

Mobile Broadband Network Evolution Towards 2015 – A Copenhagen Area Case Study

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This paper shows the first results from ongoing research collaboration between Nokia Siemens Networks, Aalborg University, and Telenor Denmark, with the target of investigating mobile broadband network evolution towards 2015. In recent years there has been a boom in mobile data traffic growth, which has been enabled by HSPA launch, flat-rate tariff, and a wide availability of USB radio modems and smart phones. Recent measurements in the Telenor Denmark network have shown a growth of more than 300% yearly, and we forecast that the traffic volume will increase exponentially with an average annual increase of 70% until 2015, i.e. a total traffic increase factor of 20–25 from 2009 to 2015. We analyse two network evolution options which both fulfil the capacity and coverage requirements. First the upgrade of the existing macro sites is considered with optimization of antenna tilting, triple carrier support, HSPA+ and 6 sectors enhancements. For the second option, the 3rd carrier is used for a micro cell deployment instead of an additional macro cell carrier. An economic evaluation of both network evolution options by means of Total Cost of Ownership (TCO) is performed. Both upgrade options meet the performance requirements and are almost equal with regard to the TCO. The analysis also indicates that LTE technology in new spectrum is required in the near future.



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1 Introduction

Telenor Denmark launched HSPA service in 2007 and shortly after a family of flat rate tariff subscriptions was promoted ranging from ‘XXS’ to ‘XXL’. Since the launch, Telenor Denmark has experienced a dramatic growth in data traffic volume; in fact the growth was as high as a factor of x4 during 2009. This continuous traffic volume increase is facilitated by several factors from technology to marketing: Introduction of HSDPA 7.2 Mbps, much improved HSPA national network coverage, and strong marketing promotion of flat rate subscriptions and bundle mobile and fixed broadband products. Furthermore Telenor Denmark is pushing a conversion of the large subscriber base of 2G only mobile devices by subsidizing 3G/HSPA enabled phones and USB dongles and bundle its success in the fixed broadband by offering a complementary mobile broadband subscription for a free trial period. On top of that, the generated traffic volume per subscriber is steadily increasing.

plane capacity. Probably the most important and uncertain parameter for forecasting the network evolution is the data traffic growth estimation. For many years we have been searching for a 3G ‘killer application’ – it seems to have appeared – and it is simply the Mobile Internet.

The high expected increase in data traffic volume as discussed above is indeed a challenge to the Telenor Denmark network for the coming years. It is important for the network evolution strategy to have tools and methods to analyze the long term scalability of the network capacity, i.e. what technology roadmap to be taken, and what the associated cost for the upgrade is. Thus, research collaboration between Nokia Siemens Networks, Aalborg University, and Telenor Denmark was initiated in 2009 with the scope of ‘Scalable Multi-radio Deployment Research’ (SMDR). The target of the project is to be able to make year-by-year network evolution forecast and to dimension and compute the corresponding Total Cost of Ownership (TCO). In order to make the study realistic and to take into account existing network assets into account, part of the network located in central Copenhagen was used for a pilot case study. The existing UMTS site and base station configurations were used as the starting configuration for the network upgrade.



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The very high growth rate of mobile data volume can be attributed to the fact that the adoption of mobile broadband data services is still in its infancy and as such, the long term growth rate is expected to become more moderate. It is generally anticipated by the mobile communication industry that the average annual growth rate will remain in the order of 50–100% for the next decade [1, 2]. Such annual data traffic growth will lead to a traffic volume increase in the range of $\sim x10 - 60$ from 2010 to 2015. The ‘always on’ property of new devices now also requires the network to handle more attached users at any given time, which also puts demands on control

For the first phase of the study, which is reported in this paper, we have focused on Downlink HSPA, and the two network evolutions options studied are:



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- 1 Capacity upgrades to the existing macro cells;
- 2 Capacity upgrades to existing macro cells and deployment of new micro cells.

In the next section, the traffic modelling and assumptions used for the analysis are discussed in detail. In section III, the Copenhagen area case study is presented, beginning with the justification of the selected network upgrade options, and the section concludes with the network performance results. Next, section IV describes the cost modelling and the TCO result of the case study. Finally, conclusions are given in Section V.



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2 Traffic Assumptions and Trends

The network traffic volume generated by data services in Telenor Denmark networks has increased dramatically since 2007. As shown in Figure 1, during 2009 the total traffic volume of the HSPA cells considered for the case study was exponentially growing with a factor of x4.

During the 12 months period of 2009, the network's 3G subscriber base has increased by 82%, and the time duration during which at least one user per cell is using HSDPA resources has increased from 14% to 38% during 24 hours' monitoring. While a cell in the network barely experienced any resource sharing a year ago, 3-4 simultaneous HSDPA users are increasingly common and some cells experienced even higher. The utilization of HSDPA resources is expected to improve as penetration of HSPA enabled devices continues to increase.

The initial Telenor Denmark 3G network rollout, in terms of base station site positions, was driven by 2G

site sharing and Rel. 99 voice and data services. For voice services, it is a well known fact that a small percentage of the sites carry a large fraction of the overall network traffic. The observation was similar at the beginning of HSPA launch. However, there is a trend towards more homogenous site load as shown in Figure 2, which shows the Cumulative Distribution Function (CDF) of the percentage of HSPA sites carrying a certain fraction of the total HSDPA traffic in the use case area. As can be seen in the figure, roughly 20% of the sites carried 60% of the traffic in December 2008. Twelve months later, 60% of the traffic was now distributed to more than 35% of the sites, indicating a more homogenous distribution of traffic and a spatial traffic distribution that may change over time. By analyzing other mobile networks in Europe, it has also been observed that the relative cell traffic density for data can be very different than from voice. The daily traffic time variation between voice and data is also very different; the voice traffic volume is almost constantly high during working hours (8 am – 5 pm), whereas data traffic volume is steadily increasing over the day and peaking at 8 pm – 10 pm. This can also be seen in the Telenor Nordic networks today.

The current cell level spatial traffic distribution and the attached number of HSDPA mobile devices on a cell level has been used direct for the traffic modelling analysis in this study.

The traffic volume, the spatial traffic distribution and number of active HSDPA users are only partial input to our network capacity analysis; the required minimum data rate per user is also essential. The required minimum user data rate is also expected to increase with time. There are several drivers for this. The offered bit rate by fixed line internet connections is

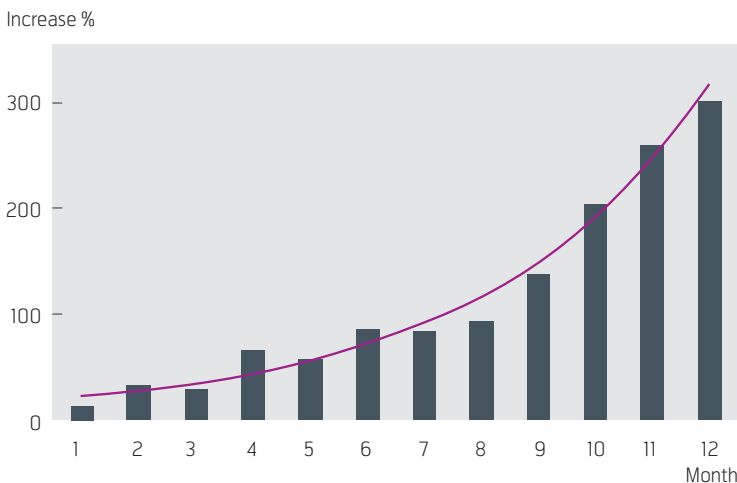


Figure 1 HSDPA traffic volume increase for a 12 month period starting from December 2008 for the HSPA cells in Copenhagen use for the case study [Telenor Denmark]

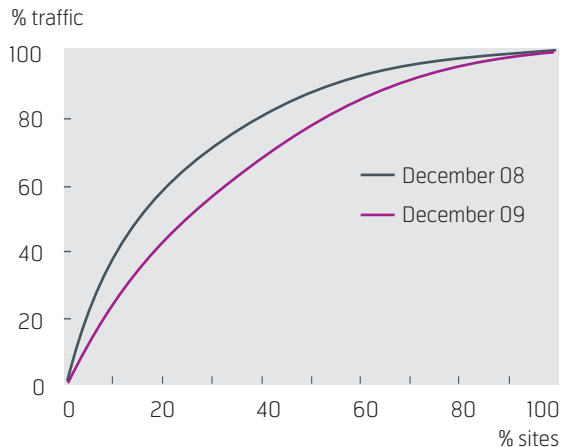


Figure 2 Percentage of total HSDPA Traffic carried by percentage of sites within the Copenhagen case study area [Telenor Denmark]

	Average Web Size	Yearly Growth
Year 1995	14.1 kB	n/a
Year 2000	30.3 kB	16.5%
Year 2003	93.7 kB	26.7%
Year 2006	230 kB	28.9%
Year 2008	312 kB	26.9%

Table 1 Summarizing the average page sizes from multiple sources [3]. Growth trend of 25% per year

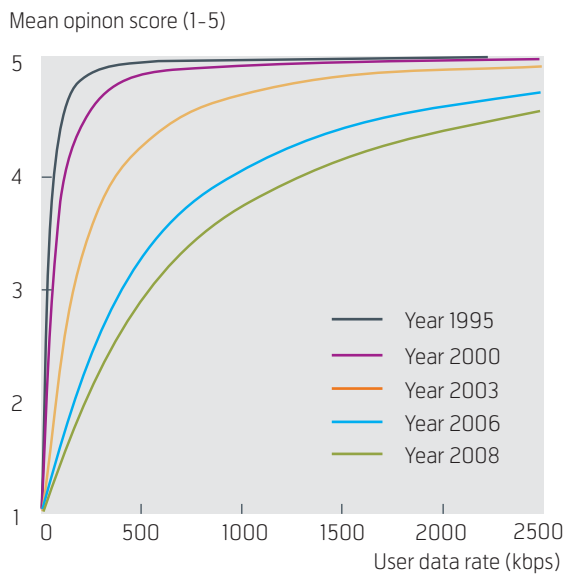


Figure 3 MOS vs data rate related to the yearly average web size [3]

steadily increasing, existing internet services and applications are becoming more data hungry, and also new services requiring high data rates are becoming widespread. Most streaming services are scalable

according to the speed of the data connection, but in most cases, there is a minimum data rate below which the user experience becomes unacceptable. Other services do not scale very well with the bit rate. For estimating the minimum data rate requirements, we have simply used web browsing as an example. During the last more than 10 years, the average annual increase in web page size has been approximately 25% as shown in Table 1. We expect this trend to continue for the next five years; ie. with ‘free of charge’ business models we see more embedded commercials using pictures and streaming.

In a user experiment for web browsing, the subjective Mean Opinion Score (MOS) was measured as a function of the latency for displaying web pages. The MOS rating is shown in Figure 3 where the different curves were obtained by convolving the growth rate of an average web page size. In short, the experiment showed that in order to obtain a ‘good’ user experience, the average latency from requesting a web page until it is downloaded and displayed should be less than 2s. Latency values of 2 – 8 seconds were rated ‘poor’ but ‘acceptable’, while larger values were rated ‘unacceptable’.

Based on the results of this experiment and the evolution in web page size, we have created a simple model for minimum user data rate requirements: 256 kbit/s in DL for 2009 and a 25% yearly increase to keep up provision of satisfactory services to end-users.

2.1 Traffic Model

The traffic model used for the study is flexible, but it was simplified during the first phase of our study:

- Spatial (active) user distribution is according to the cell level measurements for early 2009.

	2009	2010	2011	2012	2013	2014	2015
Relative number of simultaneous active users in area	1	2	3	4	5	5.5	6
Number of simultaneous active users in area	200	400	600	800	1000	1100	1200
Relative min target user DL TP	1	1.25	1.6	2	2.4	3	3.8
Min target user DL TP [kbps] < 5% outage	256	320	400	500	625	780	970
Relative minimum network capacity according to the min user TP	1	2.5	4.8	8	12	16.5	22.8
Minimum network capacity [Mbps] according to the min user TP	51	128	246	410	614	845	1167

Table 2 User number, minimum target data rate and target network capacity growth in the Copenhagen area; Throughput (TP), Downlink (DL)

- The inhomogeneous user distribution has been kept similar to that of early 2009, and the active number of users in the considered area is set to increase by a factor of x6 from 200 to 1200 in 2015.
- A best effort full-buffer traffic model was used with a minimum ‘poor’ DL user data rate of 256 kbit/s (5% outage) in 2009. The minimum data-rate is set to increase by 25% per year, ie. by a factor of x4 to 970 kbit/s in 2015. Due to the best effort full buffer traffic model, the actual user data-rate will depend on the number of active users and user locations in a cell.

The overall impact of the traffic modelling assumptions stated above is that the network capacity requirements will increase by a factor of 22.8 from 2009 to 2015, which corresponds to an average annual traffic increase of 70%. The used traffic model predicts more than 100% increase in network traffic volume at the beginning and approximately 50% during the later years. Hence, the network traffic growth is according to the general anticipated forecast as discussed in the introduction, but indeed much lower than what has been measured for 2009. Hence, the growth model used should be seen as a conservative estimate. The traffic assumption is a subject suitable for sensitivity analysis.

The year-by-year traffic model summarized in Table 2 is used for the Copenhagen case study, described in the next section.

3 Copenhagen Case Study

In this section we present the network evolution analysis for the Copenhagen case study. First we discuss the available spectrum for Telenor Denmark and the considered Network upgrade options.

For the study we define ‘capacity’ as two-fold: The number of served active users in the network with a defined minimum target throughput according to Table 2 with an outage of < 5%.

3.1 Spectrum Availability

Telenor Denmark has 2 x 9 MHz spectrum at 900 MHz, 2 x 19.4 MHz at 1800 MHz, and 2 x 15 MHz at 2100 MHz. Currently, the licence conditions are system dependent: the 900 MHz and 1800 MHz bands are assigned for GSM/GPRS/EDGE and the 2100 MHz band for UMTS. In 2010 there will be a spectrum auction in Denmark for new 2600 MHz band. It is also expected by 2011 that spectrum licence conditions will convert to a technology neutral license regime, which will give the possibility to refarm current GSM band to allow additional UMTS carriers,

or introduce LTE in multiple bands. However, due to the high GSM voice traffic volume in urban areas, the introduction of a UMTS900 carrier is considered for rural areas. For the study conducted here, we concentrate on the 2 x 15 MHz band at 2100 MHz, and we consider up to three UMTS carriers.

3.2 Other Network Upgrade Options

In order to select viable network upgrade options to support the network traffic growth until 2015, we made some initial decisions on which technologies solutions to apply, and rough capacity gains were estimated.

The following network upgrade measures are considered (also summarized in Table 3):

- **Optimal antenna tilting:** Initial investigations on applying cell level optimized antenna tilt in the network were carried out in a master thesis project [4] giving encouraging results. Such cell level optimization of tilt would in practice mean installation of remote tilting functionality. For the tilt optimization analysis, a simple geometrical Line of Sight model was used, which is in line with 3GPP studies [5]. However, we believe that such a simple tilt model generates too optimistic results for urban areas and hence, for the study we made several restrictions to the antenna tilt angles to make the performance estimate more realistic (see Table 3).
- **HSPA+:** By employing enhancements like 64QAM, Dual stream MIMO and Dual cell scheduling, HSPA+ is able to provide up to 42 Mbit/s in peak user throughput, and an upgrade to HSPA+ was considered as an attractive upgrade measure for providing higher user data rates when the network is not fully loaded. However, the network capacity gain of HSPA+ in a fully loaded network with many simultaneous active users is only estimated to be in the order of 20% [6].
- **6-Sectorization:** Most of the macro sites in the use case are three sector sites with a few exceptions of sites with one or two sectors. The upgrade to six sector sites is introduced, which gives an estimated capacity gain of up to 70% (relative to three sectors) [7,8,9].
- **Micro cells:** The deployment of new micro cells is also considered. By micro cell we mean a low cost base station with an output power in the range of 1-5 W. A deployment algorithm is used to identify the location of new micro cells, which takes both the macro cell outage, and the macro off-loading potential of the deployed micro cell into account. Statistically, micro-cells are located in high traffic

Upgrade	Upgrade Path I	Upgrade Path II	Capacity gain estimate	Description
Tilting	X	X	20%	Following Telenor restrictions (0 – 10 degree, 2 degree resolution)
2nd-carrier	X	X	100%	Sector level upgrade
HSPA+	X	X	20%	Site level upgrade, the whole site is upgraded to 2-carrier & HSPA+
3rd-carrier	X		50% (on top of 2nd-carrier)	Site level upgrade
6-sector	X	X	70%	Site level upgrade, all the carriers are upgraded
Micro		X	Capacity of micro cell on dedicated carrier is slightly higher than the macro cell capacity	Number of micro sites added: 2013 – 30, 2014 – 20, 2015 – 50
Total capacity gain	-x7.5	-x5 + Micro capacity		Total capacity gain of the network upgrade steps

Table 3 Description of the network upgrade options

density areas, where there is a relatively weak coverage by an existing macro-cell. It was decided to use a dedicated carrier for micro-cell layer, which leaves only two carriers for macro cells. The preference for dedicated carrier was based on cost, as the existing macro base station equipment in the Telenor network has only 10 MHz bandwidth.

The option of installing up to three UMTS carriers and the network upgrade options described above were put in a sequential order to create two network evolution paths for the Copenhagen case study:

- **Option I:** Optimized antenna tilt → 2nd carrier → HSPA+ → 3rd carrier → 6-sector
- **Option II:** Optimized antenna tilt → 2nd carrier → HSPA+ → 6-sector & Micro

In case the network outage is higher than 5% for a specific year, the network cell or site upgrades are forced according to the defined upgrade sequence. The network performance for the two options, in terms of outage, will have almost iso-performance. Option II can potentially provide higher network capacity by massive deployment of micro cells.

3.3 Method and Tool for Performance Analysis

In order to conduct the network evolution analysis a tool called *System and Network Planning tool (SNEPA)* was developed. The tool is an integrated network planning, dimensioning and static network simulator. The simulation part of the tool uses a snapshot Monte Carlo approach. The input, output and network upgrade options supported by SNEPA are summarized in Table 4.

Input	Output	Supported network upgrade options
<ul style="list-style-type: none"> • Current network layout, eg. site configurations and locations • Spatial user distribution • Active user number prediction • Network performance criteria, eg. outage user data rate, average user data rate • Evolution path • Clutter maps 	<ul style="list-style-type: none"> • Network configurations year by year • Performance statistics <ul style="list-style-type: none"> - Network throughput - Cell throughput - User throughput • Interface to TCO calculation 	<ul style="list-style-type: none"> • HSPA and LTE • Add carriers • Macro cell upgrade <ul style="list-style-type: none"> - Tilting optimization - Higher order sectorization (HOS) - Densification - Micro/pico cell deployment

Table 4 SNEPA input, output and supported network upgrade options

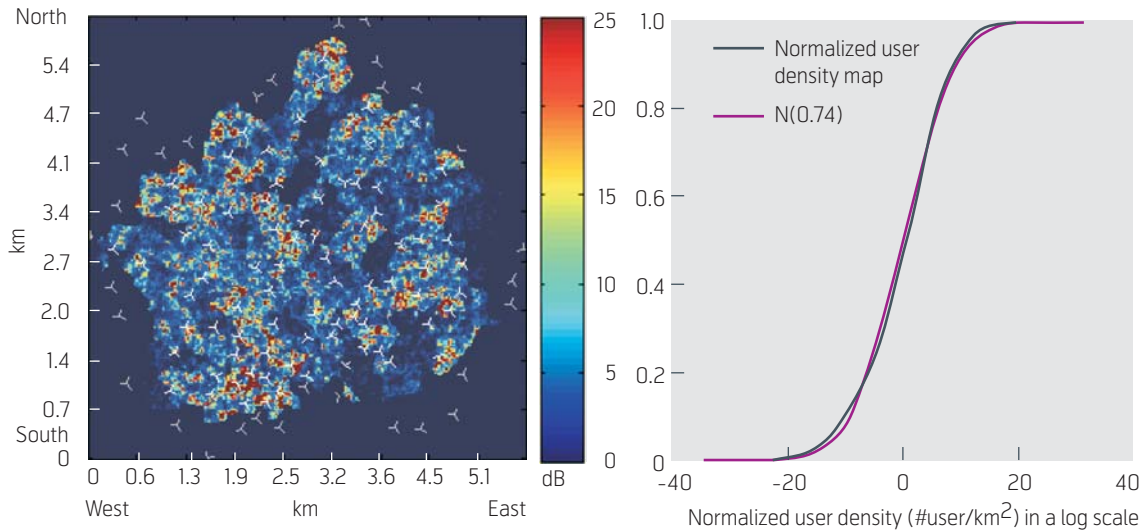


Figure 4 Left: User density map; right: CDF of the user density map in a log scale

The case study area is an approximately 5 x 5 km region located in the Copenhagen city centre. The dominance area of the outer tier sites was defined as a mask. The sites and users located in the mask area were considered as interferers only, and their statistics were not counted in the results. In total there are 82 valid macro sites in the case study area. The site density for the area of investigation is approx 3 – 5 sites/km².

The users in the network were randomly generated according to the spatial user density map. The user density map was generated according to the number of simultaneously active HSPA users of each macro cell obtained from the network log in March 2009. After taking the average over five workdays within a week; the peak hour, ie. 9 pm – 10 pm, was selected to create the user density map. The user density map almost follows a lognormal distribution with a 5 dB standard deviation. In order to generate even higher variability (hotspots) with finer granularity than the area of macro cells produces, the macro cell user density map was multiplied by a zero mean and 5 dB

standard deviation lognormal distribution (correlation distance 50 m). Hence, the user density averaged over the area macro cell is unchanged, but the lognormal distribution creates variability within the area of a macro cell according to the correlation distance. The model has no impact on the network evolution option I, but for option II the model ensures the occurrence of hot-spots within the coverage area of a micro cell, hence slightly improving the micro cell performance. Figure 4 shows the CDF of the final user density map in a log scale, which now fits a normal distribution with zero mean and 7.4 dB standard deviation.

A data rate control algorithm was implemented to introduce fairness among the active users in the network. The algorithm first allocates radio resources to provide the minimum data rate to each user. After this first step, all users will share the remaining resources, if any, in a round-robin manner.

The results for the upgrade option I and II are listed in Table 5 and Table 6, respectively. Both high and low power micro cells were evaluated for option II,

Year	Opt. tilt	2nd-carrier	HSPA+ (MIMO)	3rd-carrier	6-sector	Outage	Outage (next year)
2009	245	0	0	0	0	0.5%	0.6%
2010	245	0	0	0	0	0.6%	4.0%
2011	245	0	0	0	0	4.0%	11.1%
2012	169	73	0	3	0	4.9%	10.7%
2013	142	62	12	21	6	5.0%	10.8%
2014	94	61	12	54	24	4.9%	8.7%
2015	30	15	6	36	158	5.6%	

Table 5 Upgrade roadmap for evolution option I

Year	Opt. tilt	2nd-carrier	HSPA+ (MIMO)	6-sector	Num of Micro	Outage	Outage (next year)
2012	160	82	0	3	0	4.8%	10.7%
2013	159	83	0	3	30	4.9%	10.6%
2014	140	84	0	21	50	5.0%	9.4%
2015	61	47	12	125	100	5.6%	

Table 6 Upgrade roadmap for evolution path II (38 dBm Micro)

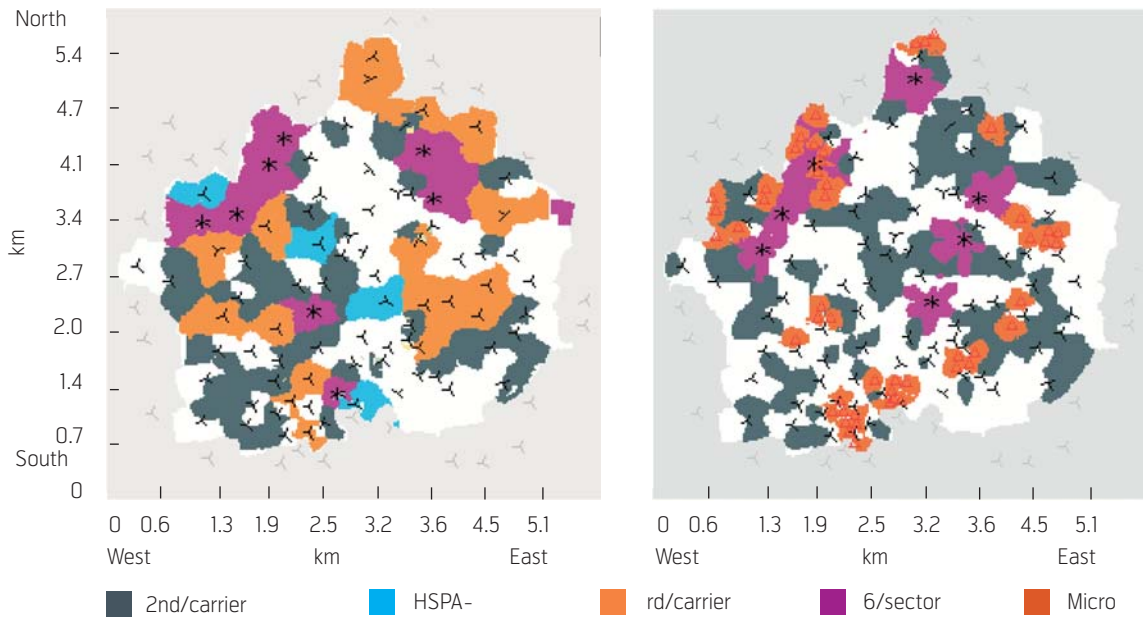


Figure 5 Network layout and upgrade levels in 2014 (left: evolution path I, right: evolution path II)

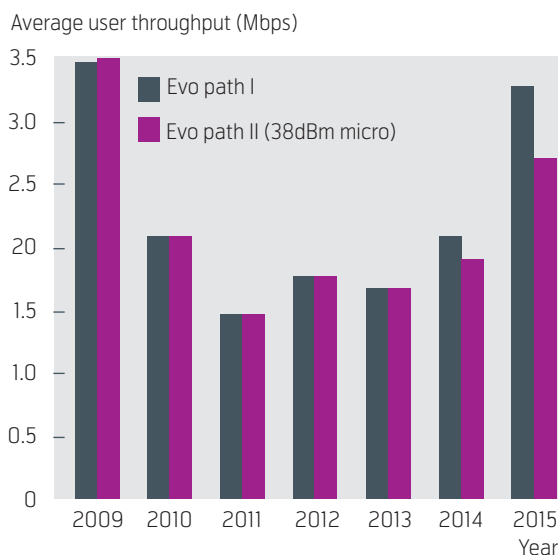


Figure 6 Per year average user throughput

but due to the similarity of the upgrade roadmaps only the performance results from the 38 dBm micro study are shown. Figure 5 visualizes the network layout and network upgrade level at 2014. For both

upgrade options, the 2nd-carrier, HSPA+ and 6-sector upgrades are required in the years 2012, 2013 and 2014, respectively. For the evolution option I, the 3rd-carrier needs to be added in 2013. In 2015, none of the two options can achieve the 5% outage target, and additional upgrades, eg. launch of LTE or more micro cells, macro cell densification have to be deployed to fulfill the performance requirement.

For option II, most of the micro cells were concentrated as clusters in high user density regions as shown in Figure 5. Inside the clusters the micro cells are interference limited. The effective radius of the micro cells is 112 metres in 2014. It may in some cases be more cost efficient to replace a micro cell cluster with a new macro site as a single macro site brings the capacity up to 12 micro cells. The macro cell densification will be evaluated in the next phase of the analysis.

The average user throughput is another important network performance parameter and is shown in Figure 6. With the best effort full-buffer traffic model, the average user throughput is fairly high in early years

when the total number of users is low. The value drops gradually from 3.5 Mbps to 1.5 Mbps until 2011 as the user number grows. Between 2012 and 2014, the throughput remains between 1.5 and 2.1 Mbps with the corresponding upgrades. In 2015 the massive 6-sector upgrade boosts the average user throughput of the two evolution paths to 2.7 and 3.3 Mbps, respectively.

4 Cost Analysis for the Copenhagen Area

In order to evaluate the impact of different network upgrade options on the business case, we choose the methodology of comparing the TCO (total cost of ownership). Cost figures for the network upgrades and other special network properties were considered to get realistic TCO results. It should be noted that for transfer of these results to other cases, it has to be examined carefully which cost conditions of this case study can be applied and which cannot.

4.1 Methodology of Cost Analysis

In order to create a fair cost comparison between network options, the target of the network upgrades summarized in Table 4 and Table 5 was to generate the so-called iso-performance in terms of network outage. By comparing the total cost of these scenarios over the defined time period, we can derive the cost value of deployment options as well as micro sites from a business perspective.

The underlying cost model depends on a wide set of parameters being considered as one time costs as well as recurring costs. One time costs comprise CAPEX (capital expenditures) and IMPEX (implementation expenditures). CAPEX is related to initial investments such as equipment costs, while IMPEX addresses one time service costs for eg. planning and implementation. On the other hand, recurring costs are referred to as OPEX (operational expenditure) and they include costs for O&M (operation & maintenance), site rent, etc. For the TCO calculation, the existing 2009 macro network was assumed as reference and only delta costs to this network were considered on a yearly basis for CAPEX, IMPEX, and OPEX. Site costs were only considered for new micro base station installations, whereas we assumed site cost to remain unchanged in the macro upgrade cases. Micro sites were assumed to be installed on walls of existing buildings. Appropriate costs for acquisition, site preparation and rent were taken into consideration. Site costs are derived from field experience. For the micro base stations both DSL backhaul and leased Ethernet were considered. CAPEX costs for macro and micro have been calculated by considering a price erosion factor with an average discount rate of 12%.

A multidimensional cost model for the iso-performance network evolution options has been developed. In particular, backhaul costs were assumed for three different price levels: High, mid and low, depending on availability of DSL-backhaul and Ethernet-based backhaul for micro sites. Cost calculations have been performed for two different types of micros, varying in transmit power (with 30 dBm and 38 dBm transmission power).

The major strategic question that we have addressed is: Is it more profitable for Telenor Denmark to deploy three carriers in the macro network than to deploy two carriers in the macro network and use the 3rd carrier for the operations of new micro BTS?

4.2 Results of TCO Calculations

In our TCO calculations we compared two different macro backhaul strategies: a backhaul strategy based on leased lines and a backhaul strategy with Telenor Denmark owned microwave/fibre connections. The comparison showed that Telenor ownership of backhaul transmission is more favourable despite the fact that in year 2012 a significant investment is required (change from pure microwave to microwave/fibre transmission network). The TCO comparison over the whole period shows that leasing backhaul lines is more expensive (more than a factor of 2) than investing in own transmission network.

The separated cost analysis for network evolution option I is shown in Figure 7. The percentages are related to the cost part of the respective upgrade step relative to the total cost of the full macro site upgrade sequence. The missing cost fraction (to make a sum of 100%) is related to software cost, which is to some

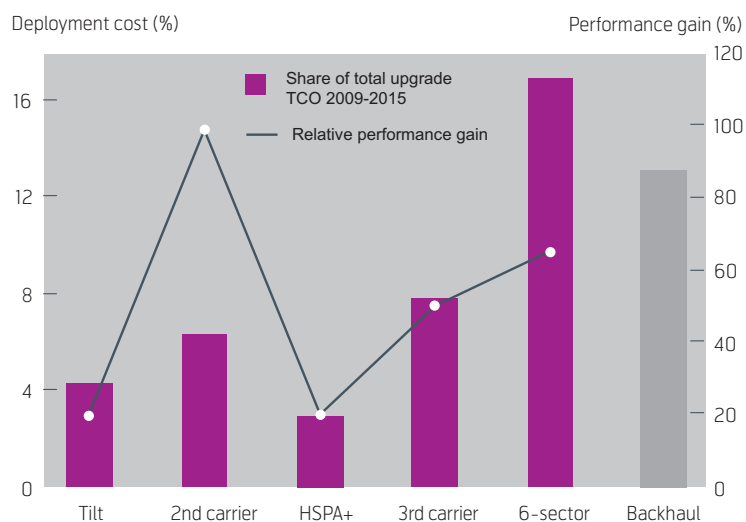


Figure 7 Evaluation of costs for the considered upgrade steps of the upgrade path and performance gain, respectively. Backhaul costs are shown for comparison and are not related to performance gain scale

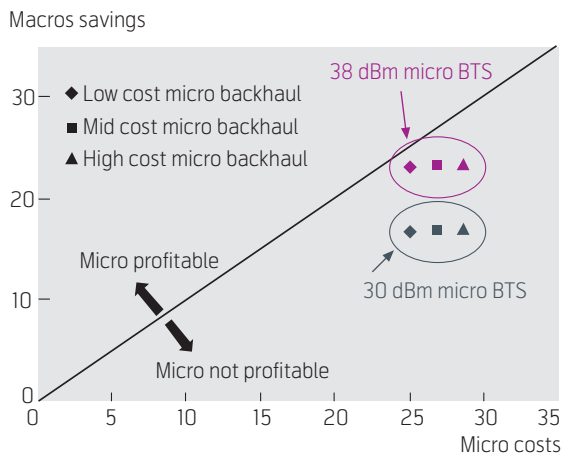


Figure 8 Micro profitability for six different scenarios. In this case no micro scenario is more cost effective than the conventional macro deployment options

extent independent of the equipment upgrade due to separate frame contracts. The backhaul costs are based on Telenor Denmark owned transmission network as discussed in the previous clause. It can be seen that the backhaul cost plays a significant role compared to site upgrade costs.

The comparison of the deployment costs with the achievable performance gain reveals that the upgrade to 2nd carrier is the most cost effective measure in the considered upgrade path. For the other upgrade steps cost versus performance shows a coarse proportionality. The 3rd carrier upgrade generates more costs than the 2nd carrier upgrade since the complete base station equipment is swapped to the new generation radio equipment with this step (from NSN Ultra Site to NSN Flexi). For the upgrade to 6-sector sites upgrade costs are considerable. This is mostly due to the fact that an upgrade of the feeders and antennas is necessary and takes the biggest part of the upgrade costs.

In order to evaluate the business impact of micro cells, we compare the costs saved in a macro network due to micro deployment with the additional cost of introducing micro cells. These can be done by calculating the TCO of the two network upgrade options with and without micro cells. If the cost savings are higher than the additional costs, we can draw the conclusion that micro cells are profitable.

In Figure 8 the y-axis shows the costs that are saved in the macro network due to the deployment of micros, and the additional costs of micro deployment are shown on the x-axis. All micro cell scenarios show that it is more profitable for Telenor Denmark to select network upgrade option I, i.e. to invest in three carrier network upgrade with only macro

cells instead of introducing micro base stations on 3rd carrier. The evaluation was done for 3 different micro backhaul scenarios as explained in the previous chapter. In the analysis of the total costs for micro base stations the costs for backhaul represent 47% – 58%, site cost 27% – 33%, and equipment cost only 15 – 21% depending on the scenario. The evaluation shows that it is very challenging to achieve profitability with micro base stations in this network. The tipping point for micro profitability can only be reached if micro cells can be deployed at lower cost. Overall, the cost analysis shows that it is worth exploiting all available upgrade options in macro networks. The introduction of micro base stations can be considered, especially in high traffic load scenarios, but should be evaluated carefully regarding accompanying cost factors, for example the backhaul and site costs.

5 Discussion & Conclusions

During 2008 and 2009, Telenor Denmark has experienced a very high growth of mobile broadband (HSDPA) traffic, due to increased penetration of smartphones, netbooks, and USB-radio modems. Telenor Denmark expects this trend to continue and has to be prepared for the required network capacity upgrades to maintain high user satisfaction.

In this paper we have presented the first results from research collaboration between Nokia Siemens Networks, Aalborg University, and Telenor Denmark focusing on mobile broadband network evolution. We have briefly presented the traffic modelling framework, the developed analysis tools, and the use case results from a 5 x 5 km area of Copenhagen UMTS network. For the case study two upgrade paths were analysed; 1) macro cell only, and 2) hybrid macro and micro cell deployment.

The network evolution analysis was based on the measured current mobile broadband traffic (HSDPA) during 2009 and a traffic growth model considering both the number of active users and a minimum required user data rate. We also introduced a spatial hot-spot traffic model.

The key findings from the first phase of the mobile broadband evolution case study analysis are:

- The traffic growth prediction and modelling is very important as the traffic growth seems to have an exponential trend. For the considered use case, we used an average annual growth of 70%, but this seems conservative compared to the actual growth during 2009. There is also a trend of a more homogeneous distribution of network data traffic among the different cells. The number of simultaneous

users is also increasing, which has a large impact on the signalling and average performance of the end user services.

- The two proposed network evolution paths can support the traffic growth until 2015 (for the considered traffic growth model). However, the growth model applied is probably too conservative and the development of next generation LTE in a new spectrum might be required long before 2015 in order to off-load the UMTS/HSPA network and to offer higher average user data rates.
- Upgrading UMTS/HSDPA macro base stations along the described path represents a valuable strategy in terms of performance versus costs. Among the investigated upgrade options, the upgrade to a second carrier as the first step is the most cost effective one. Upgrading to a 3rd carrier and 6 sector site configurations is more costly due to new RAN equipment installation, new feeder and antenna installations.
- Uplink (HSUPA) performance has also been investigated using the same upgrade path as for downlink. The results show that the network remains downlink limited in terms of outage when applying an asymmetrical minimum user data rate model of 1 : 4 (uplink : downlink).
- In this case study micro base stations are not profitable for Telenor Denmark before 2015 compared to the alternative macro base station upgrades. This is mostly due to the backhaul costs for micro base stations. Some macro base station densification should be considered to improve coverage and capacity (especially if the spatial traffic distribution changes).

Our future research work will continue to improve the analysis. Issues to be considered are:

- Multi-radio technology including both HSPA and LTE;
- Macro cell densification;
- Improved traffic modelling, user classes, multi user classes, and sensitivity analysis;
- How to increase profitability of micro base stations, especially by reducing backhaul and site related cost.

At the end of 2009 Telenor Denmark has renewed the contract with Nokia Siemens Networks for upgrading its network with the newest radio access network equipment and prepares the network for upgrade to next generation mobile services. The key message from this analysis is to have flexible and scalable site equipment to be able to smoothly upgrade the network to meet the ever higher performance requirements from both a traffic volume and end user experience viewpoint.

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