When will Exponential Mobile Growth Stop?

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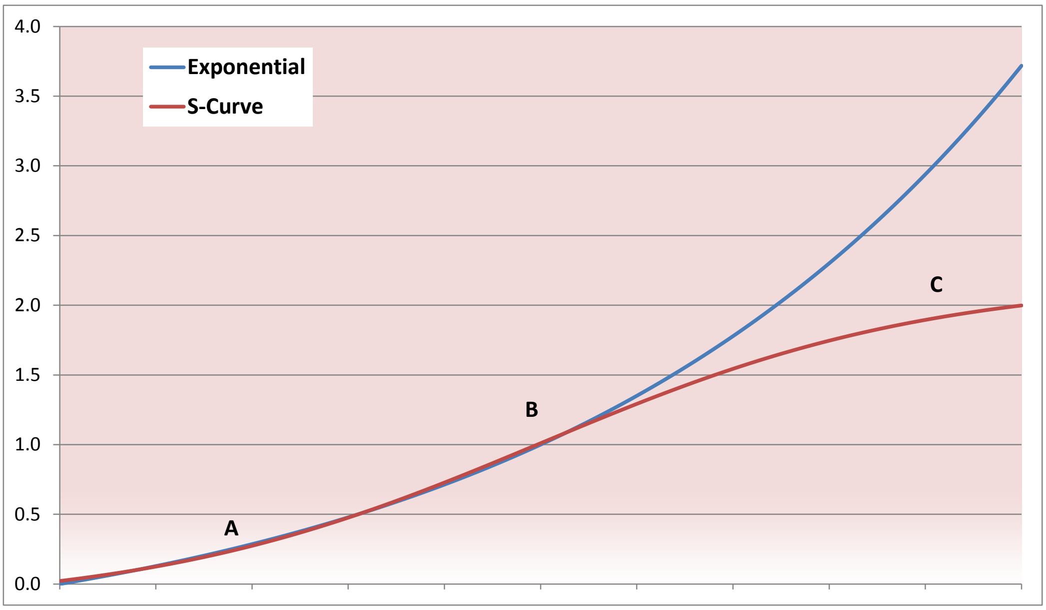
Executive Summary

The majority of predictions of future mobile data growth continue to show an exponential pattern many years into the future. For example, Report ITU-R M.2370, "IMT traffic estimates for the years 2020 to 2030" forecasts that the growth in mobile data will continue to follow an exponential pattern until the year 2030. Exponential growth can not continue indefinitely as the result would be that whatever is growing will eventually reach an infinite size. In most cases, the growth of something follows an 'S-Curve' where growth is pseudo-exponential to begin with, but where it slows down and eventually reaches equilibrium in the long term when no further growth takes place.

It can be seen below that over an initial growth period (area 'A'), an exponential curve and an S-curve have near identical values, meaning that it can be easy to mistake one for the other. However whilst an exponential curve continues to grow, an S-curve flattens off and there is a point where growth stops (area 'C'). There is also a point around the middle of the S-curve, where it begins to diverge from an exponential curve and growth briefly follows a near linear pattern (area 'B').



This report identifies how and when the growth in mobile data will slow down and the extent to which there are already signs that the inflection point in the S-curve has been reached. To do so we have taken two independent approaches:

- Firstly, we have calculated how much data an individual may be able to consume, to determine what a sensible finite limit to mobile date usage might be;
- Secondly, we have examined the growth in mobile data usage in a number of advanced countries where users are already 'ahead of the curve' with respect to demand.

Our calculations indicate that exponential growth will not continue forever and that the majority of growth in mobile data traffic will be complete by the mid 2020s. We have also identified 3 countries where mobile data growth is already showing signs of slowing down and in each case, it is clear that the reason for **this slow down is not related to spectrum availability** and that **there may only be a factor of 3 to 4 times mobile data traffic growth remaining** in those countries.

1 Introduction

1.1 Background

The majority of predictions of future mobile data growth continue to show an exponential pattern many years into the future. For example, Report ITU-R M.2370, "IMT traffic estimates for the years 2020 to 2030" forecasts that the growth in mobile data will continue to follow an exponential pattern until the year 2030. These exponential growth forecasts are leading to large demands for spectrum for IMT services, in particular for future 5G technology.

Exponential growth can not continue indefinitely as the result would be that whatever is growing will eventually reach an infinite size. In most cases, the growth of something follows an 'S-Curve' where growth is pseudo-exponential to begin with, but where it slows down and eventually reaches equilibrium in the long term when no further growth takes place.

It can be seen below that over an initial growth period (area 'A'), an exponential curve and an S-curve have near identical values, meaning that it can be easy to mistake one for the other. However whilst an exponential curve continues to grow, an S-curve flattens off and there is a point where growth stops (area 'C'). There is also a point around the middle of the S-curve, where it begins to diverge from an exponential curve and growth briefly follows a near linear pattern (area 'B').

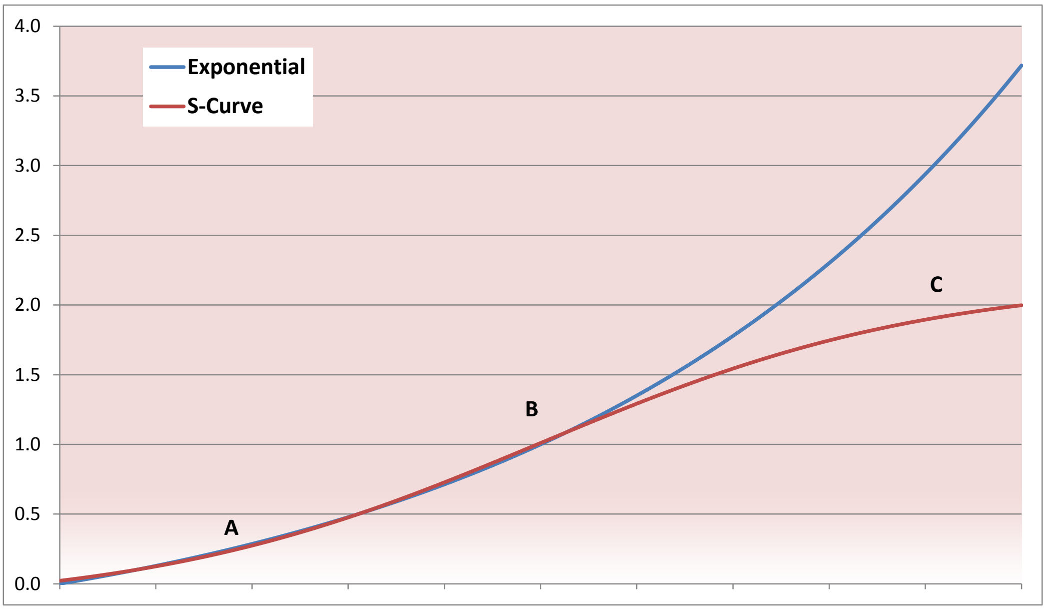


Figure 1: Comparison of exponential and S-shaped curves

Following on from research conducted by LS telcom into the accuracy of mobile spectrum demand estimates[1] and the usage of spectrum by mobile operators[2], this report explores mobile data growth forecasts to answer the question "when will exponential mobile data growth stop?"

[1] "Mobile Spectrum Requirement Estimates: Getting the Inputs Right", LS telcom and TMF Associates, August 2014

[2] "Analysis of the World-Wide Licensing and Usage of IMT Spectrum", LS telcom, September 2014

To try and answer this question taken two independent approaches:

- Firstly, we have calculated how much data an individual may be able to consume, to determine what a sensible finite limit to mobile date usage might be;
- Secondly, we have examined the growth in mobile data usage in a number of advanced countries where users are already 'ahead of the curve' with respect to demand.

Our calculations have used what most would regard as extreme values (such as every person on the planet streaming live ultra-high definition video for 16 hours every day) and yet still indicate that **exponential growth will not continue forever**, and that **the majority of growth in mobile data traffic will be complete by the mid 2020s**.

We have also identified 3 countries where mobile data growth is already showing signs of slowing down and in each case, it is clear that the reason for **this slow down is not related to spectrum availability** and that **there may only be a factor of 3 to 4 times mobile data traffic growth remaining** in those countries.

1.2 Structure of this document

The remainder of this document is structured as follows:

- Section 2 discusses the drivers of mobile data growth
- Section 3 calculates a potential long-term limit for personal and world-wide mobile data traffic
- Section 4 examines three countries where mobile data growth is slowing

2 Drivers of mobile data growth

2.1 Introduction

Growth in mobile data is fundamentally driven by two basic factors:

- Growth in the number of connections to a network; and
- Growth in the amount of data each connection uses.

We have used the term ‘connection’ rather than ‘subscriber’ because it is foreseen that in addition to humans connecting to mobile networks, an increasing number of machines will also connect to them. Whilst it is feasible to further subdivide these categories, or to introduce additional sub-categories for specific user types (e.g. business versus personal use, or pre-pay versus post-pay), to try and get a global view on future data growth, considering human subscribers and machine connections is a reasonable and pragmatic way to examine growth in mobile data.

2.2 Growth in subscribers

2.2.1 Current growth

According to figures from the Ericsson Mobility Report, the growth of new subscribers has been diminishing each year since 2013.

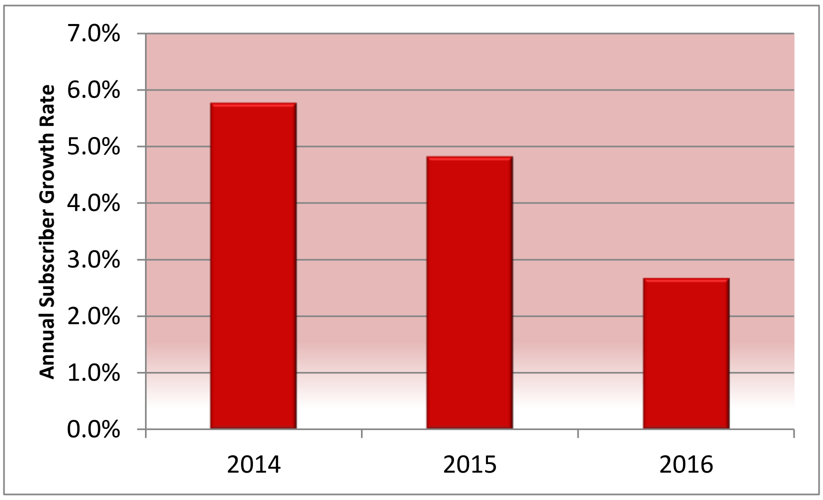


Figure 2: Global subscriber growth is slowing[3]

As of 2016, global mobile penetration stood at 101%, with some regions (Europe in particular) exceeding 130% penetration. Given that some of the population (e.g. very young children) will not have a mobile subscription, this implies that many subscribers have more than one subscription. This can be for a number of reasons:

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[3] Source: Ericsson Mobility Reports

- **On-net** mobile tariffs (e.g. making calls within the same mobile network) are cheaper than off-net calls (e.g. making calls from one mobile network to another) and thus people have multiple subscriptions to arbitrage prices;
- The **coverage or availability** of networks is poor, and hence people have subscriptions on multiple networks and choose the one with the best service in the area they are visiting;
- People have **more than one device**, for example a business phone and a private phone, or a mobile phone and a tablet.

On–net tariff arbitrage is on the decline. It is remedied by operators reducing off-net call prices and many are seeing the logic of doing this in order to retain customers. As such, we do not believe that this will be a future driver for subscriptions amongst people.

Coverage and availability are improving as networks continue to roll-out their services, however in some countries (in particular developing countries where, for example, electricity supplies can be sporadic and thus some networks may fail whilst others maintain a service) this continues to be a reason why some people may have multiple subscriptions. We would see this factor declining over time, but more slowly than on-net arbitrage.

Having more than one device is, conversely, on the increase. In addition to one or two mobile phones, many people also have a tablet or an e-reader which has a mobile data connection. There is a limit to how many devices with heavy data consumption an individual may have, however we would continue to see the number of connections rising as a result of this, in particular in the developed world where the affordability of additional devices is reasonable.

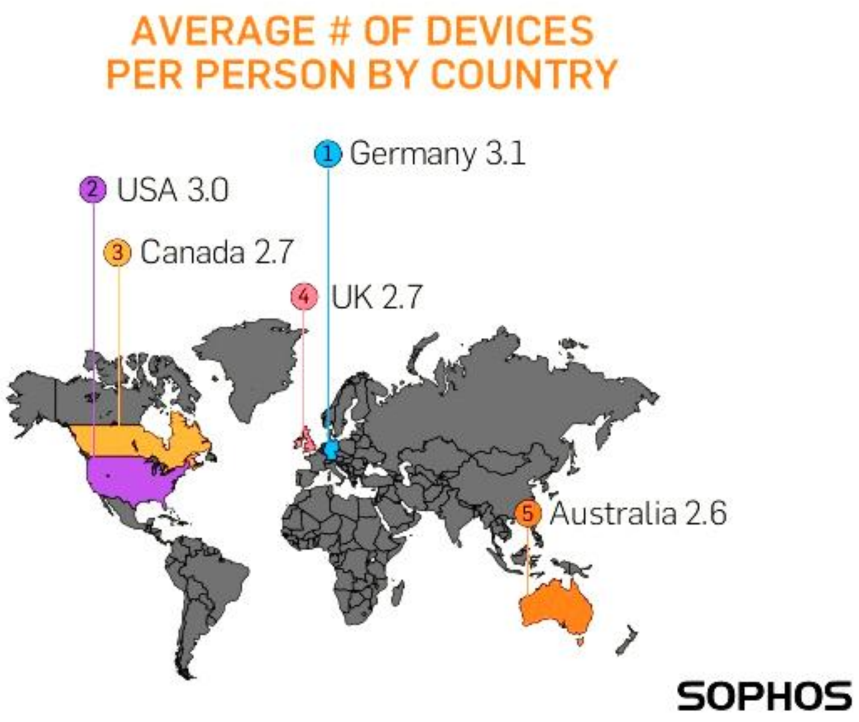

Figure 3: Number of mobile devices per person[4]

[4] Source: "How Many Devices Do You Carry?", Sophos, 2013

It is, however, questionable as to whether a user with two devices (e.g. a phone and a tablet) uses twice the amount of data. Whilst in principle one device could be being used to access a video service, with the other accessing social media, it is unlikely that both devices would be accessing different video services simultaneously. As video is the primary driver of mobile data, this suggests that though the use of a second device will have an incremental effect on the total data consumption of the person involved, having two devices will not double their data usage (see section 3.1.3 for a further discussion of this).

2.2.2 Machine Communication

In addition, the subscriber numbers reported by mobile operators include 'active SIM' cards which can include the use of the networks by some machines. For example:

- credit card machines in some stores use mobile networks to verify transactions;
- some Amazon Kindles come with free 3G to allow people to download books;
- many vending machines report their stock status via mobile networks;
- some smart meters use mobile networks (though these are often excluded from official subscriber numbers).

There is inevitably going to be a continued growth in these kinds of connections, as more machine-to-machine communication takes place. Various forecasts (e.g. CISCO, Ericsson, ITU) place the number of Internet of Things (IoT) or Machine to Machine (M2M) devices connected to mobile networks at around 2 billion by 2020. The vast majority of these devices, however, will not be transferring large amounts of data. Many of the applications of M2M or IoT are within the category of sensors, or actuators and in these cases their data requirements are very small compared with that generated by human subscribers. Whilst the number of such devices is forecast to eventually exceed that of human subscribers, their far lower data requirements are not going to have a significant impact on the traffic on mobile networks.

Various technologies such as GSM-IoT and LTE-M are being developed to support machine communication and in addition a number of bespoke technologies (such as Sigfox and LoRa) are rapidly rolling-out to provide the necessary connectivity for IoT and M2M. It is notable that all of these technologies provide relatively low bandwidth connections, implying that IoT devices will not generate large amounts of data.

Notwithstanding this, there are potential IoT applications which may use data extensively, such as video billboards or CCTV cameras. Whilst these devices have the potential to generate significant amounts of mobile data, it is by no means certain that all such devices would connect using a mobile network – many may rely on more traditional fixed or short-range wireless connections (e.g. WiFi) which for these types of application may be more reliable, have greater security, and in many cases may be more cost effective. A recent report by PWC[5] only mentions video in two IoT applications, surveillance and monitoring of road junctions (though it does not state whether this monitoring is using a mobile or fixed connection).

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[5] "Realising the benefits of mobile enabled IoT solutions", PWC, March 2015

We do not therefore regard machine communication as being the primary driver of increased mobile data traffic.

2.2.3 Source of ongoing subscriber growth

Much of the ongoing growth in new additions to mobile subscribers (as opposed to subscribers taking out multiple subscriptions) is now coming from those on lower incomes who were previously unable to afford mobile services, or who may not have had coverage which may include:

- those whose income has grown sufficiently to enable them to afford a phone and a subscription;
- those for whom a reduction in retail prices or more innovating pricing models has made a mobile device and subscription affordable;
- those for whom a mobile has become a necessity to keep in contact with others for business or personal purposes;
- those in rural or poorer areas where mobile operators had not previously provided coverage due to the poor economics of the service.

There is also potential growth from existing subscribers as not every existing subscriber necessarily employs mobile broadband services. According to the Ericsson Mobility Report, as of 2016, around 4.1 billion of the 7.5 billion subscriptions (55%) were mobile broadband, the rest were voice and text only. The growth in mobile broadband subscriptions peaked in 2015 (at 36%), and is beginning to slow down (in 2016 it was 21%). This is inevitable, as there is only around 80% growth remaining before every subscriber has mobile broadband, and this will, of course, be limited by the availability of such services, and their affordability.

Ericsson's forecast for 2020 is that there will be 8 billion mobile broadband subscriptions and 8.9 billion mobile subscriptions (annual growth rates of 10% and 2% respectively) but only 6.1 billion unique mobile subscribers (e.g. customers) from a predicted world population of around 8 billion. This represents 76% of the world population meaning that the potential additional long-term data growth caused by the remaining people is 24%.

2.3 Usage by subscribers

The amount of usage by subscribers (normally measured in Gbytes per month) is still seeing a steady increase, however there are signs that this is slowing down in some countries. This is explored further in section 4 of this report where we look at the situation in a number of countries. One thing that should be taken into account, however, is the fact that there is a very large proportion of users who generate very little traffic.

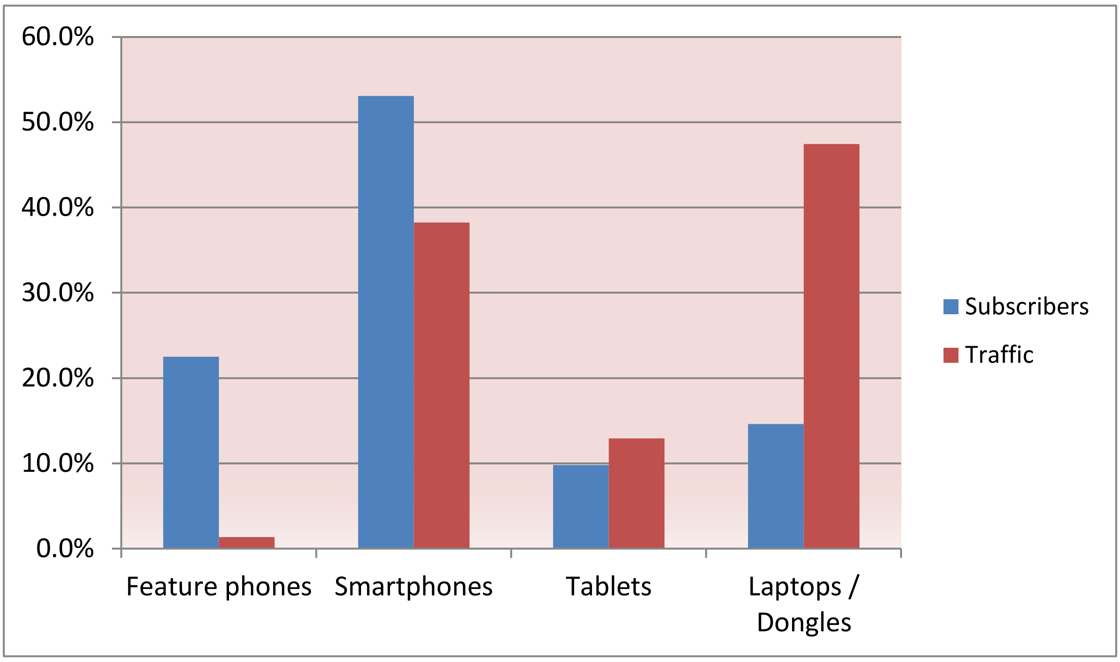


Figure 4: Traffic per device type[6]

In the example above, feature phones account for 22% of subscriptions but generate just 1.4% of the total traffic whereas laptops and dongles account for 14% of subscriptions but generate 47% of the traffic.

It is worth bearing in mind that many of those yet to be connected to mobile networks are likely to fall into lower income categories and thus are likely to have low data usage rather than being users of tablets or laptops. New users, especially those from poorer economic backgrounds, will almost inevitably have a low initial mobile data usage and their use will mostly consist of short voice calls or occasional text messages in the first instance. A study by Pew Research clearly shows the correlation between smartphone ownership and GDP, suggesting those from poorer backgrounds are far less likely to begin using mobile networks in this way.

[6] Source: J'son and Partners, Russia 2014

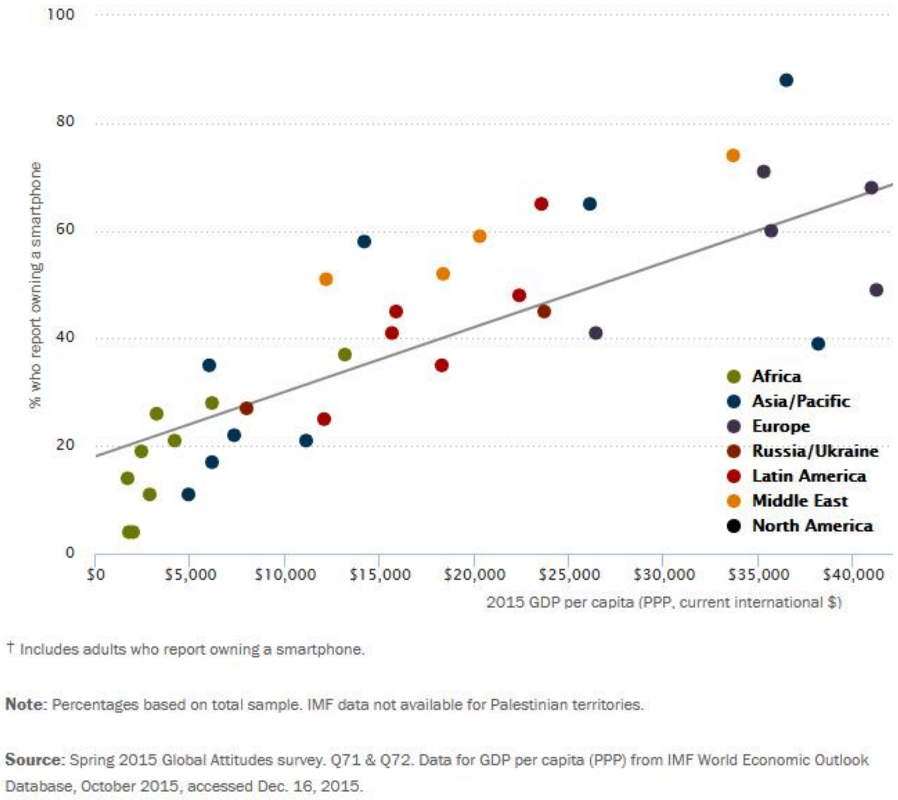


Figure 5: Smartphone ownership versus GDP[7]

Though there is therefore enormous potential for the usage by these people to grow in the long term, not least as they will be joining networks which have broadband data capabilities right away (as opposed to the early adopters who joined when mobile data capabilities were poorer) they mark the tail end of those who will reach these levels. Conversely, those who were the earliest subscribers are likely to be (for the same economic reasons) the heaviest users today. In the long term, assuming that the data use of the majority of subscribers rises to equal levels, the simple mathematical truth is that the proportion of unconnected people represents an opportunity for data growth by that same proportion. If 10% of people are yet to take up a mobile service, the long-term potential for data growth from those 10% is… 10% (i.e. even if each new user contributed the same data as existing ones, an additional 10% of users would only generate an additional 10% traffic). Thus, as we approach a point where fewer and fewer subscribers remain unconnected, the potential of those subscribers to cause growth in data demand diminishes accordingly.

[7] Source: "Smartphone Ownership and Internet Usage Continues to Climb in Emerging Economies", Pew Research, February 2016

3 Long-term limit on data use

3.1 Video as a driver

It is generally recognised that both today and over the foreseeable future, the main driver of mobile data usage is the consumption of video. For example:

- CISCO's VNI for 2017 states that 60% of all mobile traffic in 2016 was video and that this will increase to 78% by 2021.
- Ericsson's 2016 mobility report states that around 50% of all mobile traffic in 2016 was video and that this will increase to around 75% by 2022.

If the above figures are taken at face value, then scaling up the data required for video traffic by the appropriate proportion can provide a calculation of the total mobile data traffic generated by users.

It may seem that such projections may only be reasonable for the current set of services, applications and users but that there is no doubt that there will be new applications and uses that are not yet fully developed or even thought of. However as video traffic grows and assuming that this remains a fixed proportion of overall data traffic, this assumption would also provide for significant data growth opportunity in other applications. It is therefore reasonable to use video as the driver for mobile traffic even taking other services and applications into account.

The amount of data required to deliver video is fundamentally related to two aspects:

- the quality or resolution of the video; and
- the efficiency of the system used to digitally compress the video.

Each of these two aspects is discussed in more detail below.

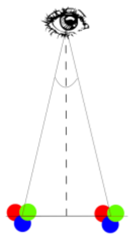
3.1.1 Video resolution

With today's mobile phones, it is possible to record and replay video with 4K resolution[8], though only very high-end phones actually have screens which can display such content and for many phones, high-definition[9] video is the best that can be displayed. In the future, it is possible that 8K video[10] will be able to be recorded on mobile devices, however with the typical size of mobile screens, the eye will not be able to detect the difference between 4K and 8K video, and hence it is not reasonable to assume that video downloads would need to use 8K, which is more likely to be used only for home cinema.

[8] 4K has a resolution of 3840 x 2160 pixels

[9] HD is generally recognised as having a resolution of 1920 x 1080 pixels

[10] 8K has a resolution of 7680 x 4320 pixels



A person with 20/20 vision holding their phone 12 inches from their eyes can see up to around 300 pixels per inch. At 4 inches distance (the closest a healthy adult can focus and the typical distance for use in virtual reality applications) they can see up to 860 pixels per inch. A device with 4K resolution and six inch screen, achieves around 740 PPI making it very close to the limit of what the eye can discern. 8K video on a typical mobile device is therefore unlikely to bring any additional benefit in terms of picture quality

For the basis of our calculations, therefore, we have assumed that 4K video is the limit of what will be needed for delivery to mobile devices. It is possible that new video formats such as immersive '360 degree surround' video may emerge, however as a worst case, this is only likely to require twice the bandwidth as a human only has two eyes with which it can experience vision.

There follows a question concerning how much video it is possible to consume. As an absolute worst-case, we will assume that the mobile phone users of the future are watching video from the time they wake, until the time they fall asleep, or approximately 16 hours per day. This is likely to be a gross exaggeration, but will at least provide an upper threshold.

3.1.2 Video compression

Video compression systems are improving all the time and much lower data rates are required to send the same quality of video. Each new generation of video encoder typically brings a 50% reduction in the amount of data required for video compared to the previous version, and over time the required bit-rate falls further as the compression techniques are optimised.

The figure below shows the bit-rate required in Mbps to deliver 720p (HD-ready) video (on the left hand axis) and 1080p (Full HD) video on the right hand axis as video compression technologies have improved from 1995 to today, as well as a projection of how these might develop to 2030.

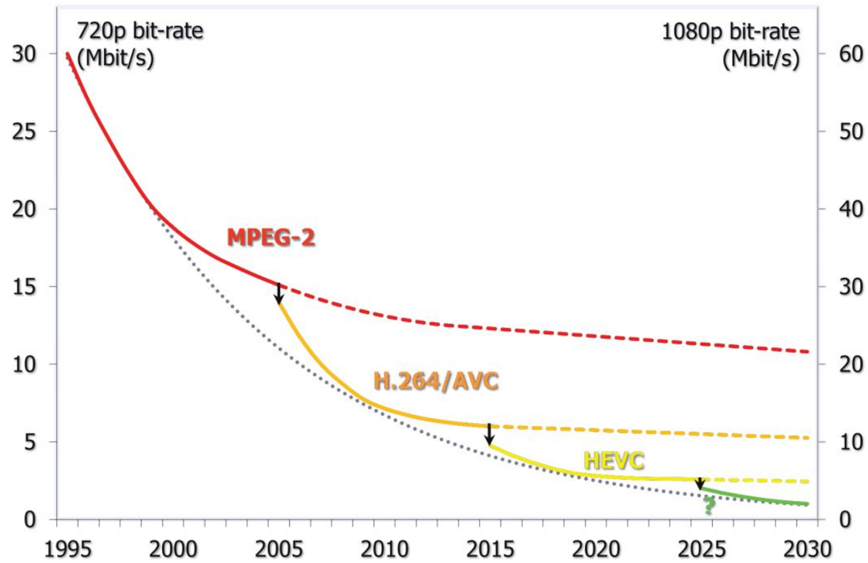


Figure 6: Bit-rate trends in practice[11]

[11] Source: "Technical Evolution of the DTT Platform", ZetaCast, January 2012

Though techniques continue to improve, the speed of progress has slowed. Nonetheless given the historic trajectory, it would be reasonable to assume that over coming years, there would be continue to be improvement in the efficiency of video compression schemes.

As of today, 4K video using HEVC video compression requires around 12 to 15 Mbps (for example to stream a 4K video on Netflix) and we shall therefore use a figure of 15 Mbps to be conservative with our calculations.

3.1.3 Using multiple devices

As has been noted in section 2.2.1, many users have more than one device and in particular may have a tablet and a mobile phone, or similar. Is it not therefore possible that users who have multiple devices may stream video on those devices, increasing overall demand?

We do not believe that this is reasonable. Whilst it may be technically feasible for users to watch video on multiple devices, it seems more likely that they would watch video on one device and use the other for connecting to social media, or checking e-mail. A study by Accenture[12] found that:

> *"as many as 87 percent of consumers are now using the TV and a second screen together, in ways that complement each other, whether that's getting more information on a TV program, accessing social media to get reactions to what they're watching on the TV screen, or shopping online."*

Although this study relates to watching television programmes (which in the study include streaming video services), it is notable that the second device is not being used for streaming video but for alternative, lower bandwidth services. As such, it would not be reasonable to assume that if there is more than 100% penetration of mobile devices, this implies that all such devices would be watching video. Instead, there is a natural limit of approximately one video stream per individual, and thus for the purposes of our calculations, the number of individuals is simply limited by the population of the planet.

[12] "Digital Video and the Connected Consumer", Accenture, 2015

3.1.4 Offloading

Recent research by Ofcom[13] states that around 70% of all data is transferred to a mobile device whilst it is connected to WiFi. The CISCO VNI provides similar statistics which show that around 60% of traffic generated by mobile devices will be offloaded (e.g. onto WiFi). An analysis of WiFi and Cellular usage in the USA conducted by Neilsen for 2016 showed that almost 80% of all mobile data traffic was carried over WiFi. In the forecasts (e.g. CISCI) these ratios remain fairly constant over time.

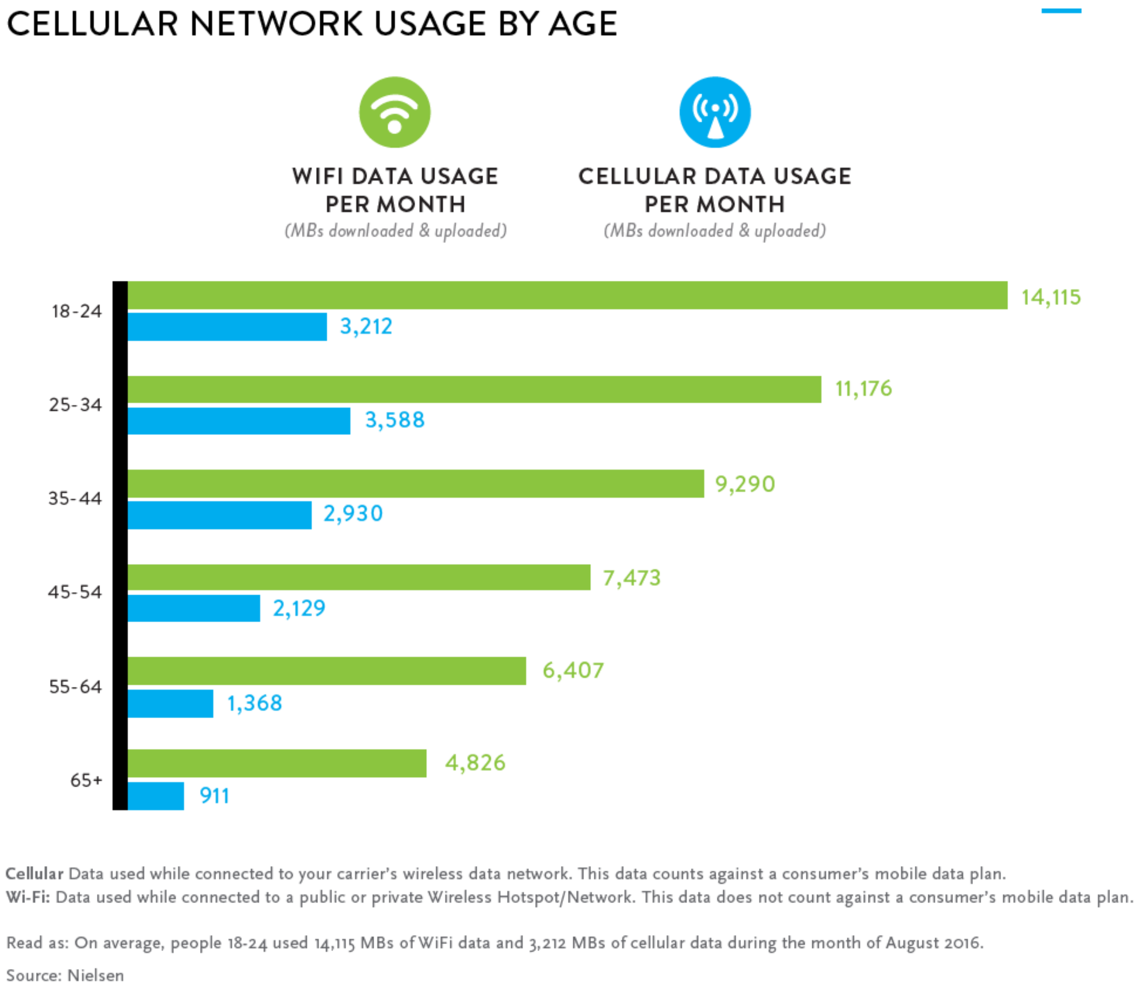


Figure 7: Cellular versus WiFi usage during 2016[14]

Arguably, with the improvements in service quality of, for example, 4G over 3G, it might be expected that consumers will rely on WiFi less, however as WiFi (e.g. at home or whilst in the office) is typically free, whereas mobile data is not, users are likely to continue to want to switch to WiFi whilst in places where it is available. It is equally true that although mobile network services and speeds are improving, so are WiFi connections as VDSL and fibre connections become more commonplace.

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[13] "The Consumer Mobile Experience", Ofcom, June 2017

[14] Source: http://www.nielsen.com/us/en/insights/news/2016/what-drives-data-usage.html

If the specific use-case of video as a driver, watching video whilst in the office is unlikely, however the vast majority of video viewing is either at home (where WiFi is available) or whilst commuting (by train or bus, but not by car unless as a passenger). As it is known that mobile coverage, especially on train journeys, can be very patchy, users often take advantage of their home (or office) WiFi to download video to their devices and store this to be watched during their commute. Thus it seems that serious video usage (e.g. watching box-sets) as opposed to casual video usage (e.g. watching short videos on Facebook) will rely more on WiFi than mobile networks. As the proportion of video on mobile devices increases, it could therefore be reasonably expected that the proportion of data that is offloaded onto WiFi will not decrease. With upcoming developments such as MU-MIMO and the use of the 60 GHz band using 802.11ad technology (known as WiGig)[15], the performance of WiFi will continue to improve and support faster and more reliable connections.

We will therefore assume that 70% of all data generated by mobile devices is offloaded onto another, non-cellular, network (e.g. WiFi).

3.1.5 Calculation

Our calculation of the long-term limit for data consumption is therefore based on the following assumptions, which we believe represent extreme values (insofar as they will yield what might be considered extreme outcomes) such that the resulting values are at the very upper end of the likely reality:

- That people will be streaming 4K quality video (though in reality many may be streaming at much lower quality than this);
- That they will watch video for 16 hours per day (e.g. every waking hour);
- That video compression techniques will gradually improve requiring 15 MBps today reducing to 5 Mbps by 2030;
- That video will be being watched by every person on the planet (but not more);
- That the proportion of data traffic generated on mobile devices that is made up of video begins at 60% in 2017, increasing to 75% by 2021 and continues to become a higher proportion beyond that;
- Data offload (e.g. onto WiFi) remains at levels of around 70% over the whole period.

To give an example, here is an example of the figures for 2017, and the associated calculation:

- Bit-rate required for 4K video: 15 Mbps.
- Data required for one person to view video for 16 hours a day:
  - Per day: 15 × 60 × 60 × 16 ÷ 8 = 108 Gbytes
  - Per month: 108 × 365.25 ÷ 12 = 3287 Gbytes
- If video is 60% of usage, then **total data per user per month** is: 3827 ÷ 60% = **5.5 Tbytes**
- Population of the World: 7 billion

[15] "802.11ad Will Vastly Enhance Wi-Fi", ABI Research, April 2016

- Mobile penetration rate (per individual): 80%
- Total mobile subscribers: 7 billion × 80% = 5.6 billion
- Total data generated on mobile devices: 5.6 billion × 5.5 Tbytes = 30680 Exabytes per month
- **Total data carried on mobile networks** after offload: 30680 Ebytes × 30% = **9200 Exabytes per month**

This figure compares with an actual value of around 10 Exabytes per month as of today. As a calculation for 2017 it has little value, not least as there is very little 4K video content, let alone devices on which to view it. Nor are many of the mobile networks around the world capable of providing 15 Mbps of data connectivity to every single user. Similarly, people do not view video for 16 hours every day. For 2017, such an exercise is a thought-piece only, however by 2035, many of the technical and content issues which make these calculations somewhat unrealistic today, should have been overcome. It remains to be seen, however, whether people do watch video for 16 hours every day.

3.1.6 Results

The results of this calculation produce a potentially surprising outcome: mobile data traffic to carry this amount of video would be higher today than it would be in the future. This is primarily because:

- Video compression algorithms will improve, reducing the amount of data needed to transmit video. We have used a very conservative set of improvements and if techniques develop faster, this would exaggerate the results.
- The proportion of mobile data traffic that is video increases, meaning that the amount of data required for other activities decreases.

Even if the amount of non-video traffic remained static, the amount of mobile data required to deliver video would still decrease, as would the annual values.

Our calculations show that in the limit, based on every mobile subscriber on the planet streaming 4K video for 16 hours per day, the amount of **global mobile data traffic would be around 3150 Exabytes per month by 2035**. This is around 315 times higher than today and represents a CAGR of just 38% per annum (i.e. lower than the current estimates of 50% per annum).

Taking, some more realistic figures such as:

- Watching video for 6 hours per day (not 16) which is closer to the average time spent per person in the USA[16], and appears to be stabilising;
- Only half of video is 4K, the remainder is lower resolution (e.g. that content which is historic in nature and was not originally recorded in 4K quality);

our calculations show that the amount of **global mobile data traffic would be around 890 Exabytes per month by 2035**. This is just 89 times higher than today and represents a CAGR of just 28%. Even this represents a value that is at the upper end of what is likely, not least some video viewing will be on devices which use alternativel forms of connectivity (e.g. fixed broadband).

[16] https://www.emarketer.com/Article/Growth-Time-Spent-with-Media-Slowing/1014042

Whilst as of today, data appears to be growing at a rate of around 50% per annum, even our most extreme calculations suggest that over the next 18 years, this rate of increase MUST slow down. This re-affirms our contention that growth of moblie data is following an S-curve and will stop being exponential at some future date.

If we try and fit an S-curve to the current 50% growth rate, but where growth slows and reaches these potential end limit values, we can clearly see that there will come a specific point where growth will begin to diverge from exponential.

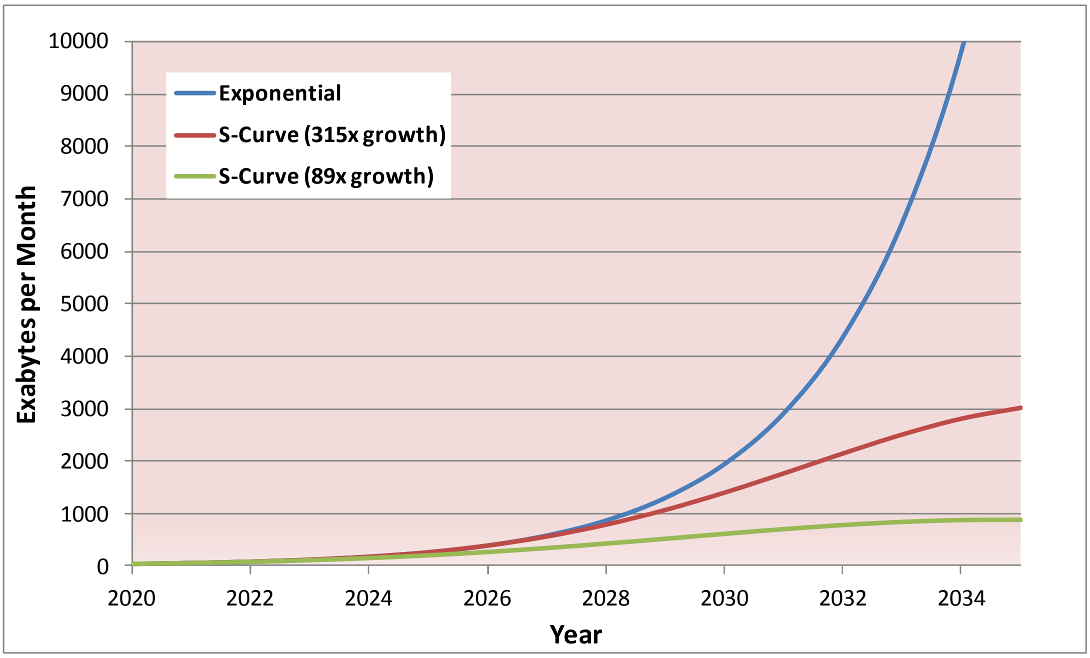

Figure 8: Fitting S-Curves to current growth plus possible end values

In the case where our most extreme value of 315 times current growth is the limit, it is clear that the growth curve will begin to diverge from exponential by around 2029. In the case where our more realistic figure is used, by 2026 there should be a noticable divergence of mobile growth from the exponential curve.

For reference, by 2035, mobile data would have grown by a factor of 1480 times if growth continuted to be exponential (at 50% growth per annum).

These divergences will become clear from the data published in the likes of the CISCO VNI and the Ericsson Mobility report. They do, however, throw into question the values in Report ITU-R M.2370, which shows growth continuing to be exponential until 2030. Even in our most extreme extrapolations of future mobile data demand, there should be a clear divergence from exponential growth by 2030.

3.1.7 Conclusions

Our calculations have attempted to identify what a limit for global mobile data traffic might be, by considering video as the primary driver of demand and using some extreme values (e.g. 16 hours per day of viewing, and all viewing in 4K quality). These extreme values lead to the outcome that growth in mobile data traffic could reach over 300 times that of today, but that it will not continue to grow beyond this. More conservative, yet still very high values, put the eventual limit of mobile data growth at just 89 times that of today.

The assumptions we have used have, in each case, assumed a maximum value and yet these still show that growth will not follow an exponential curve forever. Based on our calculations, it should become evident from real data that **growth is not following the infinate exponentual curve** by between 2026 and 2029 and indeed, by these dates, remaining growth will only be around a factor of 2 or 3. Thus we posit that:

- Mobile data growth will rise an absolute maximum factor of between 30 and 150 times between now and approximately 2027;
- After this date, remaining growth will only account for an additional factor of 2 to 3 times, reaching an ultimate limit wherein growth stops around 2033 to 2035.

3.2 Implications for spectrum demand

Our most extreme calculation suggests that mobile data traffic will top-out at 315 times today's values, and our more conservative, but still very exaggerated calculation suggests growth of 89 times that of today.

A previous LS telcom study[17], found that on average, mobile operators in countries around the world were using between 348 and 628 MHz shared between them. It also found that typically around 1000 MHz of IMT spectrum is available in any particular country but that much of this was yet to be licensed. There is therefore around 2 to 3 times more spectrum available for mobile services today than is actually in use.

At WRC-19, Agenda Item 1.13 will examine a number of new mobile frequency bands intended for 5G mobile services, namely: 24.25 - 27.5 GHz, 31.8 - 33.4 GHz, 37 - 43.5 GHz, 45.5 - 50.2 GHz, 50.4 - 52.6 GHz, 66 - 76 GHz and 81 - 86 GHz. This represents a potential for over 33 GHz of new spectrum to be made available for IMT services. If we assume that only half of this spectrum is finally agreed upon and identified for IMT services, this constitutes an additional 15 GHz or more of spectrum, representing over 30 times that which operators on average use today.

A Real Wireless study for Ofcom[18] has considered the spectrum efficiency gains of 4G (LTE) technology compared to 3G (UMTS). It concluded that basic LTE is around 1.2 times more efficient than high-end UMTS networks, but that:

> *"looking at devices available on the market today a HSUPA release 6 1x1 handset is a more typically available high end 3G device. The gain of LTE release 8 2x2 relative to this baseline changes to 3.3 times"*

As 3G technology was also more spectrally efficient than 2G technology, it is reasonable to assume that 5G technology will bring some further efficiency gains. To be conservative, let us assume that 5G is only 2 times as efficient as 4G.

With 30 times more spectrum available, and a technology which is twice as efficient as 4G, there is therefore the scope to deal with an increase in data demand of up to a factor of 60, without considering the additional capacity that will be delivered through the use of smaller and smaller cells. Whilst our more conservative yet still extreme calculation suggests data growth of 89 times compared

[17] "Analysis of the World-Wide licensing and usage of IMT Spectrum", LS telcom, September 2014

[18] "4G Capacity Gains", Real Wireless, January 2011

to today's levels, it is reasonable to believe that even this level of growth could be handled using 5G technology within only half of the spectrum that is being considered at the ITU for future IMT services.

It is worth considering that often incumbent mobile operators can be slow to introduce new technologies on top of their existing networks and that it may be newcomers who would be in a better position to leverage the benefits of 5G. This is already being seen with a range of IoT technologies which are often being rolled out by new companies rather than traditional operators. This will lead to the need for different approaches to licensing spectrum than are uased today, with a greater focus on sharing of spectrum and on making spectrum available to new and innovative service providers in a way which allows them to flourish. The future spectrum challenge is therefore not just about the amount that is identified, but in the way that that spectrum is made available to potential service providers.

4 Country case studies

4.1 Introduction

Our calculations have shown that there will be a limit to the amount of mobile data traffic and that current exponential growth is likely to slow down dramatically at some future date, potentially around 2027. In this section we examine whether there is evidence that this slow down is already taking place in specific countries. We would expect this to occur in countries:

- Where data usage is already very high;
- Where mobile networks are using relatively advanced technology (e.g. HSPA or 4G penetration is high);
- Which are highly internet literate and look to online services to meet their commercial and social needs;
- Where mobile broadband services, and the techologies required to access them, are affordable for the vast majority of the population.

These are likely to be highly developed countries, and thus it is from amongst such countries that we have sought to examine whether any slow down in growth can be identified.

4.1.1 Spectrum Efficiency Benchmark

One question that will need to be addressed, when considering why data growth may be slowing down, is whether this is caused by a lack of spectrum. One way of addressing this is to consider a country which currently has very high data usage, and to examine how much spectrum is assigned. This should then provide an indication of the achievable spectrum efficiency in delivering mobile date.

The figure below shows mobile data usage per SIM for a number of countries.

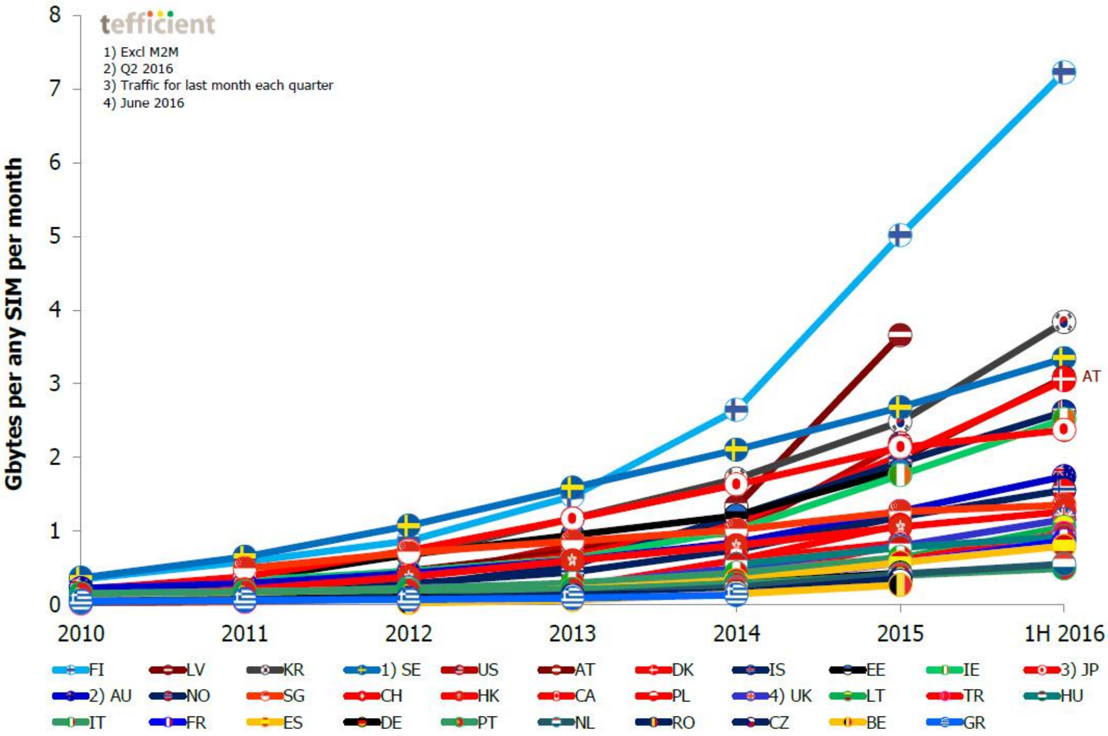

Figure 9: Mobile data usage per SIM per country[19]

Currently, the country whose users generate the most traffic per SIM card is Finland, where usage per SIM us around 7.2 Gbytes per month. The total amount of spectrum assigned to mobile operators in Finland is 770 MHz (i.e the 800, 900, 1800, 2100 and 2600 MHz bands, plus 3410 – 3590 MHz). This suggests that it is possible to deliver an average over 9 Mbytes per month per MHz of spectrum owned. This represents achievable spectrum efficiency based on today's technologies and networks and is therefore a useful benchmark in comparing efficiency in other countries

4.1.2 Selection of countries

A number of countries are beginning to show a slow down in the growth of mobile data, however in many cases this is not yet conclusive as the slow down has only occured in recent years.

For example, in the figure below, available data for a number of (European) countries is presented. Whilst it might be arguable that there is evidence of a slow-down in data growth in the Germany, South Africa and the UK these figures are not statistically significant.

[19] Source: Tefficient Industry Analysis, 2016

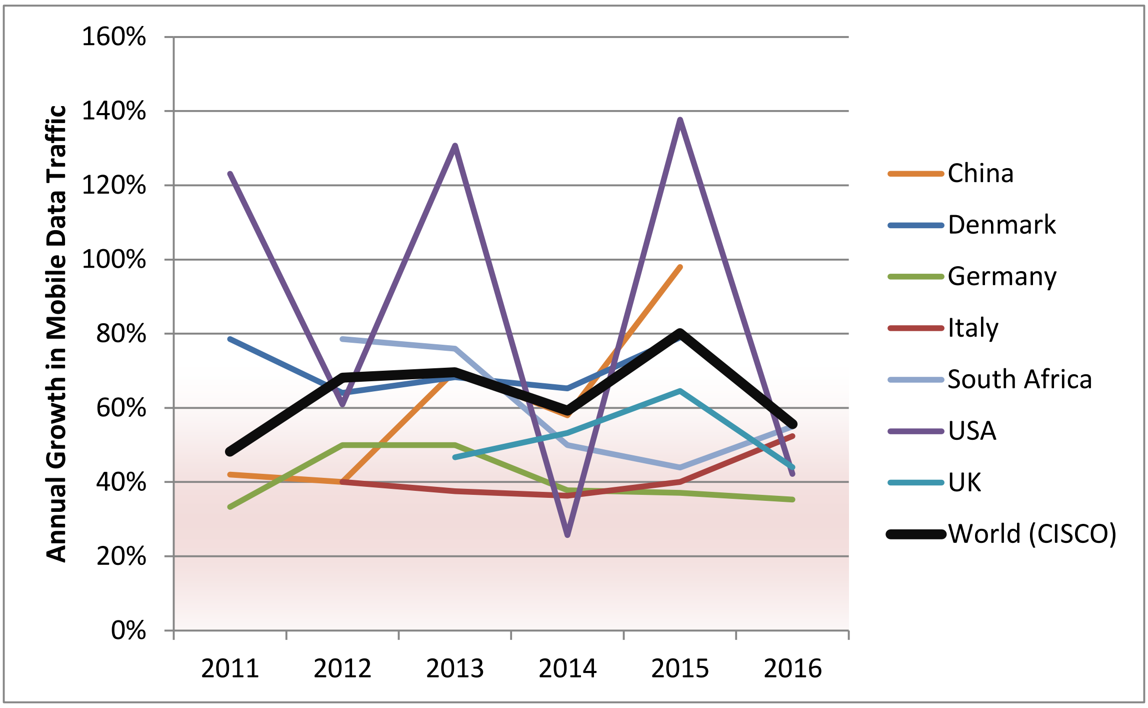

Figure 10: Mobile data growth in a number of countries

We have, however, identified a number of countries where data growth has shown a marked slow-down over recent years, specifically:

- Japan,
- Singapore, and
- Sweden

The state of the growth in these countries together with our understanding of the reasons for this slow-down are discussed below.

4.3 Japan

Mobile data traffic in Japan grew significantly during 2011 and 2012, reaching over 100% growth per annum, howver since 2014 growth has slowed significantly and as of the end of 2015, annual mobile data traffic growth stood at 40%. However it is clear to see that the trend in growth is very much downwards.

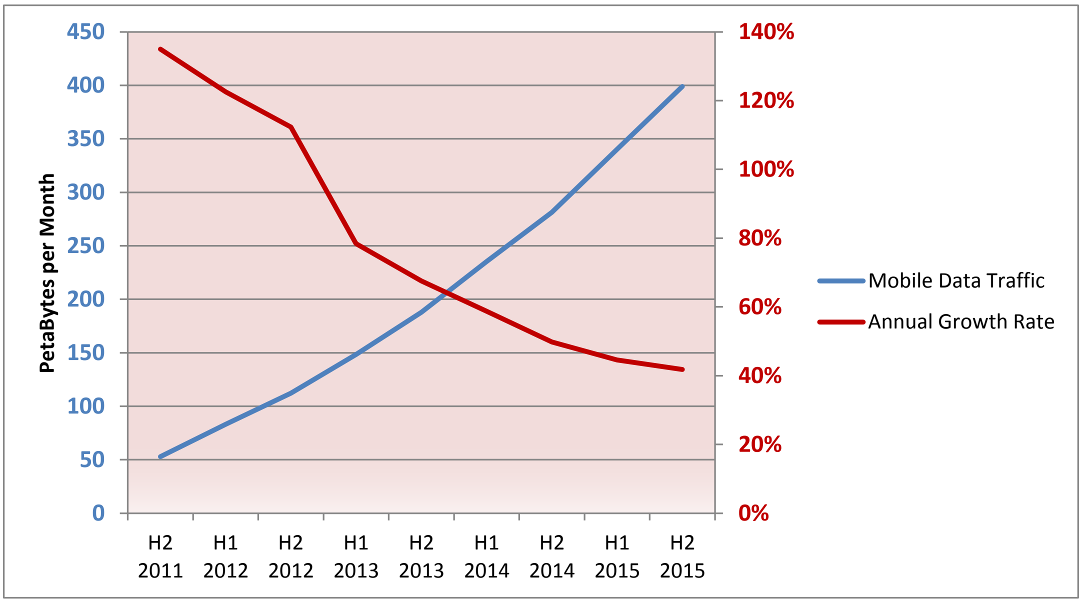

Figure 11: Growth of Mobile Data Traffic in Japan between 2011 and 2015[20]

It is interesting to note that the growth in data traffic (blue line) is approximately linear, suggesting that data growth in Japan has already reached, or is close to reaching, the inflection point in the S-curve. If this is the case, the amount of data growth that would be expected before usage flattens out would be far less than a factor of 10, and may be closer to 3 or 4 times.

Total mobile data traffic at the end of 2015 amounted to 400 Petabytes per month. The number of mobile subscribers at this time was 155 million, meaning that each subscriber generated around 2.6 Gbytes of data per month.

This has happened when operators are beginning to see a slow decline in the expenditure per household on mobile communications and thus the growth in data traffic has not resulted in any increase in revenue for the mobile operators[21].

The amount of spectrum licensed to mobile operators in Japan is 630 MHz with an additional 395 MHz being licensed as ‘fixed wireless‘ but which may be used as additional mobile spectrum. Based on the Finland benchmark, this should be enough spectrum support between 6 and 10 Gbytes of data per subscriber per month using today’s technologies and hence any slow-down in growth is unlikely to be related to a shortage of spectrum.

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[20] Source: “Status of the mobile communications traffic of Japan” Information and Communications Statistics Database, Ministry of Internal Affairs and Communications of Japan

[21] Ibid.

Japan has one of the most mature mobile markets in the world, with users regularly accessing rich content such as video, e-books, music and video games. The amount invested in mobile networks by the operators in Japan remains relatively constant at arond 1.6 Billion Yen per annum.

We have been unable to identify any significant factors which are constraining data growth in Japan and we must therefore conclude that the slow down in data growth is a result of the natural limitation of how much data it is currently possible for individuals to consume. That being said, there is one minor factor which it has been suggested may be constraining some data usage. This is the fact that in some areas of Japan, the daytime population density is very high[22]. Indeed 50% of the daytime population is concentrated in 3.7% of the overall area. This pushes population densities in excess of 20,000 people per square kilometer in some places during the daytime. It is difficult to serve these areas with very high population density with a high quality of service using existing technologies and this may be constraining usage in some areas. However the number of such areas is very small and constitutes less than 0.5% of the area of Japan.

A paper by the Japanese Fifth Generation Mobile Communications Promotion Forum (5GMF)[23] states that:

> *"...current 4G technologies, as well as its extention, may limit the growth of mobile services, especially when considering the needs for the 2020s."*

This would suggest that existing spectrum and service architectures are capable of delivering the needed connectivity for many more years yet. The report goes on to discuss 5G services and the different network architectures that 5G offers. The problems of highly dense areas can be resolved through 5G by the use of extremely small cells, supported by the use of millimetre wave spectrum which limits the coverage of the cells. Such networks are often termed HetNets, short for heterogeneous networks, due to the fact that, compared with today's 3G and 4G networks, they will have a much more varied set of cell sizes which will be able to cope with the type of heterogeneous traffic distributions found in areas such as Tokyo. Thus 5G will be able to solve many of the problems associated with highly dense traffic situations in a way that 4G can not.

[22] "Daytime and Nighttime population and Rate of daytime population to Nighttime population - Shi, Ku, Machi and Mura" Statistics Bureau of Japan

[23] "5G Mobile Communications Systems for 2020 and beyond", 5GMF, May 2016

4.5 Singapore

Mobile data traffic in Singapore is growing, but the level of growth is significantly lower than the 50% CAGR predictions of CISCO, Ericsson and the ITU. The chart below shows mobile data growth in Singapore over the period from 2011 to the end or 2016.

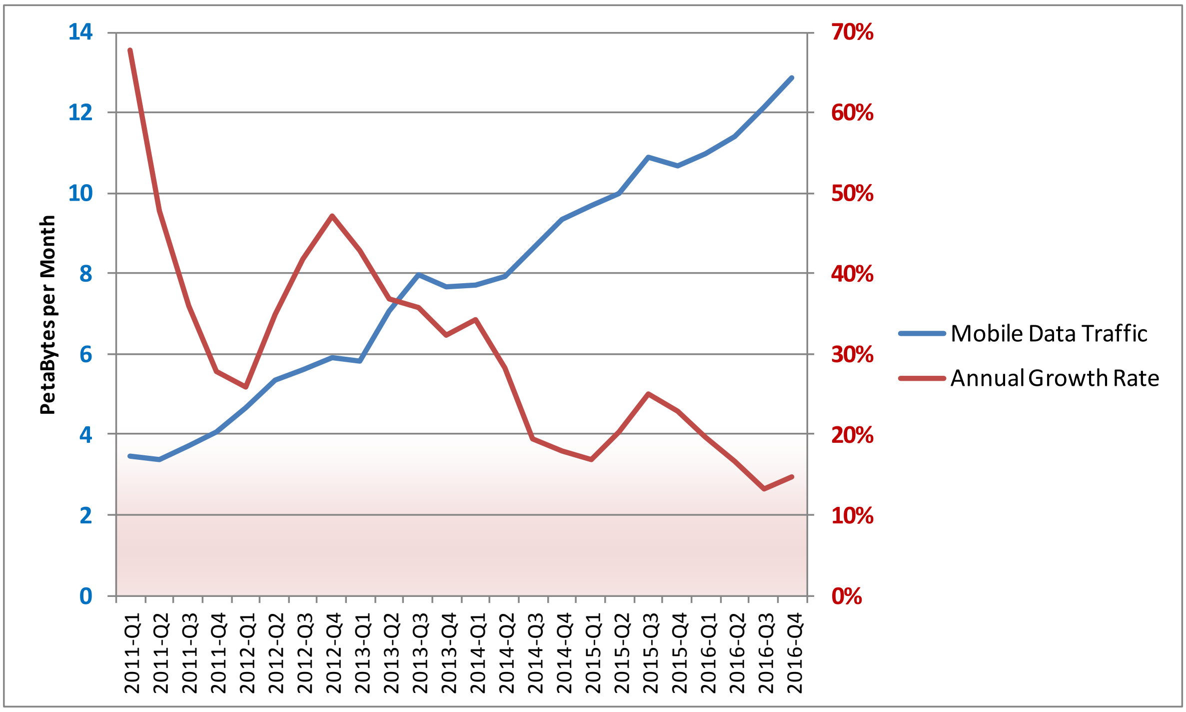

Figure 12: Growth of Mobile Data Traffic in Singapore between 2011 and 2016

Based on data published by the IMDA, mobile data traffic growth between the beginning of 2011 and the end of 2013 averaged 39% per annum. Between the beginning 2014 and the end of 2016 it averaged just 20% per annum. These are significantly lower than the 50 to 60% per year growth expected by CISCO, Ericsson or the ITU. Over the same period, the number of subscriptions has grown by an average of just 2% per annum, as the market is largely saturated (mobile penetration currently stands at 150% of the population).

It is once again interesting to note that the growth in data traffic (blue line) is approximately linear. This suggests that data growth in Singapore has already reached, or is close to reaching, the inflection point in the S-curve meaning that the amount of data growth that would be expected before usage flattens out would be far less than a factor of 10, and may be closer to 3 or 4 times.

Usage per subscriber has grown by around 23% per annum and currently stands at around 1.5 Gbytes per user per month. The total amount of spectrum assigned to mobile operators in Singapore is around 640 MHz. This suggests that it should be possible to deliver capacity of around 6 Gbytes per user per month in the spectrum available such that the current levels of traffic do not represent saturation of spectrum use.

As of the end of 2016, only around 50% of subscribers in Singapore had a 4G subscription, the remainder have only 2G or 3G subscriptions. 3G data throughput rates typically average 5 Mbps whereas 4G data throughput rates achieve nearer 30 Mbps.

There are a number of reasons why data growth in Singapore has slowed significantly. Based on discussions with staff of the regulator, the IMDA, the following main reasons have been identified as potential causes of this slow-down:

- Singapore has an extensive, free, public WiFi network (Wireless@SG) which provides connection speeds of 5 Mbps, which is as good as the 3G services provided by the mobile operators. The service is available from 10,000 hotspots across the country, in particular in public areas such as shopping malls, coffee shops and sports and music venues. Mobile devices registered for the service will automatically connect to the WiFi network when a hotspot is within range (i.e. no use-by-use user authentication is necessary). The Wireless@SG service is also available at every station on the MRT.
- Singapore is a largely ‘indoor’ country. For the majority of time, mobile subscribers are inside buildings, whether their home, office, transport hub or shopping mall. As well as home WiFi, most businesses provide their staff with a free WiFi service when they are at work. Connected with the availability of the Wireless@SG service, the proportion of time for which users are sending data via the mobile networks is relatively small compared to the amount of time they spend connected to WiFi. Thus there is a significantly higher proportion of offload to WiFi services than in some other countries.
- The most popular mobile package includes 2 Gbytes of data. If subscribers breach their monthly data limit, the cost of additional data can be high unless it is purchased in advance. Therefore, many subscribers set warnings and limits on their mobile data usage and will turn off mobile data when their monthly limit is reached. As a result of this, many subscribers have learnt that it is the streaming of video which consumes the highest amounts of mobile data, and as a result tend to refrain from watching video material unless connected to WiFi.
- Singaporeans are not heavy uploaders of video content. This may be due to cultural reasons, or may be due to the intelligence of users concerning the fact that video is a service that places heavy demand on data usage. This tends to have the knock-on effect that the viewing of video is slightly lower in Singapore than elsewhere (e.g. due to the lack of local content), however this secondary effect is less significant.

None of this has constrained mobile productivity. The Singapore government provides extensive e-Services on-line and many of these are in the main accessed from mobile devices, indicating that the lack of growth in data has not in any way stunted the use of mobile-enabled internet services.

4.7 Sweden

Mobile data traffic in Sweden grew rapidly in the first half of the decade reaching almost 100% per annum, however since 2014, growth has been far below the CISCO and Ericsson forecasts of 50% per annum. Mobile data growth is showing a very uniform slow down and was just 25% between 2015 and 2016.

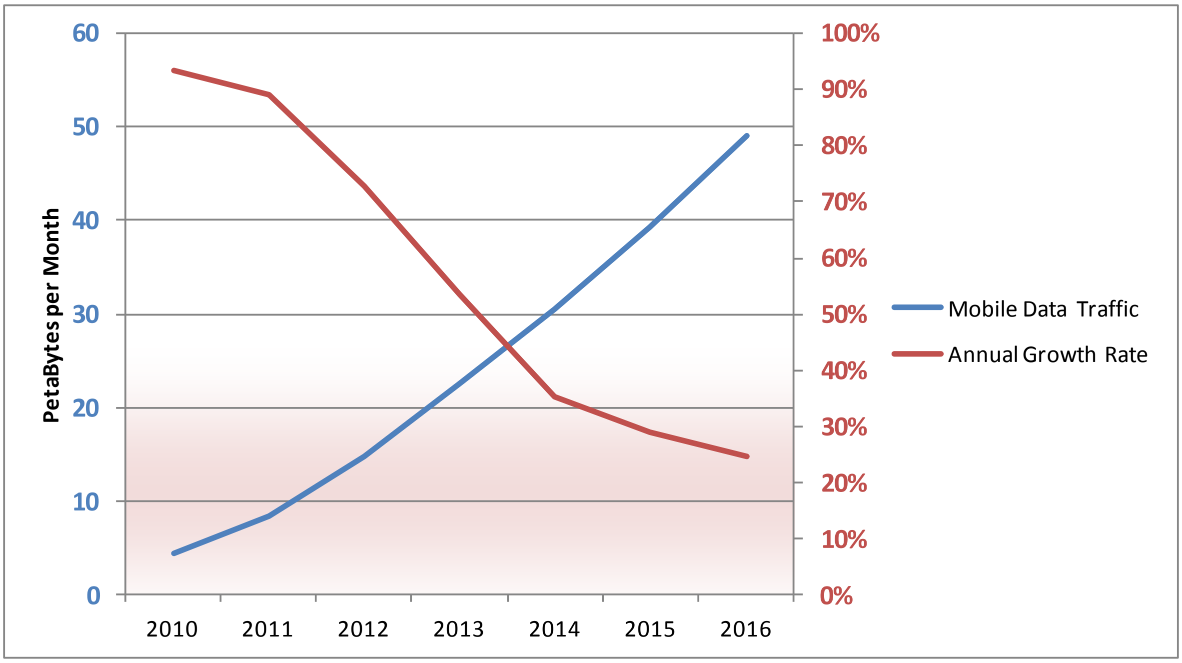

Figure 13: Growth of Mobile Data Traffic in Sweden between 2010 and 2016[24]

Once again the growth in data traffic (blue line) is approximately linear, suggesting that data growth in Sweden has already reached, or is close to reaching, the inflection point in the S-curve. This could mean that the amount of data growth that would be expected before usage flattens out would be far less than a factor of 10, and may be closer to 3 or 4 times.

Swedes are heavy users of mobile data (see for example, in Figure 7 where Sweden has the fourth highest data consumption of all the countries examined).

By 2016, the amount of mobile data traffic stood at 49 Petabytes per month, equating to around 3.3 Gbytes per user per month. The number of subscribers is relatively constant, having actuall fallen slightly (by 1%) towards the end of 2015.

Swedish mobile operators have just over 750 MHz of spectrum assigned to them, which, based on the Finnish benchmark, means they should be able to support around 7 Gbytes per user per month without additional spectrum and thus there is currently no evidence of a lack of spectrum causing the down-turn in data growth.

Whilst mobile subscriber numbers have remained relatively constant, the number of subscriptions which include a data allowance of over 1 Gbyte (per month) has grown significantly. In addition, the number of subscriptions which use 4G has grown very significantly, however as of 2016, less than

[24] Source: "The Swedish Telecommunications Market" – annual publication by PTS

50% of all subscriptions were 4G. The graph below shows how the number of subscriptions with differing data packages has changed over recent years.

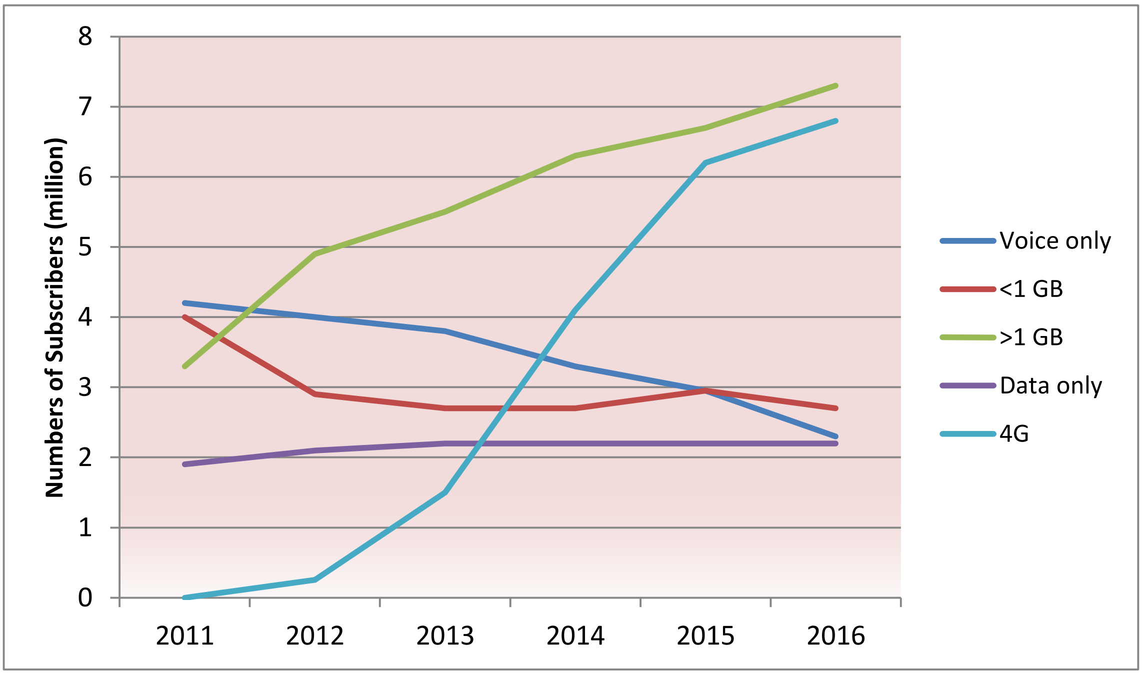

Figure 14: Subscription types for Sweden 2011 - 2016

This large growth in 4G subscriptions and those with data packages of over 1Gbyte (per month) should have driven up data usage significantly. Between 2014 and 2016 there was a 66% increase in 4G, however over the same period, the growth in mobile data traffic was only 53%. This would tend to suggest that those users who are in the process of transferring their subscriptions to 4G are not big users of the mobile internet, and that it is those who already have 4G subscriptions who are the larger users. If this trend continues, even if everyone in Sweden were to have a 4G subscription, it would not cause a doubling of mobile data traffic as those users yet to adopt 4G fall into a lower usage category. It is notable that the number of subscribers who have monthly data allowances of 1 Gbyte or less has remained fairly constant over the past 4 years, suggesting that there are a significant proportion of the population who have no appetite for consuming large amounts of mobile data.

4.8 Conclusions

We have identified a number of countries where the growth in mobile data traffic is slowing down. We have identified a number of possible reasons for this slow down:

- Good quality, free WiFi in the majority of public areas;
- Intelligent users who turn off mobile data when reaching their monthly limit;
- Possible reductions in quality and speed of connection in extremely densely populated areas being unable to be supported by 4G network architectures but which will be resolved with 5G technology;
- Remaining growth in the number of data subscriptions (e.g. 4G) coming from users with low data usage.

There is **no evidence that the slow down in data growth** in any of these countries **is being caused by a lack of spectrum**.

To test this we have considered the benchmark of Finland, which has one of the highest data consumptions per user, we have compared the amount of data being generated in these countries in the amount of spectrum available. We found that despite data growth slowing, the amount of data which the networks should be capable of delivering in the available spectrum has not reached the Finnish benchmark levels. This is a strong indicator that there is still capacity to deliver more data within the available spectrum and this supports our finding that it is not a lack of spectrum that is causing the slow down in data growth.

It is also notable that in these three countries, the data traffic growth curves are approximately linear. If data growth is following an S-curve, this suggests that the inflection point in the curve has been reached and that the amount of data growth remaining is most certainly less than a factor of 10 times, and **remaining data growth may be as little as a factor of 3 to 4 times**.