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Ericsson Mobility Report

June 2018

Letter from the publisher

2018: A pivotal year for our industry

The mobile industry has passed a number of big milestones over the last two decades, which in retrospect have led to fundamental changes to our society. When mobile data traffic surpassed mobile voice traffic in 2009, it was difficult to know what today's use of mobile technology would look like.

However, this year will likely go into the history books as the start of an even bigger societal change. 5G and the Internet of Things (IoT) promise new capabilities and use cases, which are set to impact not only consumer services but also many industries embarking on their digital transformations. 2018 will be the year for the first rollouts of 5G networks as well as large-scale deployments of cellular IoT.

This change will require the combined effort of many industry players and regulators to align on spectrum, standards and technology. A lot is already happening, and in this edition of the Ericsson Mobility Report, we take a closer look at the trends that will drive the mobile industry over the next five years.

Cellular IoT is growing fast and this has led us to significantly increase our forecast. By 2023, we now estimate around 3.5 billion cellular IoT connections. This growth is set to impact industries and businesses across many different markets.

5G will kick off with enhanced mobile broadband as its first use case. By the end of 2023, there will be 1 billion 5G subscriptions, accounting for around 20 percent of mobile data traffic. The massive ramp-up of 5G subscriptions is expected to be fueled by third-generation chipsets, which will be available from 2020 on a variety of frequency bands.

Securing the right spectrum for 5G in low, mid and high bands will be especially important in the near-term future. Global spectrum harmonization across countries will be the key to securing broad adoption and economies of scale for 5G.

In the meantime, upgrading current 4G networks with the latest technology to cater for increasing traffic volumes and enhanced customer experience will be on most service providers' agendas.

2018 may seem to be just another year for an industry that has become used to high growth in numbers for smartphone subscriptions and mobile traffic. However, with the developments in 5G and IoT, I believe it will be a pivotal year for our industry.

I hope you find the report helpful and engaging!

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	2017	2023	CAGR
Worldwide mobile subscriptions	7.8bn	8.9bn	2%
Worldwide smartphone subscriptions	4.3bn	7.2bn	9%
Worldwide mobile broadband subscriptions	5.3bn	8.3bn	8%
Worldwide LTE subscriptions	2.7bn	5.5bn	12%
Worldwide monthly data traffic per active smartphone	3.4GB	17GB	31%
Worldwide total monthly mobile data traffic	15EB	107EB	39%

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Mobile subscriptions Q1 2018

The total number of mobile subscriptions was around 7.9 billion in Q1 2018, with 98 million new subscriptions added during the quarter.

The number of mobile subscriptions grew at 4 percent year-on-year, reaching 7.9 billion in Q1. China had the most net additions during the quarter (+53 million), followed by India (+16 million), Indonesia (+6 million), Nigeria (+3 million) and Bangladesh (+2 million). The high growth in China during the quarter is likely the result of intense competition among operators, driving up the number of subscribers with multiple subscriptions.

The number of mobile broadband subscriptions[1] is growing at 20 percent year-on-year, increasing by 200 million in Q1 2018. The total is now 5.5 billion.

The number of LTE subscriptions increased by 210 million during the quarter to reach a total of 2.9 billion. The net addition for WCDMA/HSPA was around 10 million subscriptions.

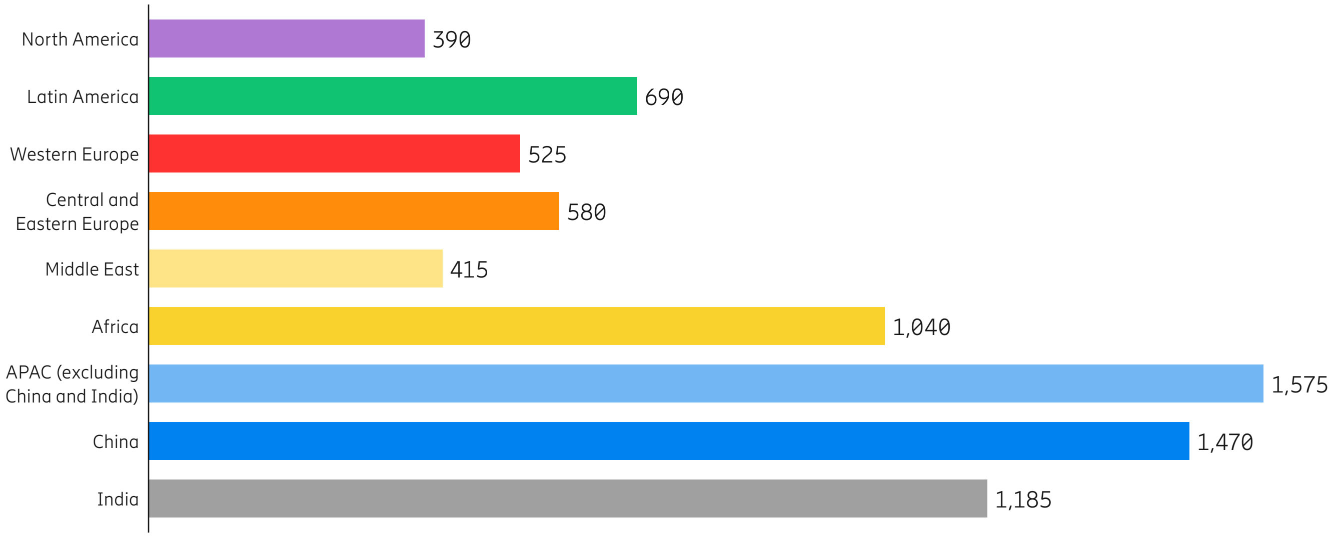
Over the same period, GSM/EDGE-only subscriptions declined by 90 million. Other technologies declined by around 32 million.

Subscriptions associated with smartphones now account for around 60 percent of all mobile phone subscriptions. The number of smartphones sold declined to around 340 million in Q1, representing around 85 percent of all mobile phones sold in the quarter.

5.5bn

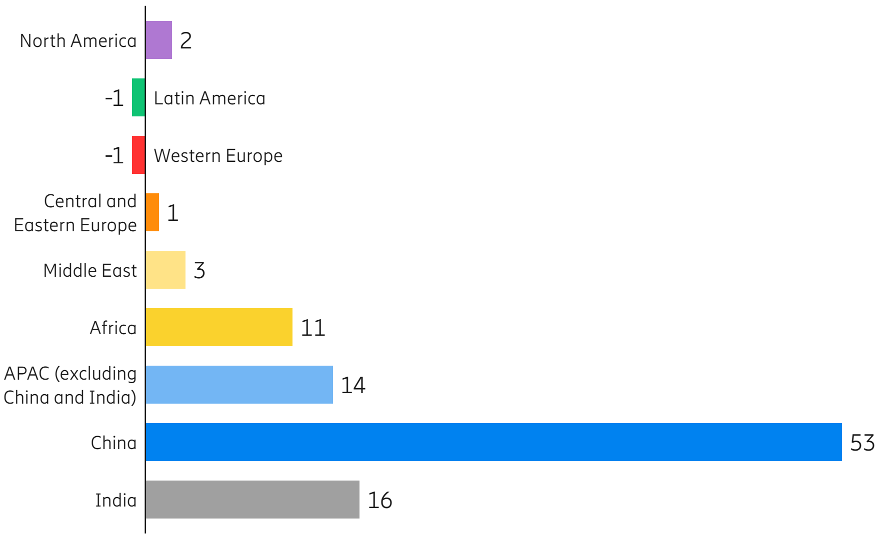
There are now 5.5 billion mobile broadband subscriptions.

Mobile subscriptions Q1 2018 (million)



[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX

New mobile subscriptions Q1 2018 (million)



98m

98 million new mobile subscriptions globally in Q1 2018.

Top 5 countries by net additions Q1 2018

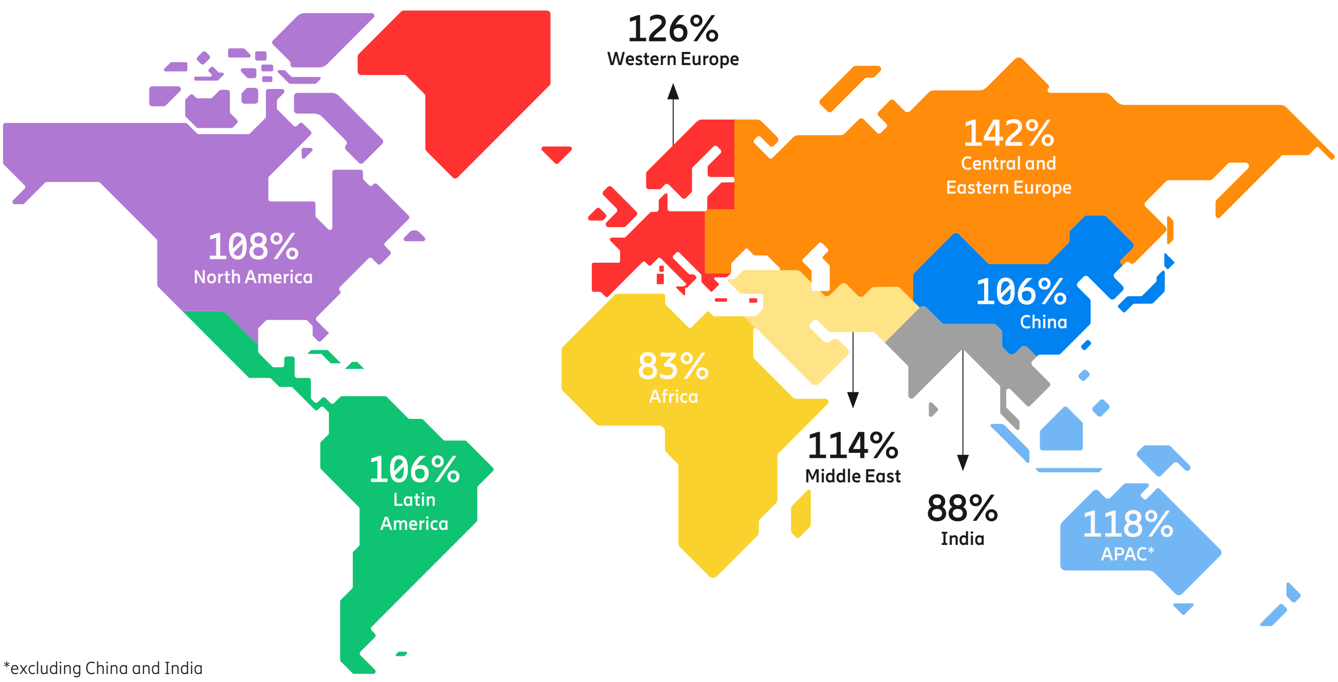
1	China	+53 million
2	India	+16 million
3	Indonesia	+6 million
4	Nigeria	+3 million
5	Bangladesh	+2 million

The number of mobile subscriptions exceeds the population in many countries, which is largely due to inactive subscriptions, multiple device ownership or optimization of subscriptions for different types of calls. As a result, the number of subscribers is lower than the number of subscriptions. Today, there are around 5.3 billion subscribers globally compared to 7.9 billion subscriptions.

104%

104 percent global subscription penetration in Q1 2018.

Subscription penetration Q1 2018 (percent of population)



*excluding China and India

Mobile subscriptions outlook

First commercial launches of 5G in 2018.

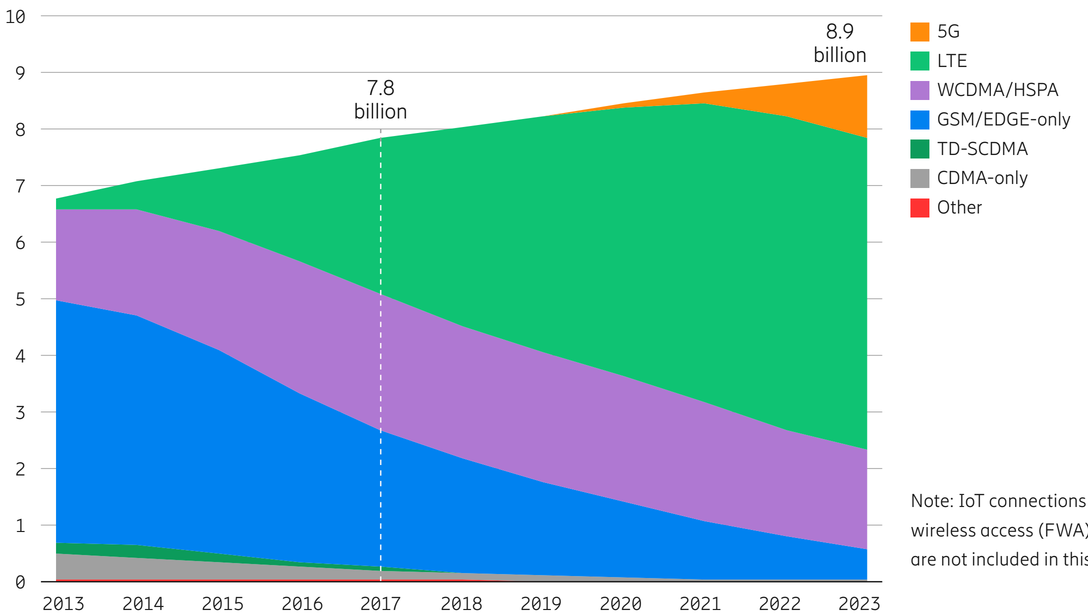
The standardization of 5G accelerated during 2017, with 3GPP Release 15 for Non-Standalone 5G New Radio (NR)[1] finalized at the end of the year. The standard for the Standalone version is expected to be completed in June 2018. This acceleration of the standardization work plan will enable early 5G deployments in several markets.

Operators in the United States will be among the first to launch 5G commercial services. The country's four major operators have publicly announced that they will begin providing 5G services between late 2018 and mid-2019. Other markets where significant 5G subscription volumes are expected early include South Korea, Japan and China. Globally, major 5G network deployments are expected from 2020. We forecast over 1 billion 5G subscriptions for enhanced mobile broadband by the end of 2023, accounting for 12 percent of all mobile subscriptions.

LTE became the dominant mobile access technology at the end of 2017. The number of LTE subscriptions continues to grow strongly and is forecast to reach 5.5 billion by the end of 2023, when it will account for more than 60 percent of all mobile subscriptions. The number of WCDMA/HSPA subscriptions is expected to decline slightly during 2018. However, the technology is still estimated to account for around one-fifth of all subscriptions in 2023.

A 5G subscription is counted as such when associated with a device that supports NR as specified in 3GPP Release 15, connected to a 5G-enabled network.

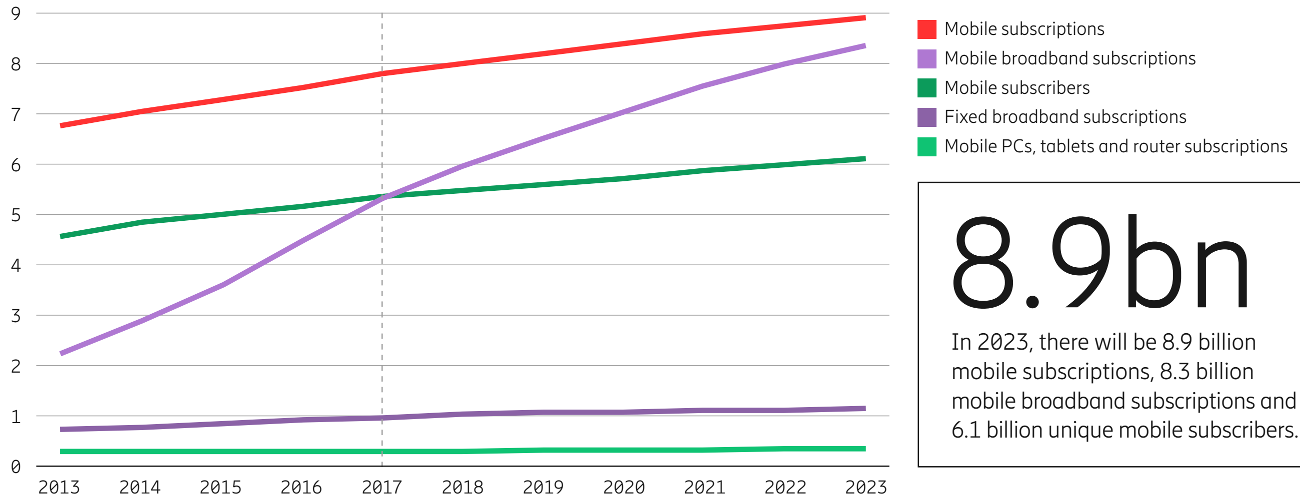
Mobile subscriptions by technology (billion)



Note: IoT connections and fixed wireless access (FWA) subscriptions are not included in this graph

[1] Non-Standalone 5G NR will utilize the existing LTE radio and Evolved Packet Core network as an anchor for mobility management and coverage, while adding a new 5G radio access carrier to enable certain 5G use cases

Subscriptions and subscribers (billion)



8.9bn

In 2023, there will be 8.9 billion mobile subscriptions, 8.3 billion mobile broadband subscriptions and 6.1 billion unique mobile subscribers.

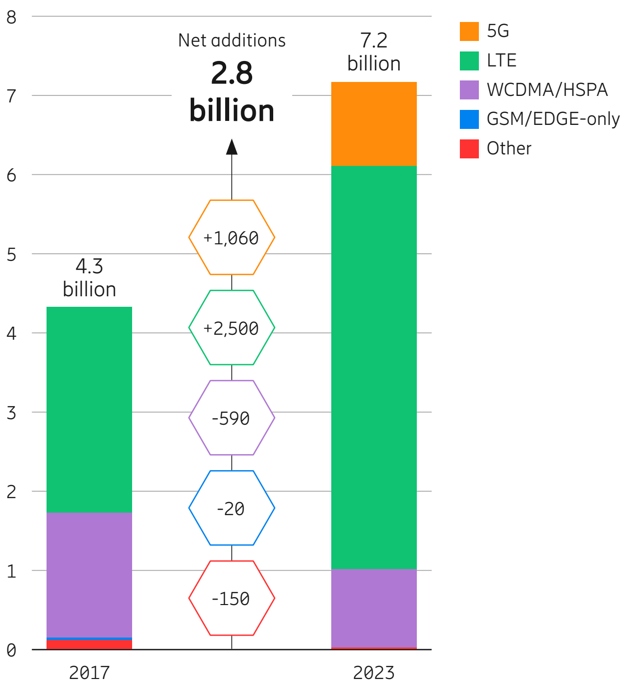
Close to 95 percent of all subscriptions will be for mobile broadband by the end of 2023.

We forecast that there will be 8.9 billion mobile subscriptions by the end of 2023. Mobile broadband subscriptions will reach 8.3 billion, accounting for close to 95 percent of all mobile subscriptions. The number of unique mobile subscribers is estimated to reach 6.1 billion by the end of the forecast period.

Mobile broadband will complement fixed broadband in some segments and will be the dominant mode of access in others.[2] Subscriptions for PCs and tablets with mobile capabilities are expected to show moderate growth, reaching 320 million in 2023.

Smartphone penetration continues to rise, driven by the increasing affordability of devices. At the end of 2017, there were 4.3 billion smartphone subscriptions, 95 percent of which were for 3G and 4G. The number of smartphone subscriptions is forecast to reach 7.2 billion in 2023, and almost all will be for mobile broadband.

Smartphone subscriptions by technology



[2] The number of fixed broadband users is at least three times the number of fixed broadband connections, due to shared subscriptions in households, enterprises and public access spots. This is the opposite of the situation for mobile phones, where subscription numbers exceed user numbers

5G device outlook

All new mobile standards go through the process of establishing a device ecosystem with interoperability – first on chipsets, then on devices.

To support the standard, the mobile network infrastructure needs to work with devices in assigned frequency bands. Now it is 5G's turn.

The figure below summarizes 5G device availability, based on first-generation chipsets following 3GPP standards. From 2020, when third-generation chipsets will be introduced, large numbers of 5G devices are expected.

Fixed wireless access and data-only devices

With 5G able to provide significantly more capacity than 4G, operators will be able to offer new differentiated services. Examples include providing broadband access and data-only connections to new customer segments.

These types of connections – using fixed wireless broadband customer-provided equipment (CPE) and pocket routers – tend to be more stationary than traditional mobile broadband. Such devices can serve many users at once and can be directly connected to power outlets or larger batteries. This makes fixed wireless a device category primed for early 5G entry. First-generation 5G data-only devices are expected from the second half of 2018.

Enhanced mobile broadband and smartphones

Today, a typical high-end smartphone supports GSM, WCDMA and LTE with more than 20 frequency bands. Smartphones will evolve to support 5G in already-available LTE bands, as well as in higher spectrum bands that will be allocated for 5G. The possibility to use multiple spectrum bands poses new challenges for the device ecosystem. These include the use of low MHz to very high GHz frequencies in the same smartphone, with LTE and 5G applied at the same time (aggregated). More efficient technologies, components and processes are required to make this possible. The first commercial smartphones supporting 5G in the mid-bands are expected in early 2019, while support for very high spectrum bands is expected in early to mid-2019.

> The first 3GPP smartphones supporting 5G are expected in early 2019.

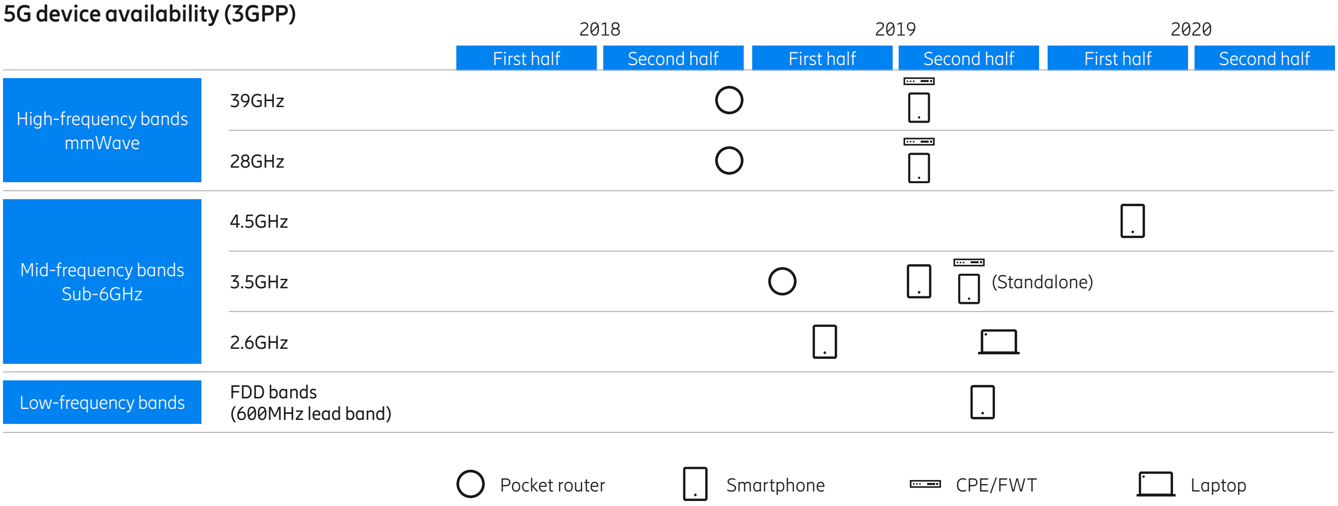
Industry and the Internet of Things

5G is also expected to empower use cases across industries. The first module-based 5G devices, supporting ultra-low latency communications for industrial process monitoring and control, are expected during 2020.

1 billion 5G devices by 2023

New cellular network technologies have a low initial penetration of compatible devices and 5G will be no different. Penetration will accelerate over chipset and device generations, as declining costs and prices increase volumes sold. By 2023, 1 billion 5G devices for enhanced mobile broadband are expected to be connected worldwide.

5G device availability (3GPP)



Note: The figure shows device availability for Non-Standalone 5G NR, with the exception of the 3.5GHz band, where Standalone is also shown

Voice over LTE outlook

At the end of 2017, VoLTE subscriptions[1] exceeded 610 million.

VoLTE creates a foundation for interoperable consumer and enterprise communication services on different devices across LTE, Wi-Fi and 5G.

VoLTE has now been launched in more than 145 networks in over 70 countries across all regions.[2] The number of VoLTE subscriptions is projected to reach 5.4 billion by the end of 2023, accounting for around 80 percent of combined LTE and 5G subscriptions.

Enabling new consumer and enterprise use cases with VoLTE

VoLTE is delivered via the IP Multimedia Subsystem (IMS). It enables operators to offer high-quality, simultaneous communication and data services on smartphones and other devices, across LTE, Wi-Fi and 5G.

Several operators have started deploying VoLTE over cloud-based core networks, to support more cost-efficient network operations and faster scaling of capacity. This network evolution builds upon Network Functions Virtualization (NFV) and enables faster launches of new services. It has been agreed in 3GPP standardization that VoLTE technology will be the foundation for enabling 5G voice calls.

Services that can already be launched as an addition to HD voice include: Wi-Fi calling, HD voice+ (improved voice quality and music within calls with the Enhanced Voice Services (EVS) codec), video communication, IP messaging with evolution to chatbots and content sharing within calls. Several devices, such as smartphones and tablets, can share the same phone number (multi-device), while a single phone can use several phone numbers (multi-persona).

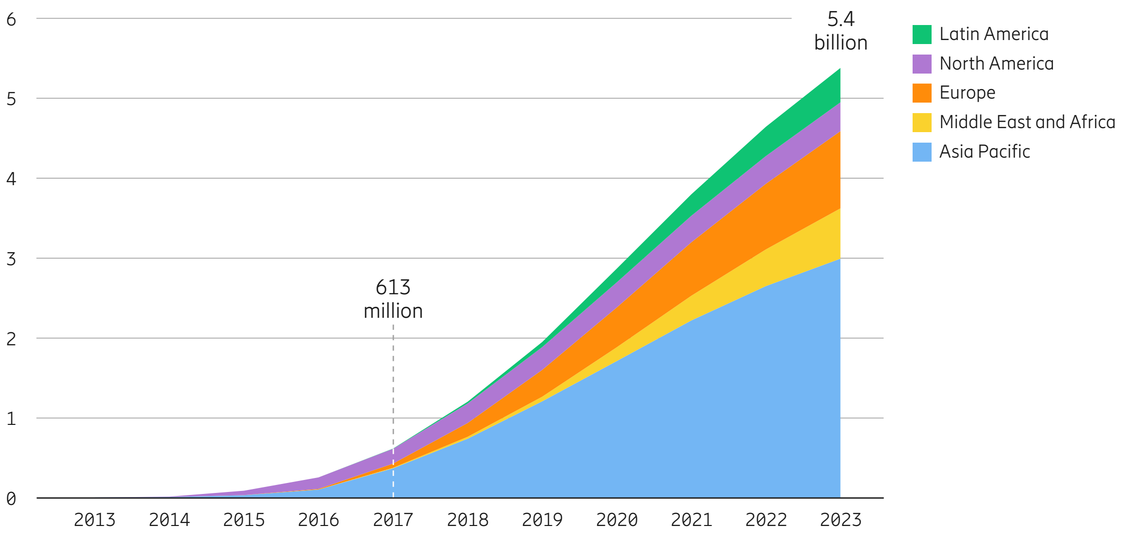
New communication service use cases in a 5G context are being explored, such as augmented reality (AR) and virtual reality (VR).

New devices with VoLTE support

There are more than 1,500 VoLTE-enabled device models.[3] Cellular smartwatches are one of the latest commercial devices to utilize VoLTE. As part of a multi-device scenario, devices such as smart speakers could also be IMS-enabled.

VoLTE support in Cat-M1-capable Internet of Things (IoT) chipsets, devices and network infrastructure is starting to be commercialized, and new use cases are being explored. Many IoT use cases could benefit from incorporating basic voice calling functionality, for example, in assistance situations or to improve business performance.

VoLTE subscriptions by region (billion)

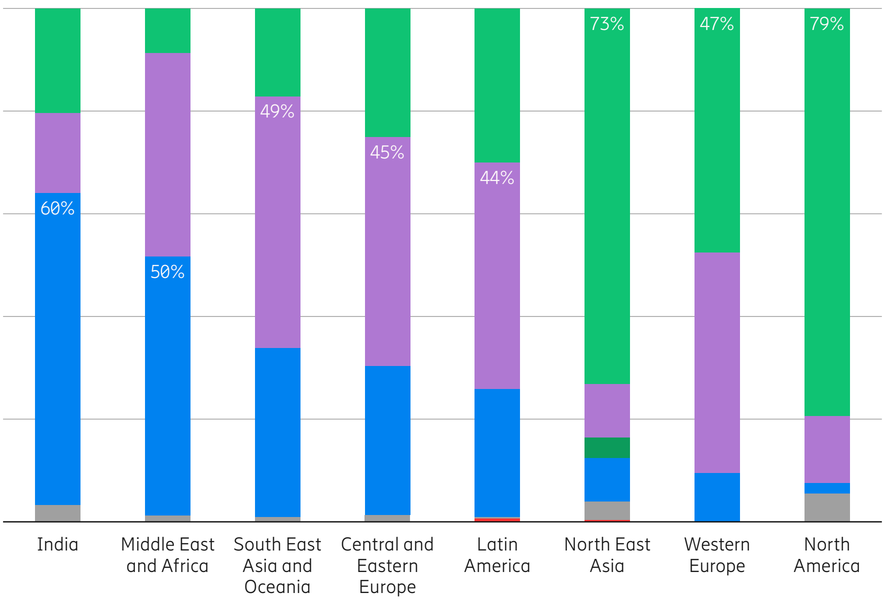


[1] A subscriber is counted as having a VoLTE subscription if making at least one VoLTE call per month
[2] GSA (April 2018)
[3] GSA (May 2018), supporting different regions and frequencies

Regional subscriptions outlook

Mobile broadband[1] drives subscription growth across all regions.

Mobile subscriptions by region and technology 2017 (percent)



68%

Globally, mobile broadband subscriptions now make up 68 percent of all mobile subscriptions.

In **India**, GSM/EDGE-only remained the dominant technology in 2017, accounting for over 60 percent of total mobile subscriptions. In late 2016 and early 2017, the country experienced strong growth in the number of LTE subscriptions, mainly due to attractive free voice and data traffic offers from one operator. As a result, LTE accounted for 20 percent of all mobile subscriptions at the end of 2017.

The transformation toward more advanced technologies is expected to continue in India and, in 2023, LTE is forecast to represent 78 percent of all mobile subscriptions. 5G subscriptions are expected to become available in 2022.

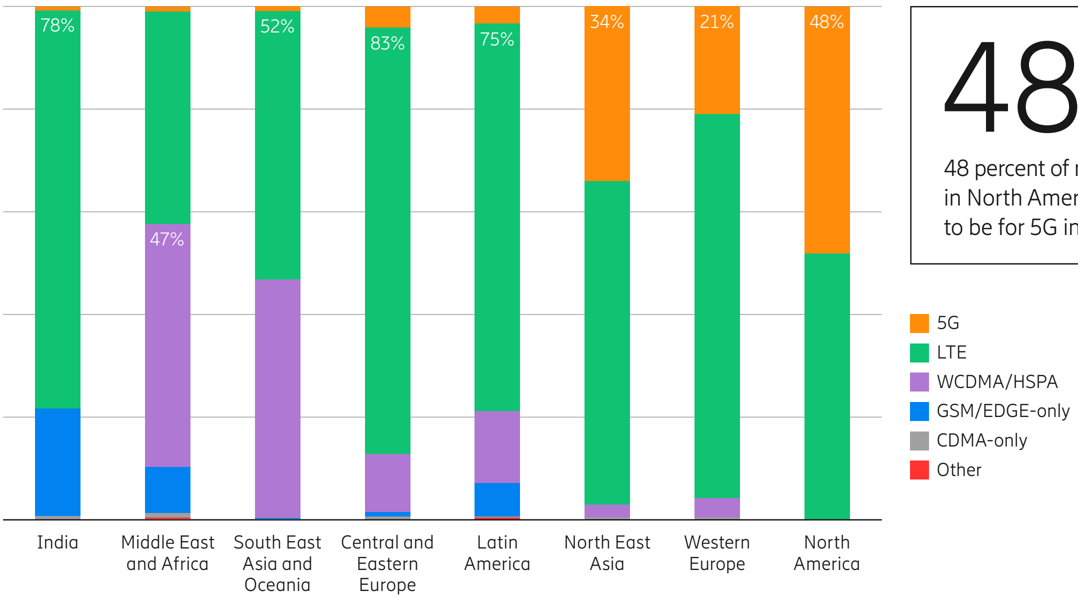
The **Middle East and Africa** comprises over 70 countries and is a diverse region. At the end of 2017, close to 20 percent of all mobile subscriptions were for LTE in the Middle East and North Africa, while in Sub-Saharan Africa, LTE only accounted for around 5 percent of subscriptions. The region is anticipated to evolve over the forecast period and, by 2023, 90 percent of subscriptions are expected to be for mobile broadband. Driving factors behind this shift include a young and growing population with increasing digital skills, as well as more affordable smartphones. In the Middle East and North Africa, significant 5G subscription volumes are expected in 2021 and in Sub-Saharan Africa in 2022.

South East Asia and Oceania includes developed markets with some of the most advanced networks in the world, as well as developing economies that have only recently launched LTE. In 2023, LTE is forecast to account for 52 percent of all mobile subscriptions in the region. 5G subscriptions are expected to become available in 2021.

In **Central and Eastern Europe**, the transition from WCDMA/HSPA to LTE is gathering further momentum. LTE is forecast to become the dominant technology in 2019 and will account for around 83 percent of all mobile subscriptions in 2023. The first 5G subscriptions are expected within the period 2020 to 2021, and will make up close to 5 percent of total subscriptions in 2023.

[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX

Mobile subscriptions by region and technology 2023 (percent)



48%

48 percent of mobile subscriptions in North America are expected to be for 5G in 2023.

In **Latin America**, WCDMA/HSPA is currently the dominant radio access technology. The distribution of technology is expected to change dramatically over the forecast period. LTE is expected to become the leading technology in 2018 and, by 2023, is anticipated to represent 75 percent of all subscriptions. The first trials and deployments of 5G are planned over the next few years.

North America, **North East Asia** and **Western Europe** have high shares of global mobile broadband subscriptions. Countries within these regions have developed economies, enabling a high adoption rate of information and communications technology.

North America currently has the highest share of LTE subscriptions, at close to 80 percent. The region is also anticipated to lead 5G uptake, with all major operators stating their intentions to deploy 5G early. Fixed wireless services based on 5G are expected to be launched in the second half of 2018, and the first mobile 5G services based on 3GPP standards are expected in late 2018. By the end of 2023, more than 48 percent of all mobile subscriptions in North America are forecast to be for 5G.

In North East Asia, the share of LTE subscriptions is high at 73 percent. The recent nationwide deployment of LTE in China resulted in close to 1 billion LTE subscriptions at the end of 2017. 5G is expected to be deployed early in South Korea, Japan and China. By the end of the forecast period in North East Asia, 5G subscription penetration is projected to exceed 34 percent.

In Western Europe, LTE became the dominant access technology at the end of last year, accounting for close to 50 percent of all subscriptions. Subscriptions for WCDMA/HSPA have declined in the region, but the technology still accounts for more than 40 percent of all mobile subscriptions. The first 5G subscriptions are expected in 2019. By the end of 2023, 5G is forecast to account for 21 percent of all mobile subscriptions in the region.

Mobile traffic Q1 2018

Mobile data traffic[1] grew 54 percent between Q1 2017 and Q1 2018.

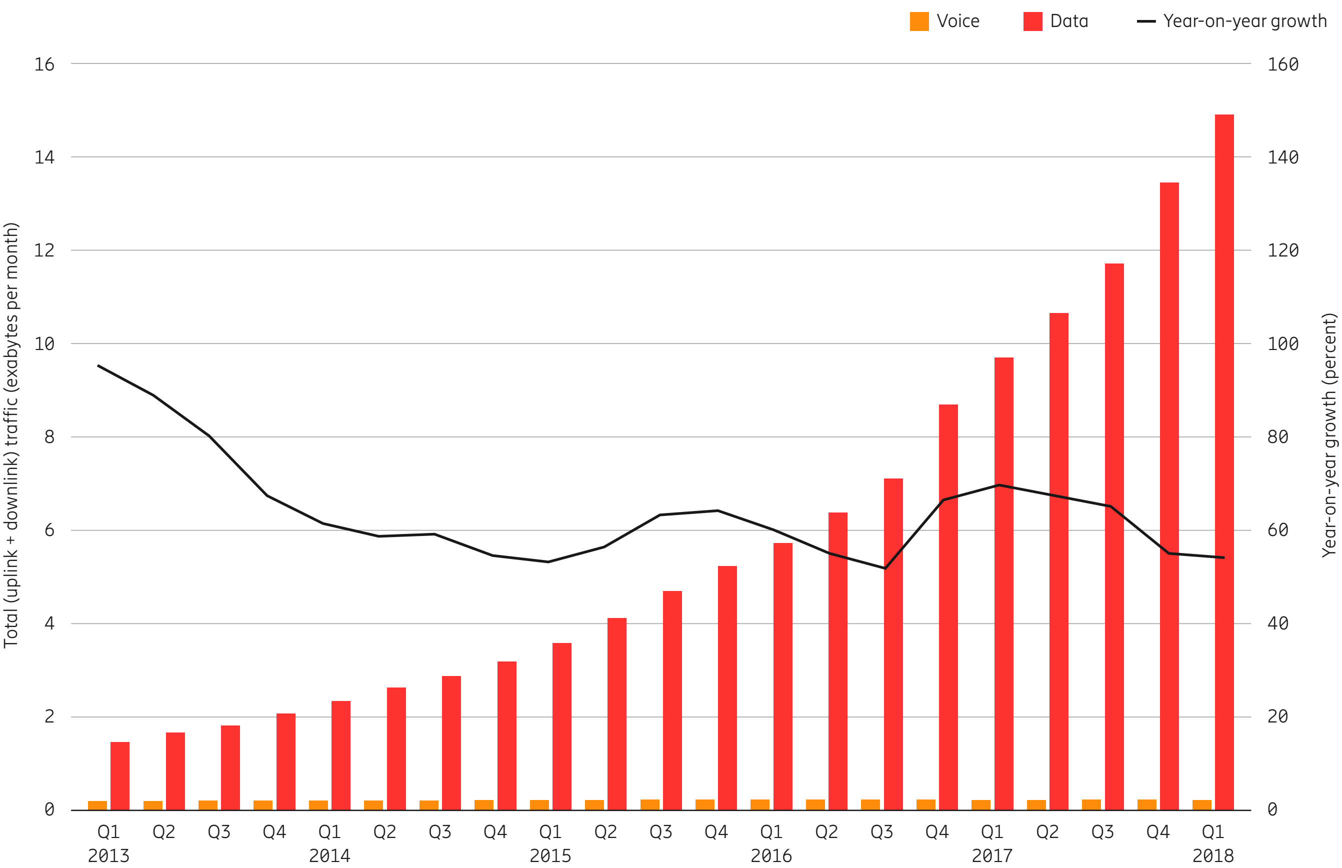
Traffic growth is driven both by the rising number of smartphone subscriptions and increasing average data volume per subscription, fueled primarily by more viewing of video content at increasingly higher resolutions.

The graph below shows total global monthly data and voice traffic from Q1 2013 to Q1 2018, along with the year-on-year percentage change for mobile data traffic.

In Q1 2018, mobile data traffic grew around 54 percent year-on-year. This was similar to the yearly growth in Q4 2017, but significantly lower than for the previous 4 quarters, when it varied between 65 and 70 percent. Starting in Q4 2016, the global traffic growth was noticeably boosted above its long-term trend line by free data traffic offers in India, resulting in a high base for comparison with the Q1 2018 traffic.

The quarter-on-quarter growth was around 11 percent.

There are large differences in traffic levels between markets, regions and operators.



Source: Ericsson traffic measurements (Q1 2018)

[1] Traffic does not include DVB-H, Wi-Fi or Mobile WiMAX. VoIP is included in data traffic

Mobile traffic by application category

Video traffic in mobile networks continues to grow, driven by increased viewing time, more embedded video in other media and evolution toward higher resolutions.

Mobile video traffic is forecast to grow by around 45 percent annually through 2023 to account for 73 percent of all mobile data traffic. Traffic from social networking is also expected to rise – increasing by 31 percent annually over the next 6 years. However, its relative share of traffic will decline from 12 percent in 2017 to around 8 percent in 2023, because of the stronger growth of video.

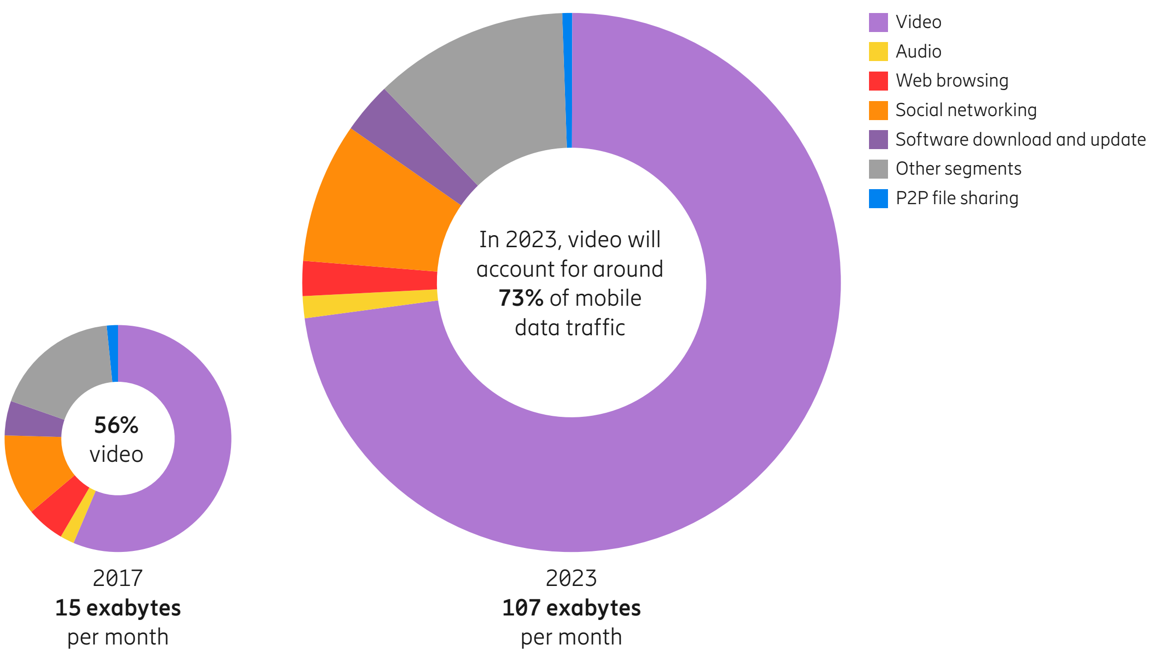
Streaming videos in different resolutions can impact data traffic consumption to a high degree. Watching HD video (720p) rather than standard resolution video (480p) typically doubles the data traffic volume, while moving to full HD (1080p) doubles it yet again.

An emerging trend with increased streaming of immersive video formats, such as 360-degree video, would also impact data traffic consumption. For example, a YouTube 360-degree video consumes four to five times as much bandwidth as a normal YouTube video at the same resolution.

The Ericsson Mobility Calculator
www.ericsson.com/mobility-report/mobility-calculator

Along with the publication of this issue of the Ericsson Mobility Report, a new interactive web application has been launched to explore the relationship between the usage of various app types and monthly traffic per subscription. The application enables an analyst or business planner to quickly and simply see the connection between the evolution toward higher video resolutions and the growth in traffic per month per subscriber. The intention is to periodically update the app types and associated data rates alongside new insights.

Mobile data traffic by application category per month (percent)



Mobile data traffic outlook

In 2023, 20 percent of mobile data traffic will be carried by 5G networks.

Monthly mobile data traffic per smartphone continues to increase in all regions. North America has the highest usage, reaching 7.2 gigabytes (GB) at the end of 2017. This figure is expected to rise to 49GB by the end of 2023. Western Europe has the second highest mobile data usage. At the end of 2017, 4GB per month per smartphone was consumed, and this figure is forecast to reach 25GB by the end of 2023.

Globally, factors that drive higher usage include improved device capabilities and more affordable data plans, as well as an increase in data-intensive content. As virtual reality (VR) and augmented reality (AR) technologies are more widely adopted, content will be even more data intensive.

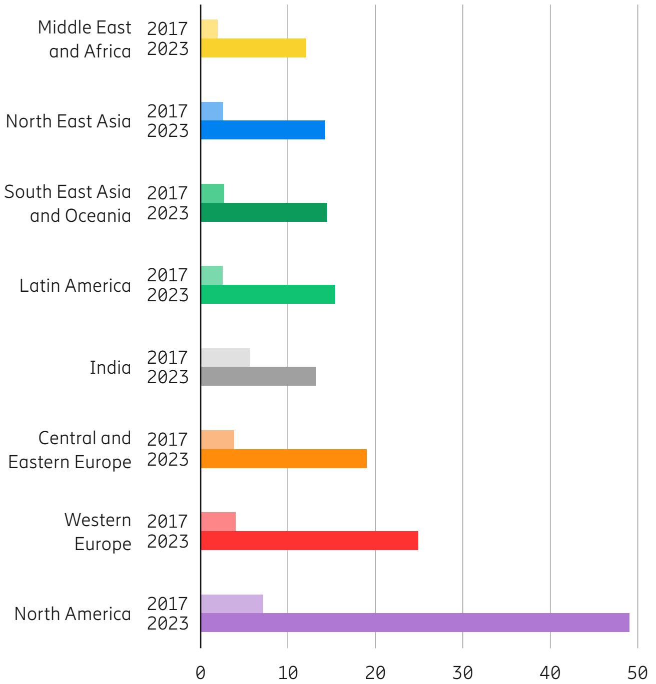
Total mobile data traffic is expected to increase by nearly eight times

Total mobile data traffic is forecast to rise at a compound annual growth rate (CAGR) of 43 percent, reaching close to 107 exabytes (EB) per month by the end of 2023. At that time, it is expected that 20 percent of mobile data traffic worldwide will be carried by 5G networks. This is 1.5 times more than the total of 4G/3G/2G traffic today. In regions with early 5G deployment, the 5G share of traffic will be higher than 20 percent.

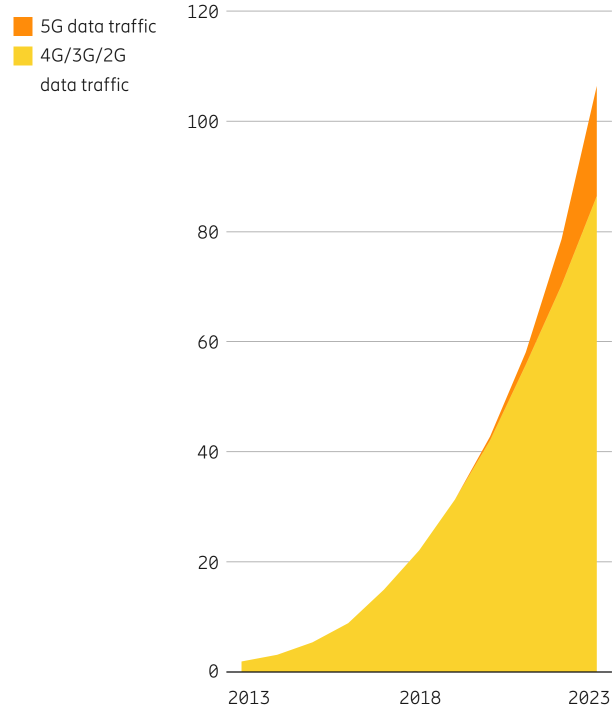
Currently, the 5G traffic forecast does not include traffic generated by fixed wireless access (FWA) services. However, as FWA is one of the early use cases planned for 5G in some regions, it could have a significant impact on the forecast figures, depending on market uptake of the service.

Today, close to 85 percent of total mobile data traffic is generated by smartphones. This figure is expected to reach 95 percent by the end of 2023.

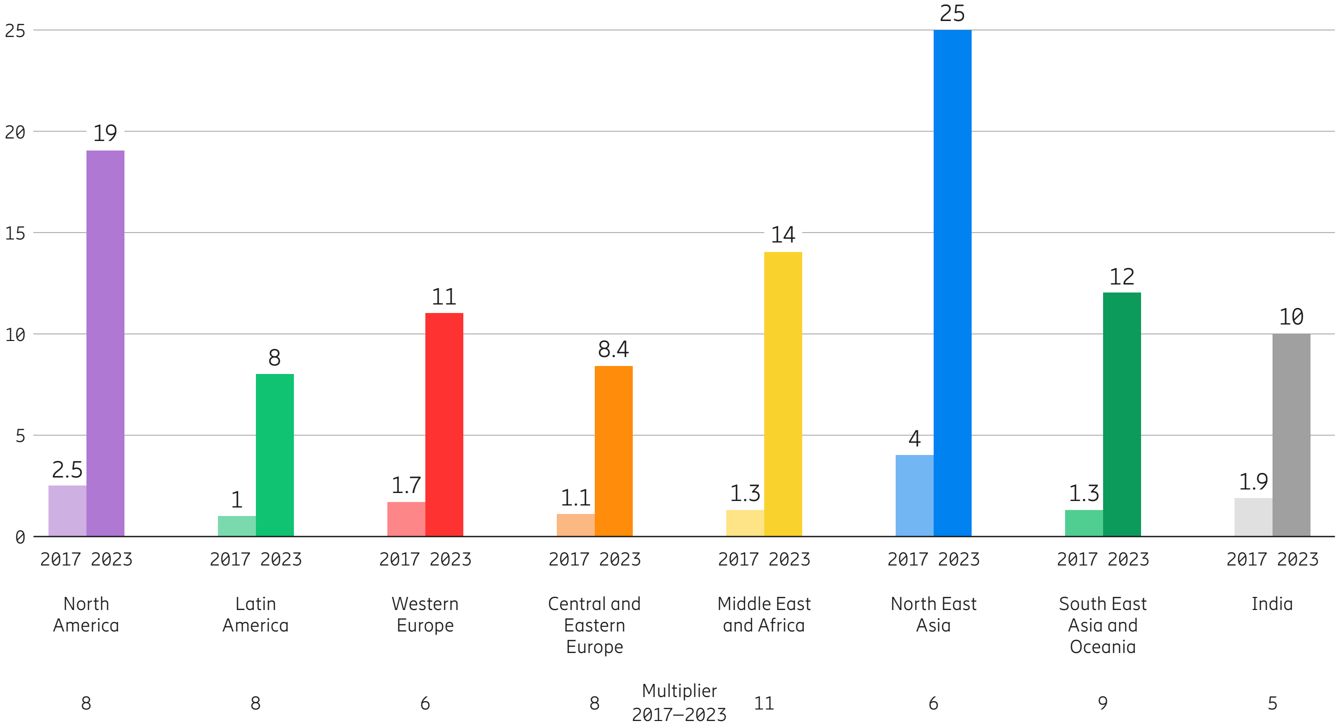
Mobile data traffic per active smartphone (gigabytes per month)



Global mobile data traffic (exabytes per month)



Regional mobile data traffic (exabytes per month)



North East Asia is set to retain the largest share of global mobile data traffic
North East Asia is the most populous region and as such has the largest share of global mobile data traffic – 27 percent at the end of 2017. This will continue into 2023, when total mobile data traffic in the region is forecast to reach 25EB per month. The rapid growth in mobile broadband subscriptions in North East Asia is expected to continue. China alone is set to add around 335 million mobile broadband subscriptions by the end of 2023, driving data traffic up to 18EB per month in the country.

In India, the total monthly mobile data traffic was 1.9EB at the end of 2017, driven by the strong growth in the number of LTE subscriptions. In 2023, the total traffic is expected to have increased by 5 times to reach 10EB.

An 11 times increase in mobile data traffic is expected in the Middle East and Africa during the forecast period, driven by an increase in smartphone penetration and investments in network performance. In 2023, total monthly mobile data traffic will reach close to 14EB in the region, representing the highest growth rate globally.

North America and Western Europe have a larger share of the total traffic volume than subscription numbers imply. This is due to well built-out LTE networks and high penetration of high-end user devices, complemented with affordable packages offering large volumes of data. This combination leads to high data usage per subscription. With increased consumption of broadband-intensive services, such as video, and new applications like VR and AR, total mobile data traffic is expected to exceed 19EB per month in North America and 11EB per month in Western Europe in 2023.

Monthly mobile data traffic in North East Asia is set to reach 25EB in 2023.

IoT connections outlook

The number of cellular IoT connections is expected to reach 3.5 billion in 2023 – increasing with an annual growth rate of 30 percent.

The forecast for cellular IoT connections has almost doubled, due to ongoing large-scale deployments in China. Of the 3.5 billion cellular IoT connections forecast for 2023, North East Asia is anticipated to account for 2.2 billion.

IoT presents opportunities for enterprises to improve efficiencies and enhance customer value. However, the IoT technology landscape remains fragmented. New massive IoT cellular technologies, such as NB-IoT and Cat-M1, are taking off and driving growth in the number of cellular IoT connections, with a CAGR of 30 percent expected between 2017 and 2023. These complementary technologies support diverse low-power wide-area (LPWA) use cases over the same underlying LTE network. See the table to the right for the connected device forecast, where the cellular IoT connections category is part of the wide-area IoT segment.

Commercial deployments of Cat-M1 and NB-IoT

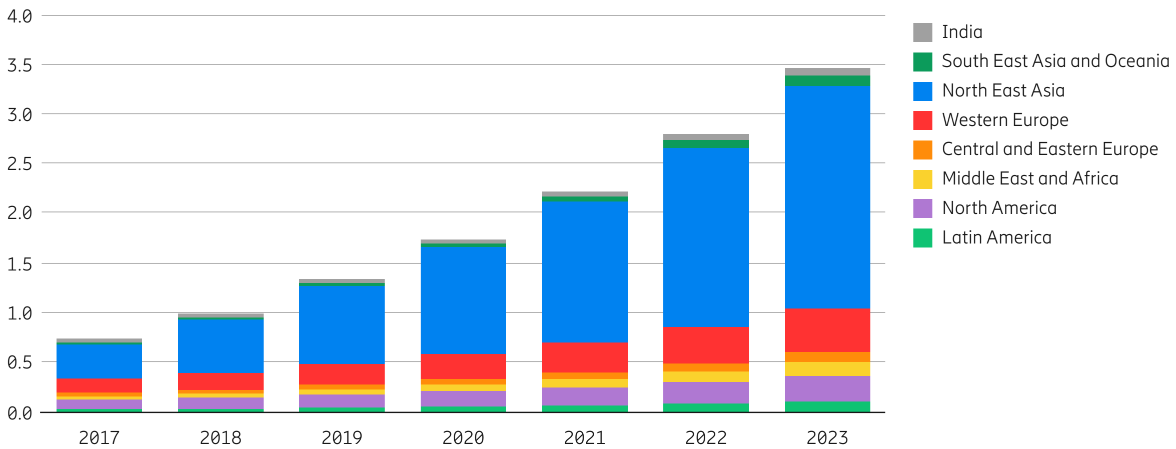
Mobile operators have commercially launched more than 60 cellular IoT networks worldwide using Cat-M1 and NB-IoT.[1] In North America, IoT applications such as logistics and fleet management are mainly supported by Cat-M1 technology. In China, NB-IoT technology has been selected for nationwide deployment to support use cases such as smart cities (for example, utility meters) and smart agriculture. Both technologies are being deployed in parallel as a complement to each other across regions worldwide.

Large-scale deployments, and the resulting high-volume chipsets, are expected to reduce chipset prices. This is leading to further acceleration of the growth in cellular IoT connections.

Connected devices (billion)

IoT	2017	2023	CAGR
Wide-area IoT	0.8	4.1	30%
Cellular IoT[2]	0.7	3.5	30%
Short-range IoT	6.2	15.7	17%
Other devices			
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.5	8.6	2%
Fixed phones	1.4	1.3	0%
Total connected devices	**17.5**	**31.4**	**11%**

Cellular IoT connections per region (billion)



[1] GSA (April 2018)
[2] These figures are also included in the figures for wide-area IoT

Network coverage

In 2023, more than 20 percent of the world's population will be covered by 5G.

Mobile service providers have been focused on providing sufficient radio signal for the world's inhabitants, which is defined as population coverage (as opposed to geographical coverage). Today, mobile networks cover around 95 percent of the world's population and this figure continues to grow.

Mobile service usage has evolved from predominantly voice to messaging and internet access, as well as to a variety of apps on a range of smart devices. This places greater demands on network performance.

LTE deployment continues to gain momentum

In terms of build-out and subscription uptake, LTE is the fastest-deployed mobile communication technology to date. It took just 5 years for LTE to cover 2.5 billion people, compared to 8 years for WCDMA/HSPA.

Several drivers are increasing the speed of LTE deployment. With the expected growth of IoT services, there is a higher demand on geographical coverage, as networks of sensors are installed in places with low population density such as agricultural areas or forestland.

LTE population coverage is currently over 60 percent and is forecast to grow to more than 85 percent in 2023.

5G population coverage estimates

In the past, mobile access technologies have first been deployed in urban areas, and then gradually expanded to areas such as suburbs and major highways.

In a similar fashion, 5G is expected to be deployed first in dense urban areas to support enhanced mobile broadband services. However, 5G is driven by use cases with a wide range of requirements. One of the first commercial uses for 5G is expected to be for FWA. It will primarily be deployed where there are limited fixed broadband alternatives available for households, implying an initial coverage build-out in suburban areas. Other use cases will come from industries such as automotive, manufacturing, utilities and healthcare, and will drive demand for dedicated coverage for a defined area.

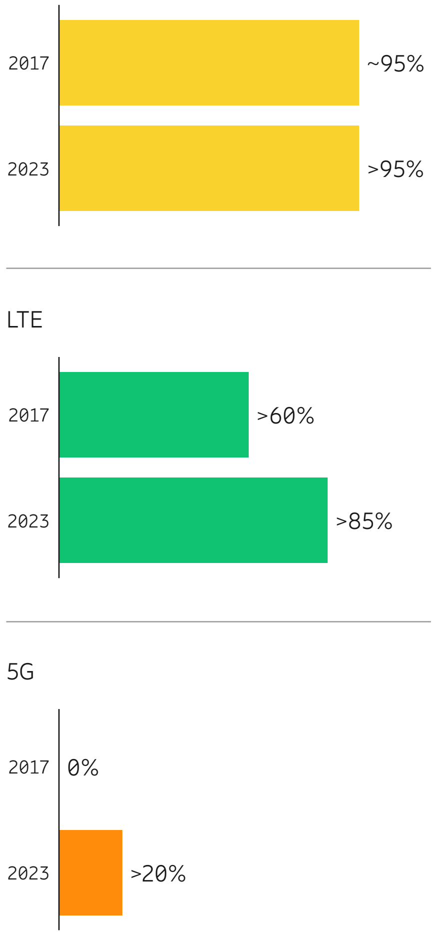
5G coverage build-out can be divided into three broad categories, based on the utilized frequency bands and corresponding radio propagation characteristics:

1. **Deployments in existing LTE bands**
   This can be achieved through new radio deployments or installing new software. Many networks can be rapidly upgraded to support 5G services in existing LTE frequency bands, for example, in low to mid-bands by using spectrum sharing between LTE and 5G.
2. **Radio deployments in new bands in the sub-6GHz range**
   From a coverage perspective, this type of deployment is similar to existing LTE deployments.
3. **Deployments in millimeter wave frequency bands**
   The inherently limited coverage in these high bands can be extended by using advanced antenna beamforming.

Given the range of options described above, a higher than usual degree of uncertainty is present in the 5G forecast. 5G coverage is estimated to exceed 20 percent in 2023.

World population coverage by technology[1]

Total population coverage of 3GPP cellular technologies



[1] The figures refer to population coverage of each technology. The ability to utilize the technology is subject to factors such as access to devices and subscriptions

Network evolution

A range of new industrial, enterprise and residential use cases beyond enhanced mobile broadband are enabled by evolving networks. Fixed wireless access (FWA) for residential use and distributed cloud for industries are two examples.

The FWA opportunity

There are nearly 2.2 billion households worldwide and less than half are forecast to have a fixed broadband connection in 2022. In many markets, continuing to build out fixed broadband infrastructure is not economically viable. The high population coverage of 3GPP cellular technologies, as well as deployments of mobile networks with increasingly high network speeds (see the figure below), opens up an opportunity for FWA deployments.

An evolving market for FWA

FWA is generating interest in the industry for the following reasons:

- Network performance is improving, making it an increasingly competitive alternative to fixed broadband
- Additional spectrum is being made available globally
- Network cost per gigabyte delivered is decreasing, creating a viable operator business case
- There is increased demand for internet access and video streaming services
- It presents a new revenue opportunity for mobile operators
- Governments in many markets are subsidizing broadband deployments as a means to stimulate economic growth

Globally, the market for FWA can be divided into three different segments:

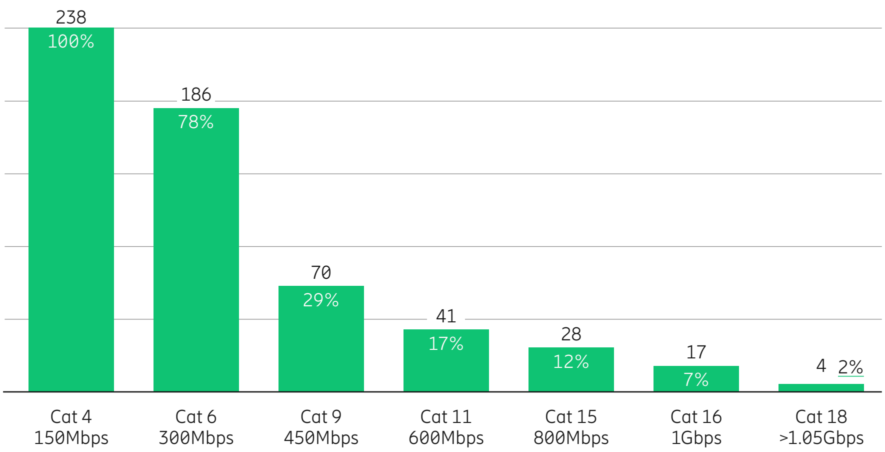
1. **Wireless fiber**
   A market competing with fixed broadband access, driving a need for higher bandwidth offerings. The objective is to provide fiber-like speeds that can meet the demand for residential streaming services, such as TV and video. Typical data speed demand ranges from 100 to 4,000Mbps.
2. **Build with precision**
   A market where there is some xDSL availability. However, there is a limited business case to provide fixed broadband alternatives. Typical data speed demand ranges from 50 to 200Mbps.
3. **Connect the unconnected**
   A market where there are virtually no existing fixed broadband alternatives, and where the dominant way of accessing the internet is through mobile networks on a smartphone. Typical data speed demand ranges from 10 to 100Mbps.

The FWA network evolution approach

A well-performing mobile broadband network is the foundation for offering an FWA service. To do this profitably, the best way to evolve the network needs to be explored. A three-step approach is being considered by operators:

1. **Utilize assets**
   This includes utilizing assets such as existing radio sites, spare load in deployed spectrum and associated deployed radio, baseband and transport equipment.
2. **Add spectrum and network capabilities**
   This includes adding spectrum, as well as radio network capabilities such as higher-order modulation, Multiple Input Multiple Output (MIMO) and beamforming, increased higher-order sectorization and 5G NR access.
3. **Densify network**
   This includes densifying the radio network grid with macro and small cells.

Percentage and number of LTE-Advanced networks supporting Cat 4, Cat 6, Cat 9, Cat 11, Cat 15, Cat 16 and Cat 18 devices



A total of 21 gigabit networks have been commercially launched.

Source: Ericsson and GSA (April 2018)

Read more about realizing smart manufacturing on page 24

The distributed cloud opportunity

Networks are evolving to handle use cases with different demands on mobility, data rates, latency, scalability, security, integrity, reliability and availability. Such demands can be met by distributed cloud architecture, which allows applications to be deployed at central, distributed and edge sites, to meet specific use case requirements.

In comparison to what is possible from central sites, providing services closer to the user reduces the network transport delay and enables faster time to content, actions and control. Executing workloads closer to the network edge also reduces the need for backhaul bandwidth and capacity, and distribution of workloads and storage over multiple sites increases availability.

Manufacturing use case requirements

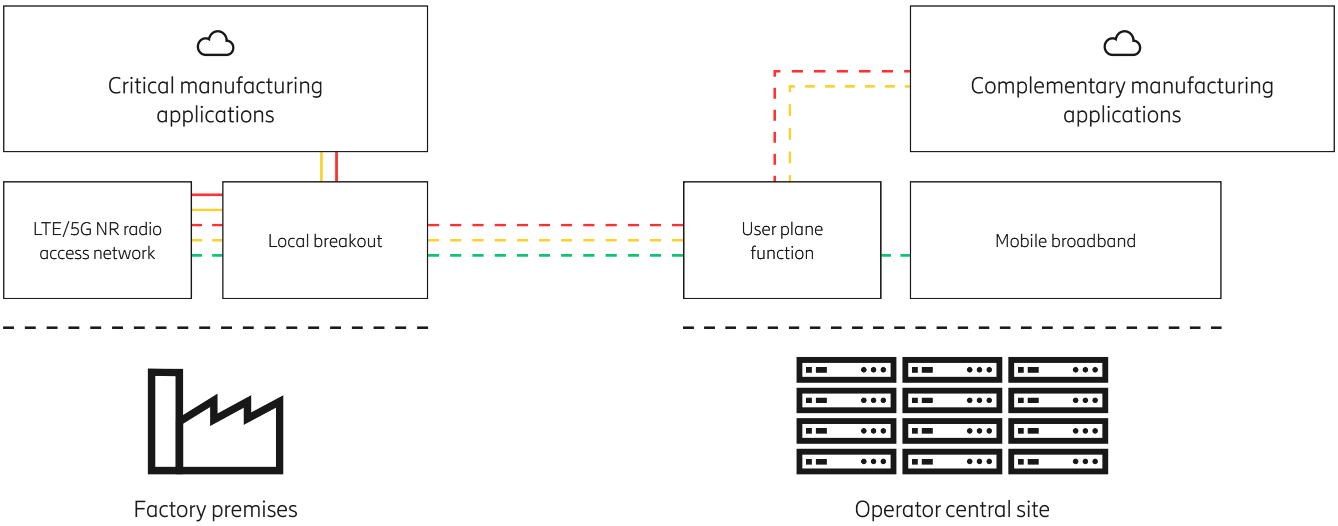
In the manufacturing industry, the digitalization of processes and workflows is creating requirements such as low latency, real-time performance, mobility, enhanced security, and ultra-reliable and very high availability. These requirements can be addressed through the capabilities of a distributed cloud.

However, connectivity requirements in a factory are very dependent on the use case and application, and so the network also needs to support service differentiation. Some use cases are possible to address with evolved 4G (LTE) technology, while others such as production and robot control may require latency between 1 and 10 milliseconds, which can only be achieved with 5G technology. Whether it is most beneficial (from both a business and use case perspective) to execute an application at a central or an edge site will differ from case to case.

On-premises cellular network deployment with edge computing

The manufacturing industry's connectivity requirements are well matched by the capabilities of cellular networks. To enable smart manufacturing, there are different network deployment options depending on the use case needs and digitalization ambitions of the factory. One option is using virtualization and Dedicated Core Networks (DECOR) to map local private networks and virtual networks running within a mobile operator's public network. A 4G and 5G network with dedicated radio base stations and Evolved Packet Core in-a-box can be deployed on the premises to ensure that traffic stays local to the site. In this case, on-premises cellular network deployment with local data breakout ensures that critical production data does not leave the premises, using Quality of Service (QoS) mechanisms to fulfill use case requirements and optimize reliability and latency. It also means that critical applications can be executed locally, independent of the macro network.

On-premises cellular network deployment with local data breakout



Network performance through the eyes of customers

Understanding the relationship between customer satisfaction, experience and network performance is the key to designing networks to drive loyalty.

In the increasingly competitive Swiss market, it has become clear that successfully attracting and retaining customers depends on providing a superior customer experience. A customer satisfaction survey carried out by Swisscom, before and after network improvements, delivered insights into how customers perceive network performance and what influences their satisfaction when using apps.

These insights were used to set up a nationwide measurement program of service key performance indicators (S-KPIs),[1] which strongly correlate to customer satisfaction and can be optimized through root cause analysis of both radio access network (RAN) and non-RAN issues.

Enhancing RAN performance

In 2017, Swisscom upgraded its mobile network in central Zürich by expanding capacity and introducing evolved network architecture. The objective was to improve customer experience despite increasingly demanding apps and growing network traffic. The project also aimed to prepare the network for a national rollout of gigabit speeds ahead of the introduction of 5G.

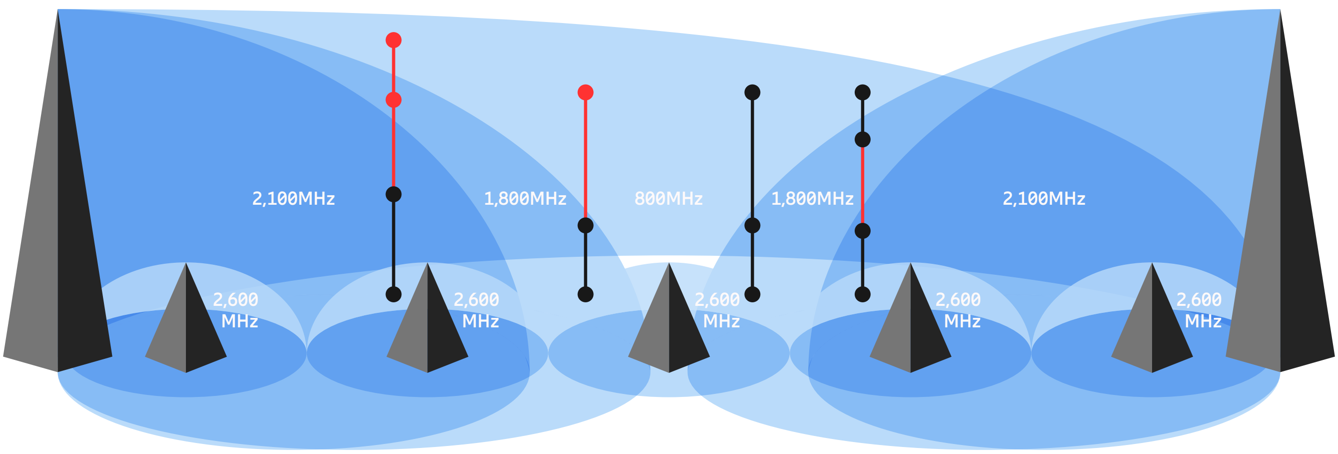
Over a three-month period, the mobile network underwent several improvements, including an evolution to Centralized RAN (C-RAN) architecture and the introduction of software to coordinate inter-site carrier aggregation.

When carriers are aggregated within and across macro and small cells, the probability of achieving performance gains increases. This leads to higher data speeds and results in a better customer experience. The solution also increases network efficiency, lowering the cost per gigabyte delivered. Through this approach, the network can be effectively coordinated to ensure the highest possible performance.

This article was written in cooperation with Swisscom, a market-leading operator based in Switzerland. Swisscom offers a range of broadband, digital TV and mobile telecommunications services for residential customers, as well as being a major provider of ICT, cloud and security services for businesses.

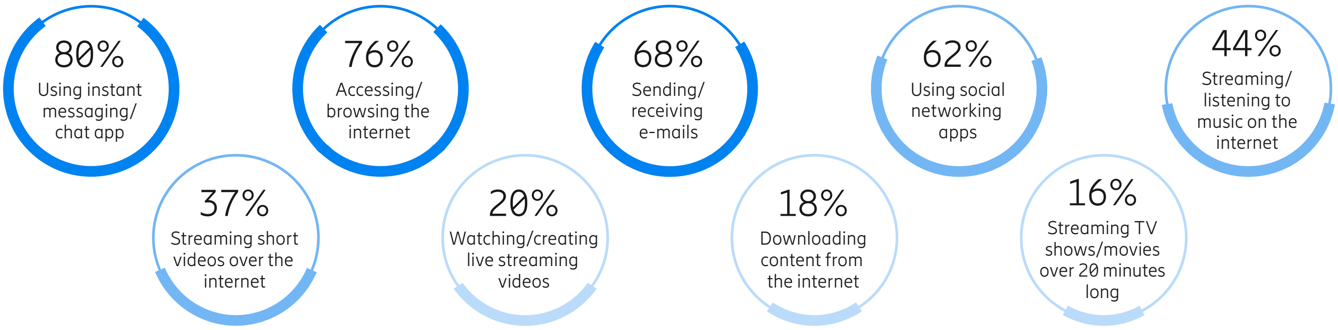
swisscom

Centralized RAN and coordination software enable inter-site carrier aggregation across macro and small cells



[1] Service key performance indicators (S-KPIs) measure the perceived user experience at application level from an end-to-end perspective (from application servers to User Equipment)

Activities performed on a daily basis by smartphone users in the test area (percent)



Source: Swisscom and Ericsson Consumer & IndustryLab (2017)
Base: Swisscom customers who are daily users of these services on their smartphones in the test area

Understanding the impact of network performance

As Swisscom implemented the mobile network performance enhancements in a limited test area, the upgrade provided an opportunity to conduct the satisfaction survey with those who spend a significant amount of time each month in the same area. The objective was to understand the impact of improved network performance on customer experience, and included insights into:

- Usage of apps and services on the 4G network – respondents' self-evaluation, validated by network data, can be seen in the figure above
- Issues and customer experience before and after network improvements
- How customers evaluate the performance of the mobile network
- Factors that drive network satisfaction and willingness to refer Swisscom to others

Improved minimum speed drives customer satisfaction

Before the network improvements were made, customers' satisfaction with speed was lowest for data-intensive apps, especially when uploading or downloading photos and videos, or streaming music and video. When the survey results were compared after the network enhancement, Swisscom's assumption that an improvement in minimum speed would result in a better customer experience was validated.

After the network enhancement, analysis of independent active speed tests on User Equipment (UE) in the test area showed a 33 percent increase in minimum speed to 8.5Mbps.

The customer survey data showed that a better experience was reported by 42 percent of daily streamers and 24 percent of all other participants. This indicates that heavy data users benefited from the network improvements. These improvements resulted in an 11 percentage point increase in willingness to refer the mobile network to others, while also reducing detractors by 26 percent.

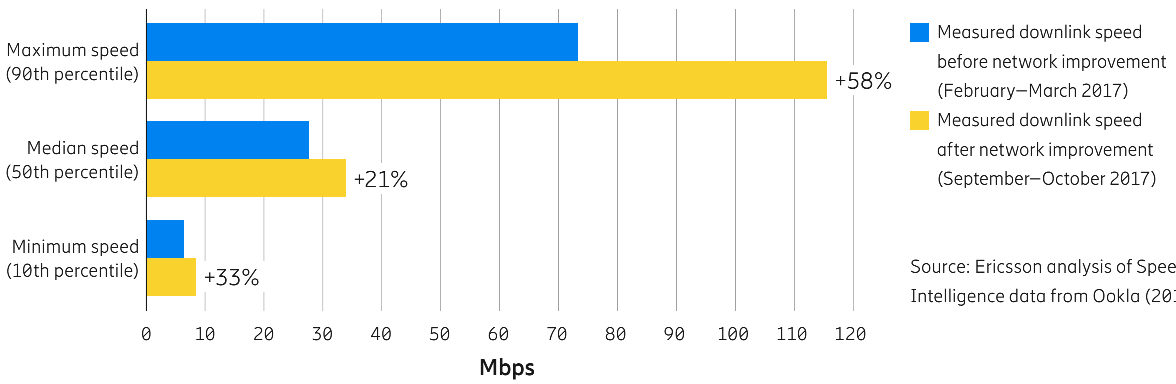
11pp

Network improvements resulted in an 11 percentage point increase in willingness to refer the mobile network to others.

33%

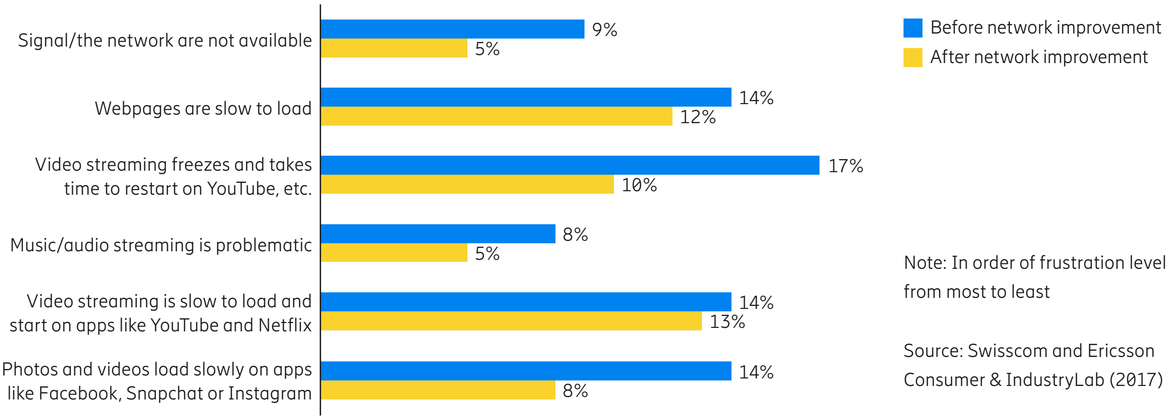
After the network enhancement, analysis of independent active speed tests on User Equipment in the test area showed a 33 percent increase in minimum speed.

Measured downlink network speeds in the test area (Mbps)



Source: Ericsson analysis of Speedtest Intelligence data from Ookla (2017)

Respondents who said they "often face" a problem on their smartphone in the test area (percent)



Note: In order of frustration level from most to least

Source: Swisscom and Ericsson Consumer & IndustryLab (2017)

Customers' most important criteria when assessing network performance
After network enhancement, respondents' satisfaction with coverage, reliability and speed had improved.

When asked how they evaluate the performance of the network, the top five criteria for all customers in order of importance were:

1. Time taken to open a webpage
2. How long it takes to transfer photos and videos in chat apps
3. How quickly e-mail attachments download
4. How long it takes for a streaming video to start
5. How often streaming video freezes

However, daily video streamers consider video start time and freezing to be more important than e-mail attachment download speed for evaluating network performance.

Speed as a quantifiable property was not important to most respondents. Only 10 percent reported that the results from speed test apps were their most important criterion for evaluating network performance. Nearly three-quarters of all respondents were not even aware of the maximum speed offered by their unlimited data subscriptions.[2]

In contrast, customers who were already dissatisfied with the mobile network ranked their criterion differently. For them, the most important indicator of network performance was video freezing, followed by results from a speed test app. A possible explanation is that this sample of users is young and digitally advanced, and therefore high-performing video is essential to satisfaction.

Improvements made to the mobile network reduced the occurrence of many frustrating issues often faced by respondents (see the figure above). Occurrence of the most frustrating issue – an unavailable network – was reduced by almost half. The second most frustrating issue – slow webpages – only improved slightly, whereas customers reported a strong reduction in the third most frustrating issue – video freezing.

Video streaming experience is critical to customer satisfaction and loyalty
As part of the second wave of the survey, Swisscom asked detailed questions about the video streaming experience after improvements were made to the network. Several aspects of the video experience were ranked differently in terms of their satisfaction and relative importance. Although customers were most satisfied with the quality of the video, the two most relatively important aspects for video satisfaction were smoothness of playback (no video freezing) and the time taken to load and start a video (see the figure on the following page).

The results also show that satisfaction with video streaming is strongly correlated with overall satisfaction. Of those who are satisfied with their video streaming experience, 8 in 10 are also satisfied with the mobile network experience. Further to this, 72 percent of users who are dissatisfied with video streaming are not satisfied with the mobile network experience. Those who are satisfied with video streaming are far more willing to refer Swisscom's mobile network than those who are not. Of the customers who were satisfied with video streaming, 88 percent had no intention of changing operator within the next 12 months. However, only 35 percent of users dissatisfied with video said they would definitely not switch.

These results show that video streaming experience is critical to customer satisfaction and loyalty, especially for younger users, and that end-to-end network design and optimization should set the goal to improve this experience.

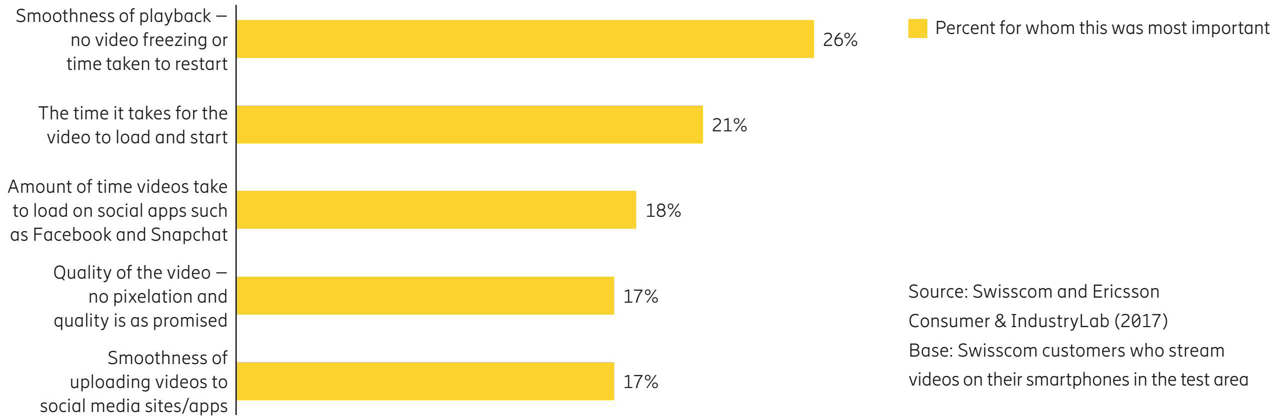
Requirement for an end-to-end perspective when optimizing experience
These results make it clear that not all aspects of the customer experience can be improved by enhancing the mobile network. Enhancing RAN does not completely address all customer experience problems. It is important to identify bottlenecks and optimize performance with an end-to-end perspective, including the app itself, the customer's device and the path data takes through the internet. In the case of slow webpage download, improving response time on the internet requires an efficient Content Delivery Network (CDN) or troubleshooting of the Domain Name System (DNS).

8 in 10

Of those who are satisfied with their video streaming experience, 8 in 10 are also satisfied with the mobile network experience.

[2] Survey respondents had post-paid subscriptions, with unlimited data volume and maximum speed limits depending on the subscription (for example: maximum 2Mbps, maximum 10Mbps or maximum 50Mbps)

Relative importance of different aspects of video in driving video streaming-related satisfaction



Source: Swisscom and Ericsson Consumer & IndustryLab (2017)
Base: Swisscom customers who stream videos on their smartphones in the test area

Translating customer experience targets into network enhancements
The customer study explored in this article identified key performance indicators (KPIs) that have a strong impact on customer satisfaction. The two most important S-KPIs were:

– Webpage download time – the most important customer criterion for evaluation of the network
– Video freezing – a criterion that has a very strong influence on satisfaction with the mobile network

These S-KPIs enable the corresponding network performance KPIs to be identified, measured and optimized, ultimately increasing customer satisfaction and retention.

Swisscom has taken further actions based on these results, and is measuring these and other S-KPIs using passive probes. This gives a network-wide view of their status.

The S-KPI approach reveals the performance of apps and services, not only within single cells but also as customers move between cells. This detects problems that are missed when monitoring individual cells. The S-KPIs are correlated with data about the RAN in a time-stamped, end-to-end session record for each customer. The network is then optimized to improve the poorly performing S-KPIs.

> Operators should explore ways to design and optimize their networks based on S-KPIs that accurately reflect customers' perception of network performance and that are important for customer satisfaction.

The insights from this survey strongly indicate that mobile networks should be designed and optimized based on KPIs that accurately reflect customers' perception of network performance and that are important for customer satisfaction and loyalty. The findings present a way to communicate with customers about the tangible benefits the mobile network delivers and which customers can directly experience, such as rapid webpage downloads and uninterrupted video streams.

The customer study and resulting insights described in this article are an important step toward understanding the relationship between customer satisfaction, customer experience and network performance. Swisscom began by investigating the impact of network improvements on customer experience and satisfaction. Once these relationships were established, the problem could be turned around; it is becoming possible to start with customer experience, then measure relevant S-KPIs and optimize the network to maximize satisfaction and loyalty. This approach will be further explored and tested to fully understand its potential.

Research methodology and segmentation
The survey was conducted in collaboration with Ericsson Consumer & IndustryLab, with 8,000 Swisscom customers invited to take part. Of these customers, 750 agreed to participate, all of whom spent at least 40 hours per month in the test area, with three-quarters living or working there. The others frequent this popular area to shop, meet with friends or clients and eat at restaurants, for example.

The survey took place in two waves: before any improvements were made to the network and one month afterwards. The 150 respondents who participated in both waves enabled a direct comparison of the customer experience before and after network enhancement.

The sample was evenly divided between genders and predominantly consisted of people from younger age groups. Only 17 percent were aged over 50 years old and 45 percent were under 30 years old. Most respondents (83 percent) were customers classified by Swisscom as digitally advanced users.[3] Almost all respondents had subscriptions with unlimited data, although subscriptions differed in terms of maximum speed (largely between 10Mbps and 50Mbps).

[3] Swisscom segments residential users according to usage of digital consumer devices, including smartphones, tablets, television and computers. The term "digitally advanced user" refers to customers in those segments that exhibit a strong interest in new technologies and use them fluidly in daily life

Realizing smart manufacturing

With the new standards in cellular connectivity, almost every asset in a factory can be connected and managed in order to solve operational challenges.

To be competitive, manufacturers seek efficiencies in production and the ability to deliver a broader mix of customized products. This requires operational processes and production lines to be integrated and adaptable to enable fast configuration changes and reduce lead times, without compromising on safety or quality.

Operational challenges are addressed by three main use case categories (see figure below). To realize these use cases, highly diverse assets must be connected on a large scale through a cost-effective and automated onboarding process. The characteristics of cellular networks make this possible.

Unlocking value with cellular connectivity

Cellular networks meet a range of requirements to support different manufacturing use cases, making it possible to securely and efficiently optimize manufacturing variables[1] with one communication system. They allow massive real-time data collection and analytics, increasing intelligent automation on the factory floor and enabling adaptive production. Cellular connectivity also enables fast and cost-efficient production line changes, as well as integration and optimization of contributing workflows.

In comparison, a fixed cabled network is mainly restricted to supporting critical applications for stationary machines, and Wi-Fi to supporting non-critical (massive) applications. In both cases, scaling connected operations is not feasible, as cables are costly to install and maintain and Wi-Fi cannot sustain high network performance.

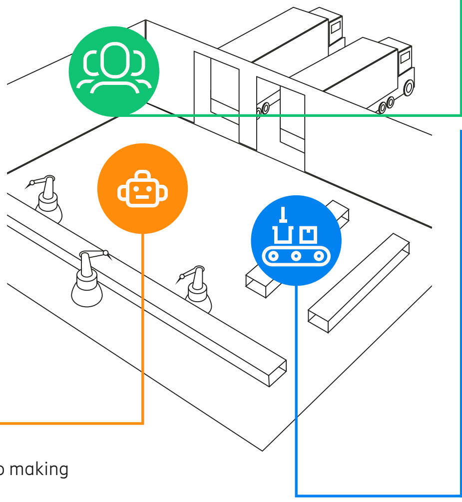
Addressing workflow challenges in manufacturing with cellular networks

As manufacturers seek to optimize utilization of every variable in production, the installed connectivity foundation (fixed or Wi-Fi) is also challenged. All variables cannot be managed with only a fixed cabled network, as a manufacturing site comprises more than stationary machines, such as rotating, moving machines and portable items: tools, materials, phones and tablets.

By connecting infrastructure, equipment and the workforce, cellular connectivity can be used to maximize data collection and provide actionable insights from different workflow processes.

Example of use cases enabled by cellular networks in a digital factory

Automation use cases
- Supply chain automation and assembly control
- Overview of entire production line and value chain processes for operational efficiency and quality
- Robot controller as cloud-based application
- Artificial intelligence automated quality testing
- Flexible production with cloud robotics

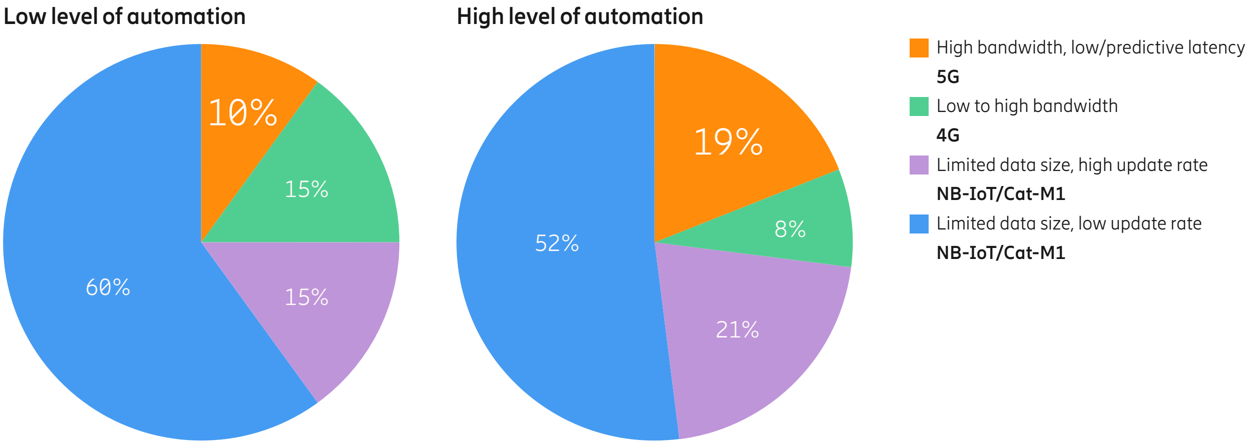


Location use cases
- Asset management
- Warehouse management
- Workforce safety and utilization

Monitoring use cases
- Remote plant monitoring
- Traffic management and route optimization (internal logistics, automated guided vehicles)
- Preventive and prescriptive maintenance
- Environmental compliance and regulations
- Workforce efficiency and manufacturing quality

[1] Manufacturing variables are all the input that goes into making the final product, including all materials and processes

Estimated share of different types of connected devices required to support use cases at a typical smart manufacturing site



Growing device, data and network demands

By 2023, the number of cellular Internet of Things (IoT) connections is forecast to reach 3.5 billion worldwide. The digitization of assets, equipment, vehicles and processes in a factory means that the number of connected devices will increase exponentially. The estimated number of connected devices needed in a typical smart factory is 0.5 per square meter.[2] This calculation is based on potential use cases and assets that would benefit from a connection.

The figure above illustrates the distribution of cellular connectivity requirements (supporting the previously mentioned use cases) in a fully deployed smart factory. The share of each type of connected device[3] depends on whether the site has a low or high level of automation.[4] Evolving to a higher level of automation will increasingly lead to a higher share of 5G connected devices. Both high bandwidth and consistently low latency are necessary to support large data volumes and real-time critical data, as well as to ensure consistent and secure communication.

Use case: Cost reductions with augmented reality

Most use cases enabled by cellular networks will reduce operational costs in a factory. One example is the testing and inspection of assets and products with augmented reality (AR). Guides and contextual information empower workers, and testing or maintenance is executed quickly with higher quality.

This use case has been implemented in a factory in Estonia, resulting in consistently improved product quality with reduced lead time. The improvement in workforce utilization and minimized scrap resulted in a cost reduction of 25 percent.

Customized production requires customized networks

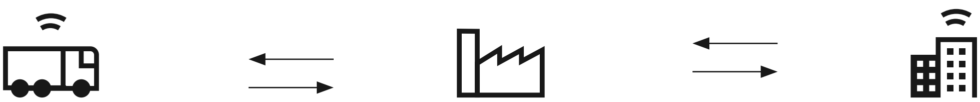
Although efficiency and quality improvements throughout the manufacturing chain are vital for success, truly competitive output will rely on customizable or adaptive production.

Network connectivity must also be customized per use case, to deliver cost-efficient performance while scaling the number of connected devices.

Cellular technology offers the capabilities to handle different use cases' service requirements by using Quality of Service (QoS) mechanisms. The importance of this will increase as manufacturers are digitalized and demand more networked capabilities beyond their sites to include logistics, suppliers and other factories.

Manufacturing comprises more than just assets and processes at the factory site. The efficiency of production is also dependent on the timely arrival of resources. Moreover, the success of manufactured products in the market depends on continuous customer feedback and co-creation. Hence, collaboration across the whole ecosystem, as seen in the figure below, results in a higher degree of product and service customization. Cellular connectivity based on 4G and 5G technologies provides the mobility, security, availability and reliability needed to realize smart manufacturing.

The future connected manufacturing industry



Connected flows
The factory is integrated with wider networks, other factories and logistics.
- Logistics securely tracked throughout manufacturing process
- Awareness of precise location of vehicles

Connected site
The factory floor is a highly specialized environment with diverse needs.
- Extreme reliability and low latency
- Secure, high reliability, high availability network

Globally connected company and products
The factory-shipped, installed and delivered goods are globally connected and serviced.
- New forms of customer engagement
- New services and partner ecosystems enabled

[2] Average number based on data from different manufacturing sites. In dense areas, the connection density could be up to one connected device per square meter
[3] The exact distribution figures for a specific manufacturing site depends on the communication needs
[4] The level of automation is a continuum from manual to fully automatic operations (Parasuraman et al., 2000)

Applying machine intelligence to network management

Advances in computing power, cloud architectures, digitalization and big data analytics are opening new opportunities for artificial intelligence (AI).

AI is making the leap from use cases that mimic human behaviors to large complex systems that leverage human capabilities. Within the field of AI, there has been rapid progress in machine intelligence, a discipline which augments the structuring and modeling of machine learning with reasoning and planning techniques.

Over the last six decades, AI has experienced recurring cycles of optimism followed by disappointment when it has not met inflated expectations. It is no secret that interest in the field is running high once again. This time, however, it is here to stay. Tools and techniques from AI are rapidly finding their way into all corners of the digital landscape. Clear examples of this development are emerging in mobile network operations and maintenance.

Managing the increasing complexity of networks

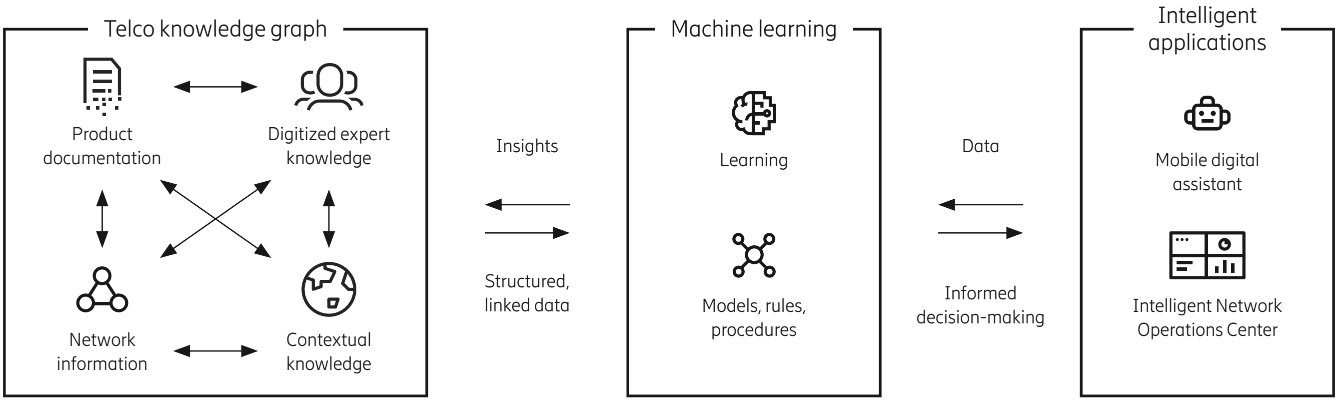
From enhanced mobile broadband to the Internet of Things (IoT), 5G will enable mobile networks to support diverse demands. Networks are rapidly growing in terms of the number of devices served and are increasingly complex. One way to handle this is to leverage the skills of experienced network engineers and technicians. AI and machine learning can be used to distribute their knowledge in autonomously managed network operations, as well as in the field, to assist installation and maintenance tasks.

Machine learning plus reasoning and planning is machine intelligence

Using structured data as the input, machine learning software builds models, rules and procedures. These results are then applied to new data as they are collected, enabling machine-based, automated decision-making. Adding further AI techniques such as reasoning and planning to machine learning enables the creation of applications we term "machine intelligence".

AI and machine learning can be used to leverage the skills of experienced engineers and technicians.

The role of structured knowledge in enabling machine intelligence and intelligent applications



Enabling machine intelligence through structured knowledge

A cornerstone in developing automated decision-making is knowledge collection and the subsequent organization of the knowledge into a graph of interlinked domains. Within the telecom industry, the knowledge that exists in the heads of experts or documented in natural language – such as product descriptions, trouble reports and customer support requests – must be transformed into structured, machine-readable data.

The structured data is referred to as the "telco knowledge graph" (see the figure above). The information is also correlated – for example, product instructions solving a specific issue in the network are linked to trouble reports, which document how the issue was solved in the field, and the empirical knowledge of experienced field technicians.

In this article, the use of the telco knowledge graph to automate aspects of network operations and maintenance is illustrated by two prototypes:

1. An application for automating Network Operations Centers (NOCs), enabling network self-recovery for machine-resolvable issues
2. A mobile digital assistant to guide field technicians through fault resolution for hardware-related errors

The intelligent NOC

As the centralized monitoring and control center of a telecom network, the primary role of an NOC is to maintain network availability and operational efficiency through fault and performance management.

Today, typical NOC challenges are largely met through technicians handling incoming alarms (fault management), identifying root causes of the alarm conditions and implementing appropriate solutions. These processes require domain experts to code solutions, which are complex to implement and maintain as the network technologies and architectures evolve.

The prototype NOC software enables automatic fault management by applying machine intelligence techniques. This enables it to:

- Map composite conditions from historical information (performing intelligent grouping of cross-domain alarms for detection using pattern mining techniques)
- Form rules from the composite conditions using machine learning
- Detect incidents based on the rules
- Identify root causes, and derive appropriate actions by mapping root causes to resolution procedures from system or solution documentation

The prototype produces rules independent of technology, topology and the architecture of the infrastructure. As a result, it is a reusable component that generates data behavior patterns for further applications in incident detection and analysis.

Network management will become a largely autonomous operation, with insights, rules, policies and workflows being continuously developed and refined. Imminent fault conditions will be predicted and corrective actions performed.

A cornerstone in developing automated decision-making is knowledge collection and the subsequent organization of the knowledge into a graph of interlinked domains.

The intelligent digital assistant

Intelligent digital assistants are a way in which machine intelligence can be applied to tasks on radio base station sites. Installation, configuration and maintenance are expensive and time consuming. The mobile device application assists technicians by performing diagnosis and troubleshooting. This reduces the time spent on site, while increasing quality assurance.

The prototype uses a combination of visual object detection technology and semantically annotated product documentation to guide a technician to complete a given task.[1] For example, in the case of troubleshooting a faulty cable adaptor, visual object detection and an augmented reality (AR) application identify and indicate the faulty port, while the steps to resolve the fault are also displayed.

Another example is the use of the application to recognize and locate various components of a radio base station. By tapping on a component's image on screen, the technician can retrieve more information about it from the documentation. The images below show the assistant in use.

Machine intelligence is used to prepare the telco knowledge graph for the process of troubleshooting. Two sets of input data are needed: a set of images for the object detector and product documentation. The documentation's references to hardware components are linked to the detected objects and vice versa.

The visual object detector is based on Convolutional Neural Network (CNN) architecture. In one step, such a system performs:

- Feature extraction from the input image pixels
- Prediction of the type of visual object
- Prediction of the location of the visual object in the scene

The object detector can be used in a client-server configuration (running on a powerful Graphics Processing Unit machine), or as a stand-alone application (running on a technician's smartphone or tablet).

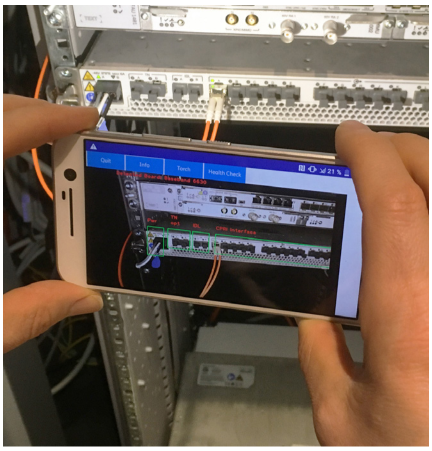
The product documentation typically exists in HTML or PDF files and follows loosely defined structural guidelines. For the content of these documents to be correctly interpreted by the application and presented to technicians, it needs to be converted to a machine-readable format through a process known as "knowledge extraction". This involves software extracting the information and transcribing it into a structured information model such as a graph.

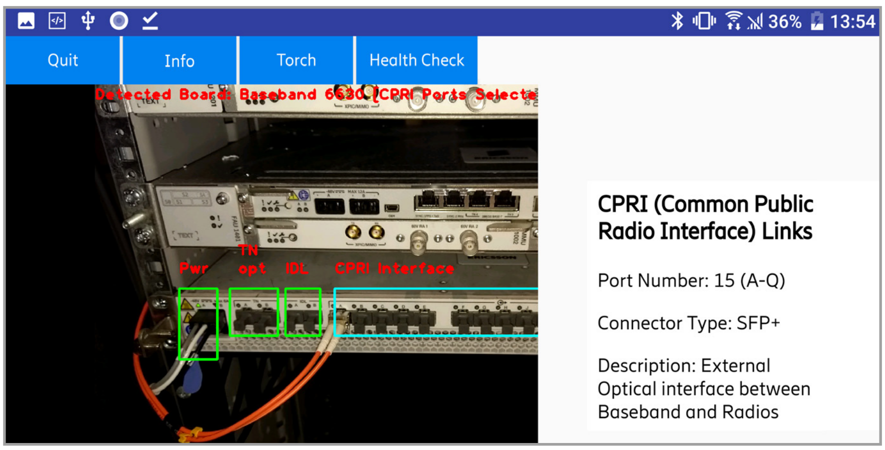
Machine intelligence will play an important role in network operations

Machine intelligence is making its way out of the lab and will increasingly be applied to mobile network operations and maintenance. Leveraging the expertise of network engineers and technicians will allow systems to expand in size and complexity while improving productivity.

> Machine intelligence is allowing systems to expand in size and complexity while improving productivity.

Technician using an intelligent digital assistant during radio base station maintenance





[1] www.ericsson.com/thinkingahead/the-networked-society-blog/2018/04/19/machine-intelligence-when-automation-is-not-an-option/#more-11693

Securing the right spectrum for 5G

The rush to implement terrestrial 5G services has already begun, with the mobile broadband industry being guided to deploy networks in different radio frequency bands.

The mobile broadband industry and the International Telecommunication Union (ITU) have already traveled quite far along the road to 5G. However, when it comes to the radio frequency spectrum issues, the road is not always straight. To secure the right 5G spectrum, there are still significant efforts needed to align allocations between countries. This is an urgent matter, as 5G networks are already being deployed in new frequency bands.

At the World Radiocommunication Conference in November 2019 (WRC-19), the member states of the ITU are expected to agree on new 5G spectrum allocations within the high bands (24.25GHz to 86GHz range). These bands are often referred to as the "millimeter wave" (mmWave) bands, and are central to supporting a wide range of new industry applications using 5G New Radio (NR) technology specified by 3GPP.

For 5G services to be successful in meeting the demands on data speeds and capacities, the agreements at the WRC-19 between the ITU member states will need to provide enough spectrum bandwidth in the right bands and under the right conditions. In this context, "conditions" refers to the requirements of use within a certain band, including co-existence with uses in adjacent bands.

The business landscape

Mobile data traffic is projected to increase by eight times over the next six years. New applications – such as augmented reality (AR), virtual reality (VR) and other increasingly immersive video formats – are emerging, along with growing demands on security and reliability. In addition, billions of new connected Internet of Things (IoT) devices are expected, with a large variety of business cases and requirements on mobile networks.

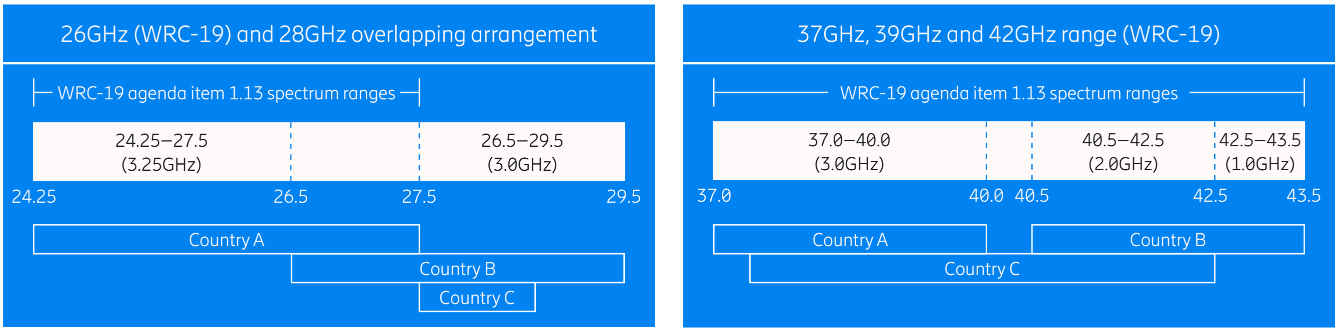
To support these demands, 5G service providers will need sufficient spectrum bandwidth. As radio wave propagation properties differ by spectrum band, it will be important to secure a combination of bands to meet both coverage (low/mid-bands) and capacity requirements (high bands).

Many of the low bands considered for 5G services have already been agreed upon by the ITU (WRC-15 or earlier). Now member states are responsible for deciding how to allocate this spectrum within their respective countries. As mentioned, decisions related to the high bands are planned to be agreed upon at the WRC-19.

Even so, as the rush to deploy 5G continues, many countries have already taken actions to allocate certain bands – both before the WRC-19 and outside the scope of the WRC-19 agenda item 1.13. This will allow for quicker deployments of 5G services but will also require dedicated efforts to harmonize these allocations between those countries.

For 5G to be successful in meeting the demands on data speeds and capacities, global harmonization of spectrum is essential.

Two examples of where spectrum harmonization can create opportunities to establish "tuning ranges"



The 5G spectrum bands

The high bands expected to be deployed early on for 5G include the 28GHz band, as well as the 26GHz, 37GHz and 39GHz bands. The 28GHz band may be used in certain countries by the end of 2018 or early 2019, while the other high bands are estimated to be available in late 2019.

Low bands below 1GHz are of interest due to their favorable radio wave propagation characteristics, as they provide coverage in remote areas and into buildings. A new band in the 600MHz range is expected to be made available by the end of 2018 for 5G services.

Part of the mid-bands between 1GHz and 7GHz is also expected to be allocated in many countries. Mid-bands within the 3.3GHz to 5GHz range will likely be made available around 2020 and are seen as important spectrum resources for terrestrial 5G access networks. The mid-bands are particularly beneficial as they offer a favorable "middle ground" between propagation characteristics (coverage) and bandwidth (capacity).

There are, of course, a number of spectrum bands already in use by service providers. In general, all the current 3GPP bands including low bands (600MHz, 700MHz, 800MHz, 850MHz and 900MHz) and mid-bands (1.5GHz, 1.7GHz, 1.8GHz, 1.9GHz, 2.1GHz, 2.3GHz and 2.6GHz) are being considered for 5G services in the future. These bands, and composite arrangements of these bands, will be central to delivering 5G coverage and capacity for enhanced mobile broadband, IoT, industrial automation and mission-critical business cases, as well as for Public Protection and Disaster Relief (PPDR) services.

In addition, 3GPP has recently started a separate Study Item to investigate the feasibility of using the 6.5GHz band (5,925MHz to 7,125MHz) for 5G services.

The importance of harmonization

As previously discussed, many countries are not waiting for 5G regulations and specifications to be completed at the WRC-19; they are already taking steps toward commercial 5G NR, with a particular focus on the spectrum range 26.5GHz to 29.5GHz (the 28GHz band). Examples include:

- In the United States, the Federal Communications Commission (FCC) has already adopted regulations governing mobile use in the 28GHz range (suggesting that satellite use will be secondary), as well as applying additional regulatory conditions. The 37GHz and 39GHz bands are also being prepared for early use.
- South Korea carried out a successful pre-commercial 5G trial using the range 26.5GHz to 29.5GHz during the Pyeongchang 2018 winter sports events. This activity was in preparation for commercial deployment, which is expected to follow a spectrum auction of the 28GHz band during 2018.
- Japan will be deploying fully commercial 5G networks for the 2020 summer sports events in Tokyo. In 2018 and 2019, the country is also carrying out a larger-scale pre-commercial field trial within the 3.7GHz, 4.5GHz and 28GHz frequency ranges.
- Regulators in Europe and China aim to deploy commercial 5G networks in the 26GHz range by 2020. In addition, they have expressed interest in subsequent deployments in the 42GHz range.
- India is considering the range 24.5GHz to 29.5GHz for commercial 5G networks, as well as the bands 37GHz, 39GHz and 42GHz.

Many countries are not waiting for 5G regulations and specifications to be completed at the WRC-19; they are already taking steps toward commercial 5G NR.

Given these activities, international harmonization of the discussed spectrum bands remains critical for the development of 5G. Countries may not always be able to use the exact same frequency bands within a certain spectrum band. The mobile industry is trying to solve this deficiency by establishing technical "tuning ranges". These are frequency ranges where the industry is able to technically mitigate that bands are being deployed differently in different countries, while still being able to develop handsets and devices that can roam between countries and be used transparently from a consumer point of view. Keeping frequency allocations within these tuning ranges would greatly benefit the industry as a whole. It would allow economies of scale to be captured for network infrastructure, mobile broadband devices and IoT devices.

In the figures above, two possible examples are shown where frequency allocations within tuning ranges have a significant positive impact. The frequency bands in the WRC-19 agenda item 1.13 are mapped over the bands being allocated by a number of the leading countries deploying 5G. If more countries adhere to these tuning ranges, the ability of 5G services to reach a global scale would significantly increase.

More advanced 5G services require wide bandwidths
In countries where 5G NR services will be deployed early, it is important to address the risk of not having a sufficient amount of licensed spectrum. Advanced 5G services are anticipated to provide significantly higher peak data rates and capacity. This will require spectrum resources to be allocated in very wide bandwidths. The need for both speed and capacity suggests that an aggregate bandwidth of 10GHz to 15GHz or more (implemented over time) will be required for these services. This means that gigahertz-wide channel blocks in bands in the 24.25GHz to 86GHz range will be needed. This is another aspect of 5G spectrum allocation that needs to be taken into account at the WRC-19.

Backhaul spectrum is key for 5G transport networks
Another key issue to be discussed at the WRC-19 is the need for additional backhaul capacity. Eventually, refarming of some of the current microwave frequency bands (such as 26GHz and 28GHz) will be required to support 5G access networks. These developments might seem to be in conflict, but they can be handled with appropriate national spectrum management.

For instance, the 32GHz band (31.8GHz to 33.4GHz) is being studied for the WRC-19 for 5G mobile access networks. However, due to limited support within the ITU, it is being positioned more as a key microwave backhaul replacement for the refarming of the 26GHz and 28GHz bands and is thus regarded as a strong candidate for a global backhaul band.

The E-band (71GHz to 76GHz paired with 81GHz to 86GHz) is an essential backhaul band of high global alignment. However, in preparation for the WRC-19, it is also being studied for 5G mobile access use. The E-band offers very wide bandwidth, enabling throughputs in the order of 10Gbps or more over several kilometers. With a microwave multi-band booster concept, like carrier aggregation in access networks, these distances can be further extended to around 10 kilometers.

In the longer term, it is clear that more backhaul spectrum will be needed to support throughputs of up to 100Gbps. In preparation for evolving 5G backhaul demands, the specifications of the W-band (92GHz to 115GHz) and D-band (130GHz to 175GHz) are being finalized in Europe and have recently started in the United States.

Local licenses for private networks
The development of private networks requiring local licensing also needs to be taken into account. A number of countries are considering awarding (or enabling service providers to lease) spectrum for local use.

Countries that wish to make spectrum available to entities on a more local basis could limit those allocations to real-estate defined areas, such as factories. This is a national decision and it is still unclear if and how countries will realize possible allocations for private networks.

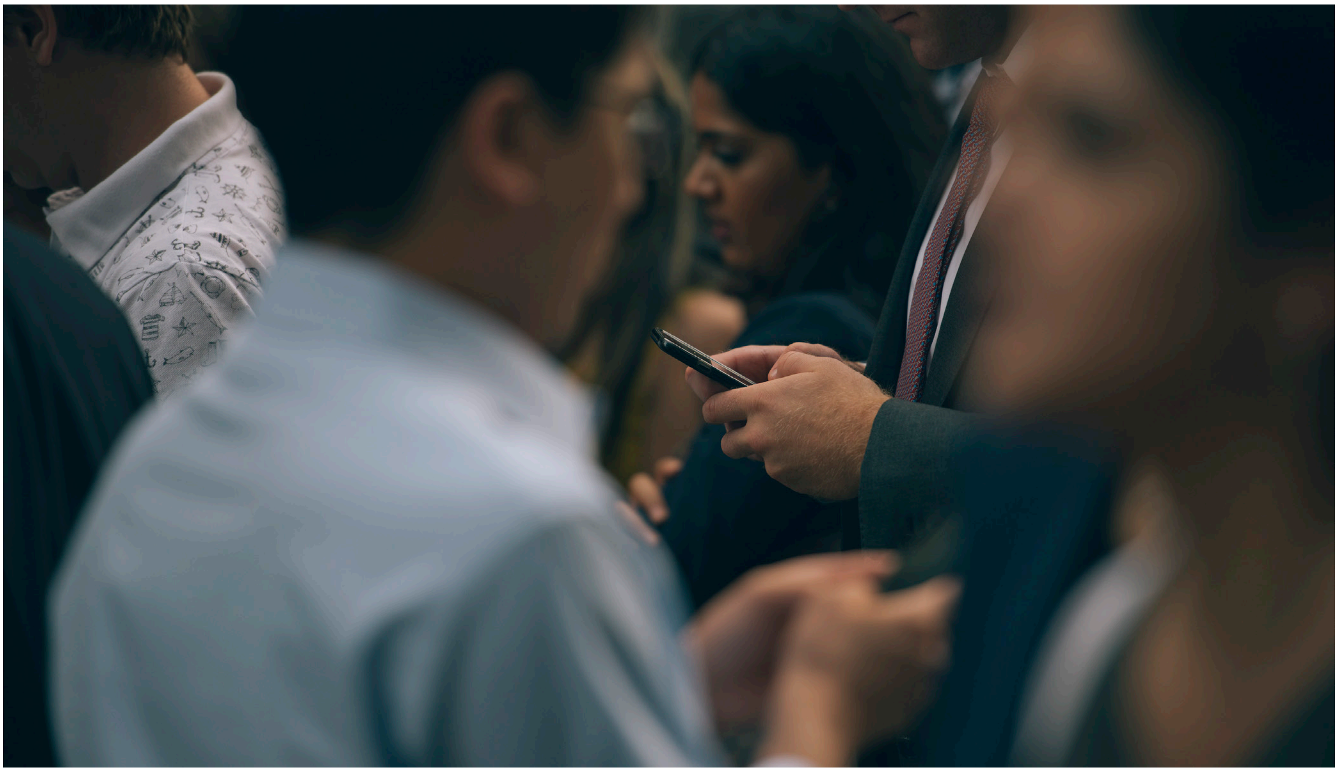
> National licensing of the right spectrum, in sufficient amounts, to terrestrial mobile broadband providers is fundamental to creating momentum for 5G service deployments.

Actions to realize the full potential of early 5G deployments
To realize the full potential of early terrestrial 5G network deployments and to meet the growing demands on network performance, significant efforts are required worldwide to reassign spectrum from underutilized applications to 5G services. This process will be most beneficial to service providers, industries and consumers if:

- Internationally harmonized high-band arrangements are applied
- Bandwidth to meet 5G access performance demands is awarded
- Spectrum for high-throughput backhaul systems is assigned
- Appropriate conditions for spectrum use are applied
- Tuning ranges are considered

National licensing of the right spectrum, in sufficient amounts, to terrestrial mobile broadband providers is fundamental to creating momentum for 5G service deployments.

Methodology



Forecast methodology
Ericsson makes forecasts on a regular basis to support internal decisions and planning, as well as market communication. The forecast period in the Mobility Report is six years, and is moved forward one year in the November report each year. The subscription and traffic forecast baseline in this report uses historical data from various sources, validated with Ericsson internal data, including extensive measurements in customer networks. Future development is estimated based on macroeconomic trends, user trends (researched by Ericsson Consumer & IndustryLab), market maturity, technology development expectations and documents – such as industry analyst reports – on national and regional levels, together with internal assumptions and analyses.

Historical data may be revised if the underlying data changes – for example, if operators report updated subscription figures.

Mobile subscriptions include all mobile technologies. Subscriptions are defined by the most advanced technology that the mobile phone and network are capable of. Figures are rounded and therefore summing up rounded data may result in slight differences from the actual totals. In the key figures tables, subscriptions have been rounded to the nearest 10th million. However, when used in highlights in the articles, subscriptions are usually expressed in full billions or to one decimal. Compound annual growth rate (CAGR) is rounded to the nearest full percentage figure, and traffic volumes are expressed in two digits, for example, 69GB/month or 8.5GB/month.

Traffic refers to aggregated traffic in mobile access networks and does not include DVB-H, Wi-Fi or Mobile WiMAX traffic. VoIP is included in data traffic.

Traffic measurements
New devices and applications affect mobile networks. Having a deep and up-to-date knowledge of the traffic characteristics of different devices and applications is important when designing, testing and managing mobile networks. Ericsson regularly performs traffic measurements in over 100 live networks covering all major regions of the world. Detailed measurements are made in a selected number of commercial WCDMA/HSPA and LTE networks with the purpose of discovering different traffic patterns. All subscriber data is made anonymous before it reaches Ericsson's analysts.

Population coverage methodology
Population coverage is estimated using a database of regional population and territory distribution based on population density. This is then combined with proprietary data on the installed base of Radio Base Stations (RBS) combined with estimated coverage per RBS for each of six population density categories (from metro to wilderness). Based on this, the portion of each area that is covered by a certain technology can be estimated, as well as the percentage of the population it represents. By aggregating these areas on a regional and global level, world population coverage per technology can be calculated.

Glossary

2G: 2nd generation mobile networks (GSM, CDMA 1x)

3G: 3rd generation mobile networks (WCDMA/HSPA, TD-SCDMA, CDMA EV-DO, Mobile WiMAX)

3GPP: 3rd Generation Partnership Project

4G: 4th generation mobile networks (LTE, LTE-A)

5G: 5th generation mobile networks (not yet standardized)

App: A software application that can be downloaded and run on a smartphone or tablet

CAGR: Compound annual growth rate

Cat-M1: A 3GPP standardized low-power wide-area (LPWA) cellular technology for IoT connectivity. Cat-M1 is a solution that can be deployed on LTE, targeting a wide range of IoT applications from simple to rich content

CDMA: Code Division Multiple Access

dB: In radio transmission, a decibel is a logarithmic unit that can be used to sum up total signal gains or losses from a transmitter to a receiver through the media a signal passes

DL: Downlink

EB: Exabyte, 10^{18} bytes

EDGE: Enhanced Data Rates for Global Evolution

EPC: Evolved Packet Core

GB: Gigabyte, 10^{9} bytes

GHz: Gigahertz, 10^{9} hertz (unit of frequency)

Gbps: Gigabits per second

GSA: Global mobile Suppliers Association

GSM: Global System for Mobile Communications

GSMA: GSM Association

HSPA: High Speed Packet Access

ICT: Information and Communications Technology

IMS: IP Multimedia Subsystem

ITU: International Telecommunication Union

IoT: Internet of Things

Kbps: Kilobits per second

LTE: Long-Term Evolution

MB: Megabyte, 10^{6} bytes

MBB: Mobile broadband (defined as CDMA2000 EV-DO, HSPA, LTE, Mobile WiMAX and TD-SCDMA)

Mbps: Megabits per second

MHz: Megahertz, 10^{6} hertz (unit of frequency)

MIMO: Multiple Input Multiple Output is the use of multiple transmitters and receivers (multiple antennas) on wireless devices for improved performance

Mobile PC: Defined as laptop or desktop PC devices with built-in cellular modem or external USB dongle

Mobile router: A device with a cellular network connection to the internet and Wi-Fi or Ethernet connection to one or several clients (such as PCs or tablets)

NB-IoT: A 3GPP standardized low-power wide-area (LPWA) cellular technology for IoT connectivity. NB-IoT is a narrowband solution that can be deployed on LTE, or as a stand-alone solution, targeting ultra-low-throughput IoT applications

NFV: Network Functions Virtualization

NR: New Radio as defined by 3GPP Release 15

OS: Operating System

PB: Petabyte, 10^{15} bytes

QAM: Quadrature Amplitude Modulation

SDN: Software-Defined Networking

Short-range IoT: Segment that largely consists of devices connected by unlicensed radio technologies, with a typical range of up to 100 meters, such as Wi-Fi, Bluetooth and Zigbee. This category also includes devices connected over fixed-line local area networks and powerline technologies

Smartphone: Mobile phone with OS capable of downloading and running "apps" e.g. iPhones, Android OS phones, Windows phones and also Symbian and Blackberry OS

TD-SCDMA: Time Division-Synchronous Code Division Multiple Access

TDD: Time Division Duplex

VoIP: Voice over IP (Internet Protocol)

VoLTE: Voice over LTE as defined by GSMA IR.92 specification. An end-to-end mobile system including IP Multimedia Subsystem (IMS), Evolved Packet Core (EPC), LTE RAN, Subscriber Data Management and OSS/BSS

UL: Uplink

WCDMA: Wideband Code Division Multiple Access

Wide-area IoT: Segment consisting of devices using cellular connections, as well as unlicensed low-power technologies, such as Sigfox and LoRa

Global and regional key figures

Ericsson Mobility Visualizer
Explore actual and forecast data from the Mobility Report in our new interactive web application. It contains a range of data types, including mobile subscriptions, mobile broadband subscriptions, mobile data traffic, traffic per application type, VoLTE statistics, monthly data usage per device and an IoT connected device forecast. Data can be exported and charts generated for publication subject to the inclusion of an Ericsson source attribution.

Find out more
Scan the QR code, or visit www.ericsson.com/mobility-report/mobility-visualizer

Global key figures

Mobile subscriptions	2016	2017	2023 forecast	CAGR** 2017–2023	Unit
Worldwide mobile subscriptions	7,500	7,790	8,880	2%	million
– Smartphone subscriptions	3,760	4,330	7,170	9%	million
– Mobile PC, tablet and mobile router* subscriptions	240	250	320	4%	million
– Mobile broadband subscriptions	4,450	5,300	8,330	8%	million
– Mobile subscriptions, GSM/EDGE-only	2,970	2,420	520	-23%	million
– Mobile subscriptions, WCDMA/HSPA	2,300	2,390	1,750	-5%	million
– Mobile subscriptions, LTE	1,890	2,740	5,490	12%	million
– Mobile subscriptions, 5G			1,080		million
Mobile data traffic*					
– Data traffic per smartphone	2.2	3.4	17	31%	GB/month
– Data traffic per mobile PC	7.8	9.8	27	18%	GB/month
– Data traffic per tablet	3.6	4.6	13	18%	GB/month
Total data traffic***					
Total mobile data traffic	8.8	15	107	39%	EB/month
– Smartphones	7.2	13	100	41%	EB/month
– Mobile PCs and routers	1.3	1.6	4.4	19%	EB/month
– Tablets	0.3	0.5	1.8	26%	EB/month
Total fixed data traffic	70	80	250	20%	EB/month

* Active devices
** CAGR is calculated on unrounded figures
*** Figures are rounded (see methodology) and therefore summing up of rounded data may result in slight differences from the actual total

[1] These figures are also included in the figures for North East Asia
[2] These figures exclude Pakistan
[3] These figures are also included in the figures for Middle East and Africa

Regional key figures

Mobile subscriptions	2016	2017	2023 forecast	CAGR** 2017–2023	Unit
North America	380	390	450	2%	million
Latin America	690	690	730	1%	million
Western Europe	520	520	550	1%	million
Central and Eastern Europe	580	590	620	1%	million
North East Asia	1,720	1,830	2,090	2%	million
China[1]	1,320	1,420	1,590	2%	million
South East Asia and Oceania	1,070	1,130	1,290	2%	million
India, Nepal and Bhutan	1,160	1,200	1,390	2%	million
Middle East and Africa[2]	1,380	1,440	1,760	3%	million
Sub-Saharan Africa[3]	660	680	930	5%	million

Smartphone subscriptions					
North America	290	310	400	4%	million
Latin America	380	420	550	5%	million
Western Europe	370	400	490	4%	million
Central and Eastern Europe	220	250	450	10%	million
North East Asia	1,290	1,400	1,980	6%	million
China[1]	1,050	1,150	1,560	5%	million
South East Asia and Oceania	470	560	1,050	11%	million
India, Nepal and Bhutan	270	380	970	17%	million
Middle East and Africa[2]	470	610	1,280	13%	million
Sub-Saharan Africa[3]	230	290	750	17%	million

Data traffic per smartphone*					
North America	5.2	7.2	49	37%	GB/month
Latin America	1.7	2.5	15	35%	GB/month
Western Europe	2.7	4.0	25	36%	GB/month
Central and Eastern Europe	2.7	3.8	18	29%	GB/month
North East Asia	1.3	2.6	14	32%	GB/month
China[1]	0.93	2.3	12	32%	GB/month
South East Asia and Oceania	1.8	2.7	14	32%	GB/month
India, Nepal and Bhutan	4.1	5.7	13	15%	GB/month
Middle East and Africa	1.3	2.0	12	35%	GB/month
Sub-Saharan Africa[3]	1.0	1.4	6.9	31%	GB/month

Total mobile data traffic					
North America	1.8	2.5	19	40%	EB/month
Latin America	0.67	1.0	8.0	41%	EB/month
Western Europe	1.2	1.7	11	36%	EB/month
Central and Eastern Europe	0.71	1.1	8.4	40%	EB/month
North East Asia	2.0	4.0	25	35%	EB/month
China[1]	1.1	2.7	18	38%	EB/month
South East Asia and Oceania	0.79	1.3	12	44%	EB/month
India, Nepal and Bhutan	1.0	1.9	10	32%	EB/month
Middle East and Africa	0.69	1.3	14	49%	EB/month
Sub-Saharan Africa[3]	0.22	0.36	4	49%	EB/month

Ericsson enables communications service providers to capture the full value of connectivity. The company's portfolio spans Networks, Digital Services, Managed Services, and Emerging Business and is designed to help our customers go digital, increase efficiency and find new revenue streams. Ericsson's investments in innovation have delivered the benefits of telephony and mobile broadband to billions of people around the world. The Ericsson stock is listed on Nasdaq Stockholm and on Nasdaq New York.

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