

Capacity utilization and fixed-to-mobile broadband substitution potential – A study of 64 European operators

Topical for operators contemplating fixed-to-mobile broadband substitution ahead of upcoming 700, 1500 (SDL), 2300, 3400-3600 MHz spectrum auctions

- Most European mobile operators utilized in 2016 a tiny fraction of their available network capacity
- There are significant fixed-to-mobile broadband substitution gains that can be realized if operators unleash the abundant capacity in their networks by offering unlimited data plans
- Mobile operators could carry today 100 GB per person per month and will soon have enough capacity (TDD/massive MIMO) for 200 GB per person per month or ≈500 GB per household

Rewheel / Digital Fuel Monitor-PRO research study, 21st March 2017

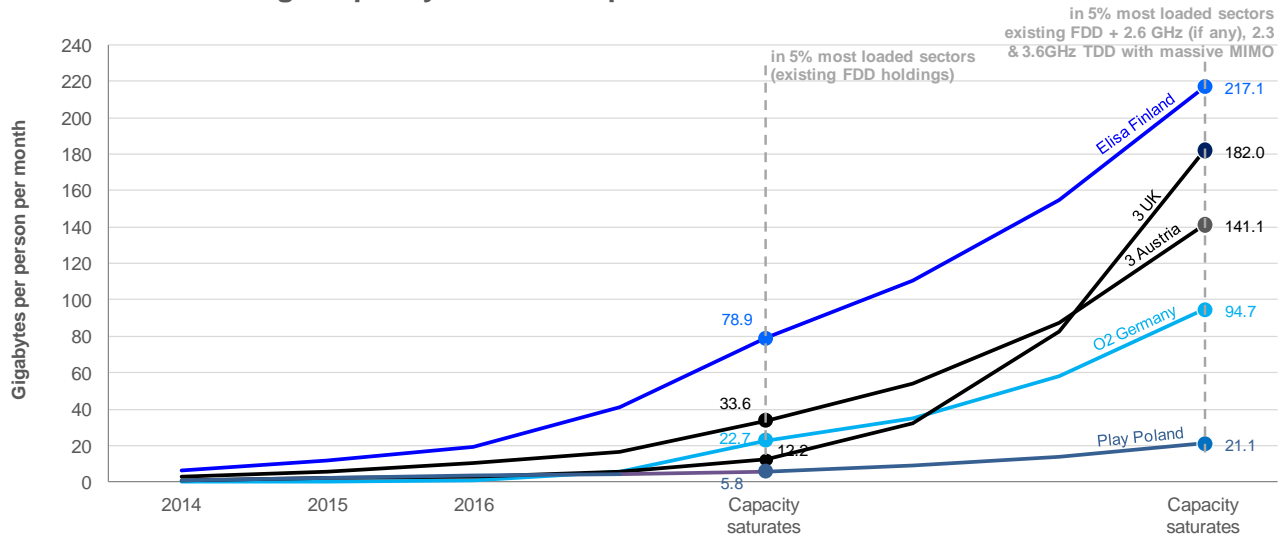
Mobile network operator name - country code	Country population 2016	Annual data volume 2016 Terabytes	Monthly data volume per pop covered Gigabytes 2016	Aggregate Downlink Busy Hour throughput Gbit/s 2016 year average	Radio network capacity utilization		Fixed-to-mobile broadband substitution potential					
					2016 year average, existing FDD spectrum holdings, existing macro site grid, 4x4 MIMO, 256 QAM, downlink	2016 year average	Incremental 100 GB/month MBB users expressed as a % of country population that can be accommodated by operator available macro grid capacity (up to 80% utilisation in 5% most loaded macro site sectors)					
					5% most loaded sectors	50% least loaded sectors	with existing FDD spectrum holdings	AND use existing 2.6GHz TDD spectrum holdings	AND use massive MIMO on existing 2.6GHz TDD spectrum holdings	AND 40MHz of 3.6GHz TDD with massive MIMO	AND 10MHz of 2.3GHz TDD with massive MIMO	Aggregate DL BH Throughput Gbit/s
Elisa-FI	5,487,308	448,500	6.8	203	20%	1.5%	21%					
DNA-FI	5,487,308	344,602	5.2	156	19%	1.5%	16%					
3-AT	8,700,471	371,000	3.6	168	24%	1.8%	8%					
Sonera-FI	5,487,308	210,344	3.2	95	10%	0.8%	21%					
3-IE	4,658,530	116,000	2.1	52	12%	1.0%	11%					
TDC-DK	5,707,251	123,082	1.8	56	13%	1.0%	9%					
Swisscom-CH	8,325,194	173,836	1.7	79	9%	0.7%	14%					
T-Mobile-AT	8,700,471	168,393	1.6	76	15%	1.2%	7%					
Telenor-NO	5,213,985	99,000	1.6	45	4%	0.3%	32%					
Telenor-SE	9,851,017	179,100	1.5	81	11%	0.8%	10%					
3-DK	5,707,251	99,112	1.4	45	28%	2.2%	3%					
Vodafone-IE	4,658,530	69,600	1.2	31	13%	1.0%	6%					
Telia-SE	9,851,017	145,776	1.2	66	6%	0.5%	14%					
3-SE	9,851,017	142,088	1.2	64	17%	1.3%	5%					
Telia-DK	5,707,251	78,800	1.2	36	7%	0.6%	11%					
A1-AT	8,700,471	121,134	1.2	55	7%	0.5%	12%					
Tele2-SE	9,851,017	132,942	1.1	60	9%	0.7%	9%					
Windtre-IT	60,665,551	760,320	1.0	344	15%	1.1%	5%					
Play-PL	37,967,209	472,200	1.0	213	48%	3.7%	1%					
Telenor-DK	5,707,251	67,323	1.0	30	7%	0.5%	11%					
Telia-NO	5,213,985	57,750	0.9	26	5%	0.4%	14%					
Meteor-IE	4,658,530	46,400	0.8	21	13%	1.0%	4%					
3-UK	65,341,183	500,460	0.6	226	21%	1.6%	2%					
Sunrise-CH	8,325,194	60,895	0.6	28	6%	0.5%	8%					
EE-UK	65,341,183	430,000	0.5	194	7%	0.5%	6%					
Salt-CH	8,325,194	50,134	0.5	23	6%	0.5%	6%					
Orange-PL	37,967,209	214,200	0.5	97	11%	0.8%	3%					
Proximus-BE	11,289,853	62,379	0.5	28	6%	0.4%	6%					
Turkcell-TR	78,741,053	431,234	0.5	195	3%	0.2%	12%					
T-Mobile-PL	37,967,209	200,234	0.4	91	8%	0.6%	4%					
Polkomtel-PL	37,967,209	198,456	0.4	90	16%	1.3%	2%					
BouyguesTelecom-FR	66,661,621	341,039	0.4	154	8%	0.6%	4%					
KPN-NL	16,979,120	82,963	0.4	38	9%	0.7%	3%					
Vodafone-IT	60,665,551	294,872	0.4	133	5%	0.4%	6%					
Avea-TR	78,741,053	360,000	0.4	163	4%	0.3%	7%					
Movistar-ES	46,438,422	210,766	0.4	95	4%	0.3%	7%					
Vodafone-ES	46,438,422	208,672	0.4	94	5%	0.4%	6%					
Vodafone-TR	78,741,053	337,972	0.4	153	5%	0.4%	5%					
FreeMobile-FR	66,661,621	283,772	0.4	128	19%	1.4%	1%					
T-Mobile-DE	82,162,000	337,000	0.3	152	3%	0.2%	8%					
TIM-IT	60,665,551	228,542	0.3	103	4%	0.3%	6%					
O2-UK	65,341,183	244,867	0.3	111	12%	0.9%	2%					
Orange-ES	46,438,422	170,234	0.3	77	4%	0.3%	6%					
Orange-FR	66,661,621	240,745	0.3	109	4%	0.3%	6%					
Vodafone-DE	82,162,000	280,071	0.3	127	4%	0.3%	6%					
O2-DE	82,162,000	269,326	0.3	122	3%	0.2%	8%					
T-Mobile-NL	16,979,120	51,852	0.3	23	4%	0.3%	4%					
T-Mobile-CZ	10,553,843	32,100	0.3	15	3%	0.3%	6%					
T-Mobile-HU	9,830,485	28,526	0.2	13	3%	0.2%	7%					
Telenor-HU	9,830,485	28,526	0.2	13	3%	0.2%	7%					
O2-PPF-CZ	10,553,843	30,145	0.2	14	3%	0.3%	6%					
Orange-BE	11,289,853	31,663	0.2	14	3%	0.3%	5%					
Vodafone-UK	65,341,183	182,948	0.2	83	4%	0.3%	4%					
Vodafone-CZ	10,553,843	29,567	0.2	13	3%	0.3%	5%					
Vodafone-NL	16,979,120	43,303	0.2	20	3%	0.3%	5%					
SFR-FR	66,661,621	170,843	0.2	77	3%	0.2%	5%					
Cosmote-EL	10,793,526	25,342	0.2	11	2%	0.2%	7%					
BASE-BE	11,289,853	25,045	0.2	11	4%	0.3%	4%					
Vodafone-HU	9,830,485	18,017	0.2	8	2%	0.2%	5%					
Vodafone-EL	10,793,526	18,469	0.1	8	2%	0.2%	6%					
ice-NO	5,213,985	8,250	0.1	4	1%	0.1%	7%					
Tele2-NL	16,979,120	20,741	0.1	9	7%	0.5%	1%					
Wind-EL	10,793,526	13,434	0.1	6	2%	0.2%	4%					
Yoigo-ES	46,438,422	50,742	0.1	23	11%	0.8%	1%					

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Mobile operator highlights

- **Elisa Finland:** 'Basically Unlimited Everything' but no TDD spectrum
- **Hutchison-3 UK:** Shied away from fixed-to-mobile broadband substitution due to limited spectrum but its recent acquisition of UK broadband that holds sizable 3.6 GHz TDD spectrum could prove a game changer
- **Hutchison-3 Austria:** Focused on fixed-to-mobile broadband substitution with unlimited MBB plans and pioneering massive MIMO for commercial use
- **Telefonica-O2 Germany:** Serious about fixed-to-mobile broadband substitution?
- **Play Poland:** Unlimited data but with caveats due to very limited network capacity
- **Remaining operators:** Findings and customized analysis available upon request

Mobile operators could carry today 100 GB/person/month. Soon will have enough capacity for 200 GB/person/month or ≈500 GB/household



Country highlights

- **Finland:** Country with highest fixed-to-mobile substitution potential, a staggering 190% of population
- **Poland:** Country with the most limited network capacity i.e. highest current network capacity utilization and lowest fixed-to-mobile broadband substitution potential
- **Tight mobile oligopolies:** In the Greek, Hungarian, Czech, Belgian and German tight mobile oligopoly markets where prices are high and data caps are very restrictive the average network capacity utilization varies from 4% in Germany to 2% in Greece. Mobile networks in these countries are literally empty

Country	Country population 2016	Annual data volume Terabytes 2016	Data volume per person per month Gigabytes 2016	Radio network capacity utilization		Fixed-to-mobile broadband substitution potential				
				5% most loaded sectors	50% least loaded sectors	with existing FDD spectrum holdings	AND use existing 2.6GHz TDD spectrum holdings	AND use massive MIMO on existing 2.6GHz TDD spectrum holdings	AND 40MHz of 3.6GHz TDD with massive MIMO	AND 10MHz of 2.3GHz TDD with massive MIMO
Finland	5,487,308	1,003,446	15.24	16%	1.3%	58%	58%	58%	163%	190%
Austria	8,700,471	660,527	6.33	15%	1.2%	27%				
Denmark	5,707,251	368,317	5.38	14%	1.1%	34%				
Sweden	9,851,017	599,906	5.07	11%	0.8%	38%				
Ireland	4,658,530	232,000	4.15	13%	1.0%	21%				
Switzerland	8,325,194	284,865	2.85	7%	0.5%	27%				
Norway	5,213,985	165,000	2.64	3%	0.3%	53%				
Poland	37,967,209	1,085,090	2.38	21%	1.6%	9%				
Italy	60,665,551	1,283,734	1.76	8%	0.6%	16%				
United Kingdom	65,341,183	1,358,275	1.73	11%	0.8%	13%				
France	66,661,621	1,036,398	1.30	9%	0.7%	16%				
Turkey	78,741,053	1,129,206	1.20	4%	0.3%	24%				
Spain	46,438,422	640,414	1.15	6%	0.5%	19%				
Netherlands	16,979,120	198,858	0.98	6%	0.4%	13%				
Germany	82,162,000	886,397	0.90	3%	0.2%	22%				
Belgium	11,289,853	119,087	0.88	4%	0.3%	15%				
Czech Republic	10,553,843	91,812	0.72	3%	0.3%	16%				
Hungary	9,830,485	75,069	0.64	3%	0.2%	19%				
Greece	10,793,526	57,245	0.44	2%	0.2%	17%				

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Context of study

Unlimited mobile data is spreading in Europe

In October 2016 we reported, in the DFMonitor 6th 2H2016 release, that unlimited mobile data is back. In Europe unlimited mobile plans resurfaced during 2016 in Austria (by all three operators), Switzerland (by all three operators), Germany, Netherlands, Denmark, Slovenia and continue to make inroads in Finland (where during the 1H2016 54% of subscribers are on unlimited data plans up from 47% in 1H2015), Latvia, Lithuania, Estonia, Poland, Ireland and the UK (where 3's unlimited plan is pushing market volume allowances higher). Most recently the 4th mobile network operator in Slovakia launched unlimited mobile data for €25 per month. Unlimited mobile data is now available in 14 European countries. Moreover, consumers can buy a 4G mobile broadband plan with unlimited volume of data for €25 or less in 6 countries: Poland, Austria, Latvia, Lithuania, Finland and Estonia.

Capacity abundance

Many in the industry have held and are still holding the mistaken conviction that mobile operators are running out or soon will run out of spectrum and network capacity. A spectrum crunch has been prophesized the last 10 years by the industry due to the explosive growth in smartphone use and proliferation of data-only connected mobile devices. However, given that the average mobile network performance and speeds have been rising¹² across the continent, miraculously, the capacity crunch is being deferred every year to the very near future. According to Akamai's 4Q2016 state of the internet report³ as LTE and LTE-Advanced spreads, the average mobile network speeds are in many EU/OECD countries similar or higher than fixed networks speeds.

4Q 2016 downlink connection speeds (Mbit/s)			
Akamai, CDN-side passive measurements			
	Fixed networks	Mobile networks (fastest first)	difference
Switzerland	21.2	31.1	9.9
United Kingdom	16.3	26.8	10.5
Cyprus	7.1	23.6	16.5
Germany	14.6	22.4	7.8
Finland	20.6	20.1	-0.5
Norway	23.6	18.2	-5.4
Belgium	15.9	17.5	1.6
Denmark	20.7	16.1	-4.6
Latvia	17.2	15.9	-1.3
Romania	16.1	15.3	-0.8
Netherlands	17.6	14.8	-2.8
Austria	13.9	14.6	0.7
Sweden	22.8	14.2	-8.6
Hungary	14.3	13.8	-0.5
Spain	15.4	13.4	-2
Slovakia	13	13.3	0.3
Ireland	15.3	12.8	-2.5
France	10	12.1	2.1
Estonia	11.4	11.4	0
Italy	8.7	11.2	2.5
Greece	7.5	11.1	3.6
Slovenia	14	11.1	-2.9
Luxembourg	11.1	10.5	-0.6
Poland	12.4	10	-2.4
Russia	11.6	9.5	-2.1
Lithuania	14.6	9.3	-5.3
Malta	12.9	9.1	-3.8
Croatia	8.2	9	0.8
Bulgaria	15.6	8.4	-7.2
Portugal	12.6	8.2	-4.4
United States	17.2	7.9	-9.3
Czech Republic	17.3	7.7	-9.6

Source: Akamai State of The Internet 4Q 2016, Rewheel/DFMonitor analysis

¹OpenSignal The State of LTE November 2016: "download speeds approach 50 Mbps in the most advanced 4G countries"

²According to Akamai 4Q2016 state of the internet report average mobile network speeds have been steadily rising in most markets

³<https://www.akamai.com/us/en/multimedia/documents/state-of-the-internet/q4-2016-state-of-the-internet-connectivity-report.pdf>

Undoubtedly, launching unlimited mobile data is the last thing that operators will do if they were facing a capacity crunch. The fact that more and more operators are launching unlimited mobile data suggests that mobile network capacity is already in abundance and incremental investments in expanding the capacity further will not yield significant, if any, CAPEX increases: a near zero marginal cost business.

Estimating network capacity utilisation

In this research study we present an estimate of the 2016 radio network capacity utilization for 64 European mobile network operators. We estimate the radio network capacity utilization of mobile operators in the 5% of their most loaded sectors and across the entire network by taking into account the existing FDD spectrum holdings, the reported (or in some cases estimated) number of macro BTS sites, the reported (or in some cases estimated) 2016 traffic volume and by applying typical data traffic geo-distribution, busy hour and spectrum efficiency profiles (corresponding to typical 4x4 MIMO and 256QAM macro sector capacity).

Our findings confirm our field experience gained through our recent spectrum valuation and fixed-to-mobile broadband substitution business case consulting engagements: many European mobile operators are currently utilizing only a tiny fraction of their available macro network capacity. The fact that most mobile networks are essentially heavily under-utilized today raises the following question: how should mobile operators put into use all the readily available mobile network capacity and improve the return on already realized investments?

Operators in Finland, Austria, Poland and other European countries have been executing mobile-centric (i.e. fixed-to-mobile broadband substitution) strategies by offering affordably priced unlimited volume smartphone and mobile broadband plans and by encouraging consumers to switch from outdated DSL-based broadband connections or expensive fibre connections to 4G mobile broadband (full mobility or home-centric stationary use) connections.

Fixed-to-mobile broadband substitution potential

Having estimated the 2016 radio network capacity utilization for each of the 64 European mobile operators, considering their existing FDD spectrum holdings, we further estimate the incremental number of 100 GB per month (average usage) mobile broadband users expressed as a percentage of country population that can be accommodated by the operators' currently available macro site network capacity. It is important to note that our capacity estimations do not include capacity enhancements from future new macro or small cell site rollouts.

2.6 GHz, 2.3 GHz and 3.4 GHz - 3.8 GHz massive MIMO capacity boost

Massive MIMO is a very promising technology that will dramatically increase the spectral efficiency and sector capacity of the macro site layer, primarily in the high frequency, TDD bands. Thanks to advanced beam forming the technology can also extend the coverage footprint and deep indoor reach of high frequency bands. More importantly, massive MIMO can make a great impact from day one because it does not need new features on the user equipment side and it is sufficient to deploy only in the most loaded sectors. Massive MIMO was a hot topic on MWC2017 and some of the most data-heavy operators, such as Hutchison in Austria, are planning to put it into commercial use in 2017. The 2.6 GHz, 2.3 GHz, and 3.4 GHz – 3.8 GHz TDD bands are ideal candidates to start deploying massive MIMO by surgically targeting the 5% - 10% most loaded sectors in the network.

We repeat the capacity dimensioning we described above for FDD spectrum holdings by also taking into account the operators' 2.6 GHz TDD spectrum holdings, if any, first without assuming massive MIMO and in the next step by assuming that all operators will significantly boost their capacity by using massive MIMO technology on their 2.6 GHz TDD spectrum. In the last two iterations we assume that each of the 64 operators will acquire 3.6 GHz and 2.3 GHz TDD spectrum and will deploy it with massive MIMO, hence significantly boosting its overall macro sector capacity.

The results show that Elisa Finland, the operator that had during 2016 the highest mobile data traffic volume normalized by the country population and a radio network capacity utilization of 20% in the 5% most loaded sectors, could accommodate with its existing FDD spectrum holdings an incremental 1.1 million 100 GB per month mobile broadband users (21% of Finnish population). If Elisa was to acquire and deploy with massive MIMO 3.6 GHz and 2.3 GHz TDD spectrum it could accommodate several million incremental mobile broadband 100 GB per month users.

Essentially Elisa's network in Finland and as well many other networks across Europe can easily accommodate today 100 GB per person per month and soon will be capable (more TDD spectrum & massive MIMO) of accommodating more than 200 GB per person per month or roughly 500 GB per household.

Upcoming 700 MHz, 1500 MHz (SDL), 2.3 GHz and 3.4 GHz – 3.8 GHz spectrum auctions

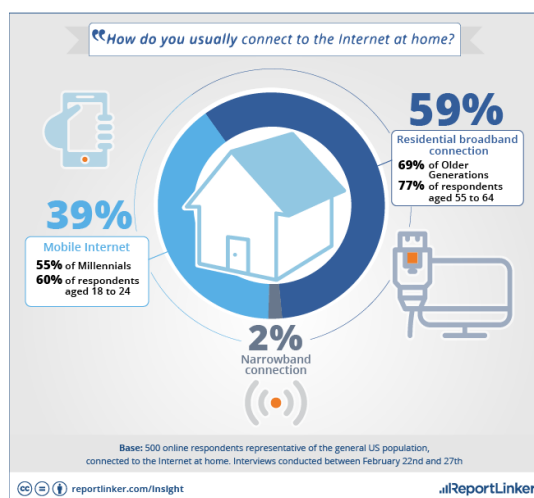
During the first half of 2017 ComReg in Ireland has scheduled an auction for assigning 350 MHz of spectrum in the 3.4 – 3.8 GHz bands and later this year Ofcom plans to auction spectrum in the 2.3 GHz (40 MHz) and 3.4 GHz (150 MHz) bands. The Dutch Ministry of Economic affairs is planning a spectrum auction in the 700 MHz, 2.1 GHz, and >6 GHz bands while the Italian government announced that it is expecting to raise up to €2.5 billion by tendering spectrum earmark for 5G in the 3.4 GHz – 3.8 GHz bands.

Our findings show that the overwhelming majority of the 64 European mobile operators we studied utilized in 2016 a tiny fraction of their available network capacity. Operators with a restrictive mobile data cap policy face no spectrum crunch in the immediate or even distant future (>10 years) unless of course they launch Finnish-like '*Basically Unlimited Everything*' plans and actively pursue fixed-to-mobile broadband substitution. So should operators rush to acquire low frequency spectrum in the 700 MHz band given that most hold similar spectrum in sub 1 GHz bands? Should they acquire high frequency TDD spectrum in the 2.3 GHz and 3.4 – 3.8 GHz bands and how much should they pay for it? What about spectrum in the millimetre wave bands?

We believe that fixed-to-mobile broadband substitution (i.e. unlimited mobile data) and the battle for the connected car (i.e. geo versus pop coverage) will be the key valuation drivers on the upcoming 5G spectrum auctions.

Fixed-to-mobile broadband substitution is here to stay

According to a new ReportLinker survey⁴ almost 40% of Americans say they use their smartphone to access the Internet at home. "In the same way mobile phones have replaced landlines, they appear to be poised to eradicate the wireless router."



⁴<http://www.reportlinker.com/insight/internet-connections.html>

FierceWireless recently reported⁵ that “Americans' ever-increasing appetite for mobile data appears to be eating into home broadband usage, according to fresh data from the National Telecommunications and Information Administration (NTIA) three-fourths of U.S. households accessing the web at home last year did so through fixed-line connections such as cable, DSL and FiOS. That's a sizable drop from the 82 percent who used fixed-line connections at home in July 2013. Over this same period, the data also shows that the proportion of online households that relied exclusively on mobile service at home doubled between 2013 and 2015, from 10 percent to 20 percent”.

In Europe more than 30% of all households were mobile broadband only households in Finland in 2016 according to data reported by Eurostat⁶. Italy had 22%, Austria 17% and Poland 17% of mobile broadband only households in 2016.

ReportLinker stated that “Another sure sign broadband is on thin ice: 55% of the Millennial generation – including 60% of younger Millennials – are using their mobile to connect to the Internet at home, according to ReportLinker's survey. By contrast, 69% of older generations prefer a broadband connection.”

We couldn't agree more. Fixed-to-mobile broadband substitution is here to stay!

⁵<http://www.fiercewireless.com/wireless/ntia-mobile-only-home-internet-users-doubles-to-20-all-americans-2015>

⁶<http://ec.europa.eu/eurostat/web/digital-economy-and-society/data/database>

Overview of modelling methodology

The main operator specific inputs in our analysis are the existing spectrum holdings in paired (FDD) 700, 800, 900, 1800, 1500 (SDL), 2100 and 2600 MHz bands and unpaired (TDD) 2.6 GHz band (tracked by the DFMonitor spectrum database), the reported or estimated number of macro sites and the reported or estimated annual (2016) data volumes.

We applied the same assumption for the number of sectors per macro site, sector spectral efficiency (using LTE 4x4 MIMO, 256QAM and as a separate step massive MIMO in the TDD bands), TD-LTE configurations (uplink/downlink capacity split), overheads between radio and user plane throughput, traffic busy hour, geo distribution and uplink/downlink volume ratio for all 64 operators.

The main operator specific outputs are the downlink sector capacity (assuming LTE 4x4 MIMO, 256 QAM and as a separate step massive MIMO in TDD bands) and the busy hour throughput in the 5% most loaded sectors.

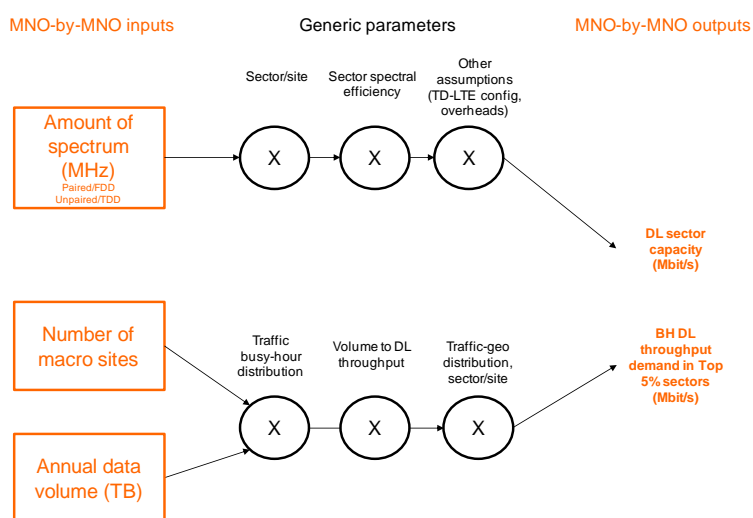
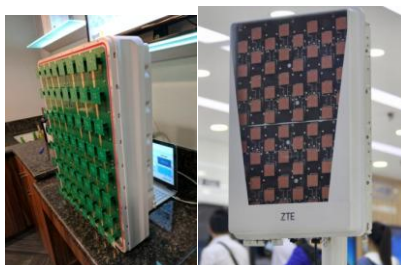


Illustration of capacity modelling methodology applied in this study

Beside the aggregate downlink busy hour throughput estimations we also estimated the macro site level backhaul throughput required for each of the 64 operators.

Our study shows that sector spectral efficiency without and with massive MIMO will be the main mobile data capacity driver going forward. We reviewed recent trial and demonstration announcements, scientific research reports, liaised with leading scientific researches in the field and as well we interviewed some massive MIMO active antenna array vendors. Based on these insights we derived a conservative massive MIMO sector spectral efficiency for the purpose of this study.



Nokia Massive MIMO 64T64R active antenna demoed with Sprint at MWC 2017, ZTE massive MIMO active antenna. Source: ZTE

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About Rewheel

Founded in 2009, Rewheel is a Helsinki-Finland based boutique management consultancy specialising in the appraisal of mobile data-centric business models with emphasis on network economics, spectrum, capacity, regulatory analysis and competition assessments.

Rewheel's clients are mainly *pro-competitive* mobile network operators, telco groups, MVNO groups, sector regulators, governments, global internet firms, mobile data-centric start ups, PE and VC investors.

We delivered spectrum valuation, mobile data strategy and network economics 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 (see: Digital Fuel Monitor) and related strategic workshops include many companies and authorities across Europe and worldwide.

Since 2010 we have been supporting many European challenger mobile operators in multiband (800, 900, 1800, 2600MHz) spectrum auctions. During 2017 we are supporting a Western European challenger operator in an upcoming 700, 1500 and 3400 to 3800 MHz multiband auction.

To learn more about our consultancy's profile visit rewheel.fi