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Conference Paper

Scenario driven requirement engineering for design and deployment of mobile communication networks

22nd European Regional Conference of the International Telecommunications Society (ITS2011), Budapest, 18 - 21 September, 2011: Innovative ICT Applications - Emerging Regulatory, Economic and Policy Issues

Provided in cooperation with:

International Telecommunications Society (ITS)

22nd European Regional ITS Conference
Budapest, 18-21 September, 2011

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Scenario driven requirement engineering for design and deployment of mobile communication networks

Abstract

The numbers of users and usage of mobile data service are increasing dramatically due to the introduction of smartphones and mobile broadband dongles. For the next decade the mobile broadband market is expected to grow and reach a level where the average data consumption per user is orders of magnitude greater than today. For the telecom industry it is a magnificent challenge to design and deploy these s high-capacity wireless networks taking into account limitations in cost, energy and radio spectrum.

The objective of this paper is to highlight the need to consider a multitude of scenarios for the requirements, design and deployment of mobile broad band networks. The R&D has for many years been targeting high peak data rates enabled by improved spectral efficiency, adding more spectrum bands, aggregation of frequency bands and offloading to local wireless networks connected via public fixed phones or broadband.
However, many of these features driving the technology development are representative for the conditions in US and Western Europe. The wireless networks also need to be designed assuming deployment in regions in the world where both the availability of spectrum as well as the penetration of fixed phones and broadband are limited.

JEL codes: L960, O320, 013

Keywords: Mobile broadband networks, cost and capacity, spectrum, deployment strategies, telecommunications, management of technology and R&D, economic development of natural resources

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1. Introduction and motivation of work

Mobile communication trends

We are currently seeing large changes at the market for mobile communication services. The numbers of users and usage increase, smartphones and mobile applications have entered the scene. We can also see how the internet and mobile communication industries are merging. Handset manufacturers and Internet companies offer mobile services and start to establish customer relations with the end-users[2].

During the last 5 years, the world has experienced an unprecedented growth in the consumption of internet and digital media through mobile broadband networks. What is more amazing is that this development is not limited to the richer part of our world but rather a Global phenomenon (Waverman et al, 2005). E.g. the data traffic in the mobile networks in Kenya grew with more than 800% during 2010. Its social and political impact is beyond our current understanding. For the next decade, the mobile broadband market is expected to continue to grow exponentially maybe reaching a level where the average data consumption per user is some 100 times greater than today. To build wireless networks for this scenario that are both energy and cost efficient is a magnificent challenge for the industry.

An overview of technology development and efforts made by manufacturers and operators is presented found in (Rubenstein, 2011). Capacity and data rates are increased by improvement of the spectral efficiency of the radio access technologies and by using wider bandwidths, i.e. more spectrum. From the peak data rates of 2 – 14 Mbps offered for 3G systems, operators now market 4G services with data rates “up to 80 Mbps”. By combining a number of frequency bands peak data rates around 1 Gbps is the target.

But peak data rates cannot be the only driver for the technology development. Firstly, very high data rates are only available very close to the base station and for a limited number of users. It is equally important to provide capacity for many users over a large area. Secondly, the development of mobile communication systems is to a large extent based on working assumptions typical for developed countries. The R&D has for many years been targeting high peak data rates enabled by improved spectral efficiency, adding more spectrum bands, aggregation of frequency bands and offloading to local wireless networks connected via public fixed phones or broadband.

Hence, the wireless networks also need to be designed assuming deployment in regions in the world where both the availability of spectrum as well as the penetration of fixed phones and broadband are limited.

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[2] Arthur D Little report "Telecom operators", March 2010.

KTH project on future mobile broadband access networks

At the research center Wireless@KTH the project on future mobile broadband access networks (MBB++) was initiated 2011. The MBB++ project is a follow up on earlier projects on the design and deployment of mobile broadband networks carried out at Wireless@KTH between 2005 and 2010. In the context a dramatically growing market for mobile broadband data where cost and energy efficiency are key, the aim of this project is to address the issues of optimum deployment strategy and network architecture for various operator and business scenarios, including M2M services and different parts of the World. The envisioned technologies are LTE-Advanced and systems beyond.

Since the demands for mobile data is growing so rapidly, the key challenge for the industry is to find solutions so that we do not have to deploy orders of magnitudes more base station to meet the bandwidth requirements. These solutions may require new network architectures that are optimized with a key focus on: technical network performance, cost and energy efficiency and environmental impact. Mobile networks are to be deployed all around the World in various countries were the political, economic and regulatory circumstances all differ. The economical differences may e.g. have an impact of the existing fixed infrastructure – which, will be shown below, has a significant impact on the roll out of the mobile infrastructure. The political and regulatory situation may affect the availability of spectrum

In the context of the global development described above, it is the ambition of the MBB++ project to study plausible future network solutions for various scenarios for deployment of mobile broadband. However, from the discussion above it is our conclusion that network design and deployment may not anymore only be a question of dimensioning according to the estimated number of users and voice minutes per users, or the GB per month and user for mobile broadband services. The design of the technical system, i.e., the wireless networks, must also consider

- The multitude in different network deployment scenarios around the world
- The role of mobile networks as an enabler for other types of services or for the development of the society[3]

The multitude in network deployment scenarios is needed in order not to tailor technical solutions to the conditions at a specific market. It may be true that the network dimensioning and deployment strategies for voice services can be adapted to different markets using the same basic line of reasoning. It is not evident that this is the case when mobile broadband networks will be deployed in regions or countries with totally different conditions. Hence, this must be investigated.

[3] Ericsson "Accelerating global development with mobile broadband", White paper, Feb 2009

Problem area and research questions

In the MBB++ project two different research questions are discussed related to the requirement engineering and specification of mobile communication networks:

1. What kind of requirements on the design and deployment of mobile communication networks can be identified due to the multitude of region specific market, demand and supply characteristics around the world?

2. What kind of new requirements or design procedures for mobile communication networks can be identified when the needs of the service or business using the connectivity is taken into account?

In this paper we will focus on the first research question. One place is like no other when it comes to geography, demographics, political, and economic conditions and also the existing telecom-infrastructure. Therefore, whenever an infrastructure for mobile broadband services is to be deployed it first has to consider:

- Geography aspects such as urban planning, rural landscape, climate
- Demographics such as population density, age, wealth and poverty
- Political conditions like market regulation, spectrum policies and availability
- Economic conditions such as GNP per capita, economic growth, willingness to pay
- Existing telecom-infrastructure for fixed and mobile phones, internet usage

Given the specific service and region where the operator intends to operate his network, the optimal network architecture and roll-out strategy may differ tremendously. For example, in India where the population is high, cost of labor is low and the availability of spectrum is low, technologies to re-use spectrum may be a key to the deployment of mobile data services. In northern Europe where spectrum availability is good but cost of labor high, low operational cost is probably of greater importance than spectrum efficiency.

In addition to the various regional differences, different sets of requirements need to be considered, e.g. internet access requires high data rates, M2M services requires low latency and low error rates, public safety services require high reliability.

Paper outline

Sections two and three describe related work and the methodology. Next, operator challenges for providing high-capacity low-cost mobile networks are described. Section five briefly describes technical solutions proposed by the telecom industry. Section six describes characteristics of different countries. The analysis in section seven is done making an assessment of how applicable the technical solutions are for different levels of fixed line penetration and amount of spectrum, i.e. for different regions in the world.

2. Related work

Data rates and capacity can be increased by using higher bandwidths, by improving the spectral efficiency of the radio access technology and by adding more base stations. A good overview of the different strategies to increase capacity is presented in (Landström et al, 2011). In this paper a combination of three main strategies is described; to improve the performance of the macro layer, to build a denser macro layer (i.e. more macro base stations) and, to add low power base nodes (i.e. so called pico or femtocell base stations).

The underlying technology development and standardization has been ongoing for many years. Mobile network operators and telecom equipment vendors join forces in the main standardization body 3GPP. The main type of radio access technology is called 3GPP Long Term Evolution (LTE) and with upcoming releases known as LTE-advanced. Features to improve the spectral efficiency and peak data rates in LTE advanced is described in many papers, e.g. (Parkvall et al, 2010). Increase of system bandwidth using aggregation of carriers or frequency bands are described in (Etemad et al, 2010).

Both marketing by mobile operators and the research efforts by telecom manufacturers has been focused on the peak data rate. As mentioned by Jan Färjh, head of Ericsson Research, we can probably see shift of focus the coming years[4].

"Close to the theoretical limit the research starts to switch focus . . . . . until now we have mostly considered the maximum data rate that can be provided by a specific technology under optimum conditions in a limited area" [i.e. close to the base station (authors comment].

"In the future it will be more important that the high data rate need to be available everywhere. Then you need cooperation between different types of networks and that the base stations cooperate more closely than today"

Related to radio capacity we also would like to mention "Cooper's law" that says that the number of "conversations" that can theoretically be conducted over a given area in all of the useful radio spectrum is doubled every two-and-a-half years (pp: 65, Webb, 2007). 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[5].

"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".

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[4] Authors translation of interview published in Swedish newspaper "Svenska Dagbladet", May 2, 2011

[5] http://www.arraycomm.com/technology/coopers-law

A similar way to structure the problem is also used in the white paper by Real wireless (2010) where the main entities are called Spectrum, Technology and Topology. For the years 2010 - 2020 Real Wireless suggests that there is a potential for a gain in capacity of the order 500-1000 times. Here, the increase of spectrum accounts for a factor of two of the capacity gain, technology a factor of three and topology a factor of almost 100.

3. Research approach, data collection and analysis

The starting point for our analysis approach is the observation that design and development of mobile communication systems to a large extent is based on working assumptions typical for developed countries. The system development has for many years been targeting high peak data rates enabled by improved spectral efficiency, adding more spectrum bands and aggregation of carriers or bands. Capacity improvements can be based on heterogeneous networks (hetnets) with small cells and offloading to local WiFi or femtocell wireless networks connected via public broadband. However, the wireless networks also need to be designed assuming that the amount of spectrum is limited and deployed in areas where there may be very low penetration of fixed broadband.

Hence, this paper takes a global approach to the problem of providing high-capacity and low-cost mobile networks. We present a framework for the development of mobile broadband networks that can be used for formulation of the requirements for mobile network design that is applicable on a global scale. The work flow is as follows:

1. Identify technology and business related challenges for mobile operators when it comes to the design and deployment of high-capacity low-cost mobile networks.
2. Identify and describe technical solutions proposed by the telecom industry in order to handle the challenges mentioned above
3. Collect data from different regions in the world in order to describe differences in fixed line penetration and the amount of spectrum allocated to mobile operators
4. Take the solutions from step 2 and make an assessment of how applicable they are for different levels of fixed line penetration and amount of spectrum, i.e. for different regions in the world.

The outcome of the analysis in step 3 is a matrix with four squares divided by two axes. The first axis is the level of advancement of ICT, which is measured as the level of fixed line penetration and the other axis represents the amount of spectrum that operators have, from a low to a large amount of spectrum.

The data set compose of a sample of 14 countries representing different areas of the world and different levels of development stages for telecommunications. The data source is ITU and The World Fact book, which is published by CIA, and primary from 2009. Given the rapid development of mobile communication the mobile penetration could be higher in a number of countries, but the fixed line penetration has not changed materially which makes the data set relevant.

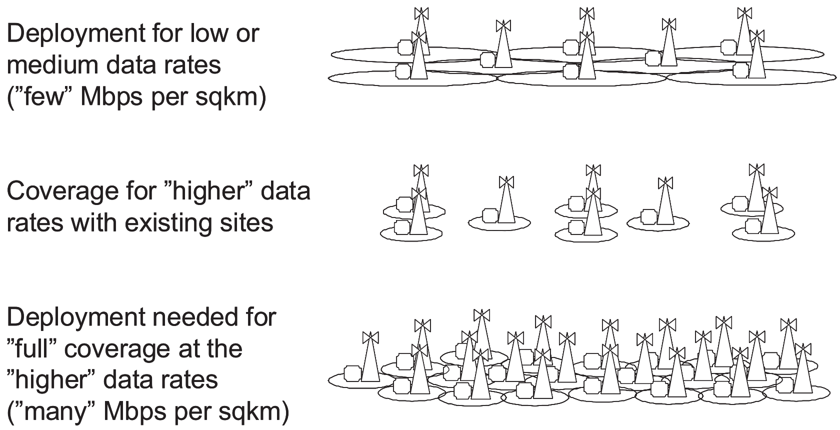
4. Operator Challenges

In this section we will list a number of network and business related challenges for mobile operators (Markendahl et al, 2009).

Scalability and cost structure of cellular systems

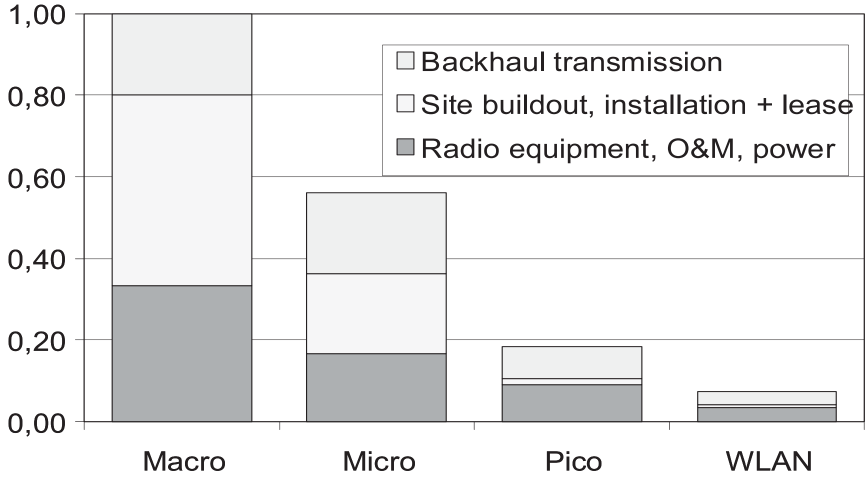
The increasing demand requires that more network capacity is deployed. One challenge is that the cost of capacity in terms of base stations and the amount of radio spectrum. For a specific amount of spectrum and for the same type of Radio Access Technology (RAT) the deployment of N times more capacity will imply N times higher network costs, see figure 1. The cost is proportional to the number of users, the demand per user, the service area and also a function of quality (Zander, 1997). Development of new technology with lower cost and increased spectrum efficiency will improve the case, but the basic scalability problem will remain. Operators have licensed spectrum at different bands, e.g. at 900, 1800, 2100 and 2600 MHz. The more bandwidth that can be used at one site the better the capacity – cost ratio.

Figure 1 More capacity per area unit implies denser networks and higher costs



Investments for the radio access network include not only costs for the radio equipment but also costs for transmission and site build out, see Figure 2. Site costs include both capex and opex, comprising costs for towers, power, installation, site survey & planning and site leases. For outdoor deployment (macro and micro base station sites) the site costs are substantial (Johansson, 2007). For indoor systems the radio equipment and transmission dominates. The transmission to the sites must be upgraded as transmission using 2 Mbps leased lines (E1) is not sufficient to current mobile broadband technologies for data traffic. It should be noted that the price erosion has a significant impact on the costs for the radio equipment as electronic equipment follows Moore's law resulting in half the cost every 18 month. However, the site costs, civil engineering, site leases do not follow Moore's law.

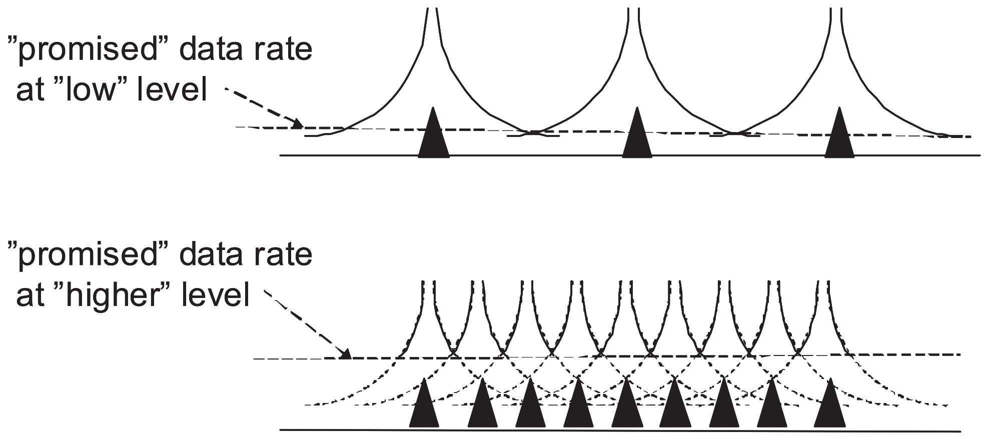
Figure 2 Example of base station cost structure including capex and opex for greenfield deployment, based on data from (Johansson, 2007)



Marketed offers, user expectations and network costs

Mobile broadband services are commonly marketed in terms of "peak rate". Current 3G offers are in the range 2 – 32 Mbps and "4G" offers are presented as "up to 80 Mbps" (Markendahl, 2011). This maximum data rate, or close to it, is possible to achieve only if the user is very close to the base station and is alone in the cell. The achievable data rate is considerably lower at the cell borders. The use of more bandwidth and "new" technology with higher spectrum efficiency will give some support, but the underlying problem with dis-satisfied users that are not receiving as high data rates as expected will remain. For operators it will be very costly to build networks where peak rates can be guaranteed over large areas. Since the data rates are reduced when the distance to the base station increases more base stations are required to be deployed, resulting in higher network costs, see Figure 3.

Figure 3 Data rate guarantees over large areas implies denser networks



Using outdoor systems to provide indoor coverage & capacity

The majority of the calculations on range are made for outdoor conditions while an increasing share of the traffic is indoors. For voice this share has been estimated to be in the range of 60 – 70 % and for mobile data an even higher share. When calculating the required coverage and number of macro base station sites operators need to take into account the indoor penetration loss. A large number of measurements have been carried out where the results show large variations in path losses caused by different types of walls. Typical figures are 10 dB for wooden houses and between 20 and 40 dB for concrete or brick walls (common in suburban and urban areas). The wall penetration losses result in reduction of radio coverage and hence a denser network needs to be deployed. As an example, for an additional loss of 15 dB the number of base stations has to be increased by a factor of seven.

Deployment and operation of indoor systems

There are a number of technical solutions dedicated for deployment inside buildings: Distributed Antennas Systems (DAS), cellular pico or femtocell base stations and repeaters. These solutions (except repeaters) require some kind of planning, installation and maintenance and can be quite costly compared to outdoor macro base stations. This is especially the case for DAS that more or less "built-in" into the building. Femtocells are small cellular base stations connected to the operator network through Internet. For limited areas and specific user groups this may be a feasible solution but for large scale deployment there are a number of problems (Markendahl, 2011):

- Femtocells and macrocells will experience interference problems both for co-channel and adjacent channel operation. Hence, dedicated femtocell bands would be beneficial but operators usually cannot "afford" to use part of the licensed spectrum.
- Femtocells are usually discussed as part of single-operator networks. This means that multiple femtocell networks would be deployed at indoor locations. This is usually not accepted by facility owners that require one common shared network (this is often the case for DAS). The facility owner also may want to be part of this cooperation. Hence, both new network sharing strategies and business models are needed.

Spectrum allocation

Mobile operators have to compete for spectrum, both with other sectors (e.g. for broadcasting or for aeronautical applications) and with other mobile operators. Spectrum can be allocated using auctions or beauty contests. This means that established operators may risk of not getting access to new frequency bands, e.g. Telia in Sweden did not get any 3G license 2000. In order to preserve competition the regulators may introduce caps on how much spectrum one actor can buy, i.e. operators are not are allowed to buy more bandwidth at an auction even if they can "afford" it.

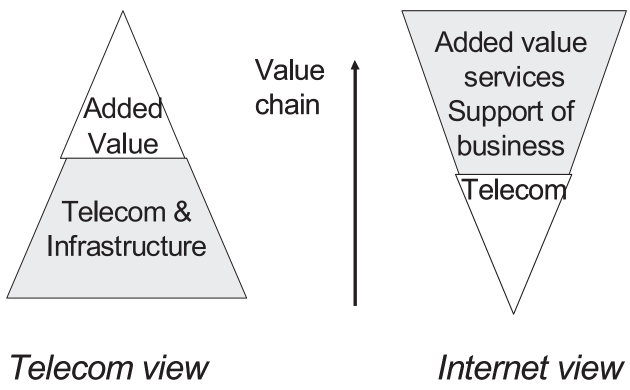
A changing business landscape

Introduction of smartphones have highlighted the changes in the business landscape for mobile services. Companies like Apple and Nokia offer services and applications and establish business relations with the end-users. The deployment and operation of telecommunication networks have traditionally been an oligopolistic infrastructure business closely connected to network properties. Long term customer relations have been very common. Large companies with solid financial resources make long term commitments when networks are deployed and upgraded.

However, with the introduction of Internet based services the business landscape has changed. "Any" actor connected to the Internet can start to do business, even with very low investments. For mobile and broadband access the service "itself" is closely related to the network and its characteristics, e.g. bit rate and coverage. For internet based services there are other company assets and capabilities than the network that enable an actor to enter and succeed in Internet based business. In addition to value added services other assets can be billing relations, local presence, payment and billing support.

There is an ongoing transition from the "telecom view" to the "Internet view". Using the telecom view the main aspect is the infrastructure; the services are added "on top of" the networks. Using the Internet view the networks are seen as a basic asset similar to roads, railways, water supply and schools that are needed in order to make markets, companies and the society function as expected. New types of actors like Google, Yahoo, Facebook and Microsoft make increasing efforts in order to obtain a share of the internet business and to connect customers more closely. The actions by terminal suppliers are already mentioned. Microsoft acquires Skype and Nokia and Microsoft join forces. At the same time mobile operators more and more start to cooperate with competitors (network sharing) or companies in other sectors (mobile payments), see (Markendahl, 2011).

Figure 4 The telecom and Internet business perspectives



Source: presentation by N. White at the Int. Telecom Users Group meeting, Stockholm, June 2008

5. The network tool-box

During the last 30 years, enormous efforts have been put into research of the basic hardware and the transmission technologies for radio networks. This research of the "physical layer" (often abbreviated as PHY) has been so successful that one may now consider the performance limits, i.e. the Shannon limit, to essentially be within reach. Instead it is now the rather the architectural and deployment aspects that determines the capacity of the network (Dohler et al, 2011).

LTE-Advance (4G) and all future standards provide a "tool box" of various features for the PHY layers that allow the operators to deploy their mobile networks in a multitude of ways (Dahlman et al 2009). Using this tool box it is then possible for the operators to "tailor" their networks to the particular circumstances in the specific region where they are operating.

Carrier aggregation

As described earlier in this paper, access to large amount of spectrum is today key for the mobile broadband operator: the larger the amount of spectrum the operator has access to, the higher peak rates and capacity he may offer. Today the ITU opens the possibility to deploy mobile broadband services in more than 40 different bands around the world. For a local operator in any specific region the "carrier aggregation" feature makes it possible for the operator to "aggregate" smaller chunks of frequency bands into the same cell – making it perhaps possible for the less fortunate operator to achieve the same amount of bandwidth as the dominating ones without having acquired 20-100MHz of continuous spectrum.

Multiple antenna support: "MIMO"

Besides access to spectrum, the spectral efficiency is a key parameter in order to determine what capacity and peak data rates the network may offer. However, the spectral efficiency is bound to the Shannon limit – a limit which today's wireless systems almost have reached (Dohler et al, 2011).

A way of getting around this limit is to install multiple antennas at both the transmitter and the receiver ends. In the event that the channel conditions are good it is then possible to transmit as many parallel data stream as there are antennas. Such "Multiple-Input-Multiple-Output", MIMO, systems are now being implemented into the standards (Dahlman et al, 2009). The main problems with these systems are at least two:

- In practice it is hard to implement many more than two antennas at both the base station and the handset

- In order for MIMO to work with high performance, exceptionally good radio propagation conditions must be in place.

Still, 2x2 MIMO is today widely implemented in the current LTE standard and, although no reference measurement data is available to the authors of this paper, it seems to perform according to expectations and at times doubling the spectral efficiency of the network. Maybe 4x4 MIMO will become widely deployed as well if it proofs to perform as expected. However, it is hard to envision higher orders of MIMO because of the difficulties of its practical implementation.

Non uniform network deployment – Hetnet

The traditional way of deploying a network is in a homogenous macro cellular layer, typically deployed with base stations with around 20W output powers, antennas with a gain of around 50 and at heights of around 25m (in towers or on roof tops). In order to deploy higher data rates and more capacity the operator then either has to provide more spectrum or build a denser grid of antennas. Unfortunately, this will increase Capex accordingly.

In order to reduce the cost of enhancing the capacity in the networks, an old idea that is now being revisited which is to deploy the networks in a heterogeneous structure. This can be done with base station with various output powers (micro-, pico- and femto base stations) and at various heights. Using such network elements the capacity can be enhanced in local areas where it is actually needed. In order to reduce the cost even further e.g. femto base stations may be deployed and configured by the user.

Mobile data off-loading

Because of the heavy load on the mobile broadband networks, in particularly urban heavily populated areas, operators often support the use of off-loading of data traffic from macrocell networks to local networks. For the end users the main benefits for doing mobile data offloading is lower cost and availability of higher bandwidth. For the mobile operators the main benefit is to reduce or delay investments in more costly macrocell base stations.

Today WiFi is the technology mainly used for off-loading, in some countries (e.g. Finland) operators more or less give away WiFi access points to their customers in order to stimulate a "spontaneous" off-loading. In the future operators envision the use of cellular low power femtocells since they (in contrast to WiFi) do operate in licensed frequency bands. However, there exist a number of radio interference problems when macrocell and femtocell networks operate in the same or adjacent channels (Markendahl, 2011). Hence, femtocell operation in dedicated bands has some advantages but at the same time it would require more allocated spectrum.

Relays and repeaters

Because of the higher and higher data rates in the network, the backhaul, i.e. the connection between the base station and the remaining network, is becoming more and more of “bottle neck”. E1 lines and DSL connections are really no longer options for LTE base stations. An alternative to fibre or MW-backhaul, is to use repeaters or relays. RF repeaters have been around for decades but relays that detects and forwards the information is a new network element in cellular systems. Repeaters and relays do not ad capacity to a network but may instead redirect the capacity to areas where it is most needed and hence also may help create revenues for the operator.

Self Optimizing Networks – SON

Self Organisation/optimization has recently become one of the hottest topics in wireless networks. The introduction of SON in wireless networks is driven by the idea that by enhancing the network automatically and adapting its configuration and parameter settings to changes in the environment based on inherently in the system available measurements, it is possible to achieve a greater network capacity but also lower the operational cost. The three domains of self-organization are (Amirijoo et al 2009)

- self-configuration
- self-optimisation
- self-healing.

Self-configuration. i.e. plug and play functionality, is a feature that today is more or less standard in modern base stations The functionality significantly reduces the deployment cost of a base station. Self Optimization is to automatically adapt the network configuration and parameter settings to changes in the environment based on key performance indicators, KPI. One feature the: Inter-cellular interference coordination, ICIC, is already part of the LTE standard and may in real-time help the operator to reduce the interference level and hence improve the capcity of the network. Self Healing is ultimate step of SON. The vision is that the network itself is able to handle disruptive events and, hence, minimize the negative consequences on services.

A problem with SON today is that the solutions today typically are “vendor specific”. For operators with a single network source this is of course not a problem. However, for incumbent operators in Europe with perhaps up to 3 co-existing networks standards operating in 5 different bands and supplied by as many different vendors, SON solutions needs to become standardized before they will be widely deployed.

6. Country characteristics

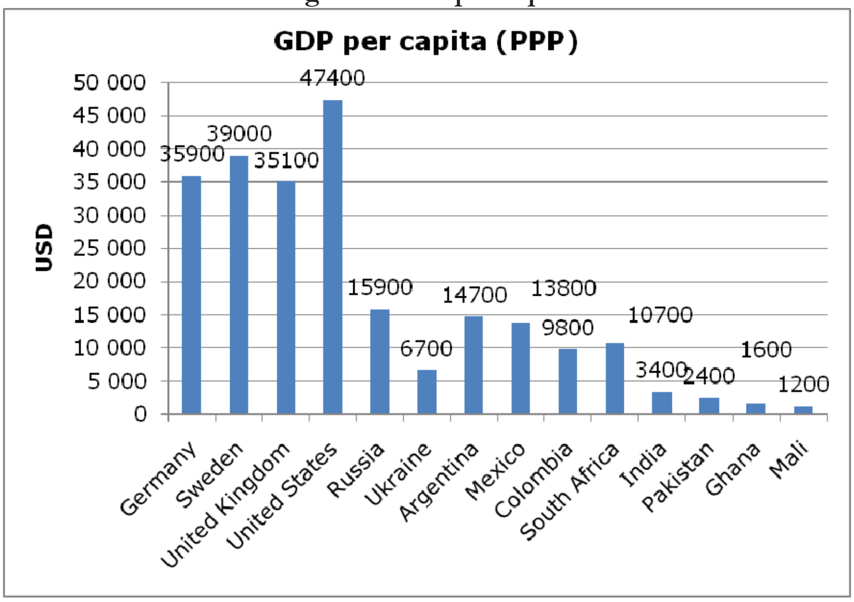
In this section we will provide empirical evidence for the multitude of conditions for deployment of mobile networks that can be expected in different regions in the world. The end result is that we can identify four different types of regions with respect to the level of fixed line penetration and the average amount of spectrum for mobile operators.

A broad range of countries

In order to establish a framework for the project and relate it to actual conditions in different parts of the world the analysis is based on a sample of 14 countries with different characteristics. Firstly, the sample covers countries like Sweden with 9 million inhabitants to India which have 1200 million inhabitants. The geographical size of the countries varies considerable from Russia which is vast with 17.1 million km^2 to Ghana which has an area of 239 000 km^2.

The 14 countries cover a broad range of economic levels, illustrated by the GDP per capita, and measured on purchasing power parity (PPP) and is an estimate for 2010.[6] Among the sample countries, the US is in the top with a GDP per capita of USD 47 400 compared to USD 1200 for Mali, as exhibited in the following figure.

Figure 5 GDP per capita



Source: The World Factbook, CIA

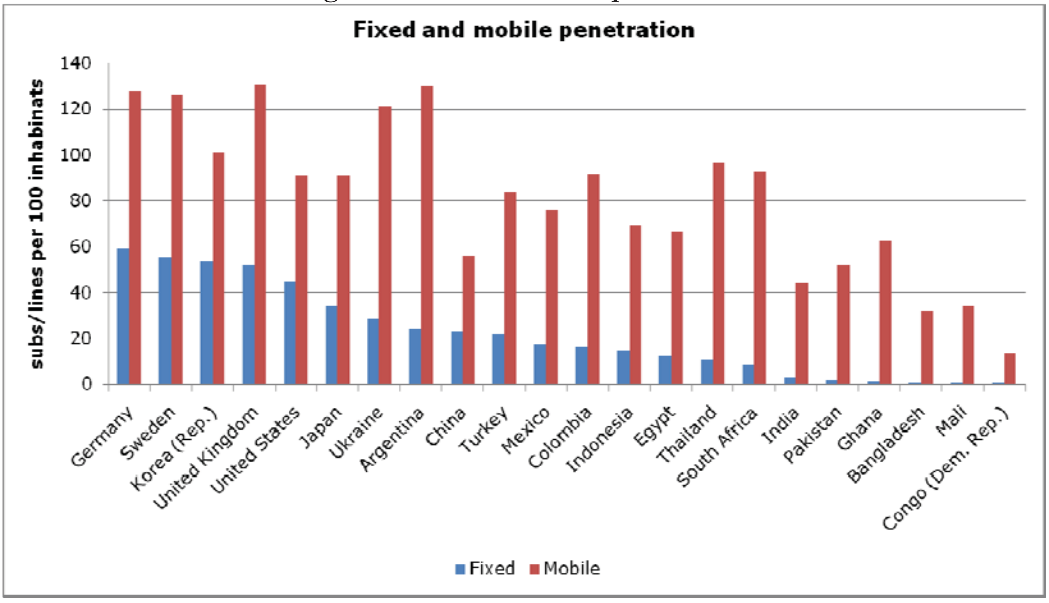
[6] Source: CIA Fact Book. The PPP method involves the use of standardized international dollar price weights, which are applied to the quantities of final goods and services produced in a given economy. See https://www.cia.gov/library/publications/the-world-factbook/index.html

Penetration of fixed lines and mobile phones

The density of fixed lines and mobile subscribers differ considerable between the 14 countries. The fixed line penetration goes from 60 lines per 100 inhabitants in Germany down to 1 fixed line per inhabitant in Ghana, and 0.60 in Mali. The equivalent number for diffusion of mobile subscribers goes from 128 mobile subscribers per 100 inhabitants in Germany down to 63 in Ghana and 34 in Mali, as illustrated by figure 6.

The fixed line density is used as an indicator for how developed the ICT sector is in the different countries. It is also giving the condition for the deployment of fiber infrastructure and by that means the basis for transmission and backhaul networks that connects base stations. The assumption is not that emerging markets will deploy fixed networks in order to replicate the development on mature markets the idea is rather that a poorly developed fixed network restricts the options for off-loading, the deployment of hot-spots, or usage of fixed broadband as an alternative to mobile broadband. The consequence is rather more pressure on mobile networks.

Figur 6 Fixed and mobile penetration



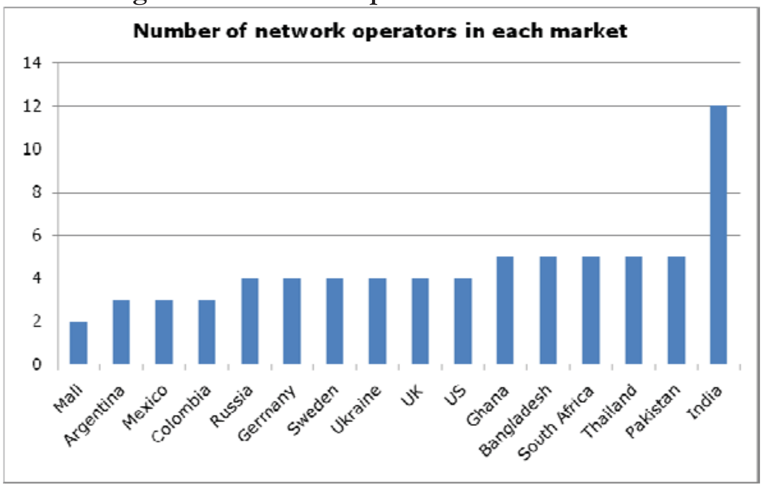
Source: ITU

A positive relationship between economic growth and investments in telecommunications infrastructure is recognized in the economic literature. It is also confirmed in this analysis by a correlation of 0.91 between GDP per capita and fixed line penetration among the 14 sample countries. The global deployment of mobile infrastructure has led to that countries with less developed economies have been able to leapfrog the development of a basic fixed infrastructure. This is illustrated by the fact that the correlation between level of GDP and mobile penetration is considerable lower compared with fixed lines as the correlation is 0.54.

Mobile operators

A cornerstone of economic theory is that competition is driving growth, it is therefore relevant to measure how many mobile network operators that are present on each market. Based on available market data the following figure show many operators that are competing on the different markets. India is a special case, and now subject to legal issue around spectrum allocation, but commonly 3-5 operators are competing on most markets.

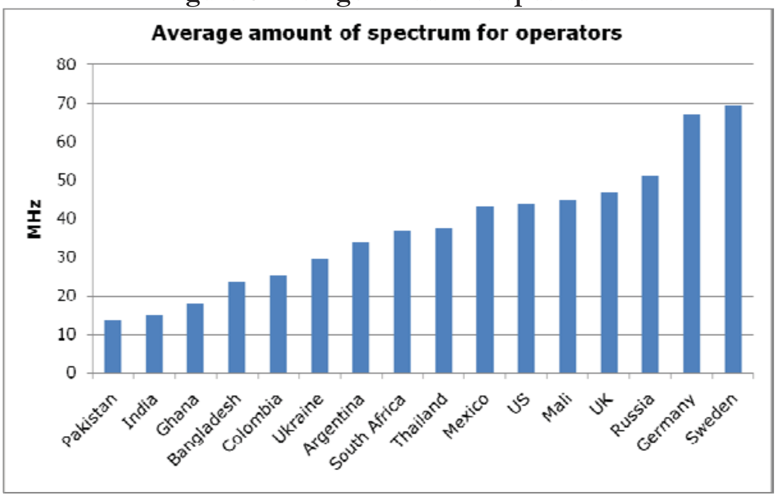
Figure 7 Number of operators on the markets



Source: National regulators, GSM World

With the growth of mobile data through the diffusion of dongles and smartphones the load on mobile networks are growing rapidly. This makes spectrum to a key asset. As the holding of spectrum differs considerable between operators on most markets we have made estimated the spectrum holding for an average operator on each market by conducting a market share weighted average holding of spectrum.

Figure 8 Average amount of spectrum



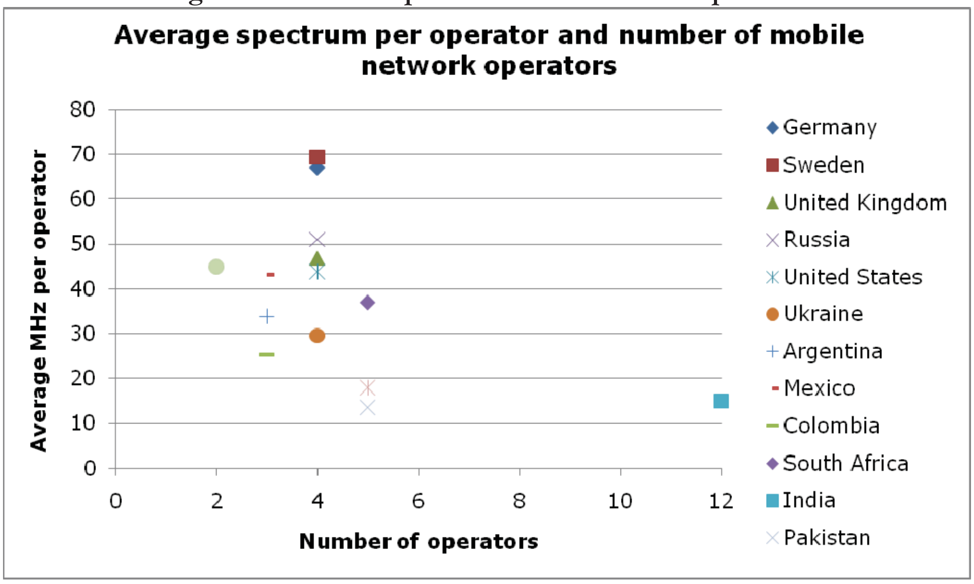
Source: National regulators, operator reports

The basis for the this calculation is the total holding of spectrum applicable for 2G, 3G and 4G multiplied with market share for each operator. The sum of spectrum the weighted average spectrum holding on each market. The graph illustrate a broad range of spectrum holdings from Pakistan and India where the operators in average hold 13-15 MHz to Germany and Sweden where operators in average have access to 67-70 MHz.

The average spectrum holding for operators influence capacity in the networks, and if it is linked to the diffusion of fixed lines it have a great impact on such strategies such as off-loading. The correlation between spectrum holding and fixed line density is 0.8 which implies that in countries with a high density of fixed lines the average operator has a relatively larger amount of spectrum compared to developing markets. This places Germany and Sweden in one corner and India and Pakistan in the opposite corner.

When comparing the number of operators and spectrum holding India stands out as it is up to 12 operators in some circles with a span from 15 MHz down to 4.4 MHz for spectrum holding, with a weighted average of 15 MHz. The number of operators on most markets is around 3-5, and the spectrum holding varies from 13.6 MHz up to 70 Mhz.

Figur 9 Amount of spectrum and number of operators



Source: National regulators, operator reports, ITU

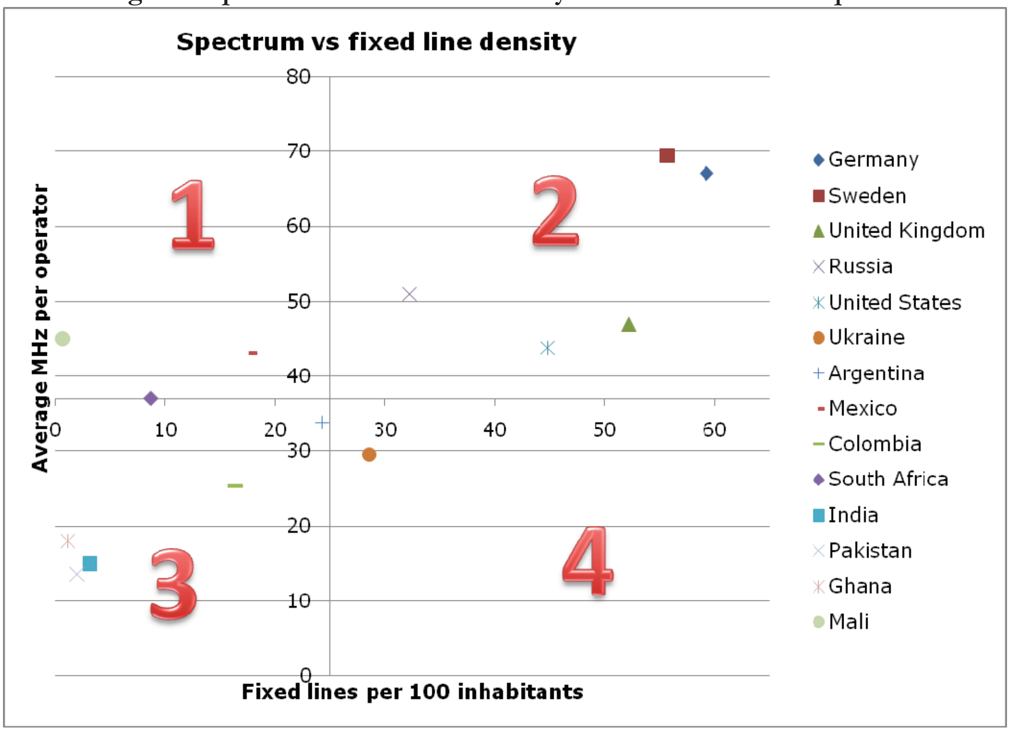
7. Analysis

Different conditions in different regions and countries

The survey of the 14 sample countries through the different parameters that have been analyzed illustrates a variety in basically two parameters: the *allocation of spectrum* to the operators, which in the case of weighted average amounts to a span from 13 up to 70 MHz, and the *fixed line penetration*, which spans from 1 up to 60 fixed lines per 100 inhabitants. The following figure illustrates four different groups of countries:

1. Low fixed line penetration, large amount of spectrum: Mali, Mexico, South Africa
2. High fixed line penetration, large amount of spectrum: Germany, Russia, Sweden, UK, US
3. Low fixed line penetration, limited amount of spectrum: Argentina, Colombia, Ghana, India, Pakistan
4. High fixed line penetration, limited amount of spectrum: Ukraine

Figur 10 Spectrum vs fixed line density - a matrix with four squares



Source: National regulators, operator reports, ITU

The requirements for operators in the four different squares are different and call for a broad variety of measures. The demand for mobile data in countries with a poorly developed fixed infrastructure makes it more challenging. In combination with spectrum holdings, which gives the economic conditions for operators it is a challenge to establish cost efficient network solutions

How different solutions can be applied in different regions

Here we will comment on the network tools described in section 5 and how suitable they are taking into account the amount of available spectrum and fixed lines. First, we describe an "author's choice" of wireless network solution assuming high availability of spectrum and high penetration of fixed phone lines and broadband connections.

Author's choice: A reference case

In countries like Sweden and Germany operators have the possibility to exploit both the spectrum availability and the existing fixed infrastructure that enables ADSL (or fiber) connection of small base stations. For macro sites the mobile operators can exploit band aggregation and combine a multitude of different bands. The author's choice of a cost-capacity optimized solution is based on *high capacity indoor femtocells* deployed in order to capture as much as possible of the indoor mobile broadband traffic and to reduce to need deployment of new macro sites for capacity reasons.

The indoor femtocells operate at a dedicated frequency band, unlicensed or common for all operators, in order to reduce or eliminate interference with macro base stations and user terminals connected to macro base stations. The femtocells operate at system bandwidth of 5 MHz or more and support high data rates. The indoor femtocell base stations are configured for public access, i.e. not only for a closed user group, and hence off-load all indoor traffic. The indoor deployment is based on a shared infrastructure that can be used by all mobile operators, i.e. no parallel indoor networks within buildings. To a large extent the deployment is based on already deployed fixed internet connections, this is another reason to share the infrastructure.

Limited amount of fixed line connections

With a limited number of fixed phone lines and ADSL connections the offloading of macrocell traffic to femtocells using public phone lines is not a large scale solution. Hetnets, femtocells and off-loading are still highly feasible solutions but the backbone and connectivity must be provided by operators.

Fiber connections to macro base stations are of course a solution, but the possibility to use a wireless backbone with microwave links must be ensured. This requires that spectrum is available at higher frequencies.

These conditions suggest solutions based on one or both of the following concepts

1. Large high capacity macro base stations with operation in multiple bands
2. Hetnets or femtocells connected by a mesh type of wireless backbone.

Existing wireless cellular transmission solutions assume connection of high capacity macro sites and are less suitable (too costly) for networks with many small nodes.

Low amount of spectrum and low fixed line penetration

The network deployment strategies are totally different if an operator has only a few MHz or if the operator has 10-20 MHz in multiple bands. The operators in countries with a low amount of spectrum ("group 3" in Figure 10) may be forced to deploy many sites in order to meet capacity demand. The situation in these countries is different are different since site construction, installation, operation and maintenance are cheaper due to lower salaries. Nevertheless, new strategies and technologies to re-use spectrum may be a key to the deployment of mobile data services in such countries. New concepts, different from those targeting countries in "group 2" in Figure 10, may need to be developed and deployed at a large scale, e.g.

- Low cost, multiband MIMO systems that enable multiple sectors for macro sites
- Aggregation targeting combination of small chunks of spectrum into medium size bands (rather than combining many 20 MHz bands into a 100 MHz band)
- Use of "low capacity and narrowband femtocells" in areas where there are some fixed phone line penetration.

Offloading may not be a general strategy for operators in countries in "group 3" but it may be feasible in urban areas where fixed line and internet connections exist. The use of *"low capacity and narrowband femtocells*" is based on the observation that femtocells concepts presented so far result in a substantial over-provisioning of capacity. State of the art femtocells using 5 MHz or more can offer a throughput above 40 Mbps. This corresponds to very large number of data users. With 5 MHz of bandwidth and an assumed spectral efficiency of 4 bps per Hz we get a capacity of 20 Mbps. This corresponds to 200 or 2000 users with a monthly usage of 10 GB and 1 GB respectively.

Hence, there would be room to reduce the bandwidth of femtocells and still be able to serve a large number of users (Markendahl, Mäkitalo and Mölleryd, 2011). As an example, with 1 MHz of bandwidth and using the assumptions above, a femtocell could serve 40 or 400 users with a monthly usage of 10 GB and 1 GB respectively. Hence, more spectrum can be allocated to macrocells. SON will be needed in order to efficiently deploy many of these narrowband femtocells.

Limited spectrum and medium-high fixed line penetration

Operators in countries with limited amount of spectrum but with high fixed line penetration ("group 4") would be able to use hetnets, femtocells and off-loading solutions. The narrowband femtocell mentioned above should be considered.

We can just note that Ukraine in addition to the mobile network operators has a number of quite large WLAN operators offering wireless Internet access.

8. Conclusions

The tremendous increase of mobile broadband usage the last years is matched by an equally tremendous development of radio access technologies. Performance in terms of data rates and cost-capacity of radio equipment has improved orders of magnitude. It is important for mobile operators to market mobile broadband services with high data rates. The research and standardization activities within the telecom industry have resulted in improvement of the spectral efficiency. By using more bandwidth higher data rates can be offered, one commonly mentioned target is 1 Gbps.

However, from the end-user point of view one can question the relevance of such targets. Today smartphone users consume 0,1 – 1 GB of data per month and laptop users with dongles consume 1-10 GB of data per month. A data rate of 1 Gbps corresponds to users downloading the monthly amount of data mentioned above in 1, 8 or 80 seconds. With the current trends of more and more smartphones the challenge would be to offer capacity and reliability to many users receiving and transmitting data all the time.

On one hand you can define challenging targets in order to show what is possible and to promote technology development. On the other hand many of the research efforts today target aspects and functionality that are less relevant in many regions of the world.

- Features to increase data rates by combining different frequency bands are less relevant in countries where there are few frequency bands to combine.
- Strategies to offload data traffic from macrocell networks to WiFi or femtocell base stations using public fixed broadband cannot be used in areas where there are no fixed line connections.
- Peak data rates of 80 Mbps and 1 Gbps is of less importance in countries where the majority of the mobile data traffic can be expected to be generated by smartphone users, smartphones that for a mass-market in many countries most likely will be less complex and costly than Iphones.

The main contribution of our paper is to highlight the need to consider a multitude of scenarios for the requirements, design and deployment of mobile broad band networks. The network design needs to consider regional features in demand, willingness to pay and the conditions for infrastructure deployment. Many of the features driving the technology development are representative for the conditions in countries like Sweden and Germany.

Our analysis shows that the availability of spectrum and fixed line infrastructure in many regions of the world is much lower than in these countries. This highlights the need for the mobile communication industry to define a set of different requirement scenarios that can initiate and drive the technology development into new directions.

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