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Mobile Broadband Expansion Calls for More Spectrum or Base Stations - Analysis of the Value of Spectrum and the Role of Spectrum Aggregation

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Mobile Broadband Expansion Calls for More Spectrum or Base Stations - Analysis of the Value of Spectrum and the Role of Spectrum Aggregation

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1. Introduction

The breakthrough for mobile broadband is taking the mobile communications industry into a new phase. The number of mobile broadband users in the world exceeds 400 million, and the share of the population in Western Europe with mobile broadband is around 10 per cent and over 15 percent in Austria and Sweden. This development has been propelled by the extensive diffusion of mobile modems (dongles) for laptops and smartphones given users ubiquitous access to mobile internet. Consequently, traffic volumes in the mobile networks have grown immensely, and the mobile data traffic surpassed the mobile voice traffic in the world by the end of 2009, and in for example Sweden, over 75 percent of the mobile traffic is data.[1]

A continued substantial growth of data traffic will inevitable force operators to upgrade capacity pushing up capex budgets. But the network upgrade could be postponed if operators are able to get access to additional spectrum, because the capacity in the network is determined by the amount of spectrum. In other words, mobile operators are facing a spectrum allocation problem. Spectrum is a finite, non-exhaustible common resource which influences the valuation, and some parts of the frequency band are more valuable than others. National European regulators are, as part of the Digital Dividend, set to release spectrum in the 800 MHz, which have very attractive characteristics for mobile operators. This in combination with spectrum in 2.6 GHz allocated for Long Term Evolution (LTE) provides operators with the means to offer attractive services to the end customers. In addition, bands currently used for GSM, especially 1800 MHz are of interest for mobile broad band access.

The competition on the mobile broadband market will also drive the demand for spectrum aggregation, part of 3GGP standard, which enables operators to combine spectrum from different frequency bands. Evolution of LTE will allow carrier aggregation and with IMT advanced bandwidths up to 100 MHz can be supported (Parkvall & Astely, 2009). The mobile equipment industry has launched flexible radio equipment capable to handle all relevant frequencies and access technologies. The fierce competition has pressed down prices enabling operators to replace existing radio equipment with new radio equipment for only EUR 10K per base station. By combining the deployment of new radio equipment and additional spectrum operators are able to increase capacity substantially. This implies that operators that are not able get access to additional spectrum are forced to deploy more base stations which will push up capex budgets substantially.

Assessing the value of spectrum is complex and involves different evaluation approaches. One cornerstone is the opportunity cost of spectrum that is related to potential cost savings in infrastructure that an operator with access to a certain band of spectrum can achieve. Another central concept revolves around the strategic value, which gives operators with access to spectrum flexibility and a competitive advantage, in terms of service offers with higher data rates, compared to competitors that does not have access to similar amount of spectrum.

[1] http://www.ericsson.com/thecompany/press/releases/2010/03/1396928, http://www.statistik.pts.se/PTS1H2009E/index.html

The aim with this paper is to present an analysis of the value of spectrum and the impact of spectrum aggregation. The value of spectrum is divided into two concepts: the engineering value and strategic value. The engineering value is derived from the impact of capital expenditures on network infrastructure when more bandwidth is available. The strategic value reflects the expected position in the market an operator will hold as a result of the assigned spectrum. The paper addresses two research questions:

1) How is the production cost affected by different levels of spectrum?
2) How does the use of spectrum aggregation influence the evaluation of spectrum?

The role and value of spectrum aggregation is carried out by modeling different operators with different amount of spectrum and cooperation strategies. As a background we can use the spectrum allocation in Sweden as an example.

The operators have deployed 2G and 3G networks with GSM using the 900 and 1800 MHz bands and WCDMA using the 2100 MHz band. Deployment of LTE ("4G") is ongoing in the 2600 MHz band and is considered for the 800 and 1800 MHz bands. Currently, the operators have between 5 and 10 MHz in the 900 MHz band. For the upcoming 800 MHz auction a spectrum cap of 10 MHz is proposed. Part of the 1800 MHz band is also considered for an auction. In the 2600 MHz band three operators have 20 MHz and one operator has 10 MHz.

Spectrum aggregation will facilitate a combination of many bands, but in our analysis we look into a special case where we consider an urban deployment using different allocation combinations in the 1800 and 2600 MHz bands. Combination of 800 and 2600 MHz bands is also of interest, but we find this less suitable as a test case since lower amounts of bandwidths (5-10 MHz) are available in the 800 MHz band. In addition, for combination of 800 and 2600 MHz the differences in coverage need to be considered. In our analysis we use different combinations of the 1800 and 2600 MHz band resulting in systems bandwidths of 10, 20 , 40 and 80 MHz[2]. The 80 MHz case also includes network and spectrum sharing of two operators.

The paper is organized as follows. Chapter 2 reviews related work and chapter 3 describes the model assumptions and framework for the analysis. Chapter 4 analyzes the engineering value in terms of network costs for different amounts of spectrum. Chapter 5 analyzes the strategic value of spectrum with focus on data rates. The main conclusions are found in chapter 6.

[2]For all the bandwidths numbers we consider both downlink and uplink, i.e. 2*10, 2*20 etc

2. Related work

2.1. Valuation of spectrum

One of the research questions that this paper addresses relates to the valuation of spectrum, which makes it relevant to apply a techno-economic approach which combines technology with economic and business aspects. Based on the literature (i.e. Doyle 2006, Qinetiq 2006) we have listed three approaches to evaluate spectrum:

- **Economic value**: The economic value of spectrum can be assessed by estimating the value of the economic activities through the contribution to the GDP by regarding spectrum as an input in the production
- **Engineering value**: The engineering value is determined by cost savings in the infrastructure of an operator's network obtained by having access to additional spectrum. It reflects the less costly configuration of the network infrastructure obtained when more spectrum is available for an operator. It could also be expressed as the opportunity cost or the marginal value of spectrum.
- **Strategic value**: The strategic value reflects the expected position and competitive advantage an operator would achieve in the market as a result of the assigned spectrum compared to another operator that would not receive the equivalent amount of spectrum.

Moreover, there are other approaches to estimate the value of spectrum, like for example, use of a benchmark value, retrieved from spectrum auctions, or tender prices for spectrum, and market transactions. Bulow, Levin and Milgrom (2009) examine prices for spectrum in auctions conducted by the FCC in the US. The authors present a theory that it is bidders' budgets as opposed to their license values that determine prices in spectrum auctions. Budget constraints set limits in spectrum auctions as it requires a substantial amount of cash-on-hand, and raising this money from external capital markets takes time. The paper raises the question why prices vary so widely over time. The argument is that operators can often substitute for additional spectrum by using existing spectrum more intensively, by building more cell sites or by using other spectrum enhancing technologies.

The value of spectrum could also be calculated on other parameters, like earnings or cash flows. Smith (1996) developed a method to calculate the opportunity cost or the marginal value of spectrum. 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. This is denoted the engineering value of spectrum. This approach is suitable to apply a Net Present Value (NPV) calculation (Sweet, 2002).

Compared to (Smith, 1996) and (Sweet et al, 2003) the contribution in this paper is to investigate both the engineering and strategic value. In addition, we take into account existing infrastructure and consider both upgrading of existing sites and deployment of new sites. We extend the analysis of capacity limited scenarios (Sweet et al, 2003) to include both capacity and coverage limited scenarios.

2.2. Techno-economic modeling and analysis of telecom networks

Another major area of techno-economic evaluation is the modeling and analysis of networks, demand, costs and revenues. These kinds of results have been reported from several European projects like TERA, TONIC, ECOSYS (Olsen, 2006), (Harno, 2002), (Loizillon, 2002). An excellent overview of the background, drivers and results of these projects can be found in (Olsen, 2009). Recent work on techno-economic evaluation for network deployment of fixed broadband is presented in (Verbrugge, 2009). For mobile broad band network costs and the relation to bandwidth and capacity was examined early by Zander (1997).

The profitability of flat rate mobile broadband per se was insisted by e.g. Blennerud (2009). Regarding the allocation of costs for voice versus mobile broadband Blennerud (2009b) argue that there is a difference in capacity of roughly 10-12 times comparing voice and HSPA bearer on 5 MHz. This leads to the conclusion that 28% of the cost should be allocated to mobile broadband. The elaborated analysis shows that the cost is EUR 1 per GB when the network runs at low utilization, while it is reduced to EUR 0.1 per GB when the network reaches a 50% utilization.

Azcoitia et al (2010) examine the value of spectrum, or rather the impact on capex depending on the spectrum band, by applying Long Run Incremental Cost (LRIC) model. It concerns deployment of a green field network for a country, like Spain, divided in four geotypes: dense urban, urban, suburban and rural. It assumes indoor coverage in the three urban areas while outdoor coverage in the sparsely populated rural area. In the analysis one 5 MHz carrier is allocated to each of the four networks that use four different frequency bands: 700MHz, 900 MHz, 2100 MHz and 2600 MHz. Moreover, the analysis differentiates between four levels of market share of the total traffic: 0%, 15%, 50% and 100%, facilitating an analysis of fixed and variable costs. Firstly, Azcoitia's analysis show that, that the variable cost increase the most at the lower frequency bands, see table I. This could be interpreted as the cell areas need to shrink when the traffic volumes increase. For 900 MHz, the difference in capex is 3x times when market share of traffic increase from 0% to 100%. Consequently, the cell areas in the higher frequency bands are already at the start smaller making less of an impact with a higher market share of traffic. Moreover, Azcoitia et al (2010) show that an operator with a 50% market share has to spend 4x times more capex when it is using 2600 MHz compared to 700 MHz. The difference is even larger when the traffic share is 15% as it require 5.6x times higher capex., see table II.

TABLE I. CAPEX COMPARISON OF NATION-WIDE SCENARIO WITH DIFFERENT TRAFFIC SHARE AND BANDS. CAPEX FOR EACH BAND IS NORMALIZED TO FIXED COST OF COVERAGE DEPLOYMENT (AZCOITIA ET AL, (2010)

	Traffic share			
	0%	15%	50%	100%
700 MHz	1,00	1,32	2,08	3,22
900 MHz	1,00	1,19	1,64	2,29
2100 MHz	1,00	1,09	1,26	1,56
2600 MHz	1,00	1,05	1,15	1,32

TABLE II. CAPEX COMPARISON OF NATION-WIDE SCENARIO WITH DIFFERENT TRAFFIC SHARE AND BANDS. CAPEX FOR EACH BAND IS NORMALIZED TO COST OF DEPLOYMENT IN 700 MHZ (AZCOITIA ET AL, (2010)

	Traffic share			
	0%	15%	50%	100%
700 MHz	1,00	1,00	1,00	1,00
900 MHz	1,69	1,52	1,34	1,20
2100 MHz	4,05	3,33	2,45	1,96
2600 MHz	7,13	5,66	3,96	2,92

Azcoitia et al (2010) underscore that bottom-up LRIC models may be used in order to measure and calculate the value of spectrum for the different mobile operators in terms of future savings in network deployment and efficiency. The paper presents a conceptual model to calculate economic value of spectrum consisting of the building blocks: revenues, demand, cost model and profit improvement.

Regarding the significance of spectrum, Stennek (2010) underscores that sufficient allocation of spectrum is a prerequisite for an operator that want to be competitive on the mobile broadband market. To provide services with lower bit rates compared to competition is a disadvantage. Based on the competition literature Stennek (2010) argue that companies willingness to pay for spectrum does not only determine how they can utilize the spectrum themselves, but also by their wish to hoard spectrum in order to prevent competition from providing high bit rate services. The author underscores that there are significant economy of scale on the market for mobile broadband as operators that utilize a large amount of spectrum yield lower costs to establish capacity and can produce services with high bit rates, at least to a certain level. Operators with large spectrum can produce services with high bitrates, proportional to spectrum up to 20 MHz. The advantage is absolute; as there is no other way to achieve the same bit rate, not possible to increase the density of base stations.

2.3. End-user perception of service quality

Pohjola & Kilkki (2006) proposed a model to analyze value creation of services based on how users behave and put value on the experience. The assumptions on user perception and rating of service quality are based on the findings by Twersky & Kahneman (1993). They use the "Expected Experience" and "Expected Value" functions to represent user happiness. If the expected value increases or decreases from the expected value an increment results in less additional "positive" experience compared to a larger "negative" experience for a similar decrement. This leads to different shape of "utility curves", i.e. how the utility for a user depends on different parameters of a service. This means that a user that expects a 4 Mbps data rate would be more disappointed for a delivered data rate of 2 Mbps (i.e. half of the offered value) than the positive experience of getter twice the offered data rate, 8 Mbps. Examples of utility functions as a function of bit rate are presented in (Sachs, 2007).This kind of "behavioral economics" proposed by Twersky & Kahneman has also been used for analysis of consumer preferences for flat rate (Mitomo et al, 2007), (Nassar & Mitomo, 2010) and for analysis of service availability and data rates Markendahl et al (2008), Pöyhönen et al (2009).

3. Methodology, models and assumptions

Rather than analyzing the allocation mechanism of spectrum, which has attracted extensive research, this paper approach the subject by combining the issue of demand for mobile broadband, cost of network deployment and significance of spectrum. The paper set out to analyze the value of spectrum from an alternative marginal cost approach (Sweet 2002). The marginal value of spectrum are calculated by using the approach developed by Smith-NERA (1996), which derive the value of spectrum from the additional cost or cost saving depending upon if operators are allocated spectrum or not, and how much spectrum that are allocated.

The role and value of spectrum aggregation is carried out by modeling four different operators. The value of spectrum is divided into two concepts: the engineering value and strategic value. The engineering value is derived from the impact of capital expenditures on network infrastructure when more bandwidth is available. The strategic value reflects the expected position in the market an operator will hold as a result of the assigned spectrum and the service offers that can be marketed in terms of data rates.

3.1. Market and demand

We focus on a limited part of the total market by modeling an Urban area where four operators each has a 25% market share. The assumption is that their mobile networks have been deployed to provide voice services, enabling us to regard the investment as sunk cost. Subsequently, networks are upgraded to LTE in order to offer high capacity mobile broadband services. We analyze four spectrum allocation alternatives:

- Using 2*10 MHz in the 2.6 GHz band, i.e. in total 2*10 MHz
- Using 2*10 MHz in both the 1.8 GHz and the 2.6 GHz bands, in total 2*20 MHz
- Using 2*20 MHz in both the 1.8 GHz and the 2.6 GHz bands, in total 2*40 MHz
- Two cooperating operators that both have 2*20 MHz in each of the 1.8 GHz and the 2.6 GHz bands, i.e. in total 2*80 MHz

We assume that the penetration rate for mobile broadband is 50%, with an ARPU (Average Revenue per User) of EUR 20 per month and subscriber. The level of data volumes is decisive in determining the load of the network. The development on the Swedish market, where mobile broadband was launched in 2006, shows an increase of average data volumes from 0.2 GB per user and month in 2006 to 2.1 GB in 2009. The monthly usage differs among the operators, e.g. the customers of operator “3” in Sweden use nearly 5 GB per month. The mobile data traffic increased with 105% during 2009, underscoring a strong demand for bandwidth. In our analysis we assume three levels of usage: 5, 20 and 80 GB per user and month. The usage is spread out over eight hours per day, translating into a busy hour rate of 12.5%, in line with industry standard.

3.2. Network modeling, coverage and capacity and data rates

We are in the following examining the key parameters, starting with coverage. The sites are equipped with base stations (radio equipment) and set up into three sectors. We model cell ranges of 0.70 km, which implies a cell area of 1.54 km^2

The next parameter is capacity, which is a function of the total number of sites, the amount of spectrum that is available and the spectral efficiency of the radio access technology (RAT). The spectral efficiency varies with the distance from the base station, typical target values are > 10 close to the base station, < 0,01 at the cell border and 1-2 as average over the whole cell (Parkvall & Astely, 2009). In our analysis of network costs, section 4, we assume an average spectrum efficiency to be 2.0 bits per Hz, which is in line with what equipment manufacturers presents. A spectrum efficiency of 2.0 bits per Hz translates into an average throughput of 40 Mbps for 20 MHz. This implies that the average data rates are considerable lower than the peak data rates that assume much higher spectral efficiency, typically 10-20 bps per Hz. Peak data rates and marketed offers will be discussed in section 5. The site capacity is calculated according to the following formula:

*Capacity = Bandwidth (MHz) * number of sites * sectors * spectrum efficiency*

The capacity is subsequently compared with the demand in order to estimate the utilization rate, and in case the network needs to be upgraded. We assume that a utilization rate of 70% is a critical level in order to maintain appropriate service levels.

3.3. Cost assumptions

The corporate assumptions relates to operational expenditures (Opex), i.e. site rent, license cost for equipment, support cost, operations and maintenance, transmission, power and other costs. Opex is set to 20% of accumulated capex, in line with estimates made by Ofcom (2009). Moreover, there is also a direct cost associated with customers, covering marketing, sales, subsidies, support, and administration, which we estimate to be EUR 80 per year and customer, based on industry benchmark.

We estimate that the initial Capex for building a site, including electronics as well as civil engineering and construction work, amounts to EUR 100 000, and depreciated over 20 years. We assume that all sites are upgraded to LTE requiring a capex amounting to EUR 30 000 per site, including transmission, which is depreciated over five years. The cost of capital (WACC) is set to 12.9%.

4. Analysis of engineering value

4.1. Four operators with different spectrum competing on one market, network costs

In this section, we analyze the engineering value of spectrum. Our analysis is conducted by comparing how the utilization level is impacted by different levels of spectrum, and when networks are forced to be upgraded. The aim is to exhibit how different levels of spectrum affect network costs, and address the first research question:

How is the production cost affected by different levels of spectrum?

The analysis will enable us to capture the implicit value of spectrum as a function of lower network cost through different levels of spectrum.

4.2. Network Analysis

The parameters in our model could be divided into five categories. The first relates to the demand function for mobile broadband, expressed as demand per km^2, derived from the estimated usage per subscriber and population density. Secondly, we estimate the average revenue per user to be EUR 20 per month, which is line with market average as Blennerud (2009) points out. Thirdly, the network load factor determines the demand in peak hour, and constitutes at least the capacity that the network has to manage. Fourthly, costs relates to operational expenditures (Opex) which makes it possible for an operator to run a mobile network with services and customers. Fifth, capex are acquisitions of equipment and establishments of the infrastructure.

The four operators in our analysis start with similar networks, equipped with the same number of sites, and splitting the market equally each having a 25% market share, but the only differentiator is the amount of spectrum allocated to each of them. It ranges from 10 MHz, 20 MHz, 40 MHz to 80 MHz applicable for LTE services. This implies that the capacity, expressed as Mbps per km^2, is 8x times higher for operator D compared to operator A, stretching from 39 to 312 Mbps per km^2, as Figure 1 shows.

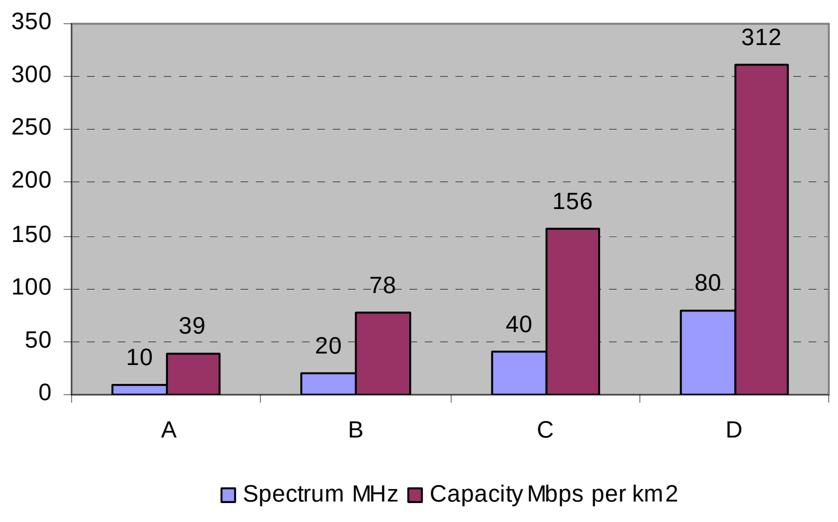

Figure 1: Spectrum, peak rate and capacity per km^2 for the four operators

All of the four networks have sufficient capacity to manage data volumes generated from an average usage of 5 GB per month and user. But with an increased usage to 20 GB per user and month operator A is required toupgrade its network, while the three other operators have sufficient capacity to manage the requested demand. However, an increased usage to 80 GB, which is 40x times higher than the current average usage in Sweden, creates capacity problem for three out of the four operators, as illustrated by Figure 2. Although, this is a theoretical illustration as it is unfeasible to run a network with a 500% load, it is an illustration on the capacity limits.

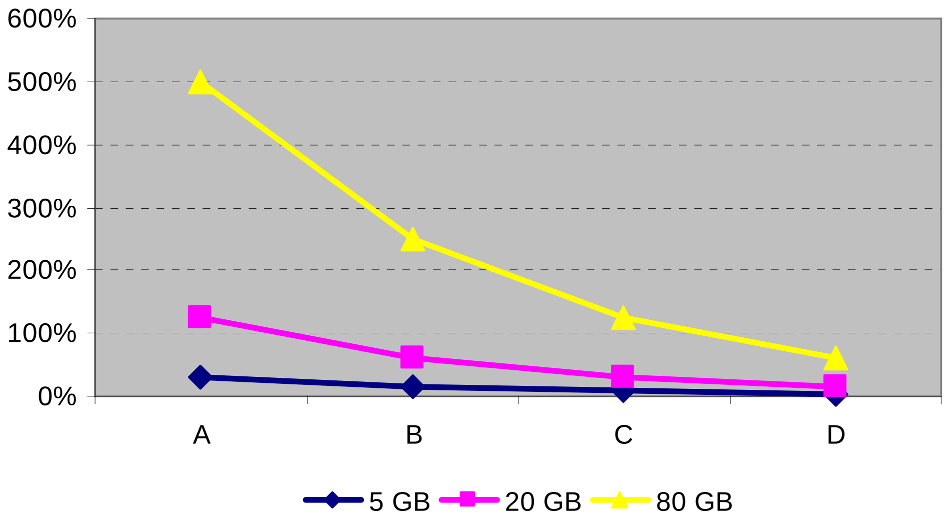

Figure 2: Utilization rate of the four networks

Consequently, operator A, B and C are forced to upgrade their networks with more sites. Operator A, which only has 10 MHz to its disposal, needs to deploy about 1000 additional sites to manage the increased traffic generated by a usage of 20 GB. Figure 3 shows the total amount of sites that are required to meet the demand for the three usage levels, implying that the initial 1300 sites are included. With an increased usage to 80 GB Operator A has to deploy an additional 7000 sites in order to meet the demand from its customer base, reaching a total of over 9400 sites. Operator B has to deploy an additional 3300 sites, reaching 4650 sites, and operator C has to roll out an additional 1055 sites, reaching a total of 2355 sites. However, Operator D is able to manage the increased demand from the customers without being forced to make any alternations to its original network.

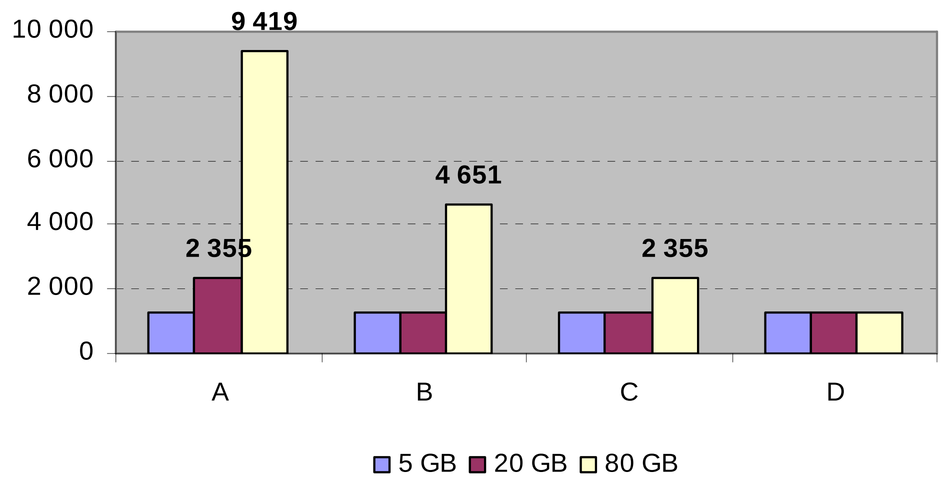

Figure 3: Number of sites required to manage increased traffic

Altogether, the increased number of sites adds up to that Operator A with an average usage of 20 GB, has to spend EUR 175m in capex, while the three other operators are not forced to make any additional investments. However, with a usage of 80 GB Operator A is forced to spend 1000m in capex, while Operator B and Operator C have to spend EUR 475 and EUR 175m respectively. Operator D, which has sufficient capacity, does not have to make any additional investments besides the initial EUR 40m capex.

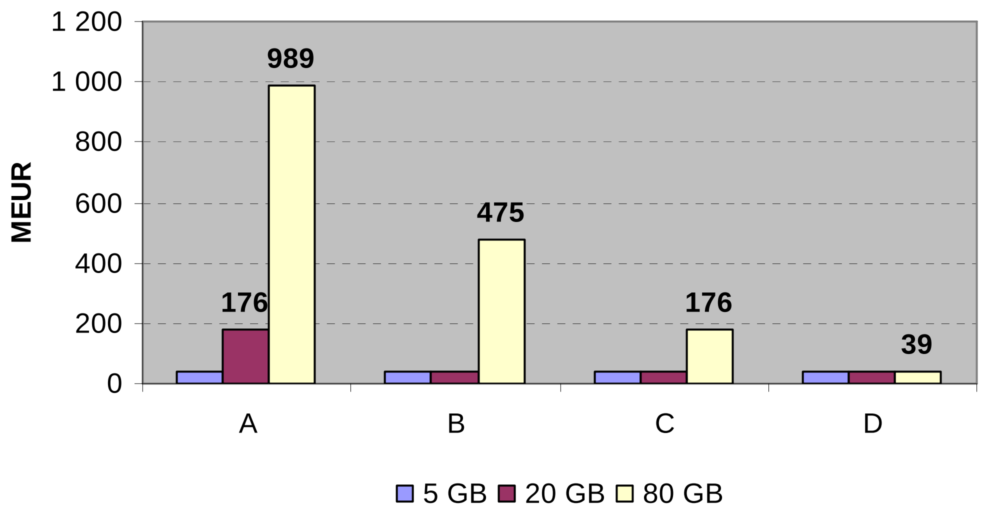

Figure 4: Capex to upgrade

The required network upgrades, which drive capex, translate into higher production cost per GB. The production cost is defined as annualized capex divided with delivered traffic, and is only covering network upgrade to LTE, excluding the initial network investment with 1300 sites, which in this analysis is regarded as a sunk cost. Given that no additional capex was required for the usage of 5GB the production cost for the four operators are all EUR 0.12 per GB. But with the increased usage, which calls for network upgrade, production cost start to deviate for the four operators. Operator A are worst off, as its production cost increase with

1% when the usage raise from 5 to 80 GB, while the other three operators are lowering their production cost at a varying degree. Unsurprisingly, Operator D is capitalizing on economy of scale as it has an extensive amount of spectrum avoiding any network upgrade. Its production cost decline 94% when the usage increase from 5 to 80 GB, and the equivalent number for Operator B and C is a decline of 51% and 80% respectively, as illustrated by Figure 5.

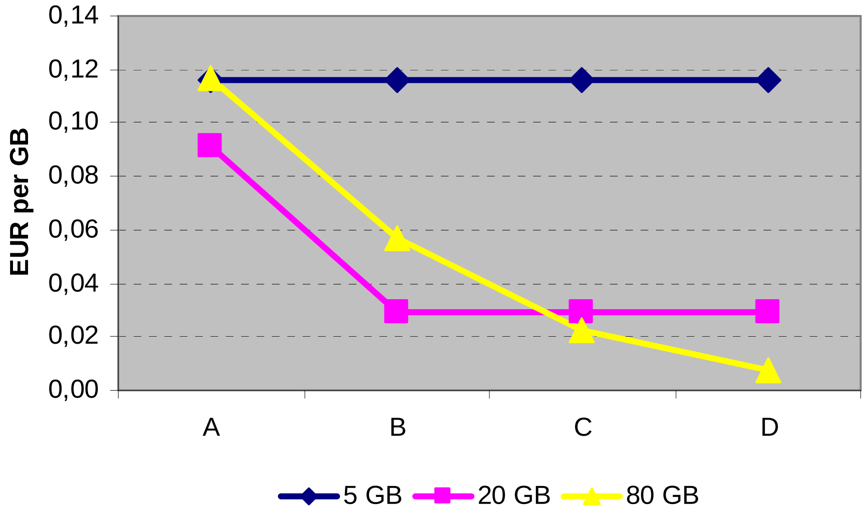

Figure 5: Annualized capex per GB

Altogether, this translates into a deviating profit margin (after annualized capex), but given the modest pressure on the networks with a usage of 5 GB the profit margin is 51% for all the four operators. This is based on the fact that historical investments for the underlying network are regarded as sunk cost. Opex is set to 20% of additional investments. Unsurprisingly, the profit margin for Operator A decline radically from 51% to 9% and reach a negative 251% margin with an 80 GB usage, severely impacted by the massive network upgrade. The profit margin for Operator B is positive up until the usage takes off to 80 GB, resulting in a negative margin of 84%, while Operator C is forced to make minor network upgrades, ending up with a 9% profit margin. Finally, Operator D maintains its profit margin of 51% demonstrating the significance of having access to ample amount of spectrum.

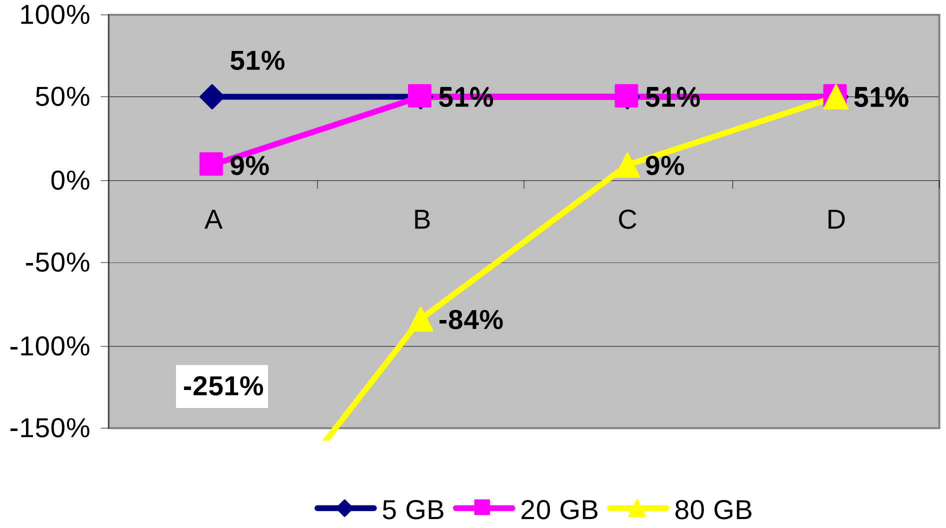

Figure 6: Profit margin after annualized capex

Altogether, the analysis has exhibit how the capacity is affected by the amount of spectrum, and how capex can compensate for a shortage of spectrum. Based on the estimated capex levels, which have been driven by the different demand levels we make an analysis of the implicit value of spectrum. We divide the capex needed to meet the demand of 80 GB with the difference in spectrum holding between operator A and Operator D. It shows that the implicit value is EUR 13.5m per MHz, The equivalent calculation is made for operator B and C which result in an implicit value of EUR 7.2m and 3.4 MHz per MHz. Subsequently, we divide these estimates with the population, in this case 4.0m, giving a estimate of EUR per MHz –Pop, which is a standard unit for spectrum, with one unit meaning one MHz of bandwidth covering one person. This gives a span from EUR 0.83 to EUR 3.40 per MHz and population.

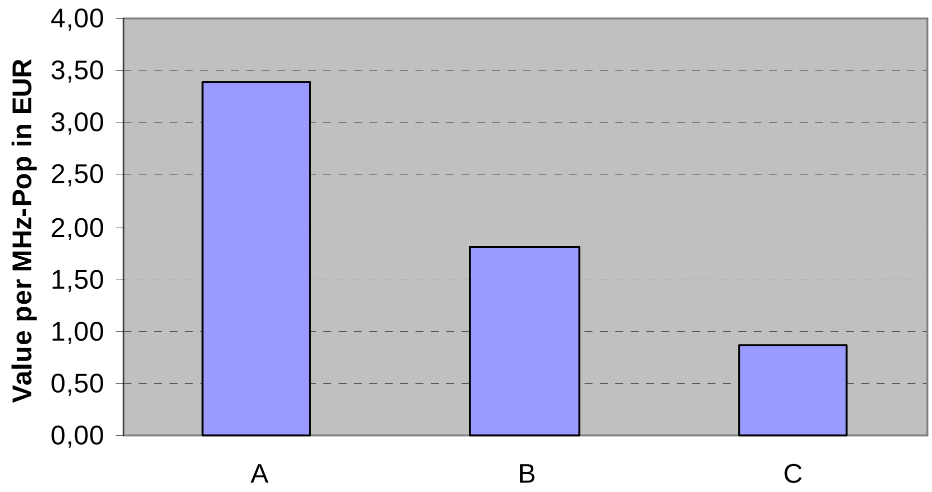

Figure 7: EUR per MHz-pop for the Operator A, B and C

Moreover, it is interesting to examine how these estimates relate to values obtained at different spectrum auctions. The German spectrum auction, completed in June 2010, reached EUR 1.54 per MHz pop for 800 MHz while just EUR 0.05 for the 2.6 GHz band. Both Sweden and Denmark reached considerable higher levels in their 2.6 GHz auctions with EUR 0.30 and EUR 0.42 respectively. The US has in four auctions reached up to USD 1.00 per MHz pop, with a wide range between the different auctions.

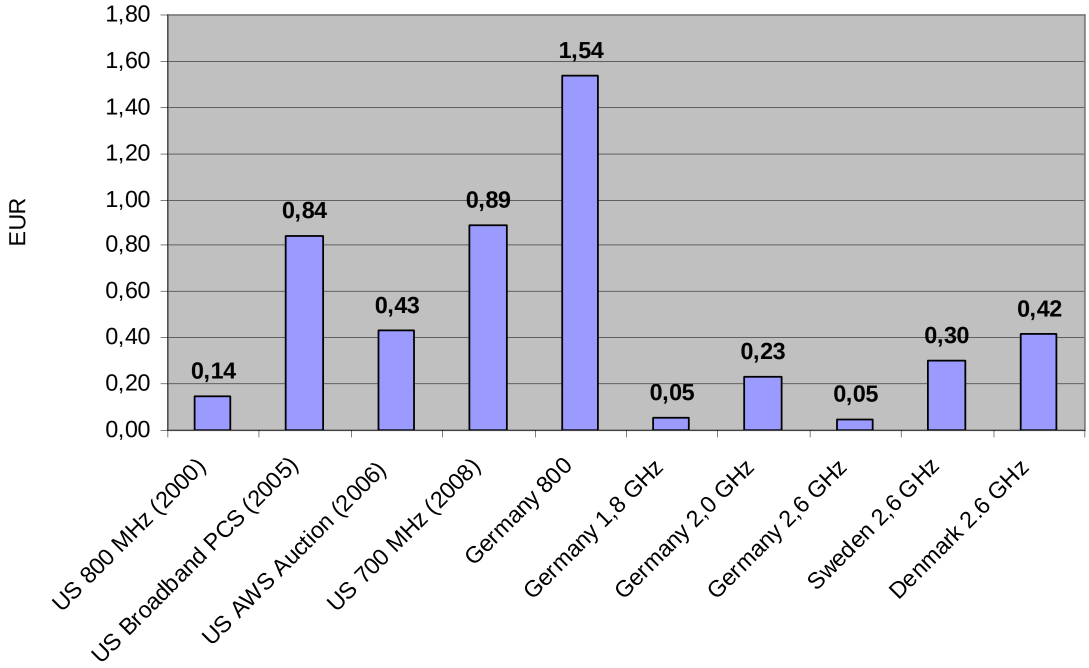

Figure 8: EUR per MHz-pop for a number of auctions in the US, Germany as well as in Sweden and Denmark (Source Bulow et al, 2009, NRAs in Germany, Denmark and Sweden

Altogether, the prices on auctions and implicit values of spectrum vary, and our analysis is limited in scope, but aimed to show the significance of spectrum and regard as an indication of the value of spectrum.

4.3. Conclusion engineering value

The analysis of this case has demonstrated three aspects. Firstly, that operators with 10 MHz has sufficient capacity to manage demand over 5 GB, assuming 250 subscribers per km^2 that share 40 Mbps per km^2. This implies that operators with less amount of spectrum have options to provide mobile broadband services. Secondly, we have made a radical assumption of usage in order to stretch the analysis and show the impact of increase usage to levels that currently looks unlikely. But the experience from the historical development of mobile communications shows that usage are difficult to predict, and the appetite for bandwith is unlimited. Given that the operators in the Nordic countries are equipped with at least 20 MHz for LTE they are relatively well prepared to meet the expected user demand for the next couple of years. Thirdly, the case, unsurprisingly, demonstrate that operators that are able to obtain more spectrum than its competition, and also pursue network sharing, and spectrum aggregation have an extensive competitive advantage as it has the lowest production cost, highest margin when the usage takes off. Moreover, it is also able to capitalizing on a strategic value of spectrum which the following chapter is elaborating.

5. Analysis of Strategic value – Impact of offered data rates

The achievable data rates and number of served users depends, as has been illustrated in the above, on the amount of bandwidth that an operator can use. In this section, we discuss how the value of spectrum can be influenced by the user perception of service quality in terms of offered and provided data rates. This has extensive implications on the service offers that operators can market, and on the market position related to what "other operators can offer"

5.1. Offered data rates

The data rate that can be offered is an important aspect when operators market their mobile broadband services. Interviews and discussions with major operators in Sweden show that the amount of spectrum, and hence the data rates that can be offered are of vital importance for the positioning on the market. Many tests of mobile broadband services are presented where the operators claim to have "the fastest" or the "the most reliable" mobile broadband service. It is also the "peak rate" that is marketed, usually denoted "up to X Mbps". This is done despite operators, vendors and users all agree that peak rate is not a correct performance measure.

Until now, with WCDMA/HSPA systems using 5 MHz of bandwidth, operators can offer the same data rates provided that they use the same radio access technology. Additional carriers are used for capacity upgrades, but are currently not be possible to use in order to increase the data rate for individual users. However, this will change when multi-carrier HSPA solutions and LTE with bandwidth up to 20 MHz will be launched. Operators with more bandwidth are able to claim that "we can offer higher data rates". Technically, the higher bandwidth has an impact on the user experience in two ways:

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

5.2. Impact of carrier aggregation and network sharing

In order to capture an understanding of the differences in service offers we compare data rate performance for four test cases of operators with different spectrum allocation. Examples of average and peak data rates are shown in Figure 9**,** based on the assumption of spectrum efficiency of 2 and 10 bps per Hz respectively. Without any carrier aggregation the system bandwidths are 10 or 20 MHz, the cases with more than 20 MHz of bandwidth will result in multiple 20 MHz systems working in parallel. With our assumptions the average data rates will be 20 or 40 Mbps and the peak data rates will be 100 or 200 Mbps.

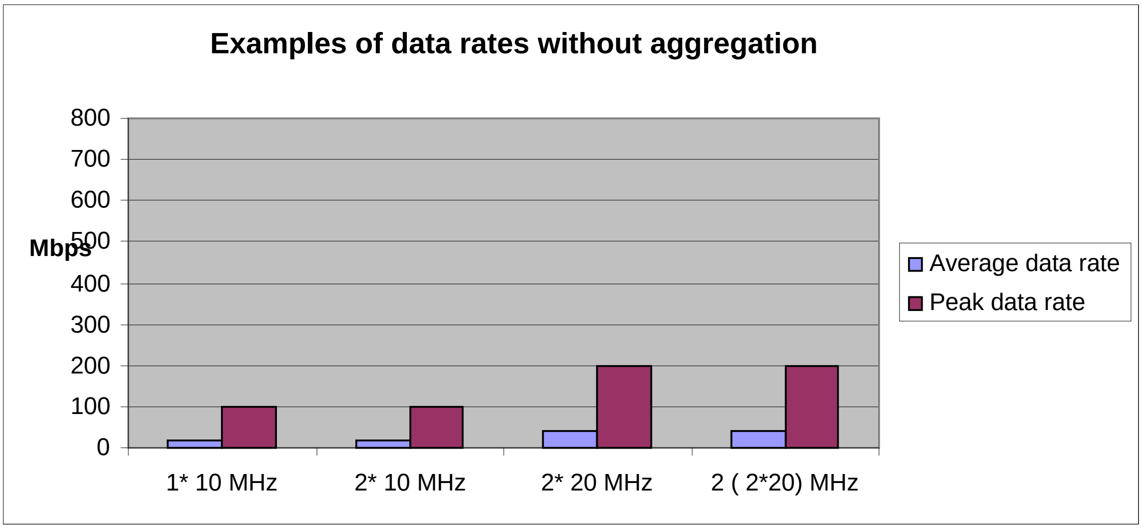

Figure 9: Examples of data rates without any carrier aggregation assuming spectral efficiency 2 bps per Hz for average and 10 bps per Hz for peak data rate

The performance will change if carrier aggregation is introduced, see Figure 10**.** The system bandwidth will increase substantially, up to 80 MHz for two cooperating operators with 2*20 MHz each. Applying the same assumption on spectrum efficiency as above the average data rates can reach 80 or 160 Mbps, and the peak data rates can be up to 400 or 800 Mbps.

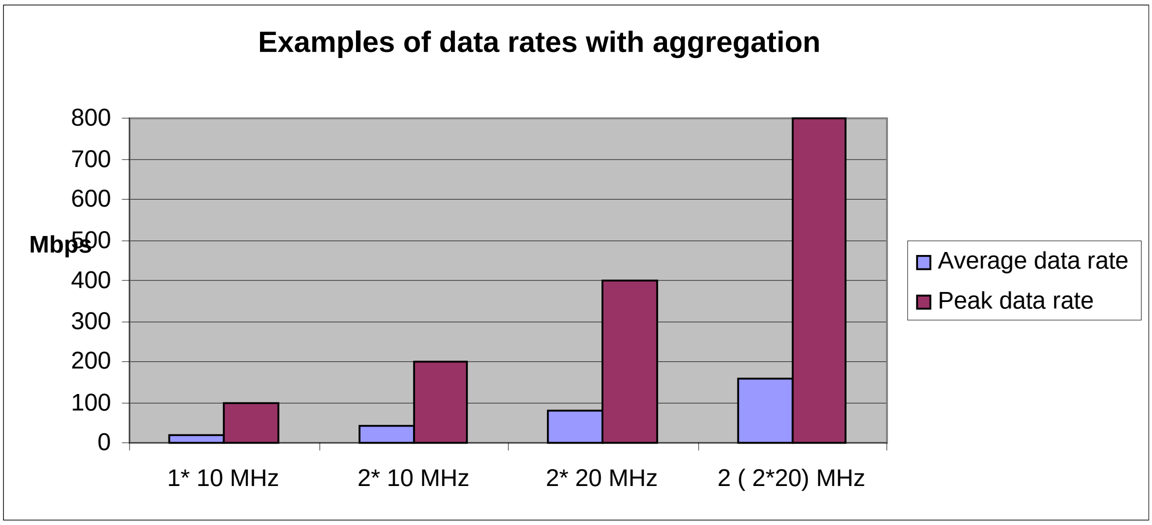

Figure 10: Examples of data rates using carrier aggregation assuming spectral efficiency 2 bps per Hz for average and 10 bps per Hz for peak data rate

When carrier aggregation is not used the data rate performance is "almost" similar for different approaches, hence the marketed offers would also be "almost" the same. However, the introduction of carrier aggregation will change the market condition dramatically since the higher total bandwidths can be used to market services with substantially higher data rates. A set of questions arise related to how these different offers will be received by the consumers, and if and how the market position will be altered.

Previous research based upon the ideas of Twersky & Kahneman indicates that it is decisive for operators to keep “the promised bit rates” whatever the absolute value may be. The user satisfaction is decreased substantially if the delivered bit rate is lower than what is promised. Figure 11 and Figure 12 are based on a user survey (Markendahl et al, 2008) and illustrate the user satisfaction (from - 10 to +10) as a function of the delivered data rate for two values of “marketed” data rate. Note that the very same delivered data rate (200-300 kbps) results in different values of user satisfaction as it depends on user expectation. The “expected value” is 200-300 and 1 - 2 Mbps in Figure 11 and Figure 12 respectively.

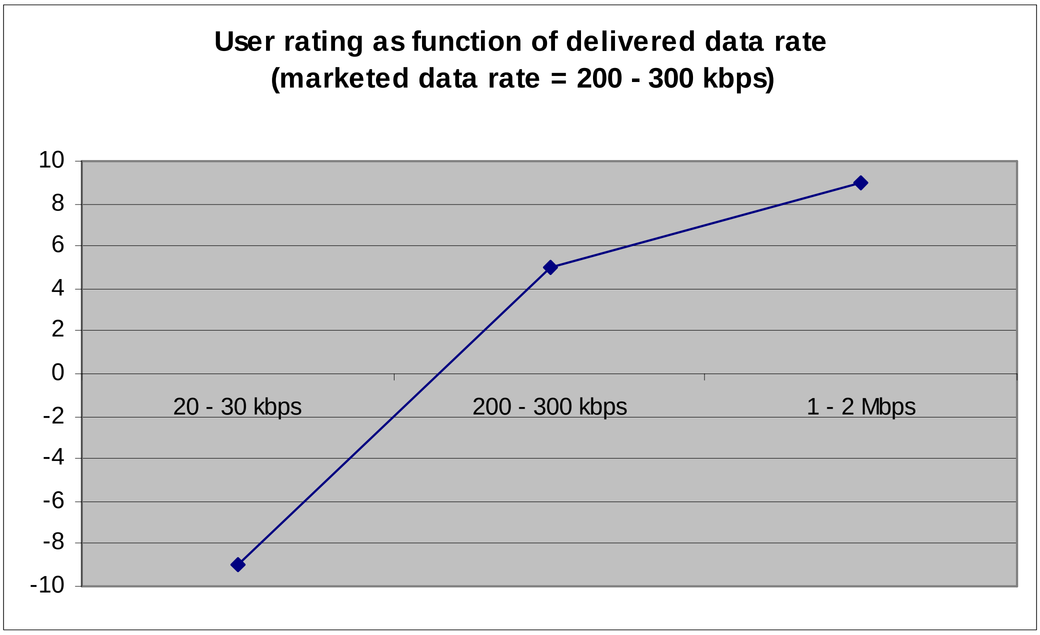

Figure 11: User satisfaction as function of delivered data rate (expected value: 200–300 kbps)

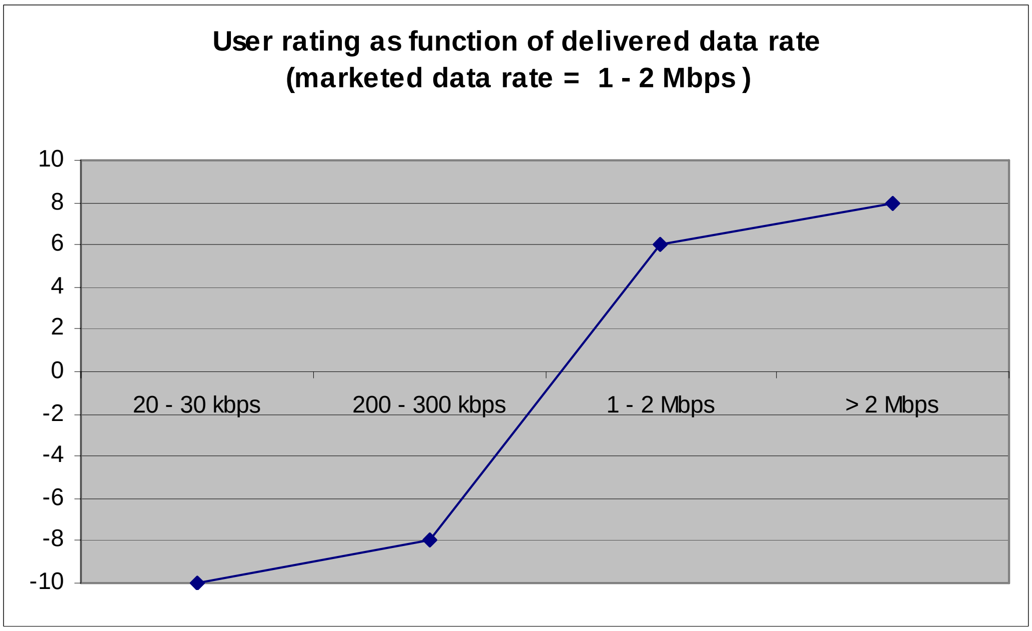

Figure 12: User satisfaction as function of delivered data rate (expected value: 1 - 2 Mbps)

5.3. Discussion

These results should be seen as illustrations of potential reactions from customers rather than a “evidence”. Moreover, more research needs to be in order to compare user response and preference to operator offers with different “expected values” and different pricing. In this context the Kano model is of interest.

Noriaki Kano developed an approach based on “Attractive Quality Creation” that usually is referred to as the “Kano Model”. When this approach was presented by Kano it challenged the traditional Customer Satisfaction Models which are based on the assumption that “More is better”, see (Walder, 1996), (Farmer, 2008). This assumes that the better the provider can perform on each service attribute the more satisfied the customers will be. This would e.g. imply a more or less linear relationship with different attributes, e.g. if the bit rate of a communication service is increased 10 times then the satisfaction of the customer will increase 10 times. In the proposed customer satisfaction model it is assumed that the performance of service attributes is not equally perceived by all customers. Many consumers can value various attributes differently. The traditional assumption on customer behavior, i.e. “more is better” is denoted “Satisfier”. Another type called “Delighter” is a customer that appreciates more attributes (and performance). Finally, a customer that requires that the service always includes all possible attributes and have the best possible performance, i.e. there are a lot of “must be features”, is called a “Dissatisfier”.

To summarize, the abovementioned research and the user survey lead to two conclusions about user expectations and user satisfaction:

- It is important to provide what is promised.
- User will notice and compare if other operators can provide “more”

Even if a high bit rate is delivered compared to today’s conditions, e.g. 20 Mbps, the user will be dissatisfied if the operator has promised 50 Mbps. In Sweden there are examples where operators behave differently when it comes to marketing of “4G services”. One operator claimed that 99% of the population will get up to 150 Mbps. At the web page it was explained that it is “up to 150 Mbps in major cities and up to 80 Mbps in rural areas” [3]. This can be compared to another operator[4] that presented their 4G services to offer “up to 150 Mbps but typical data rates will be in the range 10 – 20 Mbps”

[3] http://www.nyteknik.se/nyheter/it_telekom/mobiltele/article580890.ece

[4] http://www.ctte-conference.org/?q=node/14

6. Conclusions

Although spectrum has always been instrumental for mobile operators the new era characterized by ubiquitous communication, spearheaded by the diffusion of mobile broadband, have given a further push upwards for the valuation of spectrum. This development has been reinforced by recent spectrum auctions in, for example, Germany, Denmark, India, and the US. This paper has taken a radical approach to the increased usage of mobile broadband – estimating a mobile penetration of 50% and usage increasing from 5 GB, equivalent to what heavy users currently use in Sweden, increase to 20 GB, and subsequently 80 GB per user and month. This represents a usage 40x higher than average usage on the Swedish market. This has facilitated an analysis of how far an large spectrum holding can take an operator. Not only is an operator that is only holding 10 MHz worst off when usage reach 20 GB as it calls for network upgrades pushing up capex, it is unable to market services with equivalent bit rates as competition.

The analysis has demonstrated that the engineering value of spectrum, measured by value in EUR per MHz pop to be in the range of EUR 0.85 to EUR 3.40, compared to for example EUR 1.58 that was paid in the Germany auction for 800 MHz. However, the 2.6 GHz spectrum in Germany did only cost EUR 0.05 per MHz pop in the auction. This indicates that the implicit value of spectrum and the willingness to pay could deviate. Moreover, it also confirms that budget constraints, as Bulow et al (2009) underscore and auction process set the price, which could be considerable lower that the value that the operators ascribe to spectrum.

Concluding, we set out to explore how the production cost is affected by different levels of spectrum, and our analysis has demonstrated that an operator with more spectrum is able to capitalize on economy of scale, and achieve a higher return of investments. It is illustrated by the fact that an operator with access to 80 MHz is able to lower its production cost with 94% when the usage increase from 5 to 80 GB. The analysis has shown that there is a direct relation between the amount of spectrum and production cost, as operator with less spectrum are force to a varying degree of network upgrade which push up capex. Moreover, the control of ample spectrum holding and utilizing spectrum aggregation gives a key advantage when usage takes off and reaches really high volumes. This implies that the competition on spectrum is set to increase, and spectrum aggregation is set to play a key role on the market when the mobile broadband bandwagon is set in motion.

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