G has for many years claimed that it offers the fastest mobile broadband for 3G in Sweden. For potential mobile broadband services using LTE technology the situation would be quite different in two aspects:

1. In the 2.6 GHz band with 10 MHz 40 Mbps peak rate for LTE services can be offered compared to 80 Mbps offered by the other operators. This would have an impact on the possibilities to offer mobile services using both the 800 MHz and the 2.6 GHz bands. No plans are presented for how the 2.6 Hz band will be used.

2. No sharing agreements are announced so far. This implies a more costly network deployment and operation compared with Tele2 and Telenor.

In summary, Hi3G has less total bandwidth than the other operators and it is more fragmented. In addition to the 10 MHz in the 2.6 GHz band, Hi3G has 5 MHz in the 900 MHz band and 50 MHz unpaired spectrum in the 2.1 GHz band. No plans are presented on if or how these assets will be used.

6. Implications

Financial conditions

The profitability for the Swedish mobile operators is that TeliaSonera and Tele2 has been on par. Telenor and HI3G have steady improved its profit margin, see figure 14. The ratio between revenues and capex is shown in figure 15. The ratio has gradually decreased for TeliaSonera and Tele2 during 2008-2010, while HI3G is still on very high levels, although it has generated strong growth and Telenor is investing around 10 % of its revenues.

Figure 14 Operating profit margins

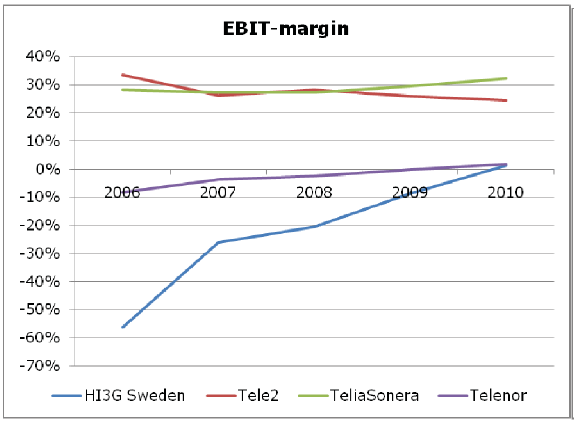
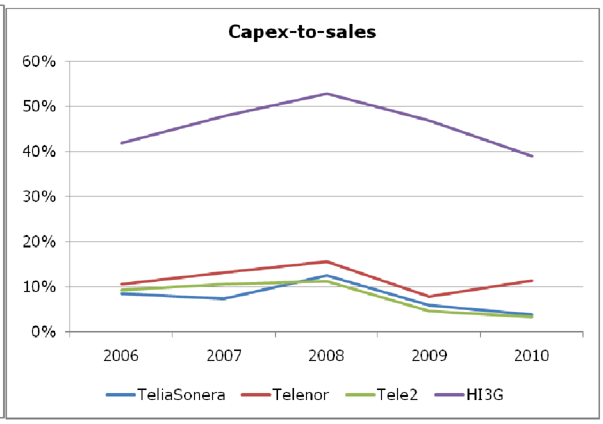


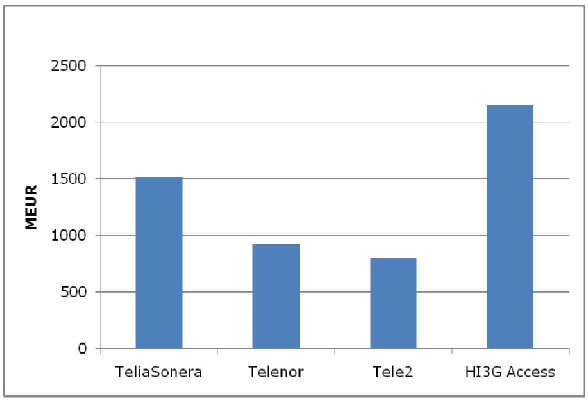
Figure 15 Capex-to-sales



Source: Company reports

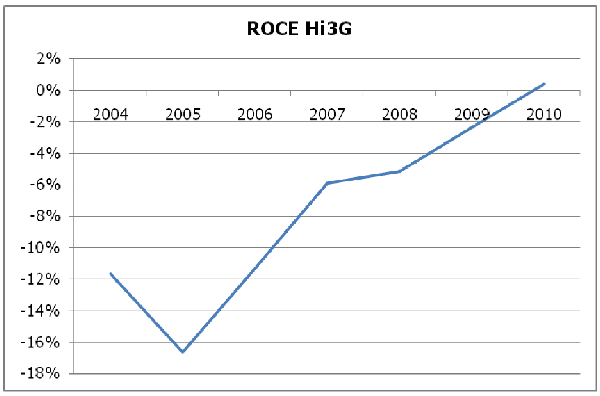
The Swedish mobile operators have in total invested EUR 5.5 bn in mobile networks during 2001-2010. HI3G, which was a new entrant through the 3G license in the year 2000, has invested EUR 2.2 bn during 2001-2010, while Tele2 has invested EUR 805 m during the same period.

Figure 16 Total mobile capex 2001-2010[12]



Source: Company reports

Figure 17 Return on Capital Employed for Hi3G



Source: HI3G Access reports

[12] Capital expenditures made by the network sharing companies SUNAB, 3GIS, and Net4Mobility has been distributed to its respectively owners.

Given that TeliaSonera, Tele2 and Telenor are running integrated operations with Group structure it is not possible to make an adequate analysis of the return for the Swedish mobile operation as such. But HI3G is reporting its Swedish operation through HI3G Access with a balance sheet which has enabled us to analyze the return on capital employed (ROCE)[13], see Figure 17.

When combining the financial conditions as summarized above with spectrum allocation situation we can conclude that Hi3G has a more challenging situation than the other operators. The total amount of spectrum is less than the others implying higher network deployment costs in in order to offer the same amount of capacity, coverage and also data rates.

Cooper´s law and the importance of spectrum

"Cooper's Law" considers the number of "conversations" that can theoretically be conducted over a given area in all of the useful radio spectrum and says that this number is doubled every two-and-a-half years. The improvement in the effectiveness of total spectrum utilization has been over a trillion times in the last 90 years, and a million times in the last 45 years.

"Of the million times improvement in the last 45 years, roughly 25 times were the result of being able to use more spectrum, 5 times can be attributed to the ability to divide the radio spectrum into narrower slices — frequency division. Modulation techniques like FM, SSB, time division multiplexing, and various approaches to spread spectrum can take credit for another 5 times or so. The remaining sixteen hundred times improvement was the result of confining the area used for individual conversations to smaller areas, what we call spectrum re-use".

Hence it is the use of small cell that accounts for the largest improvement of capacity. However, we have some comments on Cooper's law related to the value of spectrum and bandwidth.

- The increase of spectrum accounts for "just" 25 times of the 1 million improvements but it is the bandwidth that is the "raw material" and makes it possible to exploit the benefits of the other types of development.
- The operators can use the same type of modulation, radio technology and deployment strategy but it is the amount of bandwidth that makes a clear difference.
- We can also identify differences between operators and their different options when it comes to the network deployment approaches
    - Network and spectrum sharing (like 3GIS and Net4Mobility) enables both higher cost efficiency (site re-use) and the possibility to offer higher data rates
    - Operators with a large fixed network (TeliaSonera) can to a larger degree exploit offloading from macrocell networks to private WLAN or femtocell networks

[13] The calculation of ROCE is done according to the following: (total assets – current liabilities)/Operating profit

7. Conclusions and future work

This paper has compared estimates of engineering value of spectrum with prices paid at a number of spectrum auctions in primarily Sweden. The analysis also includes a discussion of drivers that have had an impact on the willingness to pay for spectrum for the Swedish mobile operators. The paper makes the assumption that auction prices are an expression for what operators are prepared to pay for spectrum.

Radio spectrum is an important asset and resource for mobile network operators. With more spectrum, i.e. wider bandwidth, operators can offer higher capacity and data rates. Use of larger bandwidths also means that capacity can be provided with fewer base station sites, i.e. with lower cost. Engineering value is one way to estimate the value of spectrum. The calculation of engineering value is based on comparison of different network deployment options using different amounts of spectrum. The main conclusions of the analysis are:

- The estimated engineering value of spectrum (in our country specific case) is significantly higher than prices paid at spectrum auctions during the last couple of years
- The control of "own" spectrum is an important driver for mobile operators which has an impact on the willingness to pay. TeliaSonera in Sweden, which does not have their own 3G license, has been very active in auctions for spectrum in 800 MHz and 2.6 GHz and also deployed the first LTE (4G) network in the world.
- Operators strive to have as much spectrum as its competitors. Less spectrum means that it has to deploy more sites in order to provide the same capacity and that lower data rates can be provided. As an example, one operator in Sweden with "less" bandwidth in the 2.6 Hz band has not yet announced any deployment plans for the acquired spectrum.
- It is essential to consider network sharing when the value of spectrum is analyzed. In addition to share auction and network deployment costs operators can combine their spectrum resources into aggregated bands and hence be able to offer higher data rates than its competitors.

Concluding, for further research we have identified two interesting areas: 1) To collect more empirical data in order to make the same kind of analysis for other countries. We would especially like to analyze countries and regions with different characteristics compared to western Europe when it comes to available amount of spectrum, the level of broadband development and consumers' willingness to pay for mobile communications. 2) To analyze in depth the drivers and "behavior" of mobile operators and relate it to theoretical frameworks, like real options theory, or the ARA model (actors, resources, activities) used by the IMP group.

References

Azcoitia S.A., M.A.M. Fernandez, L.M.G. Verdura, "Using bottom-up LRIC models to calculate radio spectrum value for mobile operators", 9th Conference on Telecommunications Internet and Media Techno Economics (CTTE), 7-9 June, 2010, p.1-7.

Bulow L. et al "Winning Play in Spectrum Auctions", Standard University, Feb 2009, available at http://economics.uchicago.edu/pdf/AWS

Beard T.R., G.S. Ford, L.J. Spiwak, M. Stern, "A Policy Framework for Spectrum Allocation in Mobile Communications, Federal Communications Law Journal, vol 63, no 2, May 2011

Doyle C.,"The Economics of Spectrum Pricing",Warwick Business School, January 2004, http://www.itu.int/osg/spu/stn/spectrum/spectrum_resources/spectrum_reform/Doyle_URSI.pdf

Johansson K., "Cost Effective Deployment Strategies for Heterogeneous Wireless Networks", PhD Dissertation, Royal Institute of Technology, Stockholm, 2007

Markendahl J., "Mobile Network Operators and Cooperation - A Tele-economic study of infrastructure sharing and mobile payments services", PhD Dissertation, Royal Institute of Technology, Stockholm, 2007, available at http://www.impgroup.org/dissertations.php

Marks P., K. Pearson, B. Williamson, P. Hansell, J. Burns, "Estimating the commercial trading value of spectrum", 2 July 2009, a Ofcom report by Plum Consulting, available at http://www.plumconsulting.co.uk/pdfs/Plum_July09_Commercial_trading_value_of_spectrum.pdf

Marks P., I. Viehoff, U. Saadat, W. Webb, "Study into the use of spectrum pricing", Appendices 1 and 2: Case Studies, Report prepared by NERA and Smith for the Radiocommunications Agency Jan 1996, available at: http://www.ofcom.org.uk/static/archive/ra/topics/spectrumprice/documents/smith/smith1.htm

Mölleryd B.G., J. Markendahl, Ö. Mäkitalo; "Spectrum valuation derived from network deployment and strategic positioning with different levels of spectrum in 800 MHz", in Proceedings of 8th Biennial and Silver Anniversary ITS Conference, Tokyo, June 2010.

Mölleryd B.G., J. Markendahl, Ö. Mäkitalo, J. Werding; "Mobile broadband expansion calls for more spectrum or base stations - analysis of value of spectrum and the role of spectrum aggregation", in Proceedings of 21st European Regional ITS Conf, Copenhagen, Sept 2010.

Sweet R.I., D. Viehoffb, N. Linardatosc, C. Kalouptsidis, "Marginal value-based pricing of additional spectrum assigned to cellular telephony operators", in Information Economics and Policy 14:3, Pages 371-384 (2002)

Zander J., "On the cost structure of Future Wireless networks", in Proceedings of IEEE VTC '97, Phoenix, AZ, May 5-7, 1997

Webb W., "Wireless Communications: The future", Wiley, 2007