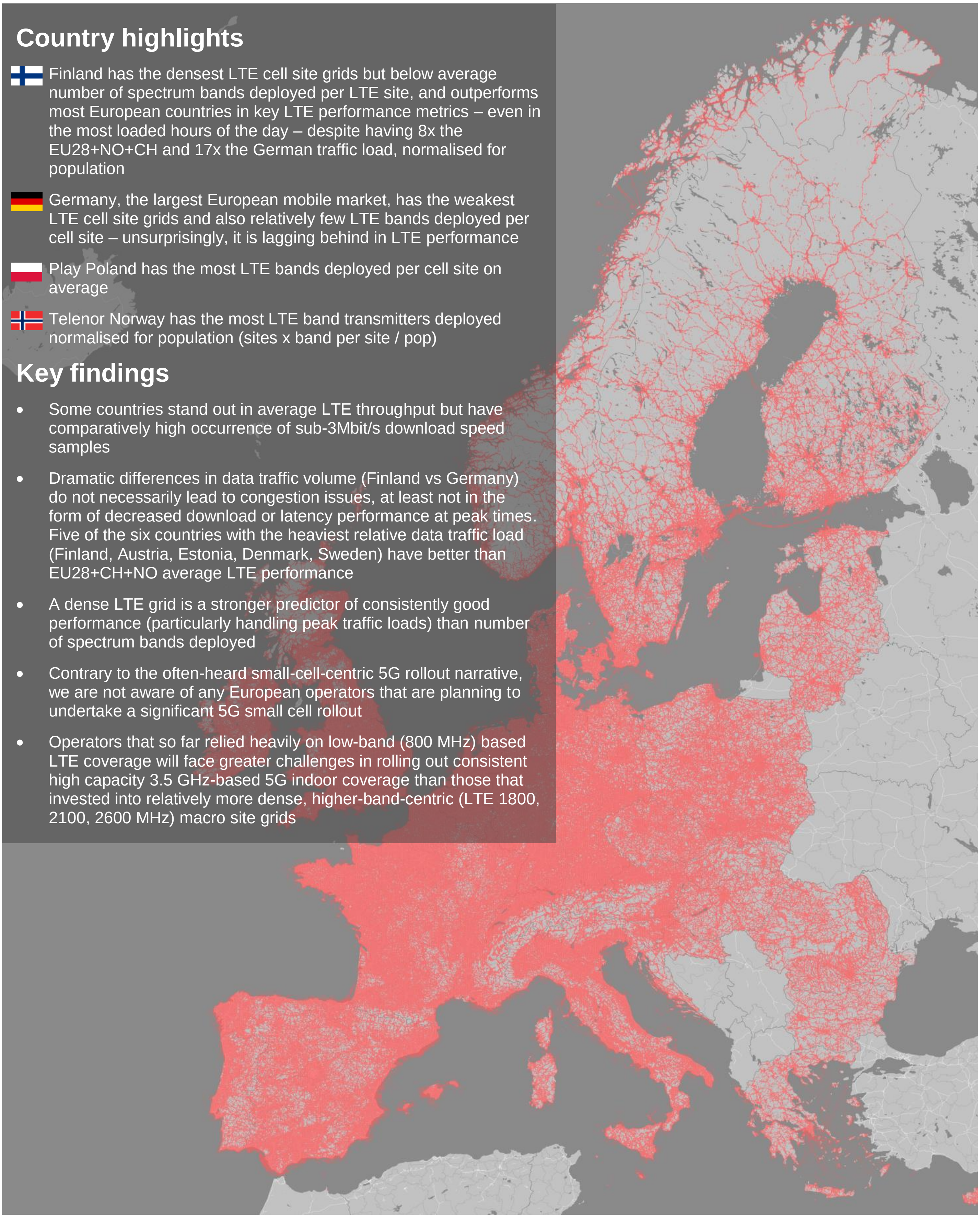
Rewheel

TUTELA

Site density is key to LTE network performance – and critical for 5G

Analysis of 99 mobile networks across EU28, Norway and Switzerland, key network performance drivers and implications on 5G infrastructure and spectrum investment strategies

Rewheel-Tutela public research study, 18th February 2019



Country highlights

- Finland has the densest LTE cell site grids but below average number of spectrum bands deployed per LTE site, and outperforms most European countries in key LTE performance metrics – even in the most loaded hours of the day – despite having 8x the EU28+NO+CH and 17x the German traffic load, normalised for population
- Germany, the largest European mobile market, has the weakest LTE cell site grids and also relatively few LTE bands deployed per cell site – unsurprisingly, it is lagging behind in LTE performance
- Play Poland has the most LTE bands deployed per cell site on average
- Telenor Norway has the most LTE band transmitters deployed normalised for population (sites x band per site / pop)

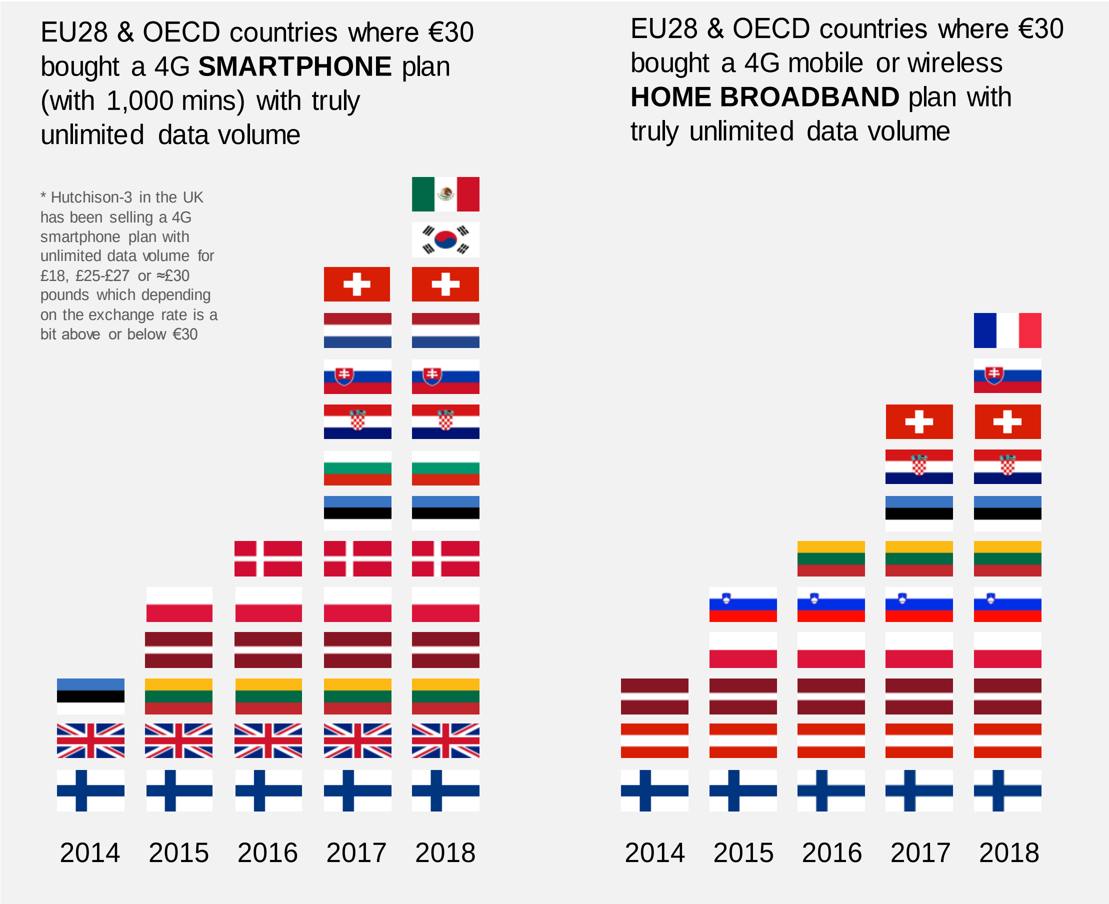
Key findings

- Some countries stand out in average LTE throughput but have comparatively high occurrence of sub-3Mbit/s download speed samples
- Dramatic differences in data traffic volume (Finland vs Germany) do not necessarily lead to congestion issues, at least not in the form of decreased download or latency performance at peak times. Five of the six countries with the heaviest relative data traffic load (Finland, Austria, Estonia, Denmark, Sweden) have better than EU28+CH+NO average LTE performance
- A dense LTE grid is a stronger predictor of consistently good performance (particularly handling peak traffic loads) than number of spectrum bands deployed
- Contrary to the often-heard small-cell-centric 5G rollout narrative, we are not aware of any European operators that are planning to undertake a significant 5G small cell rollout
- Operators that so far relied heavily on low-band (800 MHz) based LTE coverage will face greater challenges in rolling out consistent high capacity 3.5 GHz-based 5G indoor coverage than those that invested into relatively more dense, higher-band-centric (LTE 1800, 2100, 2600 MHz) macro site grids

Introduction: Europe’s great 4G divide

Apart from tracking and analysing 4G pricing, mobile data traffic growth and competition, during the last couple of years, Rewheel has been studying the spectrum holdings, macro cell site grids, radio spectrum deployment strategies and capacity utilization of European and OECD mobile networks. In our most recent study[1] we assessed the capacity and fixed-to-mobile broadband substitution potential of 80 European, US, Japanese, Korean, Australian and New Zealand mobile network operators. The capacity utilization, capacity potential and overall performance of mobile networks have been in the spotlight the last two years and have been receiving board level attention. This is not a surprise given that mobile operators have just spent or are just about to spend billions in 5G-centric spectrum auctions and considering the fact that plans with unlimited data volume (both for smartphone and 4G/5G home broadband use) have become mainstream in many markets.

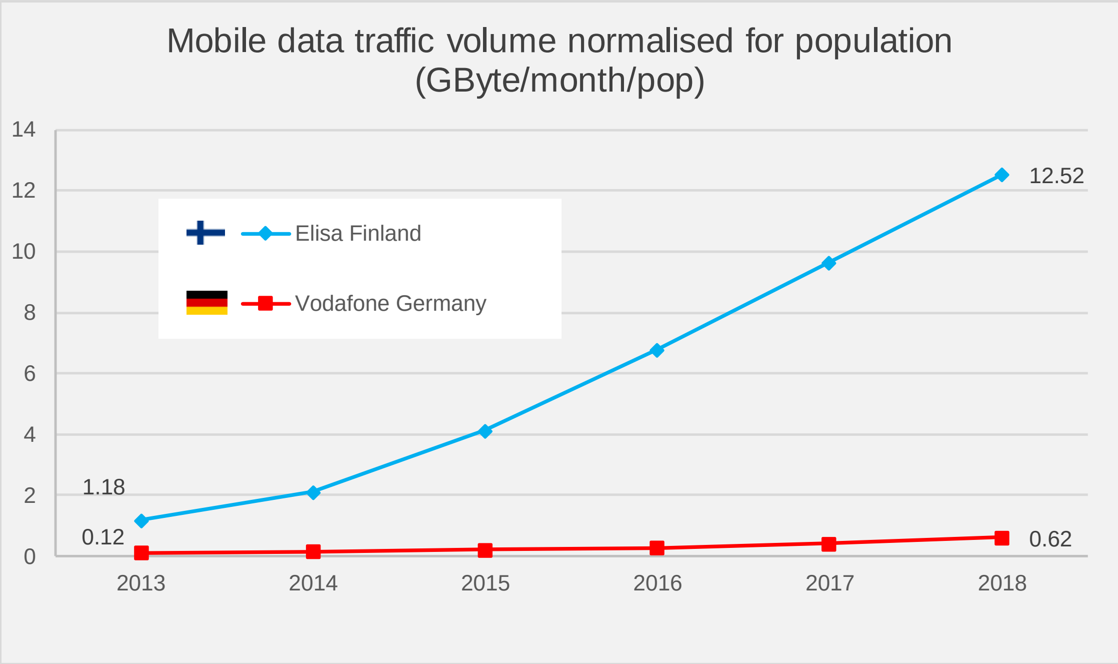
The proliferation of unlimited mobile data



Source: Rewheel

As the chart above shows, many European operators introduced mass affordable unlimited mobile data both on smartphone and mobile broadband (data-only, home broadband) tariff plans. At the same time, the data usage gap between “unlimited countries” (like Finland) and low usage countries (like Germany) has been widening, as illustrated in the chart below that compares the evolution of per capita mobile data traffic volumes consumed in Elisa Finland’s and Vodafone Germany’s network.

[1] Capacity utilization and fixed-to-mobile broadband substitution potential with existing macro site grids – 2017
http://research.rewheel.fi/insights/2018_sep_pro_capacity/



Source: Rewheel

Does the huge traffic load disparity affect the performance of LTE networks? Are heavily loaded Finnish networks performing worse than the lightly loaded German networks? All things considered, what are the key factors that drive LTE performance?

With the indispensable help of Tutela, a mobile data and analytics company serving the mobile and telecommunications industry, we conducted an in-depth analysis using Tutela's live network statistics, selected a set of LTE performance indicators and assessed the performance of 99 4G LTE EU28, Norwegian and Swiss mobile networks. In addition to exploring LTE performance, we also analysed how key LTE network architecture metrics differ across European networks.

Tutela's software is embedded in over 3000 diverse mobile applications installed on over 250 million mobile Android and iOS handsets. Tutela continuously monitors network quality of experience all across the world. It collects more than 30 billion measurements every single day, and through its interactive toolset, it enables its customers to turn those numbers into actionable intelligence for their businesses.

In addition to measuring throughput, latency and other key performance indicators, Tutela also collects detailed information on signal strength, cell site IDs and the used frequency bands. By crunching[2] Tutela's large database of roughly ten days of throughput and latency measurements and three months for cell ID and spectrum band detection, all 28 European member states plus Norway and Switzerland, we could frame key properties of 99 different European LTE networks, such as the density of the LTE cell site grids measured in terms of number of site per 1000 population, and the average number of sites where operators have already deployed LTE spectrum bands (i.e. 700, 800, 900, 1800, 2100, 2600 MHz FDD bands and the 2300 and 2600 MHz TDD bands).

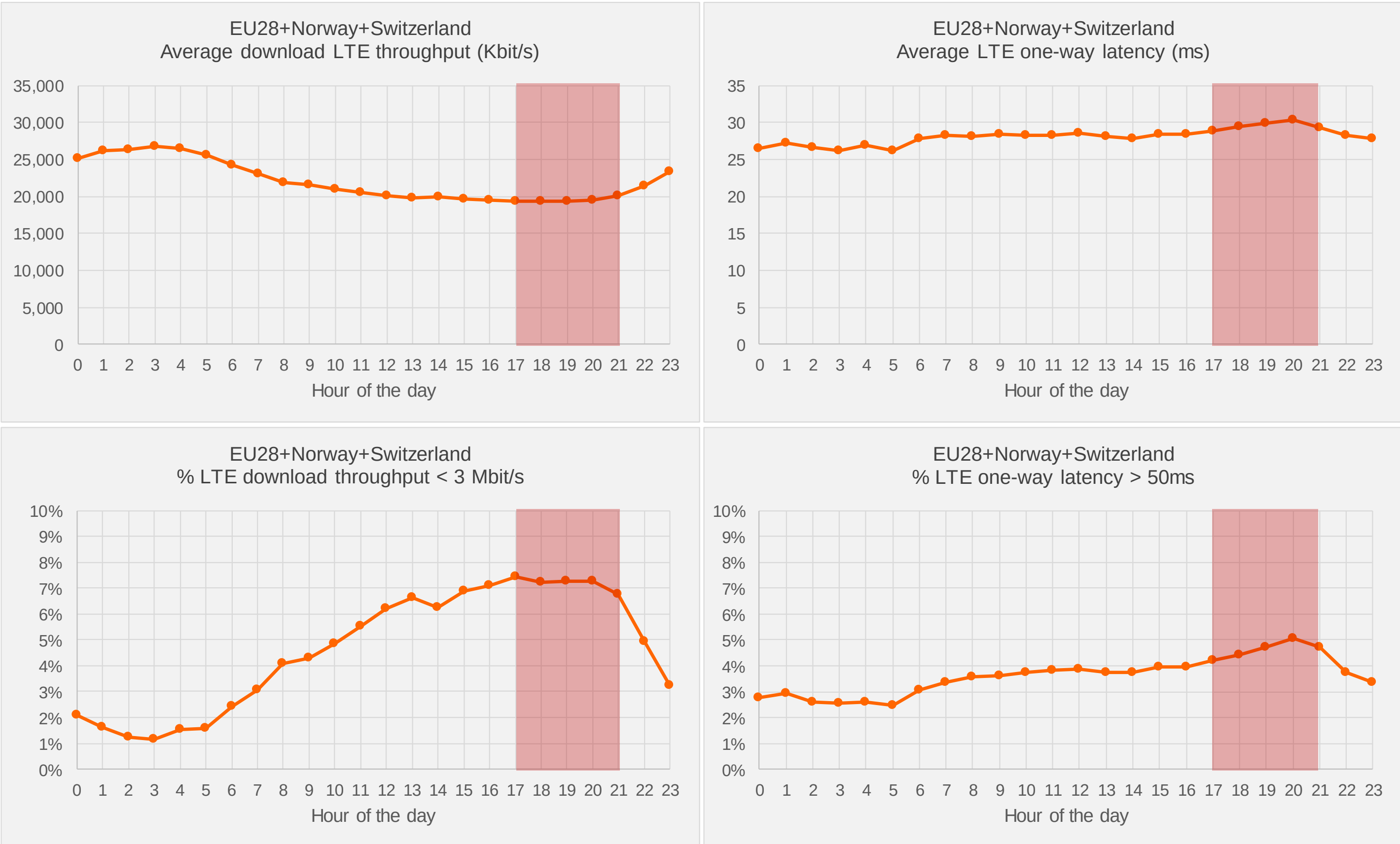
We could identify 584 thousand unique LTE cell sites (eNodeB) in the 28 EU member states, Norway and Switzerland.

[2] We extracted the relevant information by using Tutela's interactive online analysis tool Tutela Explorer

LTE performance in Europe: the big picture

First, we present the overall LTE performance level in Europe. Below we show four indicators, all aggregated for the 99 networks. The two indicators on the left-hand side show download throughput while the two on the right show latency.

As seen in the upper-left chart below, the average LTE download throughput fluctuates between 20 Mbit/s and 26 Mbit/s, depending on the hour of the day[3]. The highest throughputs are measured during early mornings hours, since these are the hours when the networks are carrying very little load. The lowest throughputs are measured in the late afternoon and evening hours. These are typically the most traffic-intensive hours, driven primarily by video consumption (Netflix, Youtube etc.). The busy hour impairment of average download throughput is clearly visible but the 26 to 20 Mbit/s drop is far from dramatic and most likely not noticed by average users. Rather than focusing on the average throughput, it is more insightful to investigate the probability of getting less than 3 Mbit/s download throughput. We drew the line at the 3 Mbit/s threshold[4] because this is how much bandwidth typical HD quality video streaming services require.



Source: Tutela measurements, Rewheel analysis

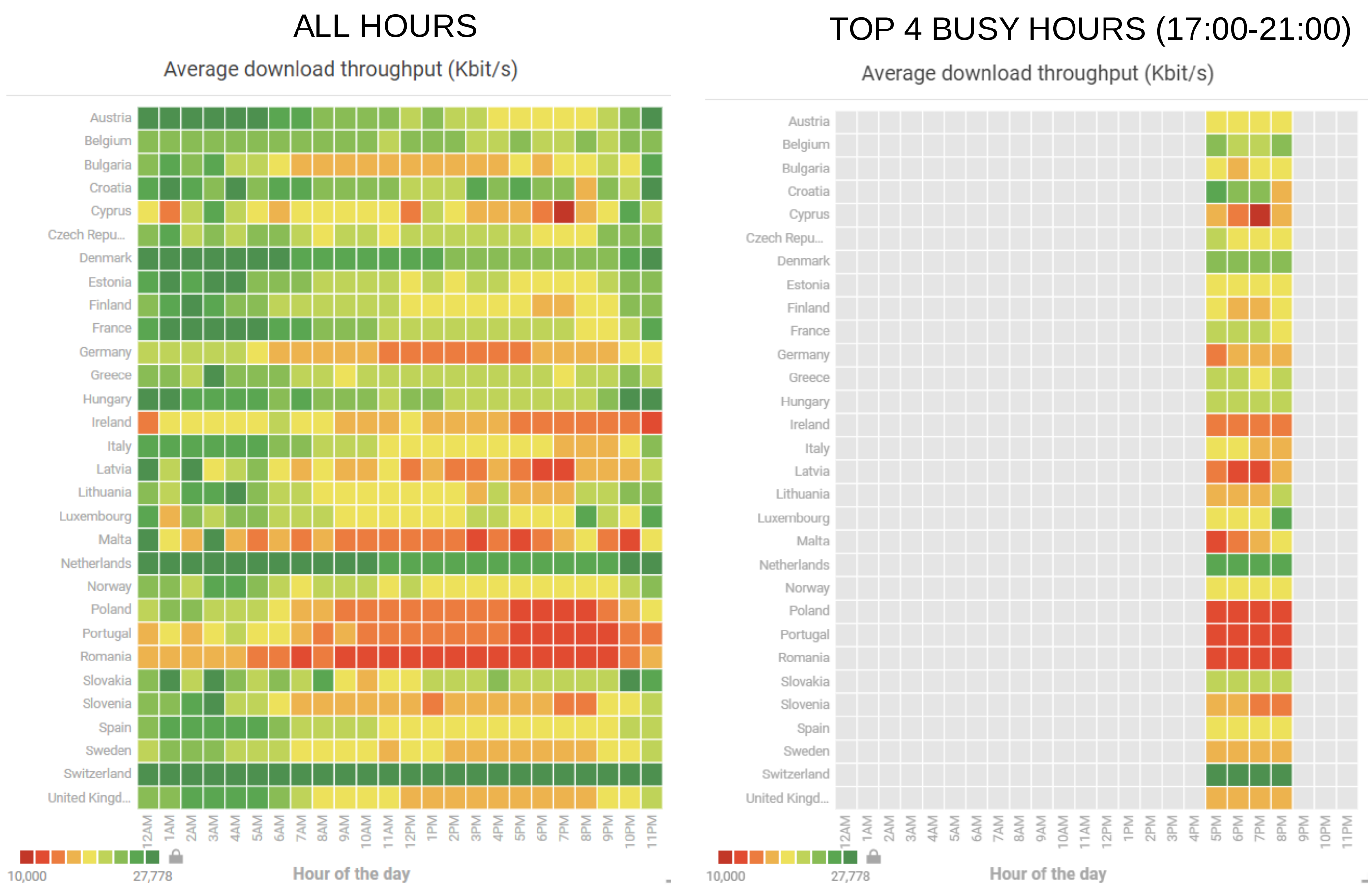
While outside peak hours the probability of getting less than 3 Mbit/s is as low as 1%, the probability during the loaded evening hours jumps to over 7%.

On the right-hand side of the chart above we show the one-way latency metrics, again as a function of the hour of the day. The EU28+NO+CH level average one-way latency is between 25 and 30ms. It elevates only slightly in the most heavily loaded hours. The probability of measuring more than 50ms latency is roughly 2.5% in the least loaded hour in increases to 5% in the busiest hour.

[3] Note that Tutela is using relatively small, 2 Mbyte file sizes for the throughput measurements. In order to reach hundreds of Mbit/s – which is technically possible in some parts of some European LTE networks, larger file sizes would be required. Tutela's methodology can be found here: https://support.tutela.com/hc/en-us/categories/115000337089-Data-and-Methodologies

[4] The 3 Mbit/s threshold is consistent with Rewheel's 4G data tariff benchmarking methodology

The “heat map” below is an extract from the Tutela Explorer tool and it shows the average throughput in all the 30 countries as the function of the hour of the day. On the right-hand side, we highlighted the five busiest hours, between 17:00 and 21:00.

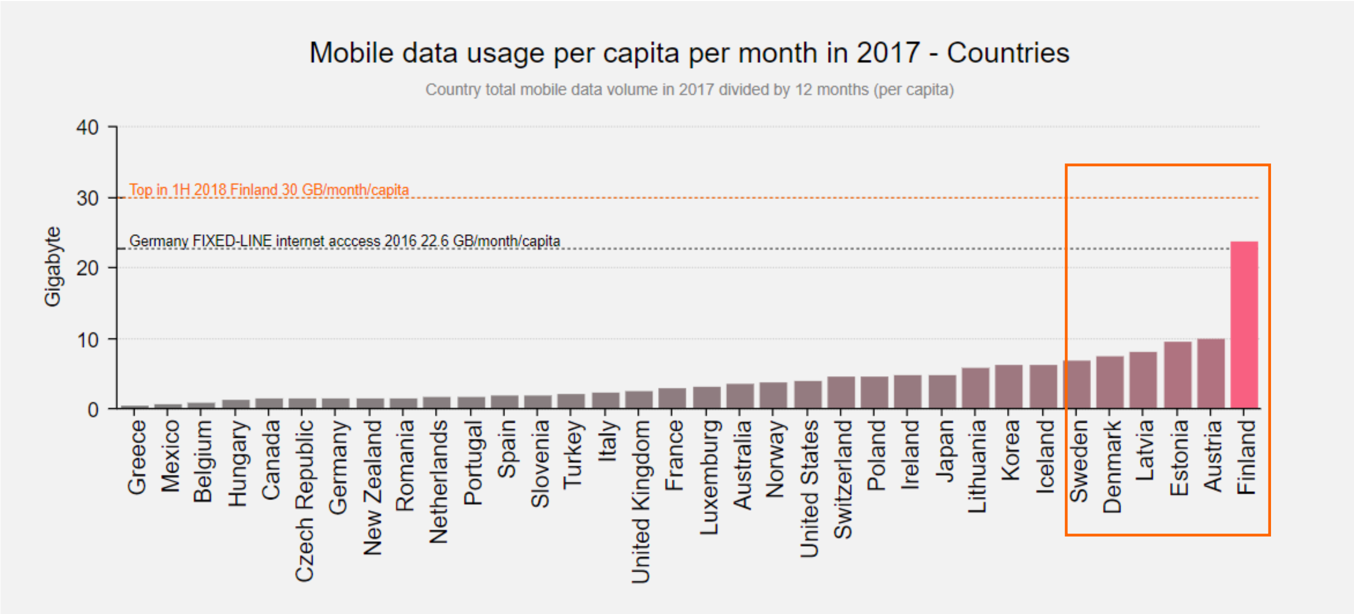


Source: Tutela Explorer

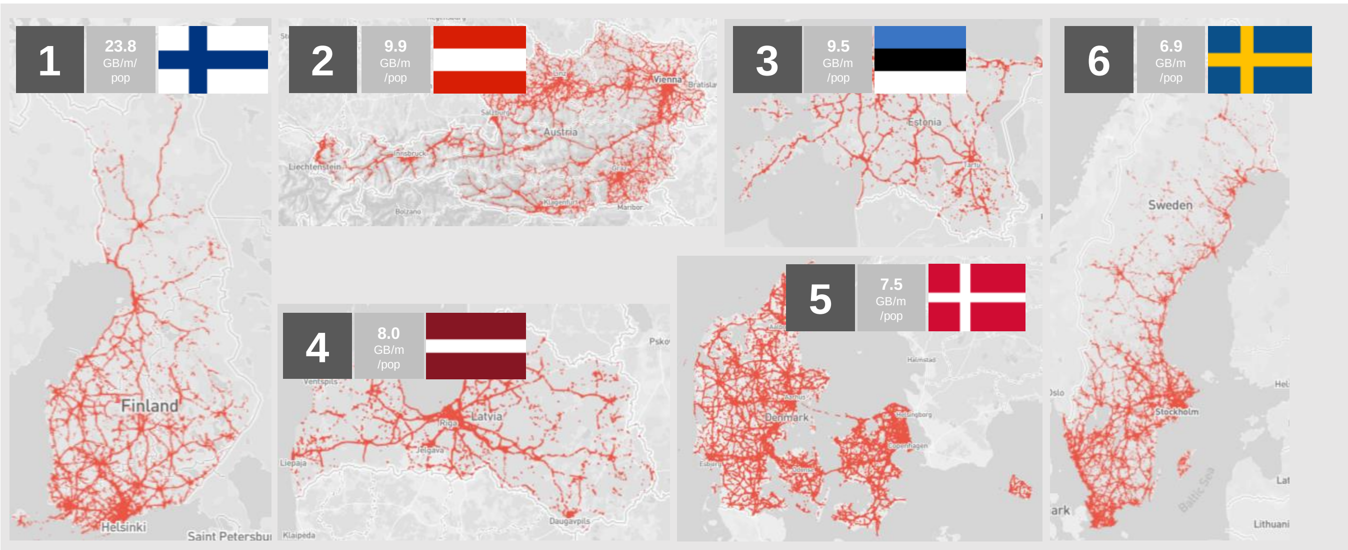
Switzerland stands out as the country with the highest average throughputs irrespective of the time of the day while Romania is the country with lowest average throughputs, not only during the busy evening hours but during almost any hour of the day.

Top 6 countries with highest mobile data traffic

Next, we examine the performance of the European countries with the most heavily-loaded mobile networks per capita. We selected Finland, Austria, Estonia, Latvia, Denmark and Sweden, based on the 2017 Rewheel EU&OECD mobile data usage benchmark[5].



Source: Rewheel



Source: Tutela Explorer, Rewheel analysis

[5] http://research.rewheel.fi/networkeconomics/

In the table below, we present five types of metrics:

1) Mobile data traffic volume per population – source: Rewheel
2) LTE eNodeB density per 1000 population – source: Tutela Explorer, Rewheel analysis
3) Average LTE signal strength (RSRP – Reference Signal Receive Power) – source: Tutela Explorer, Rewheel analysis
4) LTE download throughput – source: Tutela Explorer, Rewheel analysis
5) LTE one-way latency – source: Tutela Explorer, Rewheel analysis

In addition to the top 6 countries we also show Switzerland (the country with the best average LTE download throughputs, as seen above in the “heat map”), Germany (the largest EU country, very lightly loaded networks) and as well the overall averages for the 28 EU countries plus Norway and Switzerland (EU28+NO+CH).

LTE perfromance in Top 6 mobile data traffic countries in Europe (normalised for population)

Country	GB/Month /Pop 2017	LTE eNB per 1000 pop (detected by Tutela)	Average LTE signal strength (RSRP, dBm)	Average LTE download throughput (Mbit/s)	Average LTE download throughput (Mbit/s) in 4 BUSY HOURS	% of LTE download throughput samples below 3 Mbit/s	% of LTE download throughput samples below 3 Mbit/s in 4 BUSY HOURS	Average one-way LTE latency (ms)	Average one-way LTE latency (ms) in 4 BUSY HOURS	% of one-way LTE latency > 50ms	% of one-way LTE latency > 50ms in 4 BUSY HOURS
Finland	23.8	3.7	-95.1	21.4	19.2	3.1%	5.2%	18.4	19.2	1.1%	1.5%
Austria	9.9	2.0	-98.7	23.9	21.0	2.9%	4.7%	23.3	23.4	1.7%	1.6%
Estonia	9.5	2.5	-96.7	22.3	19.7	1.6%	4.2%	20.2	20.5	1.6%	1.4%
Latvia	8.0	1.6	-96.1	18.3	15.1	4.2%	10.4%	27.8	27.0	2.7%	1.4%
Denmark	7.5	2.2	-98.1	26.3	24.3	2.6%	4.3%	20.4	20.8	1.4%	2.5%
Sweden	6.9	2.2	-98.0	19.5	18.5	2.8%	4.4%	21.0	21.0	1.6%	1.6%
Switzerland*	4.6	1.6	-104.0	32.1	29.3	4.9%	6.3%	20.5	21.5	1.8%	2.4%
Germany	1.4	0.7	-99.9	17.4	17.2	6.7%	7.3%	21.1	20.8	1.7%	1.6%
EU28+NO+CH	2.8	1.1	-100.6	21.1	19.4	5.4%	7.3%	28.4	29.6	3.8%	4.6%

* Switzerland has very restrictive RF-EMF radiation limits, thus MNOs tend to lower downlink transmit power on cell sites, especially in urban areas

Source: Tutela Explorer, Rewheel analysis

The first thing to observe is that normalised for population, according to Tutela data and independently confirmed from our Rewheel studies[6], Finland has a very high number of LTE cell sites: over three times as many as the EU28+NO+CH average and over five times as many as Germany. In line with the high site density, the average LTE reference signal strength received by the smartphones is significantly (roughly 5 dB) stronger in Finland than in Germany and the EU28+NO+CH average. The pattern is consistent across the other five data-heavy counties: well above average site densities and stronger average received LTE signals.

Next, let’s have a look at LTE download throughputs. Finland’s performance is roughly in line with the EU28+NO+CH level average, both on the daily aggregate level (21.4 Mbit/s in Finland vs 21.1 Mbit/s EU28+NO+CH) and also if we look at the four busy hours (19.2 vs 19.4 Mbit/s). Latvia is below the average, while Denmark is significantly better than the average. Germany, the largest EU member state, with very lightly loaded networks (only 1.4 GByte/month per capita vs 23.8 GByte/month per capita in Finland in 2017), performs below the EU28+NO+CH and the top 6 heaviest traffic countries. Remarkably, Tutela measured higher average download throughputs in the busy hours in Finland and four other top data volume countries than the overall daily average throughput in the lightly loaded Germany.

We can observe a similar pattern if we look at our other throughput metric, the percentage of sub-3 Mbit/s samples. Finland performs twice as well as Germany (3.1% vs 6.7%), and all the 6 heavy traffic countries (except Latvia) perform better in the busy hours of the day than the German and EU28+NO+CH overall daily average. Interestingly, while Switzerland stands out in the average download throughput metric (32.1 Mbit/s daily average and 29.3 in the 4 busy hours), in our other – arguably more customer-relevant – throughput

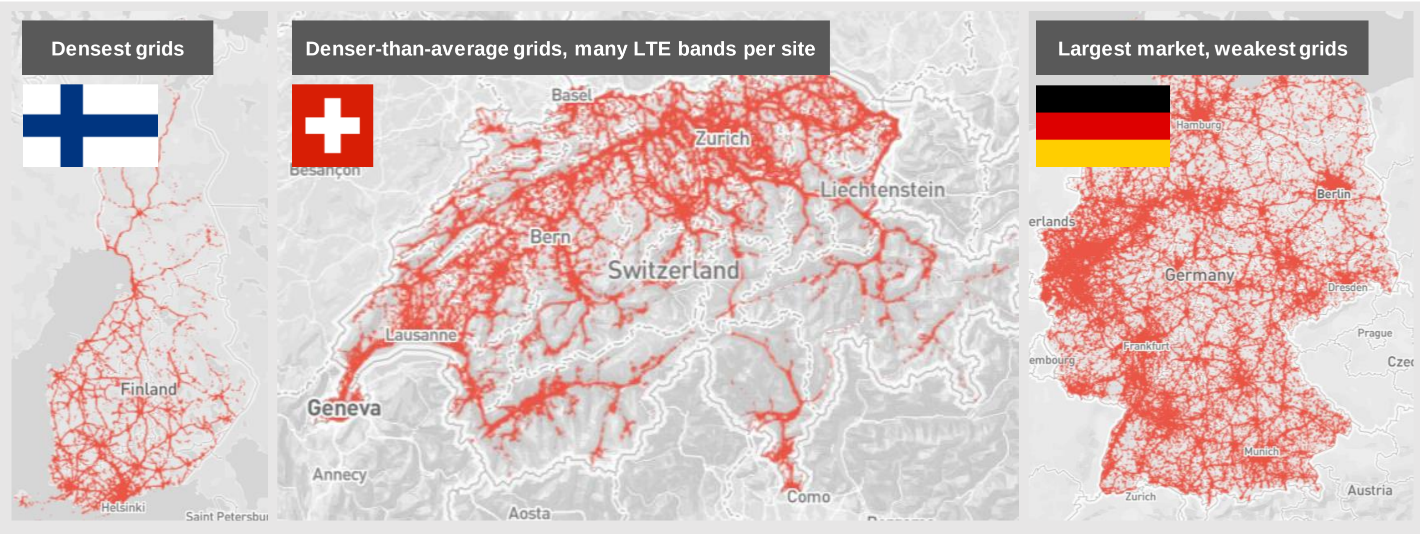
[6] http://research.rewheel.fi/downloads/Capacity_utilization_fixed_mobile_broadband_substitution_potential_2017_PUBLIC.pdf

metric, the percentage of sub-3Mbit/s throughput samples, it performs worse (4.9% daily average, 6.3% in the 4 busy hours) than the top six data traffic countries (except for Latvia in the 4 busy hours) – but it performs slightly better than the EU28+NO+CH average (5.4% daily average, 7.3% in the four busy hours).

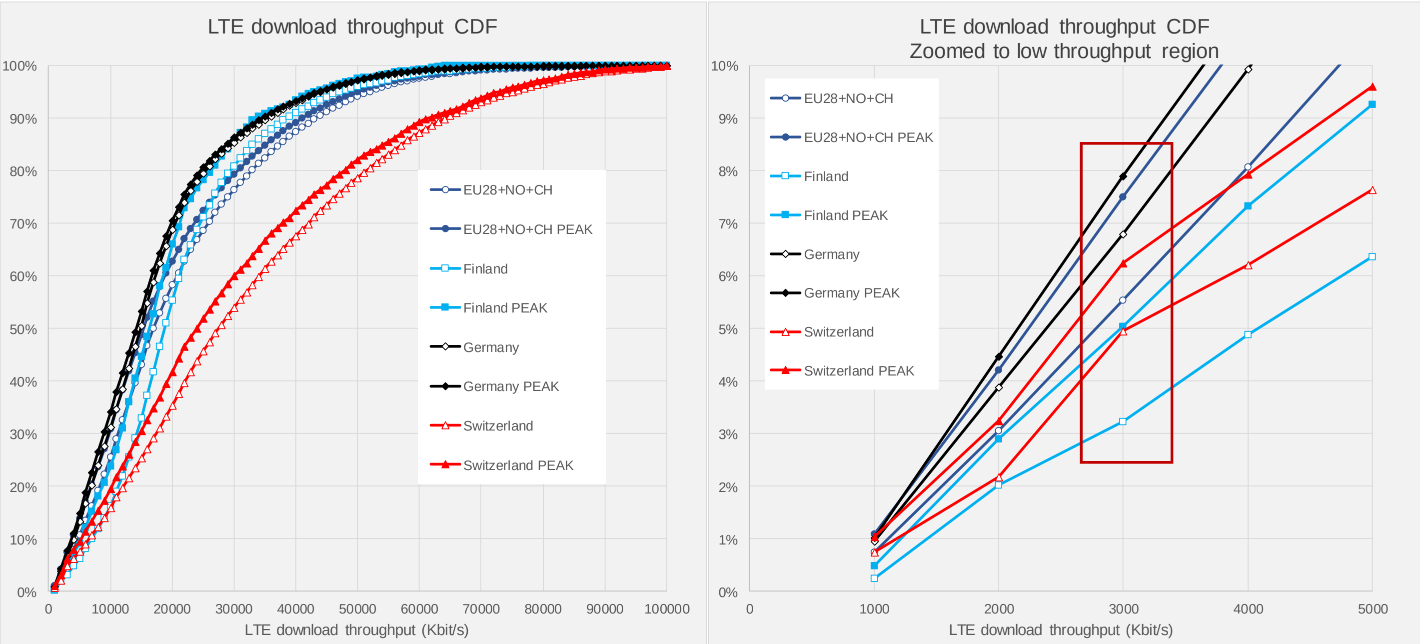
With regards to latency, Finland outperforms the EU28+NO+CH average, Germany and the rest of the top 5 traffic heavy countries, both based on the average result and in terms of the percentage of greater-than-50ms samples. The traffic heavy countries, Switzerland and Germany also show significantly lower occurrence of greater-than-50ms LTE latency than the EU28+NO+CH average.

Deep dive in three special cases: Finland, Germany, Switzerland

Let's dive a bit deeper into the network performance in the three "special" cases: Finland, Germany and Switzerland. Finland is special because of its very high data traffic load, Germany is special because of its very *low* data traffic load and large scale, and Switzerland is special because of its outstanding LTE average throughput.



Source: Tutela Explorer, Rewheel analysis



Source: Tutela measurements, Rewheel analysis

As the LTE download throughput cumulative density functions (CDF) above show, the German and Finnish performance patterns are broadly similar to the EU+NO+CH-level distribution. The medians (i.e. the 50% probability) are similar and the top 10% percentile (i.e. the 90% gridline on the vertical axis) are similar too. The peak hour (top 4 busy hours) curves shift to the left, indicating slightly degraded performance compared to the average daily performance. This suggests that the 17 times higher data volumes (normalised for population) do not play a defining role in Finnish networks' performance. In fact, if we zoom into the low, sub-5Mbit/s region – see the chart above on the right-hand side – we can see that Finnish networks perform significantly better than the EU28+NO+CH average and Germany, both in terms of daily average and busy hour performance.

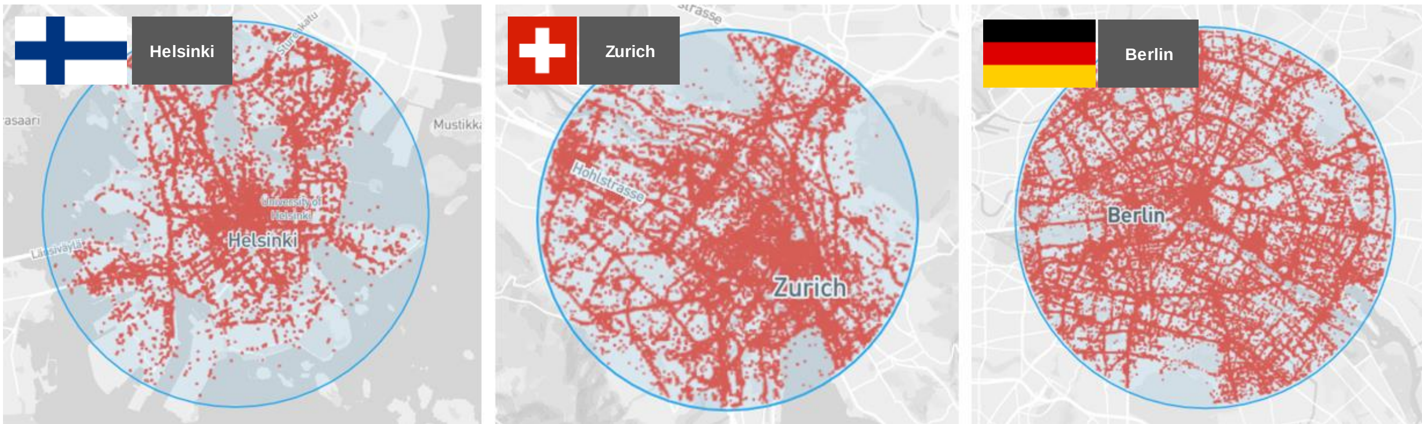
However, the overall performance of the three Swiss networks does stand out from the crowd. It is clearly visible that Swiss LTE download throughputs are much higher than Finnish, German and EU28+NO+CH average both in terms of the median and especially in the top 10% percentile. As we will show in the next part, Swiss operators have deployed among the highest number of LTE bands per site (800, 1800, 2600 and increasingly 2100 MHz too) and they also have fairly dense site grids (as shown previously, 1.6 eNB cell site per 1000 population vs 0.7 in Germany and 1.1 EU+NO+CH average).

Interestingly, Finnish operators – while not having particularly high average, median and top 10% percentile LTE download throughputs – have much less occurrence of very low throughputs than Swiss networks (see the right-hand side chart above).

A likely explanation for this interesting dichotomy is that Swiss users can get very high speeds in good radio conditions, pulling up the average, the median and the top 10% percentile statistics, but near the cell edges – where radio conditions are poorer – the throughputs cannot benefit meaningfully from the high order of LTE carrier aggregation. In the low throughput ranges of the curve, having dense grids and being close to the users appears to help more than having a Swiss-like multi-LTE band “sandwich” configuration. As we already shown previously and will analyse in more detail in the next section, Finnish operators have over three times as many LTE cell sites than the EU28+NO+CH average and more than double that of the Swiss networks, normalised for population.

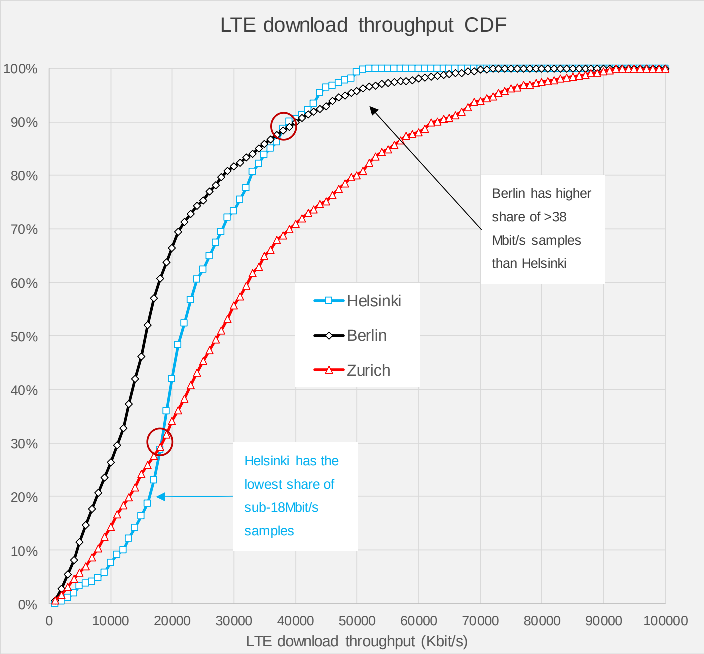
It is also important to note here that Switzerland has among the strictest electromagnetic radiation (RF-EMF) limits in the world for base stations, and operators often – especially in urban areas – must heavily restrict their cell site downlink transmission powers. This doesn’t impact performance in good radio conditions, close to the base stations (high signal to noise ratio), but leads to performance degradation in deep indoor situations and near the edges of a particular cell site’s coverage.

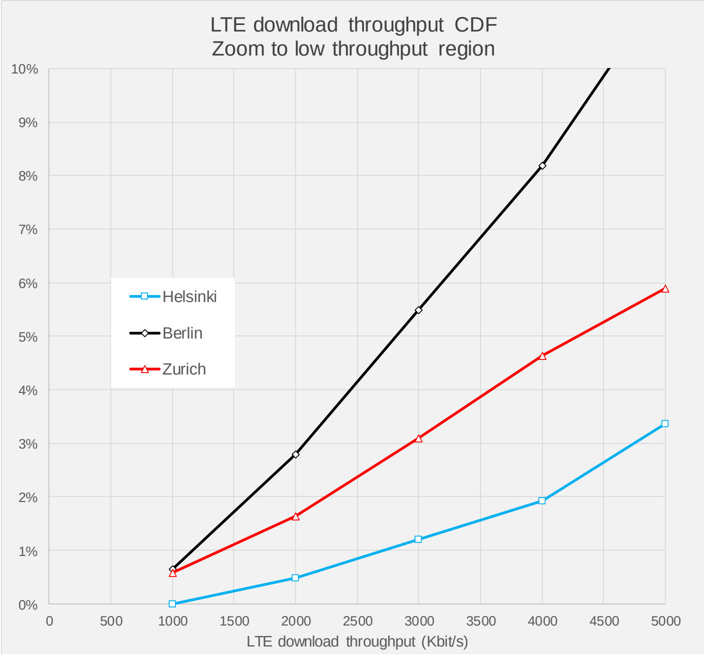
We repeated the same analysis for the downtown areas of Helsinki, Berlin and Zurich, as shown in the Tutela Explorer tool snapshots below.



Source: Tutela Explorer

As the statistical analysis (CDF) below shows the country level “macro” statistical pattern repeats itself on the city “micro” level. The probability of getting sub-3 Mbit/s LTE download throughput is much lower in Helsinki than in Zurich and Berlin, but the median throughput is highest in Zurich. Berlin underperforms Helsinki and Zurich in both the median metric and the probability of “very low” throughputs, but Berlin actually overtakes Helsinki in terms of the probability of getting a download throughput greater than 40 Mbit/s.





Source: Tutela measurements, Rewheel analysis

One of the two interesting cross-over points is just under 20 Mbit/s (30% of the samples are below that both in Helsinki and Zurich). So, if we care only about getting at least 20 Mbit/s and we don't care about getting any better speeds than that, then Helsinki is performing better than Zurich. The second cross-over point is at a little under 40 Mbit/s (90% of the samples are below that both in Helsinki and Berlin). So, while Berlin typically underperforms Helsinki, the chances of getting very high throughputs is actually higher in Berlin.

An ideal network's CDF curve shape would start with a horizontal flat line from zero at least up to the minimum required throughput (e.g. 3 Mbit/s) and then perhaps steeply shoot up, indicating a smart investment strategy where the operator avoids investing into "too good" performance that doesn't lead to an improvement in customers' quality of experience.

LTE spectrum band deployment patterns

Using Tutela's extensive data we calculated some key metrics that can show the large discrepancies in LTE site densities as well as the different spectrum band deployment strategies.

The left column (LTE eNB site per 1000 pop) of the table below shows that Finland has more than three times as many LTE sites per 1000 population than the EU28-NO-CH average. It also shows how strikingly few LTE sites Germany, the largest EU member state, has.

LTE band deployment: what % of total sites have a band deployed, on average how many bands per site are depolyed. How intensively are bands deployed per 1000 pop?

Country	LTE eNB site per 1000 pop	700 MHz	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz	2300 MHz TD	2600 MHz TD	Average # LTE band per eNB site	# LTE band per 1000 pop (# sites x # band per site / 1000 pop)
Finland	3.7	2%	69%	1%	74%	17%	22%	0%	0%	1.84	6.89
Austria	2.0	0%	58%	3%	76%	39%	28%	0%	0%	2.04	4.07
Estonia	2.5	0%	79%	0%	62%	14%	38%	0%	0%	1.94	4.88
Latvia	1.6	0%	86%	0%	75%	21%	34%	1%	1%	2.18	3.40
Denmark	2.2	0%	63%	3%	68%	25%	19%	0%	0%	1.78	4.00
Sweden	2.2	0%	81%	43%	47%	9%	57%	0%	4%	2.41	5.34
Switzerland	1.6	0%	84%	3%	89%	49%	36%	0%	0%	2.61	4.12
Germany	0.7	0%	84%	20%	64%	11%	22%	0%	0%	2.01	1.42
EU28+NO+CH	1.1	1%	80%	6%	71%	23%	30%	1%	1%	2.13	2.38

Source: Tutela measurements, Tutela post processing, Rewheel analysis

The table also shows how extensively each LTE spectrum band is deployed in different countries. The most extensively deployed LTE band in EU28+NO+CH countries is the 800MHz band (80% of the LTE sites), followed by the 1800 MHz band (71% of the LTE sites). The third one is the 2600 MHz FDD band (30%), followed by the 2100 MHz band (23%, which, as 3G/HSPA traffic is gradually fading away from the networks is being increasingly re-farmed to LTE).

Some operators, e.g. in Sweden and Germany, as seen in the table above, have started using 900 MHz for LTE quite extensively, re-farming parts of the band from GSM and 3G/HSPA. In contrast, 700 MHz hasn't yet been put into use in a meaningful manner in any of the EU28+NO+CH countries (except by Iliad in France, in roughly 40% of its LTE sites -- Iliad doesn't have any 800 MHz spectrum so unlike other operators that built up wide are LTE coverage using the 800MHz band, Iliad must rely on 700MHz). Many countries haven't even auctioned off the 700 MHz band.

Some Finnish operators have started adding LTE 700MHz on top of their LTE 800MHz layer to increase performance and capacity in very rural areas (in particular the Baltic sea archipelago, full of small summer houses, scattered far away from villages and towns), however Tutela's data shows that the band hasn't been put into use in significant number of sites (only 2% while 800MHz is used in 69%), even though Finnish operators received their 700 MHz licences in 2016.

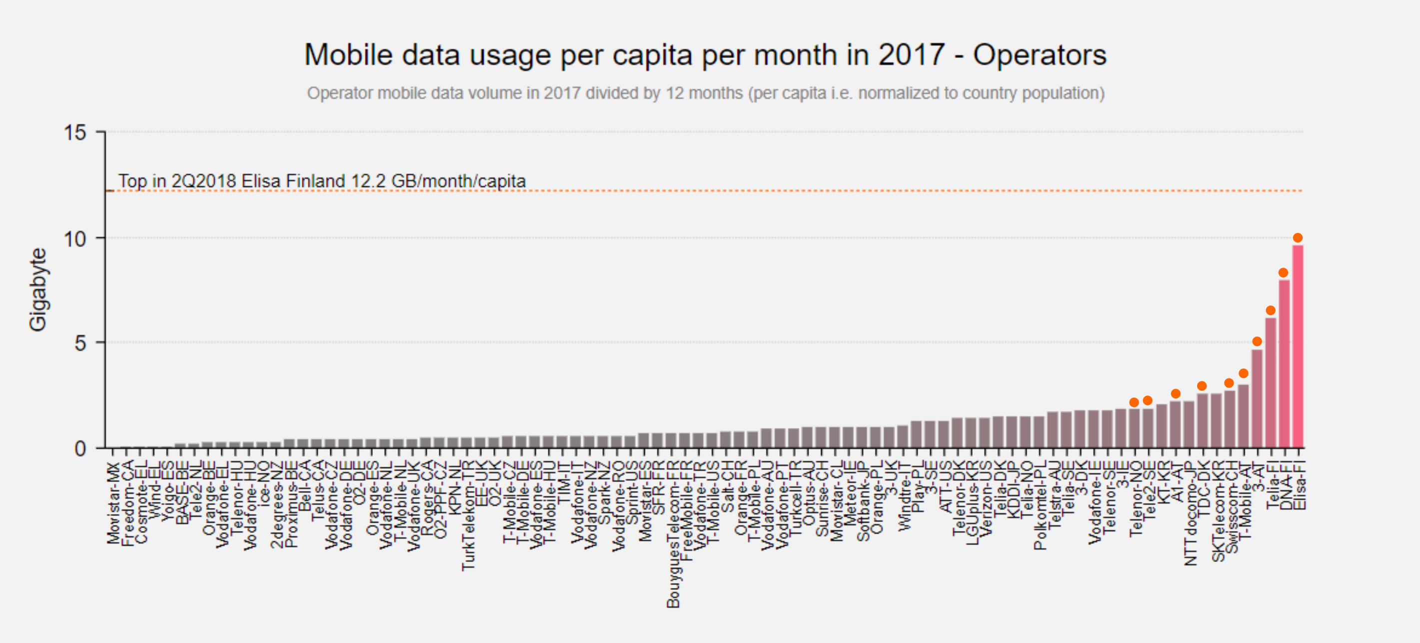
The first European country to auction the 700 MHz band was Germany in 2015[7], but so far, as confirmed by Tutela's data, operators haven't started using it. Recently Deutsche Telekom in Germany announced[8] that it will start using 700 MHz for LTE *"to expand high-speed mobile broadband services to rural and unserved areas"*.

[7] http://research.rewheel.fi/insights/2015_may_germany_auction/
[8] https://www.telegeography.com/products/commsupdate/articles/2019/02/06/telekom-applies-to-use-700mhz-spectrum-for-lte-rollout/

Exploring LTE performance drivers

In this section we present a number of scatter plot charts which we prepared to explore the relationship of four key LTE performance metrics (two for download throughput and two for latency) and important network metrics such as density of the eNBs (per 1000 pop), average number of LTE spectrum bands deployed per cell site, LTE band transmitters deployment per 1000 pop (i.e. cell sites times band per site divided by 1000 pop) and average received LTE reference signal power (RSRP). We also checked the correlation of LTE performance with amount of total FDD spectrum holding each operator has.

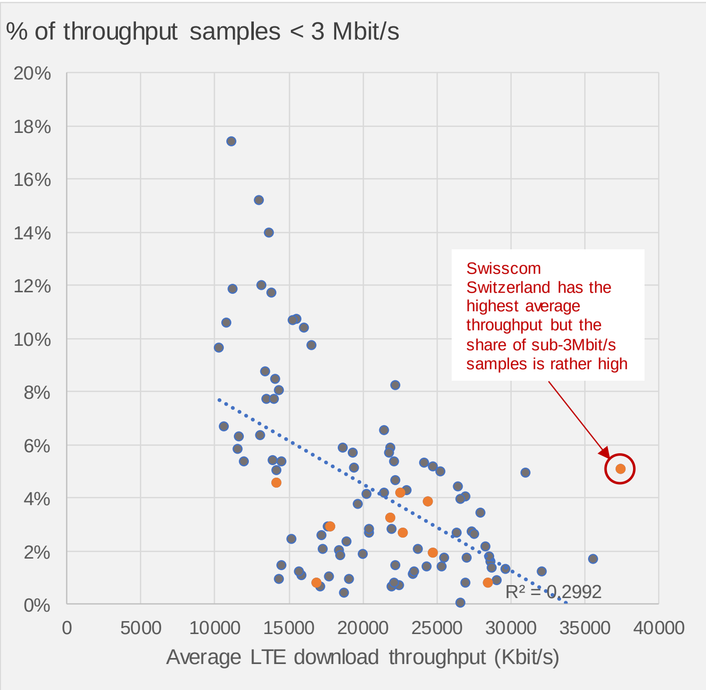
Each dot on the scatter plots represent one of the 99 mobile operators in the 28 European Union member states, Norway and Switzerland. We marked with orange colour (●) the top 10 mobile operators that carried in 2017 the highest mobile data traffic volumes normalised for population.

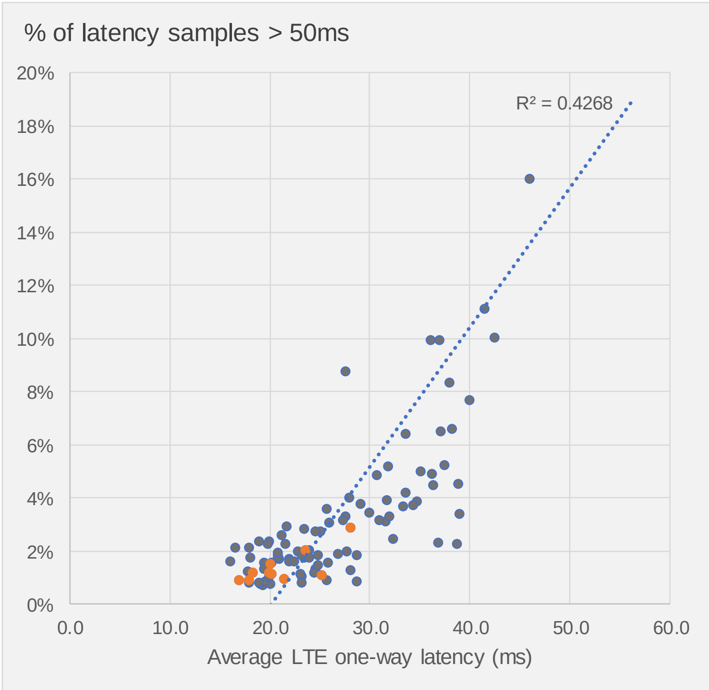


Source: http://research.rewheel.fi/networkeconomics/

Average performance vs percentage of low performance samples

The scatter plot on the left-hand side below shows that those operators that have higher average download throughputs tend to have lower occurrence of sub-3Mbit/s measurement samples. However, there are some exceptions. The operator, Swisscom in Switzerland (marked with red circle), that has the highest average download throughput happens to produce roughly five times more often (5%) sub-3 Mbit/s throughput samples than the best performing operators in this metric (roughly 1% or below). In fact, all three Swiss operators produce a similarly (4-5%) high percentage of sub-3Mbit/s samples. We suspect that the very strict Swiss RF-EMF radiation limits could play a role here. In Switzerland operators often, especially in urban areas, need to reduce the transmission power of their base station antennas to be able to comply with the EMF thresholds that are roughly 100 times (expressed in W/m2) stricter[9] than the international standard. Having relatively dense site grids and deploying many LTE bands (high order carrier aggregation, e.g. 800+1800+2100+2600 MHz) per site helps to pull up the theoretical maximum and average throughputs, but in deep indoor situations where the signal suffers large indoor penetration loss, or near the edges of the coverage, the low downlink transmit power takes its toll. Unless Switzerland relaxes the EMF radiation limits, the problem is expected to significantly impair the performance of the 3.5 GHz 5G NR layers.





Source: Tutela Explorer, Rewheel analysis

The latency pattern doesn't show a similar anomaly. The lowest average latency networks appear to have also the lowest percentage of samples that are greater than 50ms.

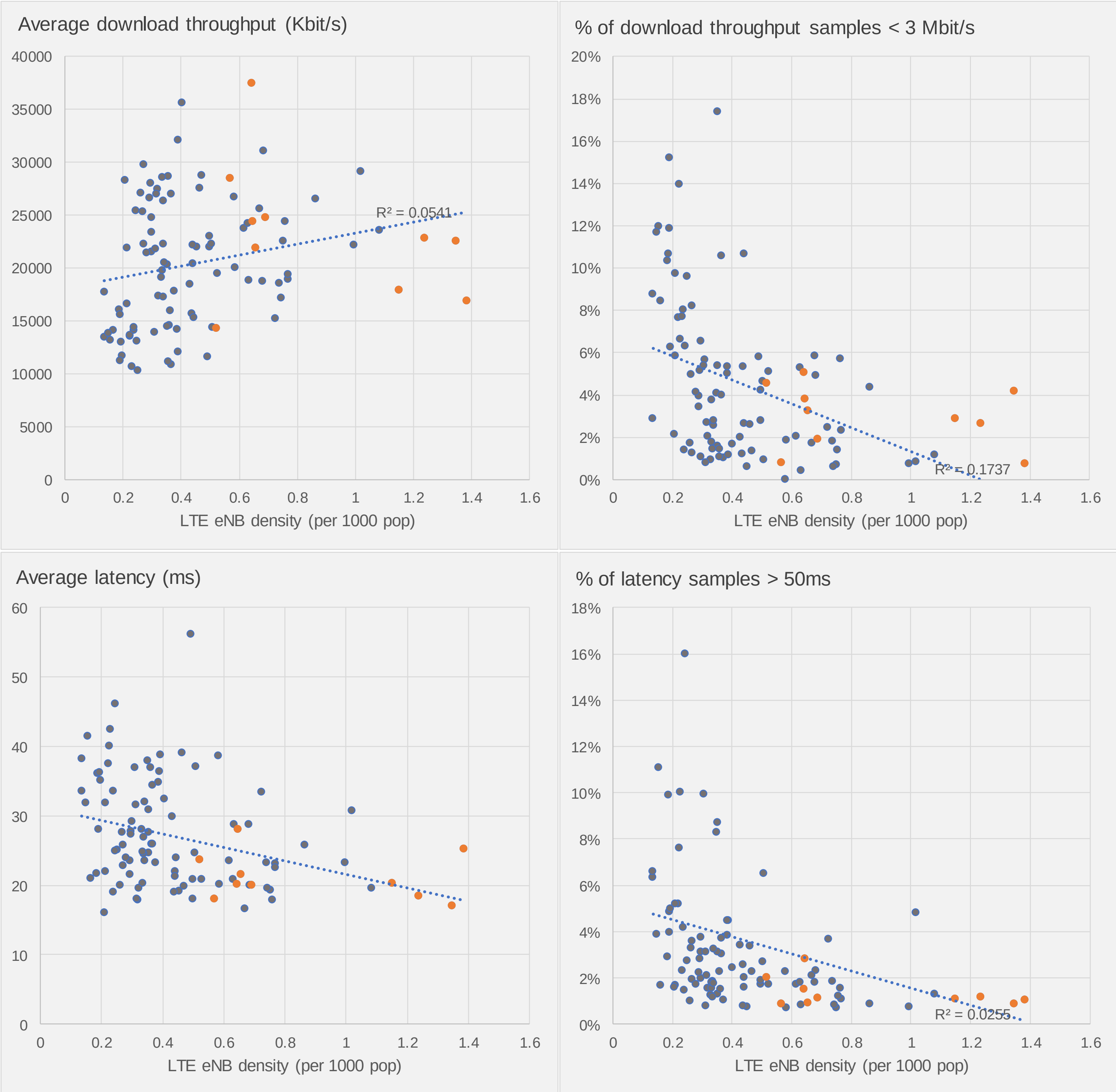
The top 10 heaviest data traffic networks (normalised for population), marked with orange colour, tend to be on the better performance regions of the scatter plots in terms of latency.

In terms of average throughput and occurrence of sub-3Mbit/s throughput the top 10 data traffic networks seem to be scattered quite randomly. The networks that have the highest occurrence of sub-3Mbit/s samples are not among the top 10 most heavily loaded networks. The network (Swisscom in Switzerland) that produced the highest average download LTE throughput is among the top 10 most heavily loaded networks.

This pattern suggests that there is no clear correlation between heavy traffic load and throughput performance.

[9] https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20171205/Documents/S3_Christer_Tornevik.pdf

Site density (eNodeB per 1000 pop)



Source: Tutela Explorer, Tutela database post processing, Rewheel analysis

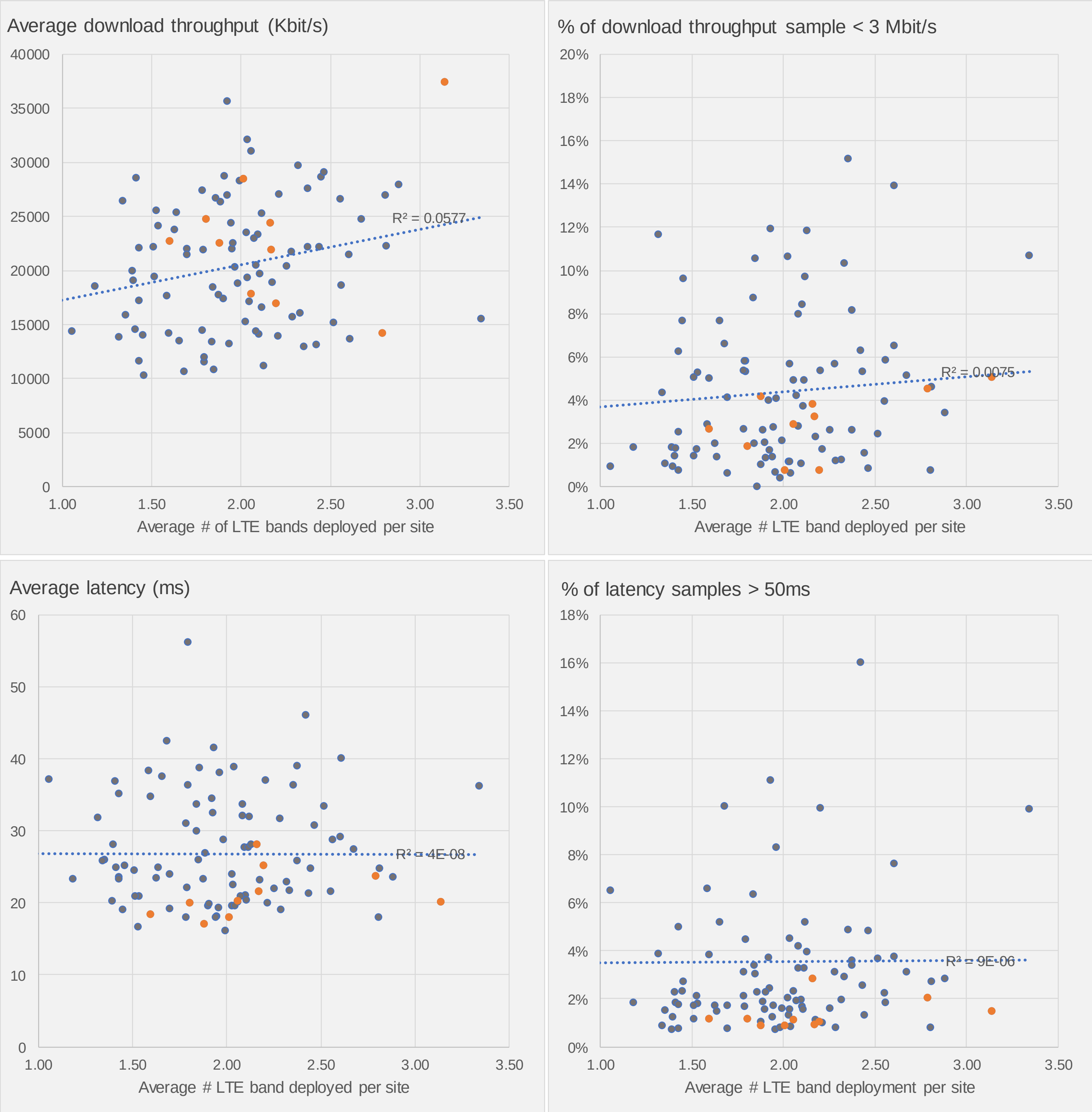
According to Tutela's measurements, Telenor Norway has the most LTE eNBs per 1000 population (1.38). Elisa Finland takes the 2nd place in this ranking (1.34), ahead of Telia Finland (1.23).

The scatter plots above indicate that directionally, more LTE cell sites per population tends to lead to higher average download throughput, lower probability of sub-3 Mbit/s throughput, lower average latency, and lower probability of getting greater than 50ms latency.

Tutela's measurements of LTE eNBs per 1000 population is in line with Rewheel's own data[10] that ranked mobile network operators according a population per macro site metric seen in the chart below. Telenor Norway is ranked 1st, Elisa in Finland 2nd and Telia in Finland 3rd.

[10] http://research.rewheel.fi/downloads/Capacity_utilization_fixed_mobile_broadband_substitution_potential_2017_PUBLIC.pdf

LTE spectrum band deployment



Source: Tutela Explorer, Tutela database post processing, Rewheel analysis

According to Tutela's measurements, Play Poland has the highest average number of LTE bands deployed per site (3.34) – see: *"Play LTE-A coverage reaches 1,705 locations"*[11] – followed by Swisscom in Switzerland (3.14) and Orange in France (2.88). Apart from the 800 MHz and 1800 MHz bands these operators have extensively deployed LTE in the 2100 MHz and 2600 MHz FDD bands too.

Tutela's data doesn't indicate particular correlation between any of the investigated two throughput and two latency metrics and the average LTE bands deployed per site. This suggests that other drivers (such as cell site density, as shown previously) play a more significant role in driving these performance metrics than the number of LTE bands deployed.

[11] https://www.telegeography.com/products/commsupdate/articles/2019/02/07/play-lte-a-coverage-reaches-1705-locations3

If we consider the top speeds that can be achieved in good radio conditions (several hundreds of megabits per second), the number of bands per site will play a key role. But Tutela's measurements (based on a relatively low 2Mbyte download file size, which is likely too small to be able to reach theoretical top speeds in the 100 Mbit/s range) indicate that typical use cases do not benefit from higher order carrier aggregation (i.e. more LTE bands per sector).

Of course, the traffic load is very unevenly distributed across the cell sites[12]. According to Rewheel's experience the top 5% most loaded sites typically carry roughly 20% of the total traffic, while the 50% least loaded sites carry only 15% of the total traffic (i.e. are nearly empty from traffic point of view). Due to this uneven traffic distribution some sites will require additional LTE band layers to avoid congestion. In this public analysis we used the simplified average band per site metric. The scatter plot based on this metric suggests that deploying high number of bands (high order carrier aggregation) "all over the place" doesn't necessarily improve user-perceived performance. Having said that, of course enabling more spectrum capacities in the most loaded cell sites is key to avoiding congestion-related performance degradation.

[12] Rewheel's network capacity model is elaborated in several reports, e.g.: http://research.rewheel.fi/insights/2018_sep_pro_capacity/

Site-band deployment per 1000 pop

Source: Tutela Explorer, Tutela database post processing, Rewheel analysis

According to Tutela's measurements and Rewheel's analysis, Telenor Norway has deployed LTE transmitters the most extensively, normalised for population (3.04 sites x bands per 1000 pop). Elisa Finland takes the 2nd place in this ranking (2.53), ahead of Telia Norway (2.51).

The scatter plots above indicate that deploying more sites and/or more bands per site lead to better throughput and latency performance metrics. Taking into account the previously shown scatter plots, we can safely assume that the main performance driver is the site density and number of bands per site plays only a marginal role, at least in terms of latency and download throughputs for 2 Mbyte file sizes.

Total FDD low-band and high-band spectrum holdings

A basic question any operator's management faces ahead of spectrum auctions is whether they will be able to capitalize on investing into more spectrum bandwidth by being able to significantly improve the user-perceived performance of their networks. The scatter plots below indicate that as expected, directionally, having stronger spectrum portfolios tend to result in better LTE performance. However, the correlation is weak and there clearly are operators that manage to achieve relatively high average LTE throughput, low share of sub-3Mbit/s throughputs, relatively low average latencies and as well low share of overly high latency samples, even though they have comparatively low aggregate bandwidth of spectrum.

Should an operator engage into an expensive bidding war to secure a bit more bandwidth of spectrum or maybe in some cases it is smarter to rather invest that money into densifying the cell site grid and/or put the existing spectrum into more extensive use? It depends on many factors. See: *"Verizon's Vestberg on balancing network capex with buying spectrum"*[13].

Source: Tutela Explorer, Rewheel EU28&OECD spectrum database, Rewheel analysis

[13] https://www.rcrwireless.com/20180521/carriers/verizon-network-capex-spectrum-tag17

Average received power (RSRP)

Source: Tutela Explorer, Rewheel analysis

An interesting angle to characterise the “strength” of the existing LTE site grids is to investigate the average signal strength (RSRP) measured by the smartphones.

In the case of denser grids, the cell site antennas tend to be closer to the phones, resulting in higher signal strength. In reality there are several factors that influence the signal strength, most importantly the downlink transmit power. As we mentioned earlier, some operators have dense grids but at the same time they need to observe very strict RF-EMF rules which prevents them from using their LTE transmitters on full power setting. Switzerland, Italy and Poland are such countries.

Implications for 5G spectrum and infrastructure investments

Using Tutela's data, our analysis of 99 European LTE networks has confirmed that there are large disparities in the densities of the existing LTE cell site grids. Networks with denser grids tend to provide higher average throughputs and more consistent LTE performance – in terms of occurrence of sub-3Mbit/s downlink throughputs – than networks that have relatively few cell sites.

Contrary to the often-heard small-cell-centric 5G rollout narrative, we are not aware of any European operators that are planning to undertake a significant 5G small cell rollout. Instead, the primary 5G investment strategy is to upgrade existing macro sites with 3.5 GHz 5GNR massive MIMO antennas and run them in tight interworking (Non-Standalone Mode) with their LTE radio access networks[14].

Optimally each operator should get 60-100 MHz of spectrum in the 3.5 GHz band (Band n78) and thanks to the 5G upgrades on the macro sites the average user throughputs, and more importantly the aggregate sector capacity, will significantly increase. As an added benefit, thanks to the so called "channel hardening property" of massive MIMO beamforming solutions (illustrated below) the reliability of the wireless links will also significantly improve, especially near the cell edges and spots with weaker coverage.

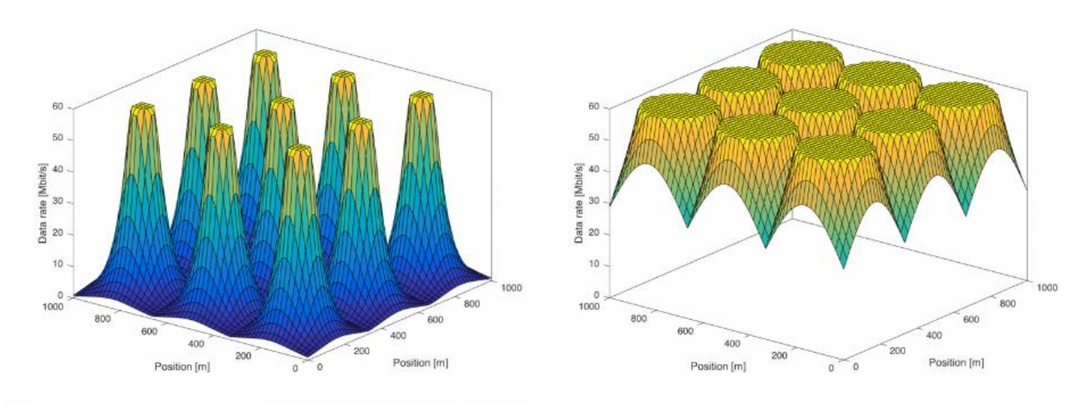


Figure 1: Variations in the downlink data rates in an area covered by nine base stations.

This figure considers an area covered by nine base stations, which are located at the middle of the nine peaks. Users that are close to one of the base stations receive the maximum downlink data rate, which in this case is 60 Mbit/s (e.g., spectral efficiency 6 bit/s/Hz over a 10 MHz channel). As a user moves away from a base station, the data rate drops rapidly. At the cell edge, where the user is equally distant from multiple base stations, the rate is nearly zero in this simulation. This is because the received signal power is low as compared to the receiver noise.

Figure 3: The number of base station antennas has been increased from 1 (as in Figure 1) to 100.

Figure 3 shows that the data rates are increased for all users, but particularly for those at the cell edge. In this simulation, everyone is now guaranteed a minimum data rate of 30 Mbit/s, while 60 Mbit/s is delivered in a large fraction of the coverage area.

Simulations showing dramatic improvement of cell-edge data rates and expansion of peak speed coverage areas.
Source: Emil Björnson, Linköping University, Sweden[15]

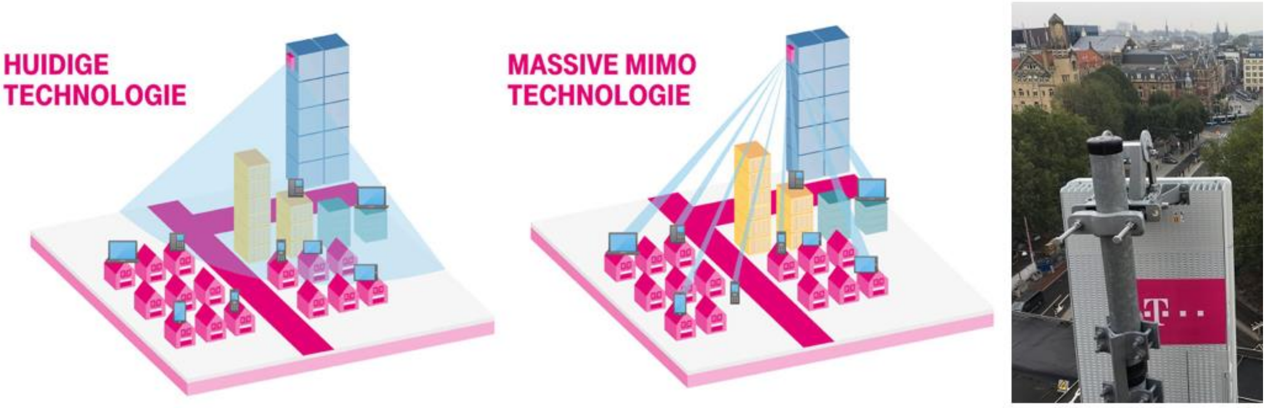
Such a macro-site-centric, outdoor-to-indoor 5G coverage rollout approach opens an interesting path toward cost efficient 4G/5G based home broadband services. T-Mobile in the Netherlands is one of the early pioneers of the concept in Europe. Late 2017, early 2018 T-Mobile started testing and deploying 2.6 GHz TD-LTE massive MIMO antennas[16] on their macro sites, and as their illustration below depicts, one of main aim is to offer reliable high capacity connectivity for home broadband customers. According to Tutela's measurement data T-Mobile Netherlands deployed 2.6 GHz TD-LTE (LTE Band 38) on roughly thousand cell sites, about one fifth of all LTE sites. Tutela's data also shows that T-Mobile clearly has the densest LTE site grid in the Netherlands (they did not buy 800 MHz spectrum so they had to rely more heavily on higher frequency bands and denser site grid).

[14] We also expect that some of the LTE bands (primarily 800 MHz) will be switched to LTE/5G coexistence mode in order to maximise the coverage footprint where 5G smartphones display a 5G icon – even though this type of low-band 5G coverage won't provide meaningfully higher throughputs or lower latency than what can be achieved with LTE

[15] http://ma-mimo.ellintech.se/2017/03/02/improving-the-cell-edge-performance

[16] https://newsroom.t-mobile.nl/t-mobile-netherlands-activates-first-antenna-with-5g-technology-in-amsterdam/

T-Mobile Netherlands introducing 2.6 GHz TD-LTE with Massive MIMO for home broadband



Source: T-Mobile Netherlands

Elisa and other Finnish operators also indicated their ambitions to use 3.5 GHz 5G for home broadband connectivity, based on the macro site outdoor-to-indoor concept. In August 2018 Elisa invited Rewheel to test[17] its 5G trial network, which they opened for public users. The photo below shows the Huawei 3.5 GHz 5G massive MIMO antenna deployed next to the 2G/3G/4G passive antennas and radio units on an urban rooftop macro site.

Elisa Finland 3.5GHz 5GNR 64T64R active antenna deployed on a macro site in Tampere

. Photo: Rewheel

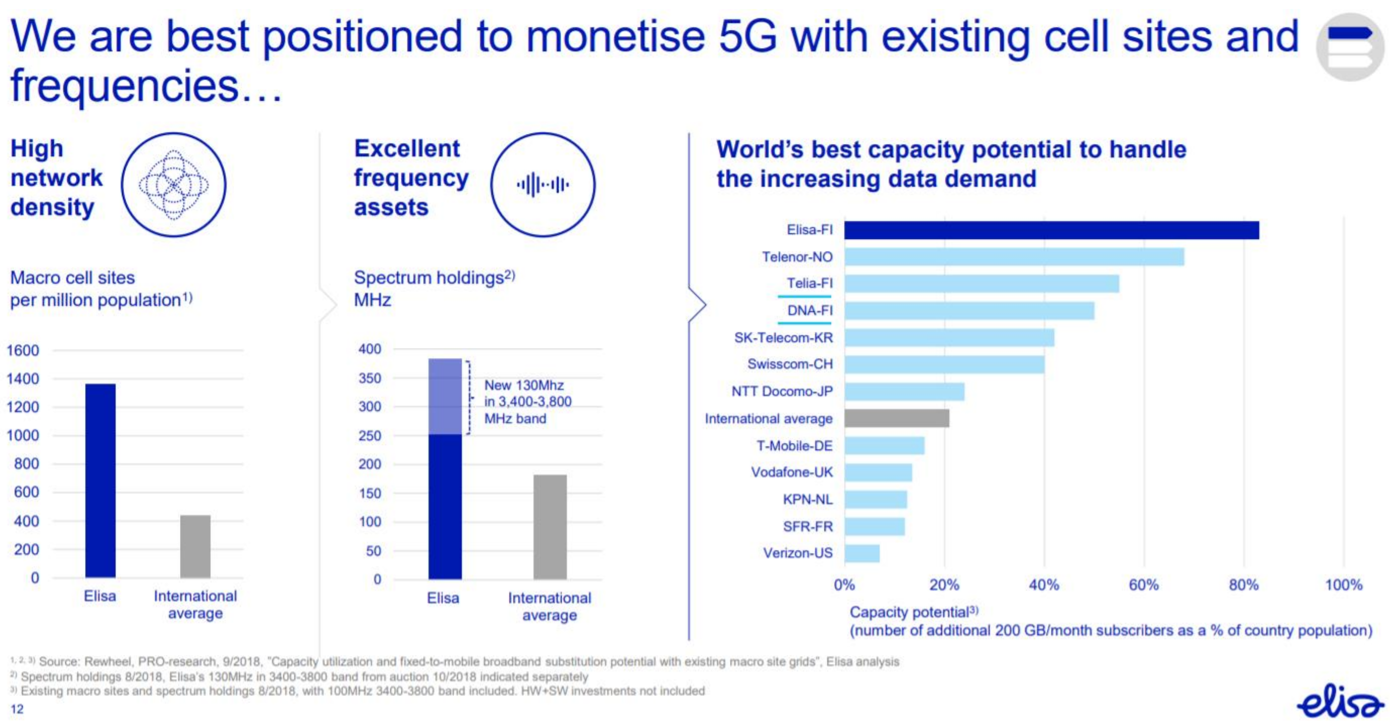
The propagation characteristics (penetration through walls and windows) of the 3.5 GHz band are worse than that of the lower LTE spectrum bands. This handicap is expected to be partly compensated by massive MIMO beamforming technology and so-called uplink/downlink decoupling[18].

Elisa Finland's 5G expert publicly stated: *"I have a positive feeling that with dual connectivity the NR 3.5 GHz coverage in practice is not too much compromised compared to LTE coverage from the same sites"* [19].

Presenting Rewheel's analysis, Elisa's Group CEO showed to analysts and investors that their dense macro site grids and substantial spectrum holdings (Elisa secured 130 MHz in the 3.5 GHz band in the 2018 spectrum auction) will ensure that they can continue the

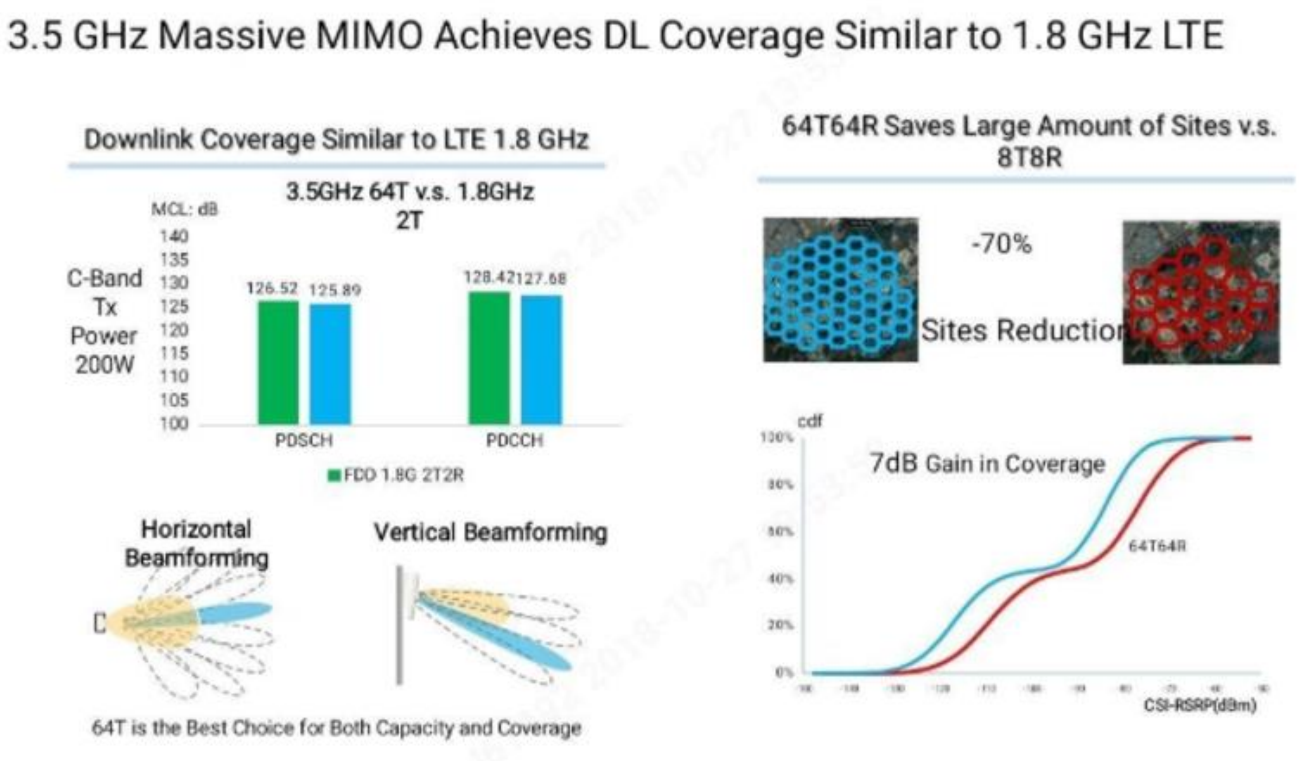
[17] http://research.rewheel.fi/insights/2018_aug_elisa_5G_tampere/
[18] http://research.rewheel.fi/downloads/Rewheel%20trying%20Elisa's%205G%20network%20in%20Tampere_17082018_PUBLIC.pdf
[19] Source: Linkedin comment

unlimited mobile data drive and address the home broadband market (in areas where Elisa is not present with its own high speed fixed-line access infrastructure), without hiking network Capex.



Source: Elisa Capital Market Day 2018 CEO presentation[20] (presenting Rewheel's analysis)

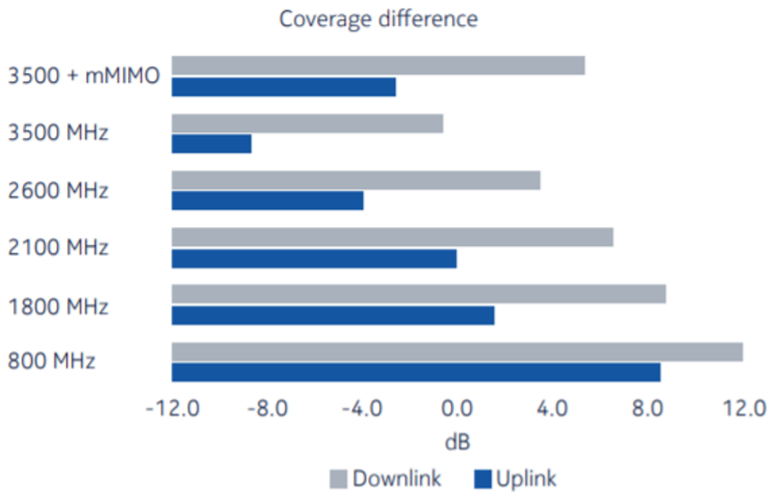
The picture below shows that Huawei expects that the beam forming gain of the massive MIMO antenna will partly compensate for the worse penetration properties of the 3.5 GHz (C-Band) such that it will be able to achieve similar downlink coverage as LTE 1800, if deployed on the same macro site grid.



Source: Huawei[21]

[20] https://corporate.elisa.com/attachment/content/1_Elisa_CMD_2018_Group_Overview.pdf
[21] ITU Workshop September 2018 https://www.itu.int/en/ITU-D/Regional-Presence/CIS/Documents/Events/2018/09_Almaty/Presentations/ITU%20Workshop%2017.09.2018%20-%20Dmitry%20Polpudenko.pdf

As shown below, Nokia shares Huawei's views.



"The figure illustrates the relative outdoor coverage for the different frequencies compared to a 2100 MHz uplink. The calculation assumes the Okumura-Hata propagation model, a downlink that is 8 dB better than the uplink, and a massive MIMO (mMIMO) gain of 6 dB compared to 2x2MIMO. This calculation shows that 5G at 3500 MHz downlink with massive MIMO can exceed LTE1800 MHz 2x2MIMO coverage" (Nokia)

Source: Nokia[22]

Ericsson's field measurements also confirm the feasibility of the high-band LTE macro grid based 5G NR coverage approach: *"The massive MIMO enabled beamforming gain is larger than the additional propagation loss compared to a 2.1 GHz LTE band. This is very promising for 3.5 GHz NR deployment on existing LTE site grid (for example EUTRA bands 1, 3, 7, 33, 38, 40, 41, 42, 43, 48). Indoor coverage is also predicted to be feasible and on par with LTE. In older type of buildings coverage in whole cell area is expected while indoor solutions are likely needed in selected modern buildings, as for LTE. The measured indoor coverage was in line with predictions"*[23]

Bottomline: operators like the ones in Finland, that historically invested into denser 2G/3G/4G macro site grids will be better positioned to deploy a high and consistent performance 5G coverage layer, especially indoors. Those operators that so far relied heavily on the low-band (800 MHz) spectrum and less dense grids to create LTE indoor coverage in suburban and rural areas will face greater challenges in rolling out a strong and consistent 3.5 GHz-based high capacity 5G layer than those that relied more heavily on the higher (1800 MHz, 2600 MHz) LTE bands deployed on relatively denser site grids.

[22] Nokia White Paper "5G deployment below 6 GHz" https://www.rrt.lt/wp-content/uploads/2018/10/Nokia_5G_Deployment_below_6GHz_White_Paper_EN.pdf
[23] https://www.ericsson.com/assets/local/publications/conference-papers/5g_nr_sub6_coverage.pdf

Preparing to make prudent investment decisions

In the next couple of years, as the 5G ecosystem matures and 4G/5G-centric spectrum bands (3.5 GHz, 700 MHz, 700SDL, 1400SDL, 2300 TDD) are auctioned off in Europe, operators must appraise their investment options and make some high impact, strategic spectrum and infrastructure investment decisions, in the order of hundreds of millions to billions of Euros. Rewheel and Tutela can add significant value in these situations.

Our aim with this public paper was to demonstrate the potential that lies in the combination of Tutela's measurement capabilities and Rewheel's industry insights. Below we list some more in-depth analysis directions where this approach can add tangible value to our clients' strategic decision making:

- The low (700, 800, 900 MHz) spectrum bands, while can play an important role in enabling nationwide the "5G icon" on the handsets (unlocking the "5G marketing value"), won't be able to provide sufficient single user throughput, let alone aggregate sector capacity[24] for a meaningful 4G/5G home broadband proposition[25]. A weaker site grid lowers the potential 3.5 GHz indoor coverage footprint and addressable 4G/5G home broadband market. Is the existing cell site grid dense enough for a meaningful LTE/5G based home broadband push? If yes, then which parts of the coverage footprint should be prioritised (site grid analysis selectively for different area types, urban, suburban, rural)? What does the 4G/5G FMS business case look like under different traffic forecast scenarios taking into account both coverage and capacity aspects?

- Balancing network investments with buying spectrum. A weak macro cell site grid lowers the addressable 5G home broadband market or conversely increases the site grid densification Capex and Opex burden (if it is possible at all to build significant number of new macro sites given e.g. permitting hurdles)

- Spectrum acquisition strategy and valuation: considering the above factors, what is the maximum price it is worth paying for various spectrum combinations and how much needs to be set-aside for site grid infrastructure investments?

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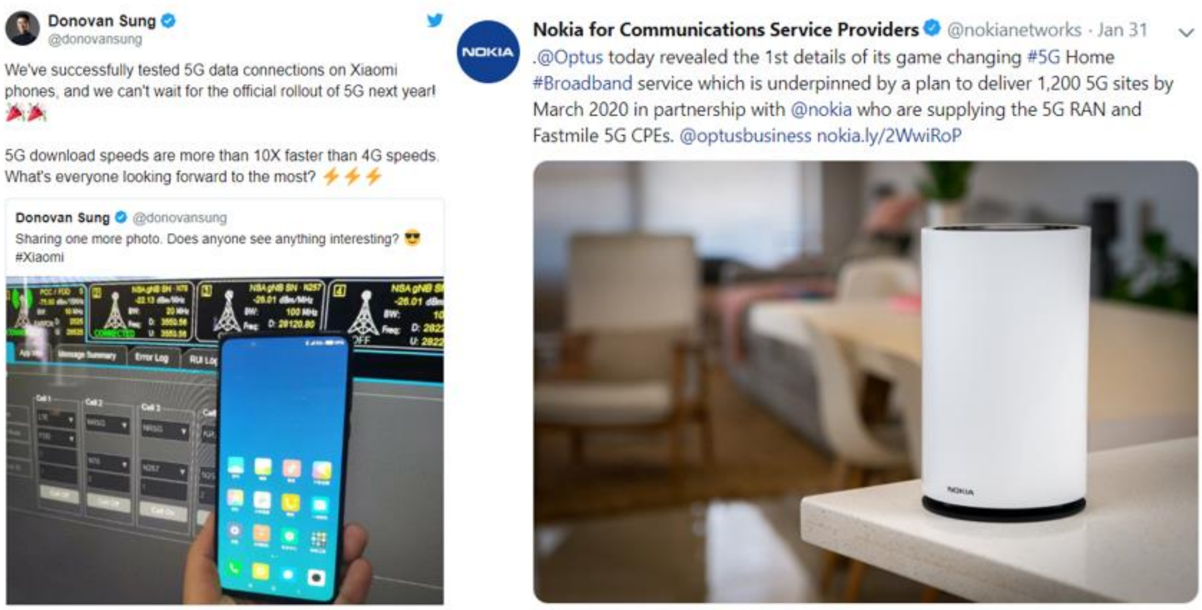
5GNR smartphones and home broadband CPEs are to be commercially launched in 2019



Source: Xiaomi, Nokia, Twitter

[24] Massive MIMO antenna arrays would be impractically large in the low-bands due to the long wavelength. Furthermore, the areas that are covered only by the low-bands are typically too far away from the cell sites to be able to meaningfully benefit from beam forming.
[25] Possible options low-band 5G deployment options are 5G-LTE Dual Connectivity (e.g. 700 MHz is dedicated to 5G NR, aggregated with the 800, 1800, 2100, 2600 are run in LTE CA mode), or 5G/LTE dynamic time domain and resource block level coexistence in e.g. the 800 MHz band.

Methodological notes

We used two Tutela databases for the analysis:

- For the throughput and latency metrics we used the live dataset of the Tutela Explorer tool, with roughly 10 days of data from the end of January 2019

- For the site density and spectrum band deployment analysis we used a larger database, containing measurements from a 3 month long (1st October 2018-31st December 2018) period

For downlink throughput measurement Tutela (by default) uses a 2Mbyte download file size. Tutela's network tests simulate typical user mobile behaviour, such as accessing websites or downloading images, rather than stress testing maximum potential speeds for mobile networks under optimum test conditions, giving genuine insight into real world customer experience.

For this high level, country-by-county comparison we used the eNodeB per 1000 pop site density metric. Site per km^2 may be a more adequate metric e.g. if we assess the likely 5G coverage potential of specific urban, suburban and rural geographical areas. Tutela has the capability to analyse site densities and band deployment on selected geographical areas such as cities or specific area types.

We chose the number of LTE bands per site as a simple metric to characterise capacity, however it doesn't take into account the actual bandwidth of each band deployed (e.g. 2x10 MHz or 2x20 MHz in the 2100 MHz FDD band). Some of the smartphones let the Tutela code access information on the carrier bandwidth (MHz) per LTE band, allowing for a deeper capacity analysis than presented in this report.

There is significant variation in the radio performance and capabilities of various smartphone brands and models. An operator where lower end phones are overrepresented (e.g. a challenger brand that targets lower end of the market) may show worse LTE network performance than an operator – with similar spectrum and network deployment – that has a user base that is equipped with more expensive, more advanced phones (e.g. higher order carrier aggregation, 4x4 MIMO etc). Tutela's measurements do register phone brand, model and operating system version but it was beyond the scope of this public report to explore the phone performance factor.

The detailed description of Tutela's measurement methodology and collected data points is available at the link below (free website registration required):

https://support.tutela.com/hc/en-us/categories/115000337089-Data-and-Methodologies

About Tutela

Tutela is a crowd sourcing based mobile network performance measurement specialist firm. **Tutela crowdsources more mobile network statistics than any other company in the world**, collecting over 30 billion location-based mobile quality data points every day, from over 250 million mobile handsets, embedded into the codes of over three thousand partner applications like games and weather apps (Tutela pays to the app's developers in return for hosting its code). In addition to measuring throughput, latency and other key performance indicators, Tutela also collects detailed information on signal strength, cell site IDs and the used frequency bands.

At Tutela we understand the importance of having the right information at the right time. Together with a great team of passionate experts, we developed a unique way of collecting large amounts of data. Collaborating with application developers and industry professionals, we provide businesses the means to make well informed decisions.

Contact: Tom Luke, Vice President, **tl@tutela.com**

About Rewheel

New radio spectrum bands, 4.5G and 5G technology, unlimited mobile data plans and the Internet of Things radically change mobile network operators' cost, revenue and profitability dynamics. ***Rewheel's mission is to help operators prepare for the paradigm shift*** *in* ***network and spectrum strategy****,* ***spectrum valuation****,* ***network sharing****,* ***M&A****,* ***MVNO economics*** *and* ***mobile data pricing****.*

Founded in 2009, Rewheel is a Finland based boutique management consultancy. Our clients are mainly European mobile network operators, telco groups, MVNO groups, sector regulators, governments, global internet firms, mobile data-centric start ups, PE and VC investors.

We delivered management consultancy work for clients in the United Kingdom, United States, Ireland, Switzerland, Finland, Sweden, Belgium, Greece, Poland, Slovenia, Hungary, Russia, Romania. Buyers of our research reports and related strategic workshops include many companies and authorities across Europe and worldwide.

Since 2010 we have been supporting a number of European challenger mobile operators in multiband (700, 700 SDL, 800, 900, 1400 SDL, 1800, 2600, 3.5 GHz) auctions with spectrum valuation and strategic advisory services.

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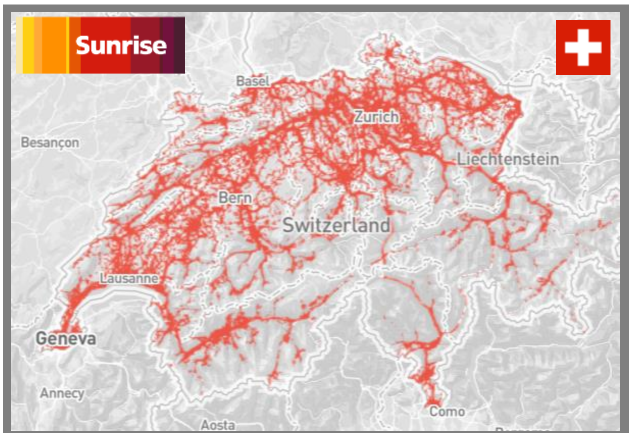
For further research reports visit **research.rewheel.fi.** To learn more about our consultancy's profile visit **www.rewheel.fi** or please contact us at **research@rewheel.fi** or **+358442032339**.



Most recently, Rewheel has been supporting the Swiss unlimited mobile data challenger Sunrise in spectrum strategy, multi-band spectrum valuation modelling, 4G/5G fixed-to-mobile broadband substitution business case and advocacy support services in preparation for the 700-700SDL-1400SDL-2600-3600 MHz multi-band spectrum auction. The auction concluded in February 2019. Sunrise successfully secured – among others – 100 MHz in the 3.5 GHz band, spending a total of 89 million Swiss Francs. Sunrise aims to attack the Swiss home broadband market outside the larger cities by using its 4G/5G based mobile infrastructure.

"We prepared meticulously for the auction, resulting in prudent use of our resources to secure valuable spectrum. This clever bidding strategy has secured the implementation of our 5G strategy as planned. Our entire frequency portfolio of existing and new frequencies enables us to deliver the outstanding network quality and capacity needed in the years to come. We were able to acquire the strategically most important bands at a very favourable price per MHz, even better than the competition. A look abroad shows that providers in countries like Italy and the UK had to spend much more money for the most important frequencies. We are therefore very satisfied with the outcome of the auction."
– said Sunrise's CEO Mr. Olaf Swantee

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