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ERICSSON MOBILITY REPORT

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As Ericsson's newly appointed CSO, I am proud to take over as publisher of the Ericsson Mobility Report. Over the last five years, we have published insights and data points that clearly illustrate the tremendous evolution of mobile technology.

Recently, the industry has taken major steps to progress network evolution, including the approval of the Non-Standalone 5G New Radio (NR) that will enable early 5G deployments. By 2022, we anticipate that there will be more than half a billion 5G subscriptions, with a population coverage of 15 percent.

Mobile broadband continues to grow strongly. On average, more than 1 million new mobile broadband subscribers will be added every day up to the end of 2022.

The total traffic in mobile networks increased by 70 percent between the end of Q1 2016 and the end of Q1 2017. Part of this increase was due to one Indian operator's introductory LTE offer that included free data traffic.

In this edition, we have included four feature articles, exploring various aspects of the mobile industry. The findings presented range from how leveraging existing mobile infrastructure is the most cost-effective way to connect the 50 percent of the global population that still doesn't have internet access, to how attributes of 5G will make public transport using autonomous vehicles safer.

I hope you find this report engaging and valuable. All our content is available at **www.ericsson.com/mobility-report**

PUBLISHER

Niklas Heuveldop,
Chief Strategy Officer
and Senior Vice President
Technology and Emerging Business

| 2016 | 7.5B |
| 2022 | 9B |

CAGR 3%

WORLDWIDE MOBILE SUBSCRIPTIONS

| 2016 | 8.8EB |
| 2022 | 71EB |

CAGR 42%

WORLDWIDE TOTAL MOBILE DATA TRAFFIC

WORLDWIDE DATA TRAFFIC PER SMARTPHONE

| 2016 | 2.1GB |
| 2022 | 12GB |

CAGR 33%

CONTENTS

2016 3.9B
2022 6.8B

WORLDWIDE SMARTPHONE SUBSCRIPTIONS

CAGR 10%

2016 4.4B
2022 8.3B

WORLDWIDE MOBILE BROADBAND SUBSCRIPTIONS

CAGR 11%

2016 1.9B
2022 5B

WORLDWIDE LTE SUBSCRIPTIONS

CAGR 18%

Forecast

Articles

MOBILE SUBSCRIPTIONS Q1 2017

Globally, 107 million new mobile subscriptions were added in Q1, reaching a total of 7.6 billion

Mobile subscriptions are growing at around 4 percent year-on-year, reaching 7.6 billion in Q1. India grew the most in terms of net additions during the quarter (+43 million), followed by China (+24 million), Indonesia (+10 million), Pakistan (+5 million) and Nigeria (+3 million). The strong subscription growth in India was mainly due to an attractive LTE "welcome offer" by one operator, with free voice and data.

Mobile broadband subscriptions[1] are growing by around 25 percent year-on-year, increasing by approximately 240 million in Q1 2017 alone. The total number of mobile broadband subscriptions is now around 4.6 billion.
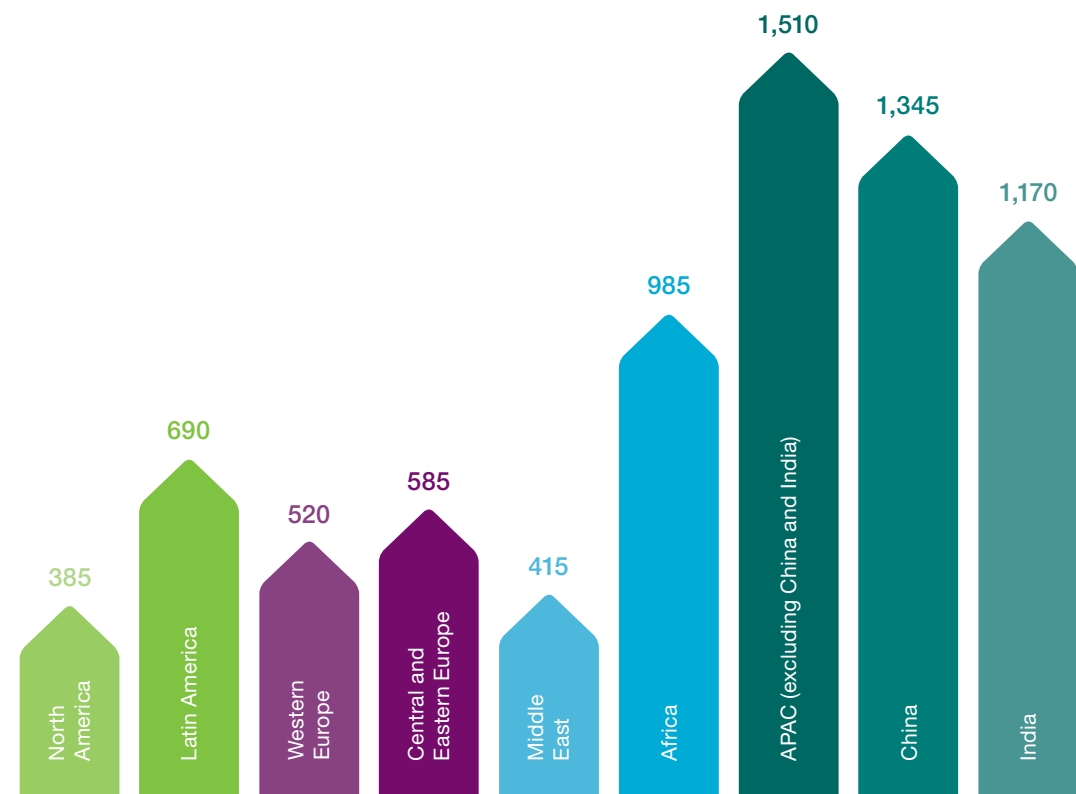
LTE subscriptions continue to grow strongly, with 250 million new subscriptions added during Q1 2017 to reach a total of around 2.1 billion. The net addition for WCDMA/HSPA was around 10 million subscriptions during the quarter.

LTE subscriptions reached a total of 2.1 billion in Q1 2017

The majority of 3G/4G subscriptions have access to GSM/EDGE as a fallback. During Q1 2017, GSM/EDGE-only subscriptions declined by 110 million. Other technologies declined by 40 million.

Subscriptions associated with smartphones have surpassed those for basic phones. Of all subscriptions, 55 percent are now for smartphones and, in Q1, smartphones accounted for 80 percent of all mobile phones sold.

Mobile subscriptions (millions)

Region	Millions
North America	385
Latin America	690
Western Europe	520
Central and Eastern Europe	585
Middle East	415
Africa	985
APAC (excluding China and India)	1,510
China	1,345
India	1,170

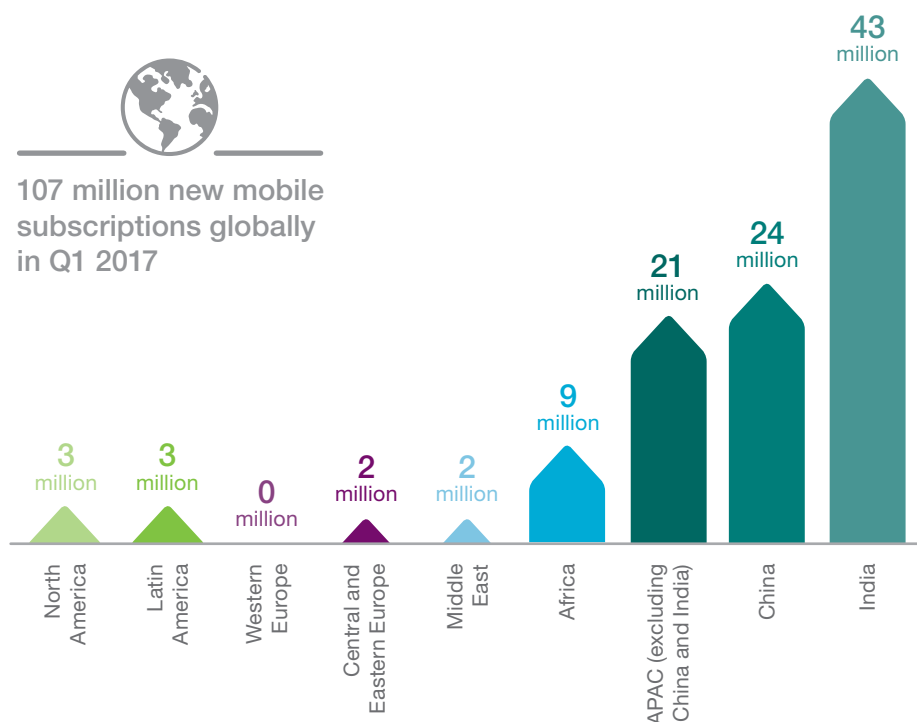[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX
Note: WCDMA without HSPA and GPRS/EDGE (2G) are not included

New mobile subscriptions Q1 2017

107 million new mobile subscriptions globally in Q1 2017

Bar chart values:
- North America: 3 million
- Latin America: 3 million
- Western Europe: 0 million
- Central and Eastern Europe: 2 million
- Middle East: 2 million
- Africa: 9 million
- APAC (excluding China and India): 21 million
- China: 24 million
- India: 43 million

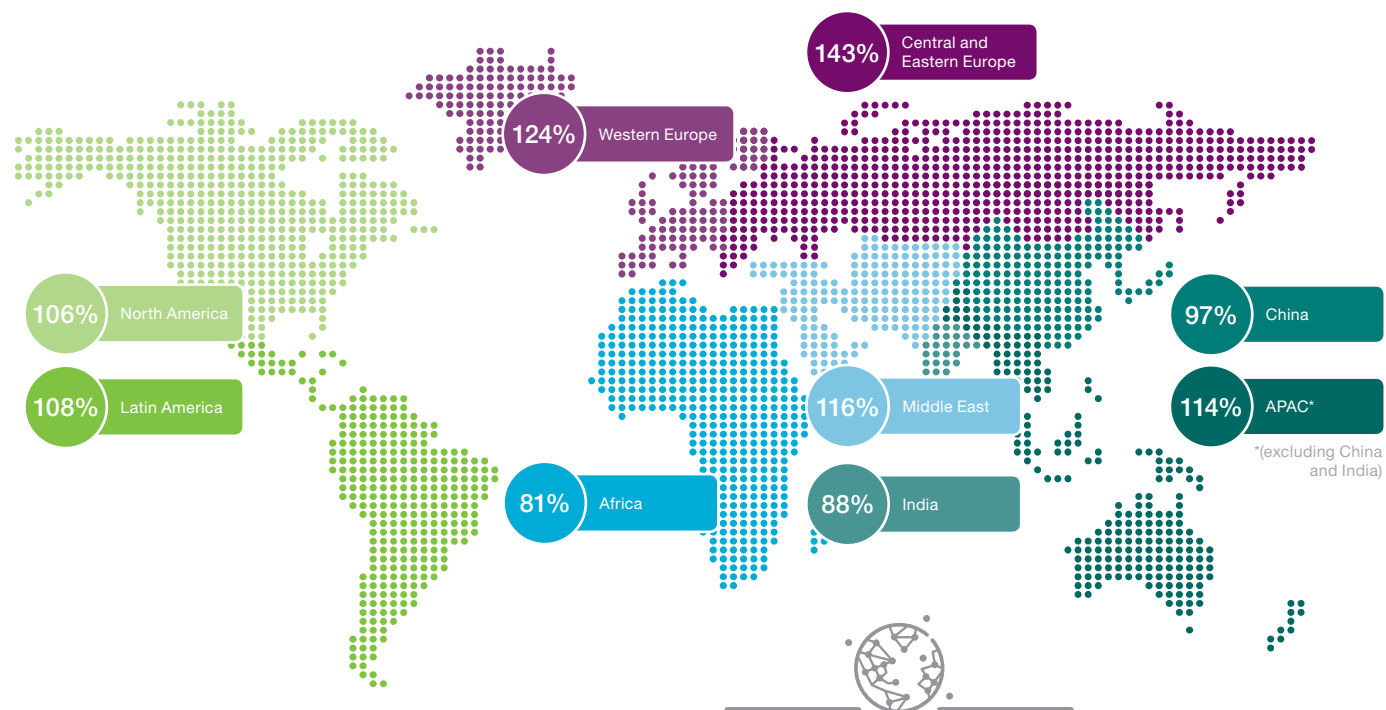### Top 5 countries by net additions Q1 2017

1. India — +43 million
2. China — +24 million
3. Indonesia — +10 million
4. Pakistan — +5 million
5. Nigeria — +3 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 5.2 billion subscribers globally compared to 7.6 billion subscriptions.

5.2 BILLION subscribers

Subscription penetration (percent of population):
- North America: 106%
- Latin America: 108%
- Western Europe: 124%
- Central and Eastern Europe: 143%
- Middle East: 116%
- Africa: 81%
- India: 88%
- China: 97%
- APAC*: 114%

*(excluding China and India)

Subscription penetration (percent of population)

102% global subscription penetration in Q1 2017

MOBILE SUBSCRIPTIONS OUTLOOK

Acceleration of the 5G New Radio (NR) standardization schedule will enable large-scale trials and deployments of 5G in 2019. The number of 5G subscriptions is forecast to exceed half a billion by the end of 2022

In March 2017, 3GPP approved acceleration of the 5G NR standardization schedule by introducing an intermediate milestone for an early variant called Non-Standalone 5G NR.[1] This will enable early 5G deployments and support the requirements for enhanced mobile broadband services.

Early 5G deployments are anticipated in several markets. In 2022, the number of 5G subscriptions is forecast to reach more than 500 million. A 5G subscription will require a device capable of supporting 5G services and use cases, and that is connected to a 5G-enabled network.

Over time, 5G will enable a wide range of use cases for massive Internet of Things (IoT) and critical communication.

GSM/EDGE-only still constitutes the largest category of mobile subscriptions. However, LTE is anticipated to become the dominant mobile access technology in 2018, and will likely reach 5 billion subscriptions by the end of 2022. By this time, the number of LTE subscriptions will be more than seven times the GSM/EDGE-only subscriptions, while the corresponding number for WCDMA/HSPA subscriptions will be four times. In developing markets,

GSM/EDGE will still account for a significant share of subscriptions, and across all regions, most 3G/4G subscriptions will still have access to GSM/EDGE as a fallback. GSM/EDGE will also continue to play an important role in IoT applications.

> **5G subscriptions will exceed half a billion by the end of 2022**

Mobile subscriptions by technology (billion)

> **5 billion LTE subscriptions by the end of 2022**

Legend:
- 5G
- LTE
- WCDMA/HSPA
- GSM/EDGE-only
- TD-SCDMA
- CDMA-only
- Other
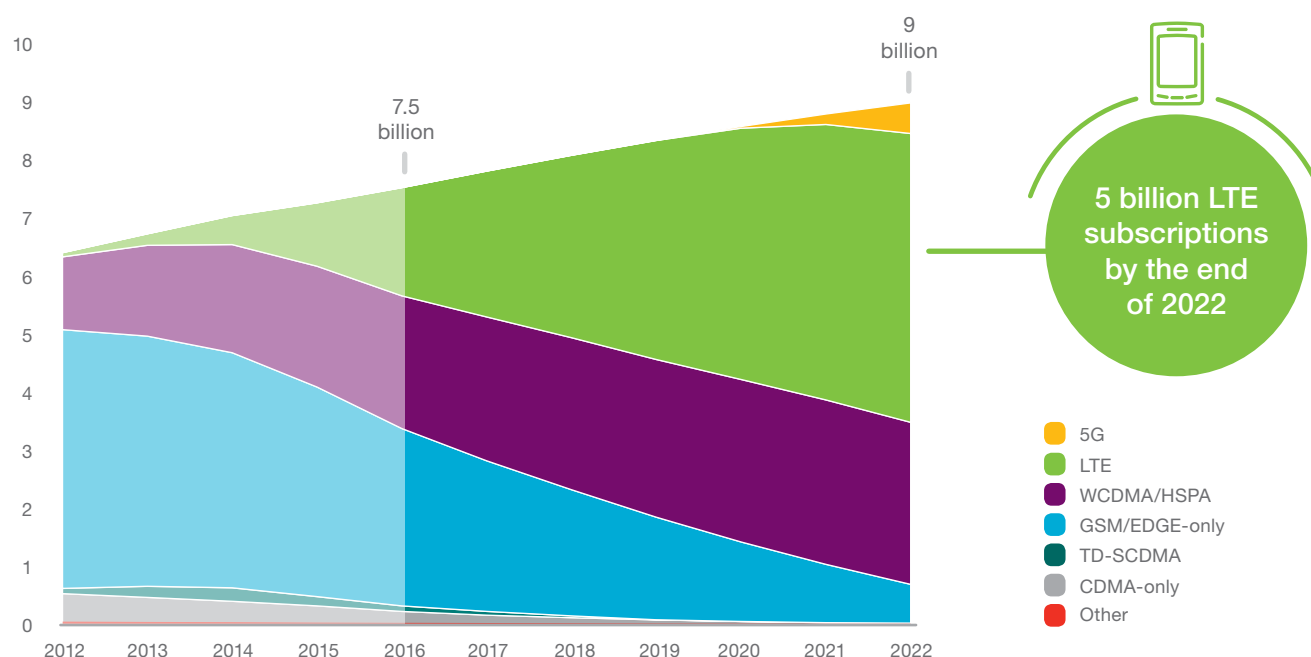
[1] Non-Standalone 5G NR will utilize the existing LTE radio sand Evolved Packet Core network as an anchor for mobility management and coverage, while adding a new 5G radio access carrier to enable certain 5G use cases starting in 2019
Figure note: IoT connections and Fixed Wireless Access (FWA) subscriptions are not included in the above graph

Subscriptions/lines, subscribers (billion)
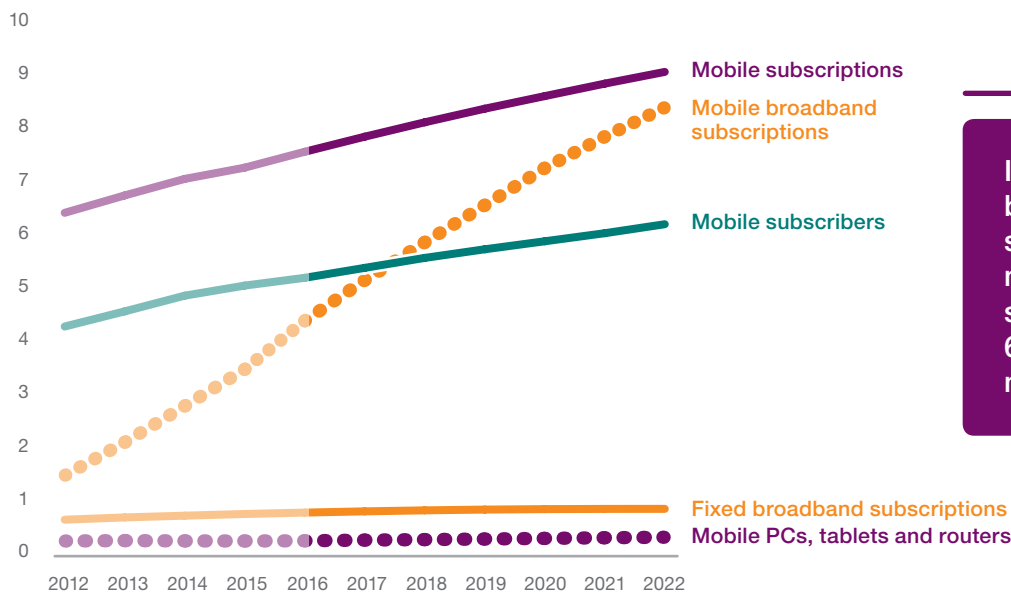
In 2022, there will be 9 billion mobile subscriptions, 8.3 billion mobile broadband subscriptions and 6.2 billion unique mobile subscribers

Mobile broadband will account for more than 90 percent of all subscriptions by 2022

It's anticipated that by the end of 2022 there will be 9 billion mobile subscriptions. Mobile broadband subscriptions will reach 8.3 billion, thereby accounting for more than

90 percent of all mobile subscriptions. The number of unique mobile subscribers is estimated to reach 6.2 billion by the end of 2022.

Mobile broadband will complement fixed broadband in some segments, and will be the dominant mode of access in others.[2] Many PCs and

tablets are currently used without a mobile subscription, with one reason for this being the price difference between Wi-Fi-only models and those with mobile capabilities. Subscriptions for PCs and tablets with mobile capabilities are expected to have a moderate growth, reaching 320 million in 2022.

90 percent of smartphone subscriptions are for 3G and 4G

Greater device affordability is driving increased smartphone adoption. At the end of 2016, there were 3.9 billion smartphone subscriptions. The majority of these subscriptions (90 percent) were for 3G and 4G. By 2022, the number of smartphone subscriptions is forecast to reach 6.8 billion; almost all of these will be for mobile broadband.
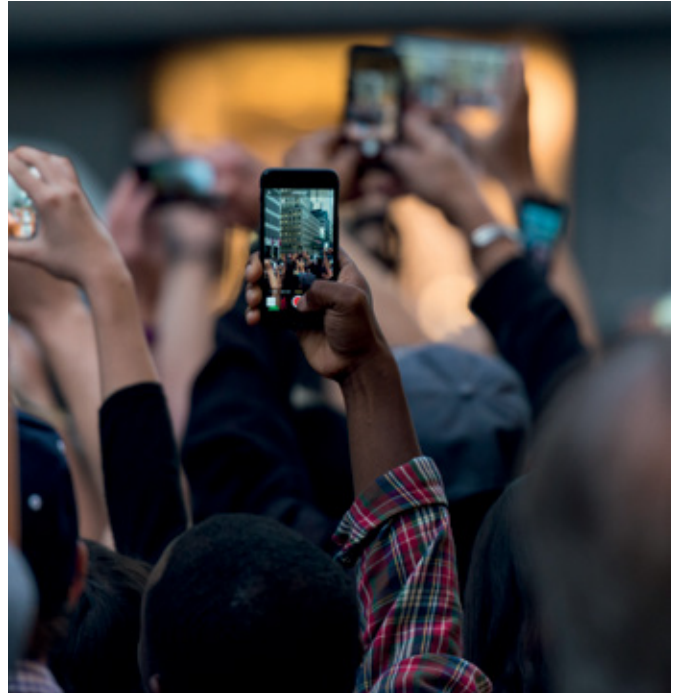
Smartphone subscriptions by technology
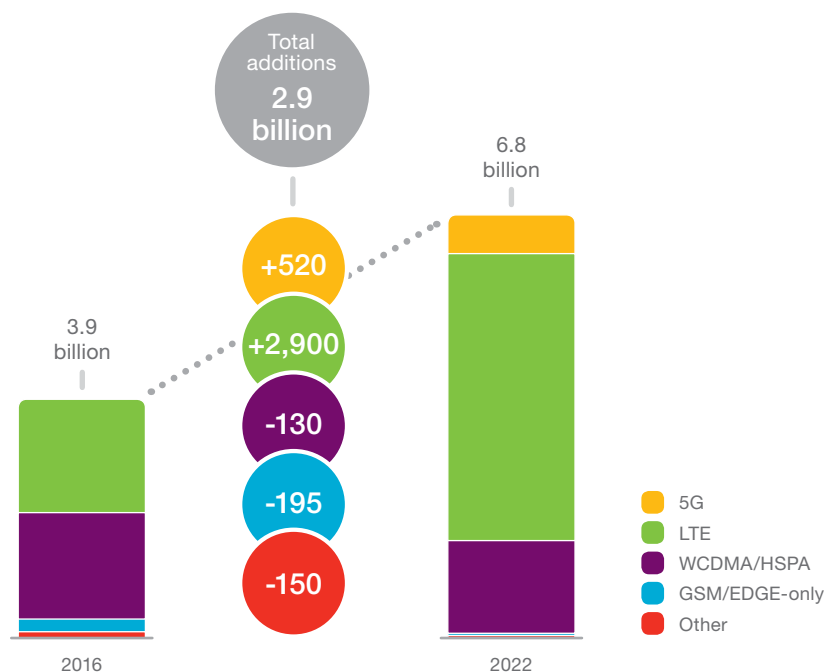
[2] The number of fixed broadband users is at least three times the number of fixed broadband connections, due to shared subscriptions in households, enterprises and public access spots. This is the opposite of the situation for mobile phones, where subscription numbers exceed user numbers
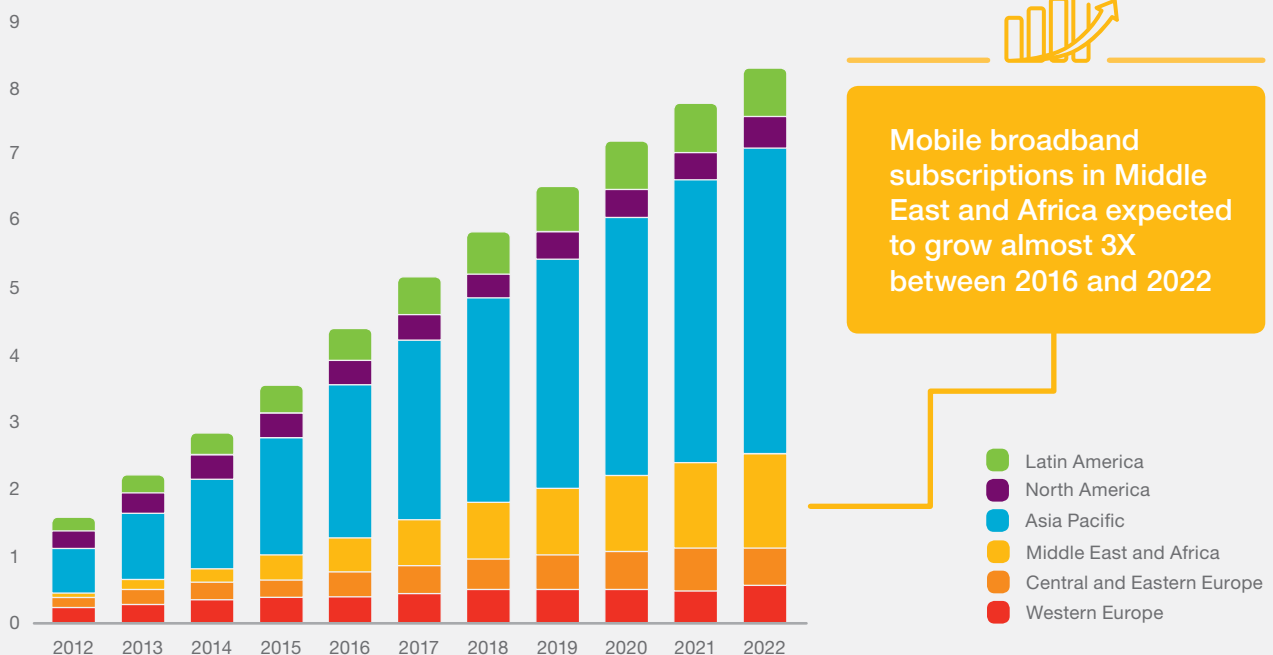
REGIONAL SUBSCRIPTIONS OUTLOOK

Mobile broadband drives subscription growth across all regions

The number of mobile subscriptions continues to grow across the regions, fueled by a strong uptake in mobile broadband.[1] As shown in the graph on page 9, mobile broadband subscriptions make up between 50 and 85 percent of all mobile subscriptions in 5 out of 6 regions. Many consumers in developing markets first experience the internet through mobile networks on a smartphone.

In Middle East and Africa, where the penetration of mobile broadband is currently lower than in other regions, the number of mobile broadband subscriptions is expected to increase significantly. Driving factors include a growing young population and more affordable smartphones. In mature markets, mobile broadband subscription growth is largely due to individuals connecting more devices.

Mobile broadband subscriptions by region (billion)

Mobile broadband subscriptions in Middle East and Africa expected to grow almost 3X between 2016 and 2022

Legend:
- Latin America
- North America
- Asia Pacific
- Middle East and Africa
- Central and Eastern Europe
- Western Europe

[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX
Note: WCDMA without HSPA and GPRS/EDGE (2G) are not included

Mobile subscriptions by region and technology (percent)

Legend: 5G · WCDMA/HSPA · TD-SCDMA · Other · LTE · GSM/EDGE-only · CDMA-only

Chart data labels:

- **Middle East and Africa** — 2016: 60% GSM/EDGE-only; 2022: 50% WCDMA/HSPA
- **Asia Pacific** — 2016: 40% GSM/EDGE-only; 2022: 10% 5G, 55% LTE
- **Latin America** — 2016: 50% WCDMA/HSPA; 2022: 65% LTE
- **Central and Eastern Europe** — 2016: 45% WCDMA/HSPA; 2022: 70% LTE
- **Western Europe** — 2016: 50% WCDMA/HSPA; 2022: 90% LTE
- **North America** — 2016: 70% LTE; 2022: 25% 5G

Vast regional variations as networks evolve

Over the forecast period, Middle East and Africa will dramatically shift from a region with a majority of GSM/EDGE-only subscriptions, to a region where 80 percent of the subscriptions will be WCDMA/HSPA and LTE. However, GSM/EDGE-only subscriptions will still account for a significant share of subscriptions by 2022.

In Latin America, WCDMA/HSPA and LTE already account for around 65 percent of all mobile subscriptions – a number that is expected to increase to 95 percent in 2022.

Asia Pacific is a diverse region. In China, the ongoing deployment of LTE is expected to result in more than 1.3 billion LTE subscriptions by the end of 2022, making up around 80 percent of all mobile subscriptions. Across the entire region, however, LTE will represent just 55 percent of all mobile subscriptions by the end of the same period. 5G will account for around 10 percent of the region's subscriptions in 2022, with deployments starting in South Korea, Japan and China. All three countries will host international sporting events in the coming six years, and intend to launch 5G services in conjunction with the events.

In Central and Eastern Europe, the share of LTE subscriptions is anticipated to grow significantly; from around 15 percent at the end of 2016, to 70 percent in 2022.

> 25% of subscriptions in North America and 10% in Asia Pacific will be for 5G in 2022

At 85 percent, the share of mobile broadband subscriptions in Western Europe is high due to well-developed WCDMA/HSPA networks and early LTE rollout. In 2022, the regional share of 5G subscriptions is expected to be 5 percent.

Overall, North America has the highest share of LTE subscriptions because of rapid migration from CDMA and WCDMA/HSPA-based networks. This trend is set to continue with 5G, as leading operators in the region have stated their intention to expand into pre-standardized 5G already in 2017. As such, the region will have the highest share of 5G subscriptions in 2022 at 25 percent.

VOICE OVER LTE OUTLOOK

The number of VoLTE subscriptions[1] continues to grow, and is expected to exceed 540 million by the end of 2017

VoLTE has now been launched in more than 100 networks in 55 countries. Based on recent measurements in operator networks, a stronger growth than anticipated has resulted in a significant upward adjustment of our forecast. The number of VoLTE subscriptions is now projected to reach 4.6 billion by the end of 2022, making up more than 90 percent of all LTE subscriptions globally.

The network measurements show uneven uptake across regions. In the US, Japan, South Korea and Canada, VoLTE uptake was very strong in 2016, with most networks having more than 60 percent of voice calls on LTE smartphones provisioned using VoLTE. In some networks this figure was close to 80 percent.

In Europe, the service is used by fewer people, as many launched networks still require subscribers to configure VoLTE themselves in the device settings, or to buy a special VoLTE subscription. Past launches of the service demonstrate that for VoLTE usage to take off, automatic operator provisioning is necessary. In these circumstances, the VoLTE penetration then quickly rises to the percentage of LTE smartphones that are VoLTE-enabled. Due to launches in China and India, more affordable VoLTE devices will be available sooner than expected.

VoLTE technology is the foundation for communication services on any device over LTE, Wi-Fi and 5G

VoLTE is delivered via the IP Multimedia Subsystem (IMS) and enables operators to offer high-quality, simultaneous voice and LTE data services on smartphones and other devices. Additional IMS-based consumer and enterprise communication services include: HD voice, HD voice+ and music within calls (new voice codec Enhanced Voice Services (EVS)), video communication, IP messaging and evolution to chat bots, content sharing within calls, multi-device and new service innovations.

There are currently more than 1,000 VoLTE-enabled device models, supporting different regions and frequencies.[2]

Wi-Fi calling is built on the same core network systems as VoLTE, and enables operators to extend their voice service to places with limited cellular coverage. Over 50 Wi-Fi calling networks have been launched in more than 30 countries.[3]

Use cases with VoLTE calls for IoT (Cat-M1) are starting to develop, extending mobile voice service capabilities to the emerging IoT device ecosystem.

VoLTE technology will also be used as the foundation for enabling current and new communication services in 5G networks.

VoLTE subscriptions by region (billion)

Legend:
- Latin America
- North America
- Asia Pacific
- Middle East and Africa
- Europe
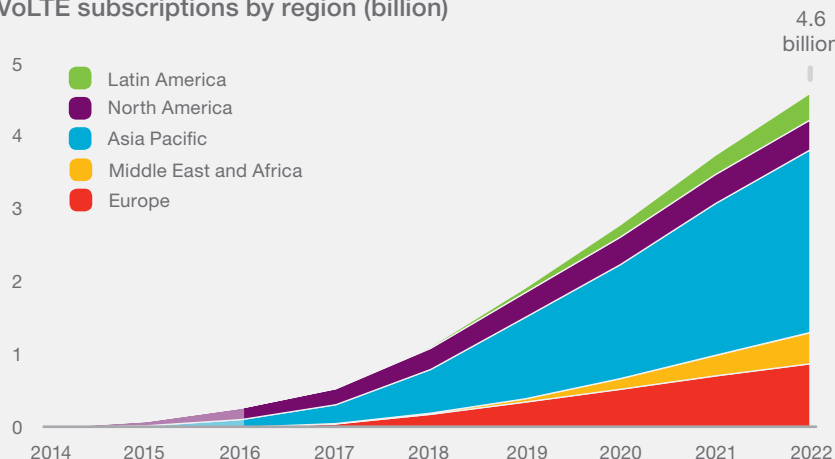
4.6 billion

VoLTE subscriptions expected to reach 4.6 billion in 2022

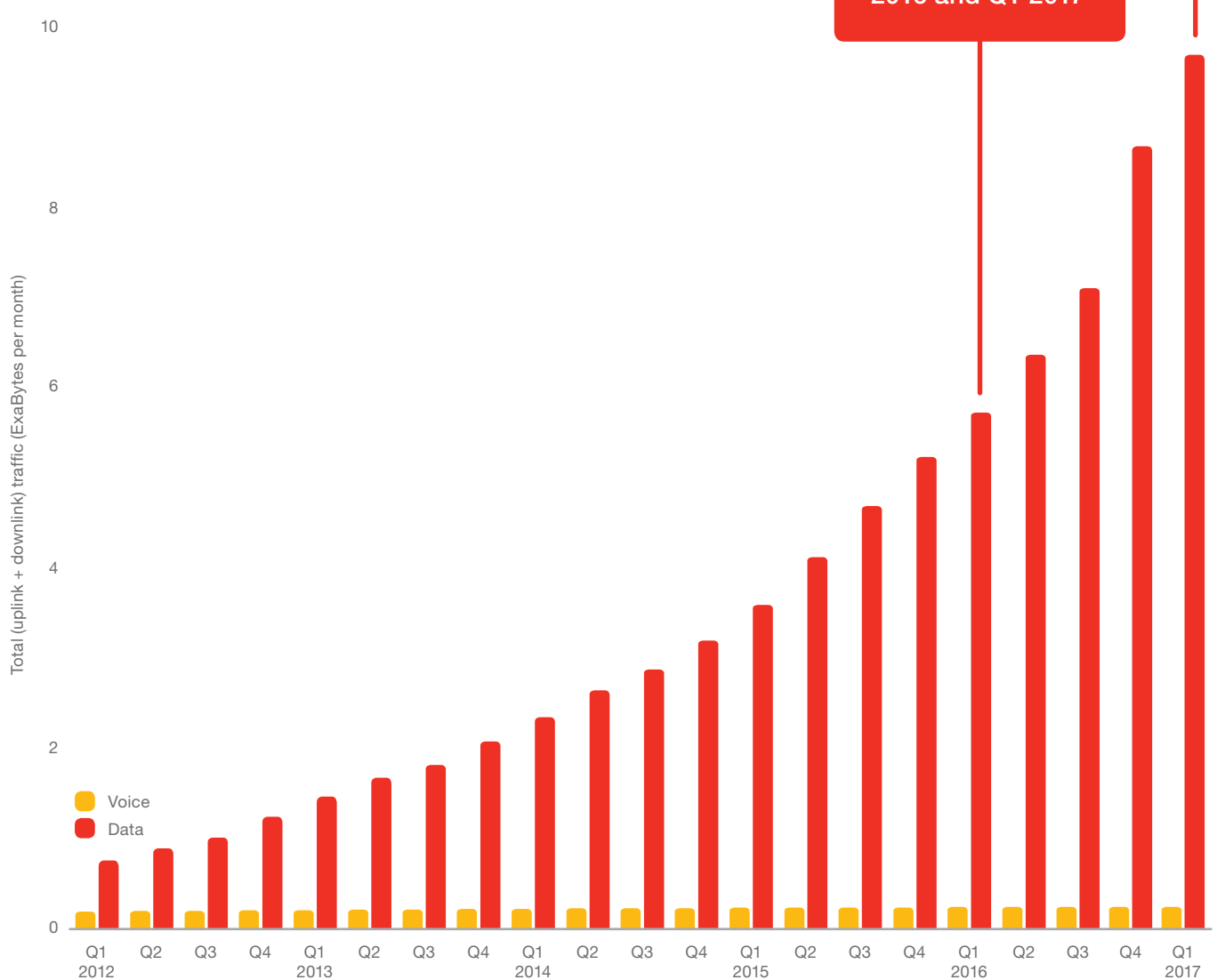[1] A subscriber is counted as having a VoLTE subscription if making at least one VoLTE call per month
[2] GSA (April 2017)
[3] GSMA (March 2017)

MOBILE TRAFFIC Q1 2017

Mobile data traffic continues to grow, and the graph below shows total global monthly data and voice traffic from Q1 2012 to Q1 2017.[1] It depicts a continued strong growth in data traffic, while voice traffic grows in the mid-single digits per year. This growth is driven by increased smartphone subscriptions and average data volume per subscription, fueled primarily by more viewing of video content. Recent introductory free data traffic offers in India have pushed up the global traffic noticeably – whether the volumes remain when pricing is applied remains to be seen.

Data traffic grew around 12 percent quarter-on-quarter and around 70 percent year-on-year. However, there are large differences in traffic levels between markets, regions and operators.

Data traffic grew 70% between Q1 2016 and Q1 2017

Total (uplink + downlink) traffic (ExaBytes per month)

Legend:
- Voice
- Data

X-axis: Q1 2012, Q2, Q3, Q4, Q1 2013, Q2, Q3, Q4, Q1 2014, Q2, Q3, Q4, Q1 2015, Q2, Q3, Q4, Q1 2016, Q2, Q3, Q4, Q1 2017

Source: Ericsson traffic measurements (Q1 2017)

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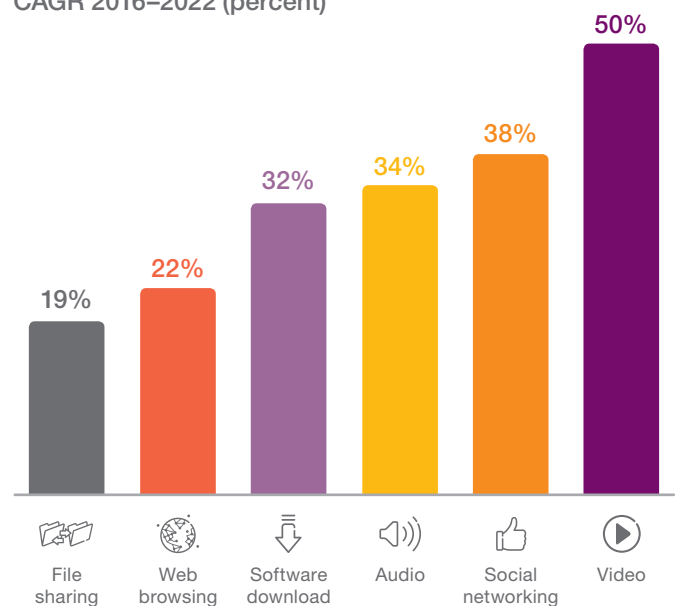
MOBILE TRAFFIC BY APPLICATION CATEGORY

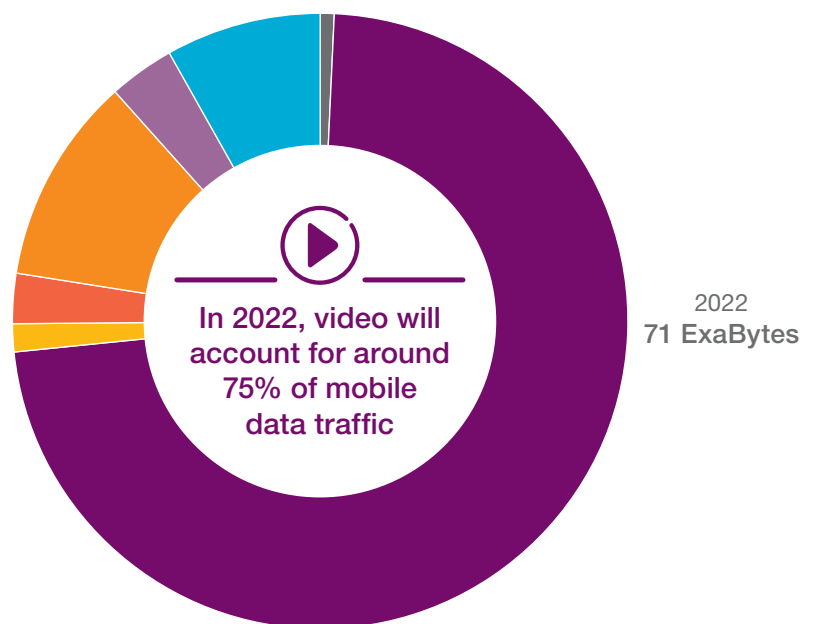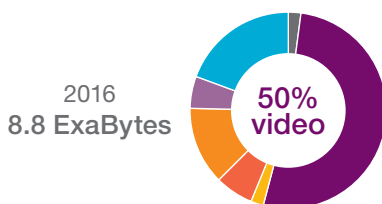## Mobile video traffic is increasingly dominant

Mobile video traffic is forecast to grow by around 50 percent annually through 2022 to account for nearly 3 quarters of all mobile data traffic. Social networking is expected to grow by 38 percent annually over the next 6 years. However, its relative share of traffic will decline from 13 percent in 2016 to around 11 percent in 2022, as a result of the stronger growth in video. Other application categories have annual growth rates ranging from 19 to 34 percent, so are shrinking as a proportion of overall traffic. Additionally, the use of embedded video in social media and webpages continues to grow, fueled by larger device screens, higher resolution and new platforms supporting live streaming. Embedded video in social media and webpages is counted as video traffic in the forecast and network measurements.

The emergence of new applications can shift the relative volumes of different types of traffic, and the proliferation of different sized smart devices will also affect the traffic mix; for example, tablets are associated with a higher share of video traffic than smartphones. Typically, smartphones are used more than tablets for watching short video content, but tablets are used more for watching longer video content.[1]

Mobile traffic by application category
CAGR 2016–2022 (percent)

File sharing	Web browsing	Software download	Audio	Social networking	Video
19%	22%	32%	34%	38%	50%

Mobile data traffic by application category per month (ExaBytes)

- Video
- Audio
- Web browsing
- Social networking
- Software download
- Other
- File sharing

2016
8.8 ExaBytes

50% video

In 2022, video will account for around 75% of mobile data traffic

2022
71 ExaBytes

[1] Ericsson ConsumerLab, TV and Media (2016)

Mobile data traffic volumes by application category and device type (percent)

Legend:
- File sharing
- Video
- Audio
- Web browsing
- Social networking
- Software download
- Real-time communications
- Other
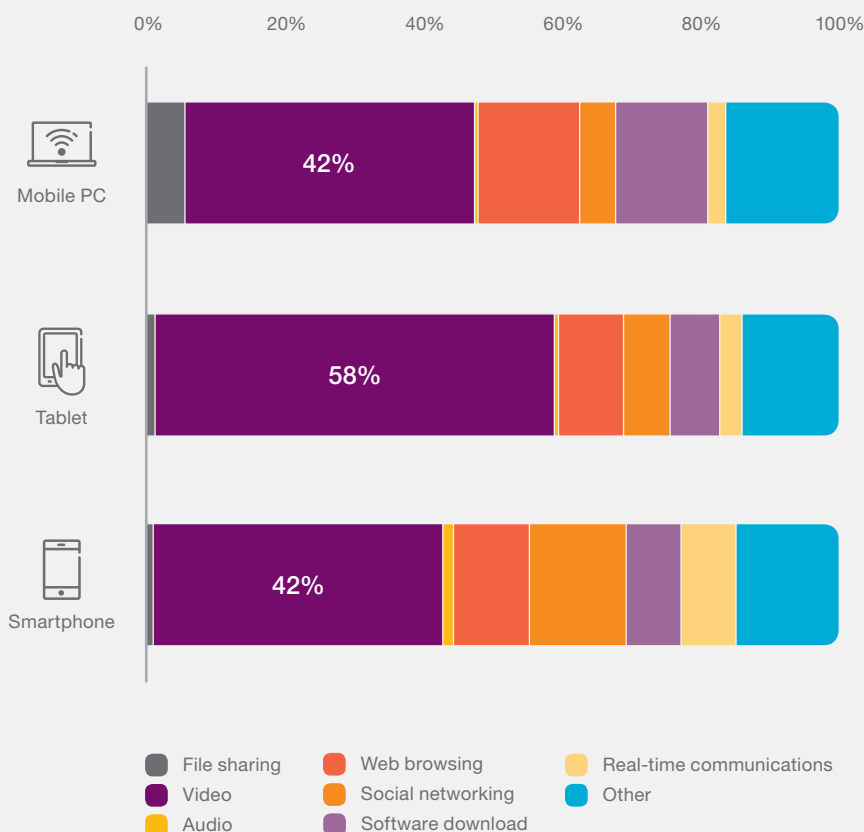
The share of video traffic approached 60% on tablets in the second half of 2016

Mobile PC: 42%
Tablet: 58%
Smartphone: 42%

Source: Ericsson network traffic measurements (2016)

Video traffic dominates across devices

Average values from measurements in a selected number of commercial HSPA and LTE networks in the Americas, Asia and Europe in 2016 show that, regardless of device type, video was the largest contributor to traffic volumes. However, there was a large variation between networks.

Compared to similar measurements made in the second half of 2015, the share of video traffic was still increasing on tablets, approaching 60 percent of total traffic in the second half of 2016. On smartphones, the share of video traffic was slightly lower than 12 months earlier. YouTube still dominates video traffic in most mobile networks, although it is being challenged by local players in some countries. YouTube traffic accounts for 40–70 percent of total video traffic for almost all measured networks, regardless of device type. YouTube is also the most used on-demand video service in the world, with 70 percent of consumers using it at least on a weekly basis.[2] Netflix is now available in most markets, and in some places its share of video traffic can reach 10–20 percent of total mobile video traffic. In other markets, Netflix's share of traffic is still very small.

The share of traditional social network traffic (excluding embedded video), such as Facebook and Twitter, decreased for all device types, while more communication-oriented services like Snapchat and WhatsApp increased. Traffic for these services is included in the real-time communications category in the figure above. However, social networking was still the second largest traffic volume contributor for smartphones. Consumer research shows that social networking and instant messaging are the second most popular internet activities for consumers, with over 65 percent of internet users utilizing the services daily. Only general internet browsing is more popular, with over 85 percent of users doing it daily.[3]

The share of traffic for software updates increased slightly compared to measurements in 2015, presumably due to more frequent updates of apps.
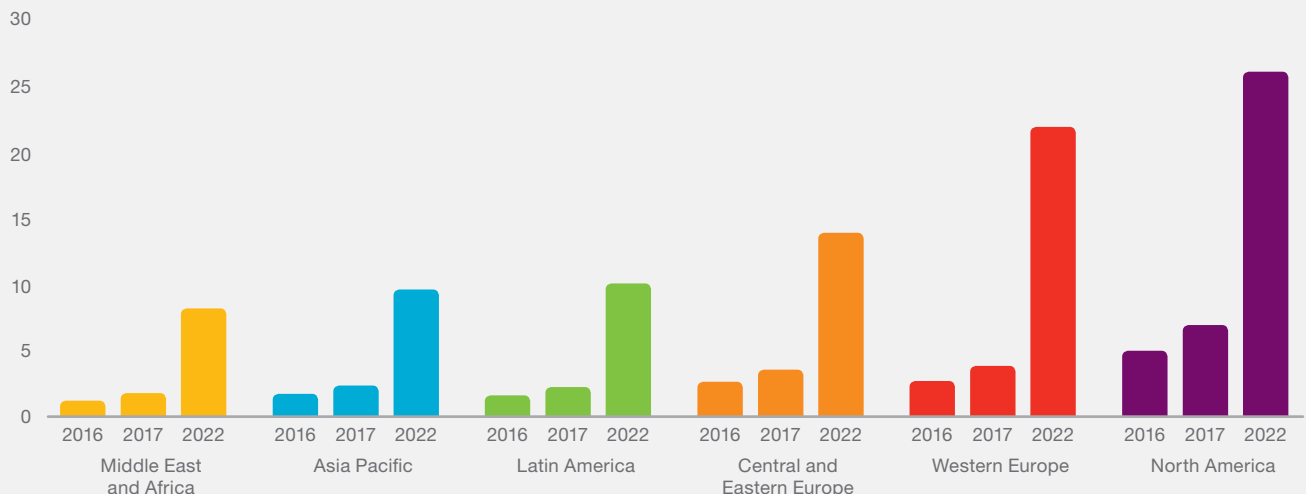
File sharing was more prominent on mobile PCs than on other devices, but decreased overall, constituting around 5 percent of traffic. The very small proportion of file sharing associated with smartphones and tablets came predominantly from tethering traffic.

MOBILE TRAFFIC OUTLOOK

Data traffic per active smartphone (GB per month)

Middle East and Africa | Asia Pacific | Latin America | Central and Eastern Europe | Western Europe | North America

In 2022, monthly mobile data traffic per active smartphone in North America will reach 26 GB

Monthly data traffic per smartphone continues to increase in all regions, despite large differences in data consumption patterns between networks, markets and subscriber segments. North America has the highest usage and traffic is expected to reach 6.9 GB per month per active smartphone by the end of 2017. This is almost twice as high as Western Europe – the region with the second highest usage – where it is set to reach 3.9 GB per month per smartphone by the end of 2017.

In 2022, North America will still be the region with the highest monthly usage at 26 GB, but other regions will be catching up. Factors that will drive usage include an increase in the number of LTE subscriptions, improved device capabilities and more attractive data plans, as well as an increase in data-intensive content.

Total mobile data traffic is expected to rise at a compound annual growth rate (CAGR) of 42 percent

Going forwards, traffic generated by smartphones will dominate even more than it does today. Between the end of 2016 and 2022, smartphone traffic is expected to increase by nine times, and total mobile traffic for all devices by eight times. By the end of the forecast period, more than 90 percent of mobile data traffic will come from smartphones.
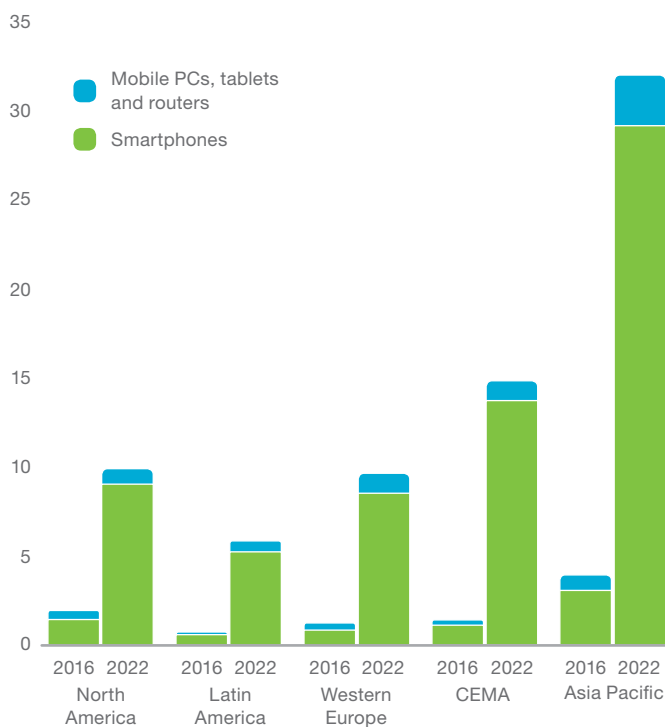
Global mobile traffic (ExaBytes per month)

More than 90% of mobile data traffic will come from smartphones in 2022

- Data: Smartphones
- Data: Mobile PCs, tablets and routers
- Voice
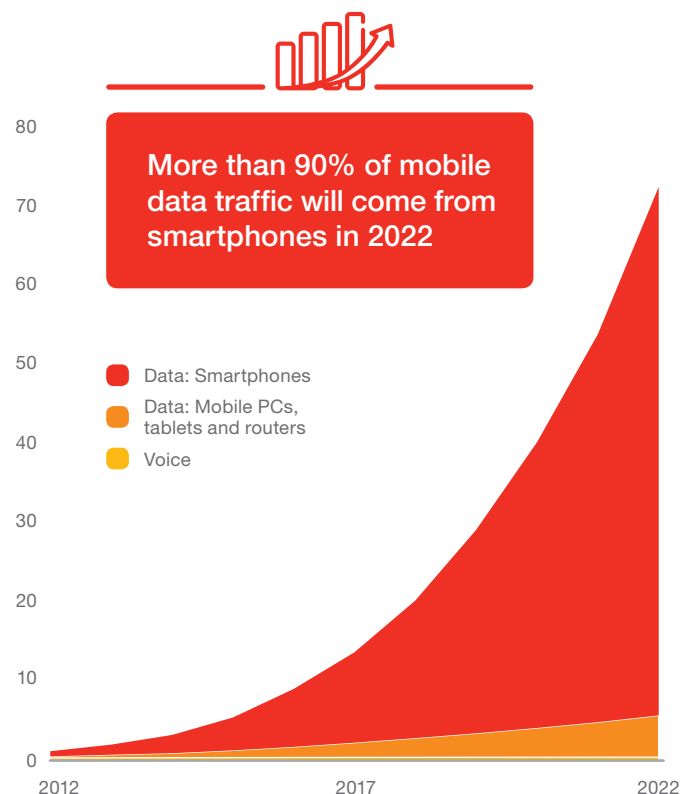
Mobile data traffic by region	2016 (EB/month)	Multiplier 2016–2022
Asia Pacific	3.7	8
CEMA	1.4	11
Western Europe	1.2	8
North America	1.8	5
Latin America	0.7	8

Global mobile data traffic (ExaBytes per month)

Legend:
- Mobile PCs, tablets and routers
- Smartphones

(Bar chart showing values from 0 to 35 on the y-axis, with paired bars for 2016 and 2022 for each region: North America, Latin America, Western Europe, CEMA, Asia Pacific)

As the most populous region, Asia Pacific has the largest share of mobile data traffic. This will continue into 2022, when the total mobile traffic in the region is expected to exceed 30 ExaBytes (EB). A rapid growth in mobile broadband subscriptions is expected, with China alone set to add 495 million mobile broadband subscriptions between the end of 2016 and 2022

The level of mobile broadband maturity still varies greatly between countries in Asia Pacific. For instance, South Korea and Japan engaged in early deployment of LTE with a fast uptake, and markets like Singapore and Hong Kong are also highly advanced. In less developed countries, GSM is still the dominant technology, and insufficient network quality and the cost of data subscriptions remain barriers to higher mobile data consumption.

The region spanning Central and Eastern Europe and Middle East and Africa (CEMA) will experience an elevenfold increase in mobile data traffic up to the end of 2022. This is driven by a strong growth in LTE and smartphone subscriptions, as well as a demand for data-intensive applications like video.

North America and Western Europe currently have a larger share of total traffic volume than their subscription numbers imply. This is due to a greater penetration of high-end user devices and well built-out WCDMA and LTE networks, complemented with affordable packages offering large volumes of data. This combination leads to high data usage per subscription.

In 2022, there will be eleven times more mobile data traffic in Central and Eastern Europe and Middle East and Africa (CEMA)

INTERNET OF THINGS OUTLOOK

The number of connected IoT devices is growing, driven by an increasing range of use cases and business models, and supported by falling device costs

Around 29 billion connected devices[1] are forecast by 2022, of which around 18 billion will be related to IoT. Connected IoT devices include connected cars, machines, meters, sensors, point-of-sales terminals, consumer electronics[2] and wearables. Between 2016 and 2022, IoT devices are expected to increase at a CAGR of 21 percent, driven by new use cases.

IoT device connections

In the figure below, IoT is divided into short-range and wide-area segments. The short-range segment 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.

The wide-area segment consists of devices using cellular connections, as well as unlicensed low-power technologies, such as Sigfox, LoRa and RPMA. Presently, the dominating technology in this segment is GSM/GPRS.

1.5 billion IoT devices with cellular connections by 2022

At the end of 2016, there were around 0.4 billion IoT devices with cellular connections. Due to increased industry focus

and 3GPP standardization of cellular IoT technologies, this number is projected to reach 1.5 billion in 2022, or around 70 percent of the wide-area category.

Within the wide-area IoT segment, two distinct sub-segments with different requirements have emerged: massive and critical applications.

Massive IoT connections are characterized by high connection volumes and small data traffic volumes, low-cost devices and low energy consumption. Many things will be connected through capillary networks.[3]

Critical IoT connections place very different demands on the network: ultra-reliability, availability, low latency and high data throughput. Declining modem costs, evolving LTE functionality and 5G capabilities are all expected to extend the range of applications for critical IoT deployments. There are, however, many use cases between these two extremes, which today rely on 2G, 3G or 4G connectivity.

The first cellular IoT networks supporting massive IoT applications, based on Cat-M1 and Narrow Band-IoT (NB-IoT) technologies[4], were launched in early 2017. Several operators are expected to deploy cellular IoT networks in 2017.

Connected devices (billions)
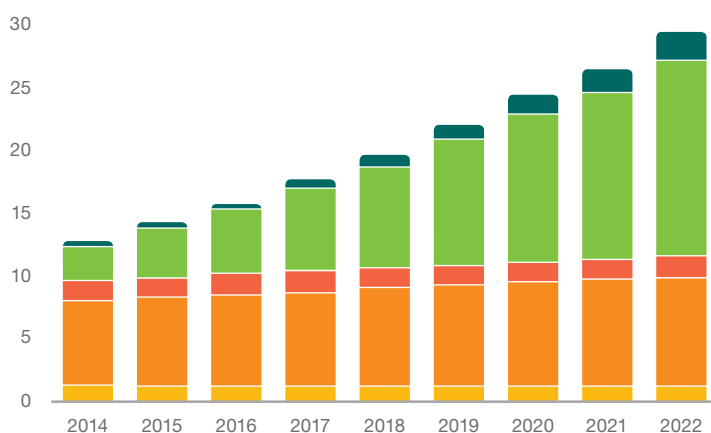
		2016	2022	CAGR
	Wide-area IoT	0.4	2.1	30%
	Short-range IoT	5.2	15.5	20%
	PC/laptop/tablet	1.6	1.7	0%
	Mobile phones	7.3	8.6	3%
	Fixed phones	1.4	1.3	0%
		16 billion	29 billion	

[1] In our forecast, a connected device is a physical object that has a processor, enabling communication over a network interface
Note: Traditional landline phones are included for legacy reasons
[2] Including: Smart TVs, digital media boxes, Blu-Ray players, gaming consoles, audio/video (AV) receivers, etc.

[3] Connected devices connecting to a wide-area network through a common gateway
[4] Cat-M1 supports a wide range of IoT applications, including content-rich ones, and NB-IoT is streamlined for ultra-low throughput applications. Both these technologies are deployed in LTE networks

POPULATION COVERAGE

In 2022, around 15 percent of the world's population will be covered by 5G

Population coverage is the percentage of the world's inhabitants that have sufficient radio signal to connect to a mobile network. The ability to utilize the technology is subject to factors such as access to devices and subscriptions. Population coverage by technology shows how mobile networks increasingly provide greater coverage at higher speeds.

Today, mobile networks cover around 95 percent of the world's population and continue to expand. For mobile broadband (WCDMA/HSPA or later technology), population coverage is currently at around 80 percent and forecast to grow to around 95 percent in 2022. In some markets, it is expected that earlier generation systems will be closed down as subscribers move on to more capable devices, enabling refarming of the spectrum. North America, in particular, is expected to close GSM networks before 2022, and leading operators have announced time plans for this.

LTE is the fastest-deployed mobile communication technology

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.

The rapid introduction of offerings based on LTE in the US and China is the main reason for this faster deployment speed, creating a mass market and economies of scale in a short time. Other significant factors include the demand for improved user experience and faster networks, and an attractive device and app ecosystem coupled with low cost per megabyte. LTE population coverage is currently around 55 percent and forecast to grow to more than 80 percent in 2022.

### 5G coverage will begin in major metro areas

The speed of 5G network deployment will depend on the growth of the complete ecosystem, and will be impacted by the availability of 5G-capable devices and decisions on spectrum allocation.

It is expected that many operators will deploy 5G commercially from 2020, in line with the time plan for 5G standardization. Early commercial deployments of Non-Standalone (NSA) 5G and pre-standard networks are anticipated in several markets,

World population coverage by technology[1]

Total population coverage of 3GPP cellular technologies

2016	~95%
2022	>95%
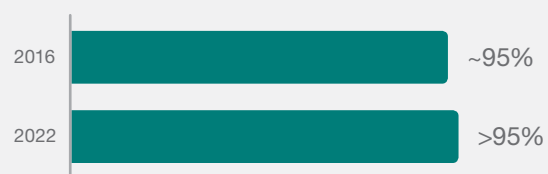
LTE is driven by demand for improved user experience and faster networks

2016	~55%
2022	>80%
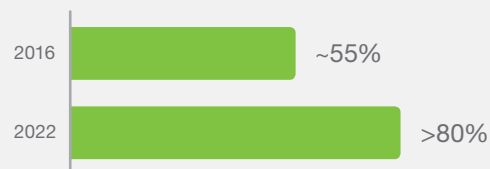
5G coverage will commence in metropolitan and urban areas

2016	0%
2022	~15%
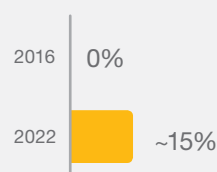
driven by the need for enhanced mobile broadband and as a complement to fixed broadband internet services.

Over time, 5G will enable a wide range of use cases for the IoT. Acceleration of the 5G NR standardization schedule will enable large-scale trials and deployments of 5G in 2019. The adoption rate of 5G mobile broadband is expected to be similar to that of LTE, and rollout will commence in major metro areas, reaching around 15 percent population coverage by 2022.

[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

Network evolution is driven by demand for improved user experience and cost-efficient network operations, as well as operator interest in exploring new revenue opportunities in the IoT and enterprise services market. Providing such services will put new requirements on the networks; these include increased data throughput capacity, lower latency and evolved capabilities for management and orchestration of both services and networks

Mobile networks are evolving to deliver enhanced mobile broadband and communication services with high data throughput, quality of service and low latency requirements, as well as new IoT services with strong requirements on characteristics such as scalability, reliability, availability and latency. Significant radio performance enhancements, together with a more flexible and agile core network, will enable operators to serve a much broader range of use cases in the future.

> Networks are evolving to meet the needs of new use cases, which will have diverse performance requirements

Enhancing radio network performance

Operators have deployed multi-standard access networks with GSM, HSPA and LTE, and are adding more spectrum bands to increase capacity and improve user experience. The majority of operators are expected to have five spectrum bands deployed in the coming years, making it vital to maximize the spectral efficiency and utilization of these bands.

In addition, to get the maximum performance out of each spectrum band, most networks will have multi-layered deployment; that is, a combination of macro and small cells. Network software will optimize the coordination between the standards, bands and layers to further increase capacity and throughput.

Gigabit LTE network deployments in progress

Operators are evolving their existing LTE networks to LTE-Advanced (LTE-A) networks with Category[1] (Cat) 4, 6, 9, 11 and 16 implementations, combining lower and higher frequency bands (both for FDD and TDD modes). This will lead to a wider coverage area, increased network capacity and faster data speeds. With Gigabit LTE (Cat 16), fiber-like mobile broadband speeds are achieved. This means people can enjoy their apps, music streaming and video content, for example, with less performance degradation, even during peak times or in crowded places. Gigabit LTE is enabled by LTE-A features, including 4x4 Multiple Input Multiple Output (MIMO) antenna technology, three-channel carrier aggregation and higher order modulation schemes.

There are currently 591 commercial LTE networks deployed in 189 countries. Out of these, 194 have been upgraded to LTE-A networks.

Percentage and number of LTE-Advanced networks supporting Cat 4, Cat 6, Cat 9, Cat 11 and Cat 16 devices
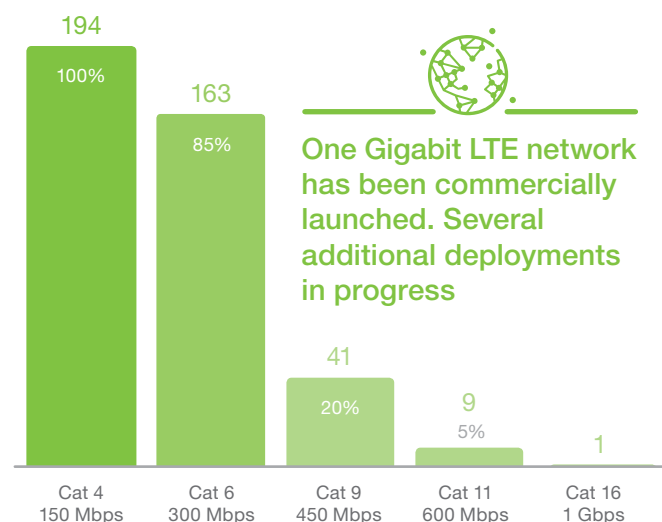
One Gigabit LTE network has been commercially launched. Several additional deployments in progress

Cat 4 150 Mbps	Cat 6 300 Mbps	Cat 9 450 Mbps	Cat 11 600 Mbps	Cat 16 1 Gbps
194 100%	163 85%	41 20%	9 5%	1

Source: Ericsson and GSA (May 2017)

[1] Category (Cat) labels the theoretical maximum speed a mobile device supports. The higher the Cat number, the faster the speeds

Examples of use case evolution and supporting network technologies

	Current services	On the road to 5G	5G experiences
Enhanced mobile broadband	Browsing, social media, music, video	Fixed Wireless Access, interactive live concerts and sport events	4K/8K videos, mobile AR/VR gaming, immersive media
Automotive	Wi-Fi hotspots, on-demand GPS map data	Predictive vehicle maintenance, capturing real-time sensor data for different services	Autonomous vehicle control, cooperative collision avoidance, vulnerable road user discovery
Manufacturing	Connected goods, intra-inter enterprise communication	Process automation and flow management, remote supervision and control of machines and materials	Remote control of robots, augmented reality support in training, maintenance, construction, repair
Energy and utilities	Smart metering, dynamic and bidirectional grid	Distributed energy resource management, distribution automation	Control of edge-of-grid generation, virtual power plant, real-time load balancing
Healthcare	Remote patient monitoring, connected ambulance, electronic health records	Telesurgery, augmented reality aiding medical treatment	Precision medicine, remote robotic surgery
Network technologies	> Multi-standard network > Cat-M1/NB-IoT > Cloud optimized network functions > VNF orchestration	> Gigabit LTE > Massive MIMO > Network slicing > Dynamic service orchestration > Predictive analytics	> New Radio (NR) > Virtualized RAN > Federated network slicing > Distributed cloud > Real-time machine learning/AI

More flexible and agile network

Cloud-enabled telecom core networks with NFV and SDN, enabling more agile networks, have started to be commercially deployed. These networks will be managed by service and network orchestration systems, which will shorten time to market when launching new services and make network operations more efficient. This will also pave the way for network slicing.

Network slicing segments a physical network into multiple virtual networks. It will enable operators to provide service differentiation for a diverse range of applications, users, verticals and business models in a more cost-efficient manner. The operator will be able to create and manage network slices that fulfill required criteria for different use cases and market scenarios. A network slice would last throughout the intended service lifetime and would provide full network function support to the devices connected with the network slice. Resources for the network slices can be set up based on various service demands. For example, a network slice set up to provide connectivity for smart meters that connects the devices with a high availability, with a given latency, data rate and security level. Another network slice could provide instant access to network capacity, or coverage for mission-critical services in the event of an emergency. These types of network slices could be prearranged through business agreements and provided on demand.

Distributed cloud is another technology that enables distributed workloads and compute resources to be deployed close to where they are being used. This enables critical latency-sensitive applications and increases service reliability.

Evolution of use cases

A broader range of use cases will evolve over time, along with implementation of supporting network technologies.

The demands of numerous existing and new use cases can be fulfilled on evolved 4G (LTE) networks. As networks evolve, there will be even more opportunities to enhance the existing use cases, as well as to meet the demands of more new use cases when 5G is implemented.

The first commercial use of 5G is expected to be for enhanced mobile broadband and Fixed Wireless Access (FWA). Enhanced mobile broadband will provide very high system peak rates in the gigabit-per-second range, meeting the performance requirements of high-demand applications – such as augmented and virtual reality (AR/VR) and ultra-high-definition (UHD) video (4K/8K) – within a targeted coverage area. With 5G set to provide 10 to 100 times more capacity than 4G, it has the potential to enable cost-efficient FWA solutions on a massive scale.

Beyond enhanced mobile broadband, networks will be able to handle use cases with different demands on mobility, data rates, latency, reliability and device density. These cases will come from industries such as automotive, manufacturing, energy and utilities and healthcare. As indicated in the figure above, evolving networks will serve an increasing amount of use cases over time, governed by the specific use case requirements.

ENABLING INTERNET FOR ALL

Mobile networks have brought voice and internet services to billions of people around the globe over the last 25 years. Despite this, more than 50 percent of the world's population still doesn't have internet access. The most cost-efficient way to bring more people online is to leverage existing mobile network infrastructure. However, the main challenges in connecting the unconnected are primarily related to affordability, literacy, and provision of relevant services – rather than the availability of technology

As part of the 70th session of the United Nations General Assembly held in September 2015, 193 world leaders committed to 17 Sustainable Development Goals (SDGs) over the next 15 years. Achieving the SDGs will mean leveraging existing and widely-deployed technologies, such as mobile broadband, to help overcome social and financial exclusion in developing countries.

Globally, the most widely used means of accessing the internet is through mobile networks and a mobile device; however, over 50 percent of the world's population doesn't have internet access. An overwhelming majority of the population without access to the internet live in developing countries. Internet access is a fundamental enabler for improving quality of life, as it provides the opportunity to access useful information and services. This is a critical factor in fulfilling the SDGs. Through selective investment with mature mobile broadband technologies[1], operators can sustainably expand mobile broadband coverage by upgrading existing 2G sites, as well as targeting uncovered areas with new deployments.

More than 1 million new mobile broadband subscribers every day

At the end of 2016, around 3.2 billion subscribers out of the world's total population of 7.4 billion had access to the internet via mobile broadband technology. It is forecast that an additional 2.6 billion subscribers will have mobile broadband internet access by 2022. This corresponds to an average of more than 1 million new mobile broadband subscribers being added every day through to the end of 2022. Key drivers behind this subscriber uptake are a growing young population with increasing digital skills, and decreasing smartphone prices, as well as continued deployment of 3G and 4G mobile broadband technologies in developing markets.

Estimated number of people without mobile broadband connection in 2022

No mobile coverage
300 million

2G-only coverage
300 million

1,500 million

3G/4G coverage
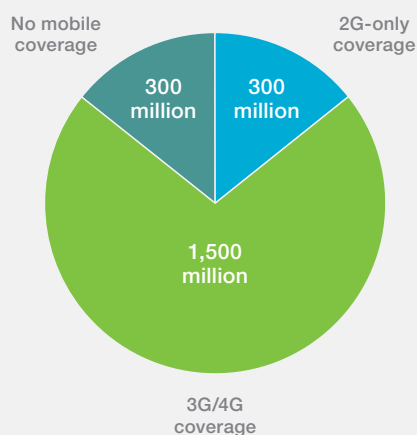
70% of the 2.1 billion people without a mobile broadband connection in 2022 will have mobile broadband coverage

[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX
Note: WCDMA without HSPA and GPRS/EDGE (2G) are not included

Mobile broadband networks – population coverage and subscribers (billion)
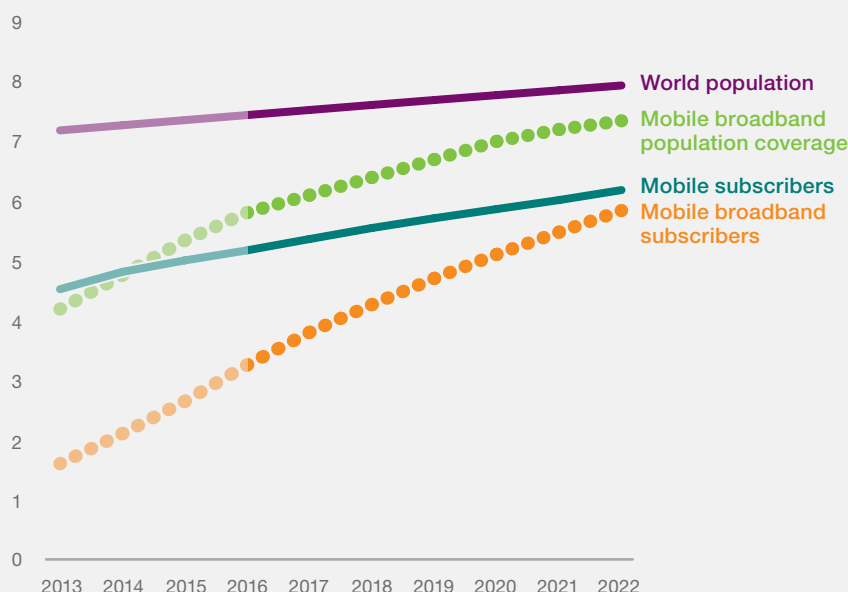
The world's population is increasingly being connected to mobile broadband networks

Connecting the unconnected with mobile broadband

As more radio base stations are deployed, the world's mobile network population coverage[2] continues to increase. At the current trajectory, mobile broadband will provide network coverage to around 95 percent of the world's population by 2022. To address the very low average revenue per user (ARPU) customer segments, expansion of network coverage requires capex and opex-efficient solutions. Telecom operators, vendors, governments and regulators should continue to address affordability and uptake of services usage in parallel with mobile broadband technology deployment. For example:

> Develop cost/benefit-based business models targeting urban and rural areas

> Nurture ecosystems for local apps and content development in local languages

> Prioritize development of ICT literacy and skills

The main barrier to internet access will not be the availability of network technology, but rather illiteracy, affordability and perceived relevance of digital services.

By 2022, there will be an estimated 5.8 billion mobile broadband subscribers, which means there will still be around 2.1 billion people[3] without mobile broadband connection. Out of those, 1.5 billion will be within mobile broadband coverage, but will have no subscription to such a service. The 300 million people within 2G-only coverage could be provided with mobile broadband coverage at a relatively low incremental network cost by an upgrade of existing 2G sites with 3G/4G technology.

The main barriers to internet access will be illiteracy, affordability and perceived relevance of digital services – not availability of network technology

App coverage for the unconnected

The vast majority of those connected to the internet are 3G and 4G subscribers on mobile broadband networks. Some subscribers remain on 2G, which provides significant value to everyday life – including the possibility to use basic data services – but does not offer the full benefits of mobile broadband, or access to a wider range of services.

There is no universally agreed industry definition of broadband, or the minimum required service level for a user to be qualified as connected to the internet. Today, radio base stations in mobile broadband networks can deliver very high throughput and low latency – enough to serve the most demanding mobile applications. Mobile services can have very different sets of network performance needs (for example, a mobile banking app typically requires less from the network than a video-based app). The network performance needed for each user is therefore dependent on the specific service at a given time. The challenge is to build out enough bandwidth at site-to-site distances to enable sufficient performance throughout each cell.

[2] Population coverage is the percentage of the world's population that has sufficient radio signal to connect to a mobile network
[3] According to UN world population estimates, there will be 700 million people under the age of 5 in 2022. Most of these are assumed not to have a mobile broadband connection

Example of the difference between web page download times in live 2G and 4G networks[4]

42 seconds — 2G

1.3 seconds — 4G
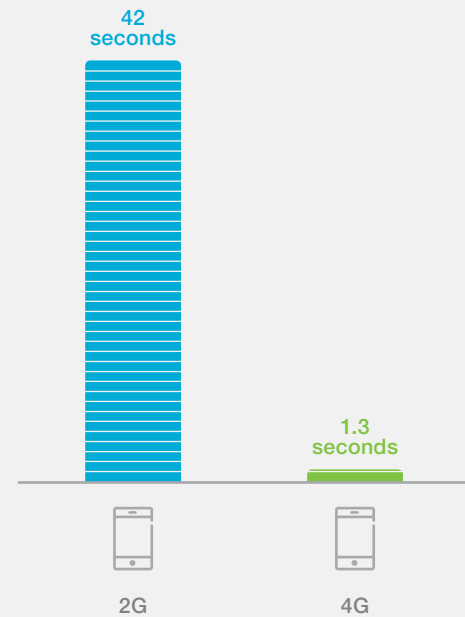
Mobile broadband in areas with existing 2G coverage

In areas with existing 2G coverage, upgrading sites to 3G or 4G will provide mobile broadband network coverage and additional capacity for voice services. This would require a very low incremental investment compared to aerial access solutions, as most of the costly items – including tower, power, security and backhaul – are already available at the existing site. Typically, there is also no additional spectrum cost. Comparing web browsing download times in live 2G and 4G networks highlights the significant improvements to the user experience that an upgrade enables.

Factors such as demand for connectivity, availability of device types, cost sensitivity among mobile subscribers and operator business case will influence whether upgrading to 3G or 4G coverage will be preferred as an initial solution. Some steps to increase mobile broadband penetration are as follows:

> **Identifying potential mobile broadband subscribers' locations**
To optimize investment decisions, operators should identify which sites to upgrade from 2G to 3G and/or 4G for the best return on investment. One of several ways to do this is by using call data records associated with the existing 2G network. Information in call data records can determine which existing 2G sites have the highest number of expected mobile broadband-capable users.

> **Mapping spectrum assets, technology choices and device capabilities of the subscriber base**
The network operator should map how its spectrum assets match the capabilities of its subscribers' device capabilities. Existing spectrum assets, spectrum refarming opportunities and device penetration (supported technology and bands) influence the revenue potential of 3G and 4G deployments.

> **Building selective cost-efficient coverage**
In areas with moderate traffic demands, operators can cover significantly larger geographical areas with mobile broadband solutions designed for cost-efficient coverage, based on traffic predictions indicating the best sites for mobile broadband expansion.

To select which 2G sites to upgrade, a first step could be to identify those with the most subscribers with 3G/4G-capable phones attached

Upgrading 2G sites with 3G/4G technology

Upgrading existing 2G sites to 3G or 4G operating at low bands is possible on the existing network grid, and there is potential to utilize larger antennas and beamforming to increase 4G coverage and capacity even further.

Today, there are hundreds of thousands of legacy 2G sites suitable for a cost-efficient 3G/4G technology upgrade. For example, compared to deploying new conventional 3G sites, the reuse of existing 2G combined with new 3G equipment can result in total cost of ownership (TCO) savings of more than 60 percent. To select which 2G sites to upgrade, a first step could be to identify those with the most subscribers with 3G/4G-capable phones attached.
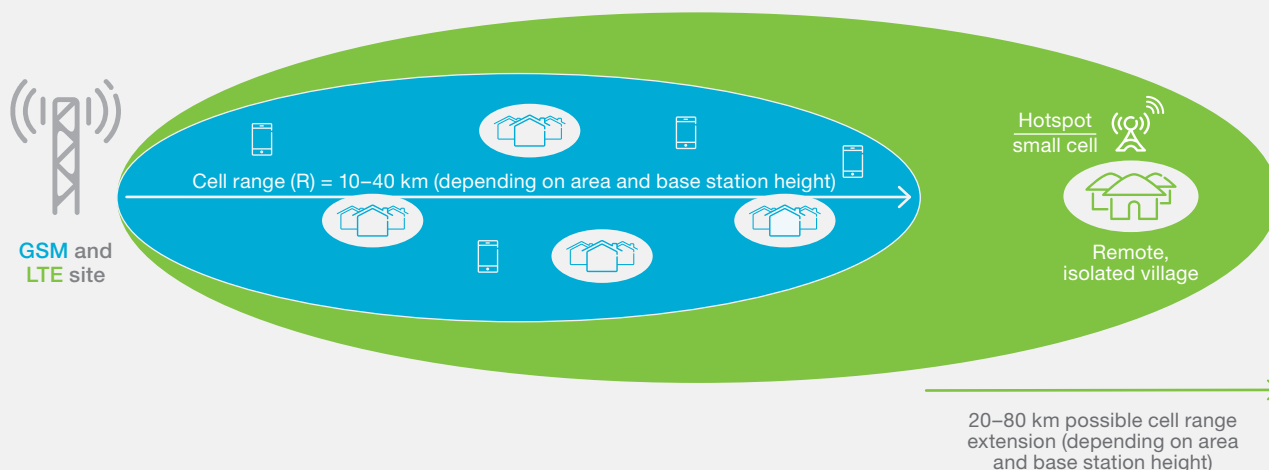
[4] Measurements done in 2016. Download time for KEPLER webpage from etsi.org (many small objects)

Example of solutions for providing mobile broadband coverage in remote rural areas

Cell range (R) = 10–40 km (depending on area and base station height)

GSM and LTE site

Hotspot / small cell

Remote, isolated village

20–80 km possible cell range extension (depending on area and base station height)

Mobile broadband for areas without existing coverage

Extending mobile broadband coverage to populations that reside outside any existing mobile coverage area is more challenging, as they are typically spread over large areas at different geographical locations. For instance, villages may be geographically concentrated, or isolated and distant from concentrated areas in some rural locations.

Assume a scenario where several villages have access to 2G coverage and some villages are outside any mobile coverage. Different solutions to provide mobile broadband coverage can be applied.

Villages within existing 2G coverage area:

> Can easily be provided with mobile broadband coverage by site upgrade to 3G or to 4G. Comparing 2G cell coverage with 3G or 4G on the same frequency band, a coverage gain of up to 7 dB could be achieved due to a better link budget, which translates into a doubling of the cell range.[5] Using LTE (4G) with beamforming has the potential to double this extended cell range again, i.e. achieving a fourfold extension[6] compared to the base case with 2G

Villages outside existing 2G coverage area:

> For important hotspots in a village, such as schools and hospitals, an outdoor high-gain antenna can be used to provide broadband access to the premises (fixed wireless). This solution requires low investment and the 4G site can serve a hotspot that is located 20–80 km outside the 2G coverage range. In this scenario, the school or hospital is equipped with a roof-top antenna, which as an example, would get 3 Mbps downlink speed[7] at a distance 100 km away from the 4G-upgraded base station site using 2x10 MHz of spectrum

> To reach one or more villages outside a 2G coverage area, an alternative solution could be to deploy a small cell, with backhaul to a macro site using microwave technology. In the case where the villages are isolated and further away from an aggregation point than a single microwave link can reach, satellite backhaul can be used

Scale effects of mobile broadband technologies

Today's mobile broadband technologies and building practices have two major advantages:

> Scalability of technology, as the demand for performance grows

> Economies of scale, as solutions that have the greatest volumes continuously achieve decreasing cost per unit of output

This enables deployment of cost-effective mobile coverage solutions, making it possible to connect low-income subscriber groups with low-cost, low-energy solutions where needed, in presently uncovered areas.

At the current trajectory, mobile broadband will provide network coverage to around 95 percent of the world's population by 2022. Further adoption of internet services depends on how the barriers outlined in this article are addressed by governments, regulators, network operators and service providers.

At the current trajectory, mobile broadband will provide network coverage to around 95% of the world's population by 2022

[5] Assuming free-space propagation loss
[6] Calculation based on using eight antenna elements
[7] Wireless indoor coverage, roof-top antenna and LTE modem connected to e.g. a Wi-Fi router

NETWORK OPTIMIZATION THROUGH ANALYTICS

Mobile broadband operators are faced with commercial and technical pressures to continually enhance their services. As the need for performance increases, so must the rate of network application software upgrades and network optimization. Operator dtac in Thailand has met these challenges by applying analytics to both improve and accelerate network optimization

Mobile networks were initially built for services such as voice and text messaging, which have relatively stable performance requirements. These were managed by tracking and optimizing a number of key performance indicators (KPIs) focusing on availability, retention and quality. With additional services such as web browsing, social media and video streaming, the focus has shifted to user experience-based service KPIs, designed to reflect the rapidly evolving requirements of popular apps such as Facebook, YouTube, Instagram, and Line, which dominate network traffic today.

This article was made in cooperation with dtac, one of the leading mobile operators in Thailand. It provides mobile services to approximately 25 million subscribers. dtac emphasizes using the internet and digital services to empower society.

The evolution of user experience in mobile networks

Time-to-content (TTC) and consistency for web browsing and video streaming have a significant effect on how users perceive their network. Operators are extending network performance monitoring beyond traditional KPIs, to incorporate new service KPIs that reflect users' changing needs and app developments.

Providing high peak data throughput for users has long been a fundamental target for operators. While it remains a focal point, service KPIs such as TTC are becoming more important. TTC is dependent on throughput ramp-up time and hence fast resource allocation. LTE networks optimized to reach very high peak throughput several seconds after a session is set up do not necessarily provide the best app user experience. Ultimately, the goal of user experience optimization is to ramp up throughput as high as possible, as fast as possible.

Given the above, mobile network operators are faced with two distinct but interrelated challenges:

> Rapid changes in mobile broadband and the increasing frequency of network application software updates leave less time to complete network improvement and optimization projects between software updates

> As the focus of network performance shifts to user experience, ways to translate service KPIs into network KPIs must be developed to meet subscribers' expectations

Advanced analytics to speed up improvements of network quality and user experience

The answer to these challenges lies in big data, analytics and machine learning. New tools and processes for network optimization are being developed and tested. Part of the solution is to adapt some of the same tools that enable a faster pace of software development to network improvement projects in live networks.

System application software development increasingly employs advanced analytical tools that enable process automation. The same methods are now also starting to be utilized in network improvement and optimization processes, vastly speeding up statistical analysis of all aspects of a network's performance. This allows the rapid addition, change or tuning of many network functions over a short time.

Relating service KPIs, such as TTC or video re-buffering, to network KPIs, such as channel quality or cell load, is usually accomplished by correlating data from drive tests or on-device measurements with network KPIs. In order to speed up the process, the solution is to increase the use of data analytics to develop predictive models. This will allow an operator to directly address the user experience, such as TTC for typical webpage loading or streaming video.

Throughput ramp-up for YouTube sessions

Throughput ramp-up improvements reduced TTC by up to 62%

━━ DL throughput (after optimization)

━━ DL throughput (before optimization)
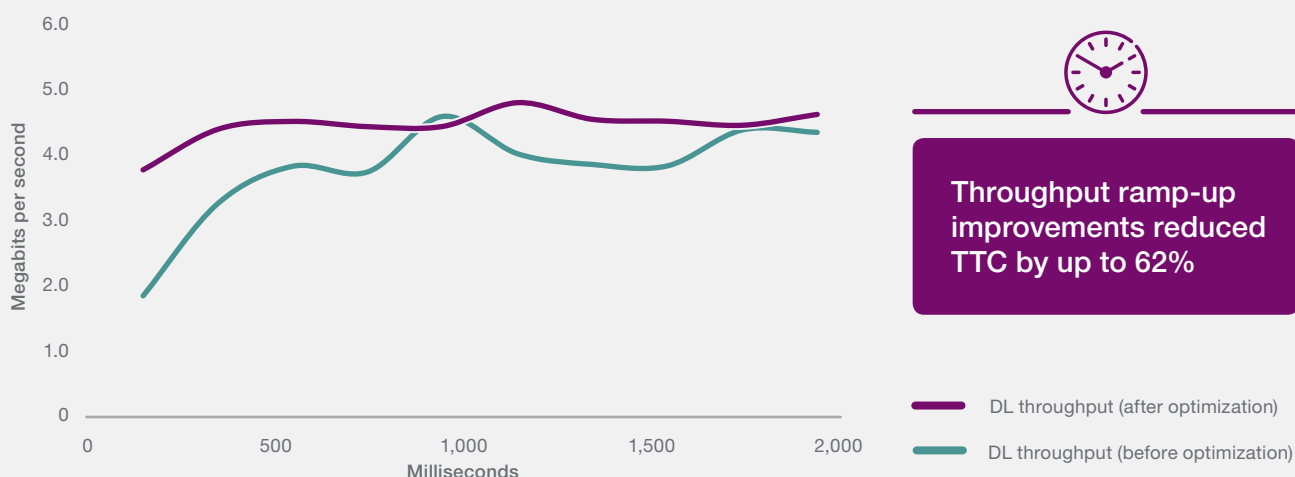
Mobile broadband operator dtac in Thailand has been using these methods to accelerate their network improvement and optimization projects for both WCDMA and LTE. Faced with a highly competitive market environment, the mobile broadband operator is enhancing network performance to support a push to unlimited data plans for postpaid subscriptions. This is reflected in the doubling of 4G subscriptions between Q1 2016 and Q1 2017, along with an increase in data traffic per subscriber from 2.5 GB to 4.4 GB per month. Postpaid subscriptions also increased 18 percent year-on-year.

A typical optimization project, which historically took several months to complete, now takes less than a quarter of the time. Us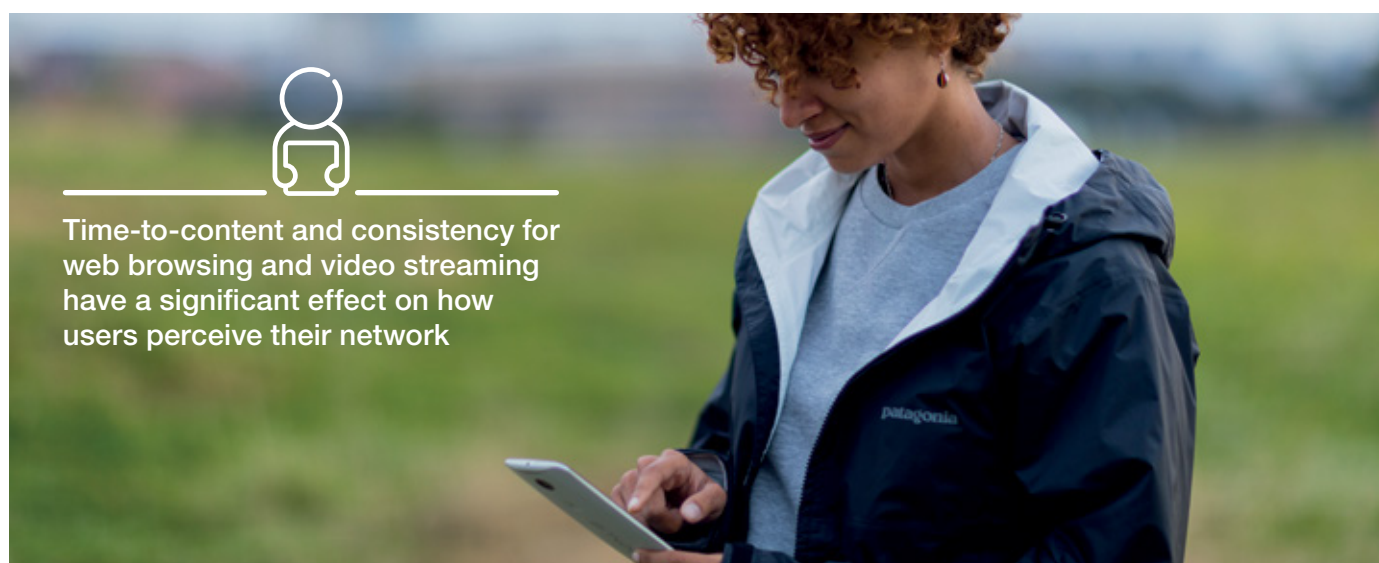ing analytics-driven user experience optimization has enabled dtac to dramatically reduce both time and resources devoted to network optimization. It can manage more frequent software and application updates, and focus on network enhancements that support strategic commercial goals. In addition, advanced analytics were used by dtac to mitigate risk and facilitate an aggressive network improvement project, whereby a large number of changes could be deployed in a condensed time frame without jeopardizing network integrity or user perception.

Improving time-to-content with enhanced throughput ramp-up

Downlink throughput is a major contributor to TTC. However, a clear example of applying analytics to optimization is the identification of throughput ramp-up as another key factor to improve, as well as the steps needed to address it. By optimizing characteristics such as resource allocation, latency and control channel efficiencies, ramp-up was significantly enhanced. This allowed dtac to deliver performance improvements that were directly visible to consumers, even though peak throughput was similar once the download process had ramped up. The throughput ramp-up improvements directly reduced YouTube TTC for both WCDMA (which saw a 43 percent reduction) and LTE (which saw a 62 percent reduction). The figure above illustrates the download progression, measured in megabits per second, before and after the LTE optimization project.

Powerful analytics models provide operators with effective tools to not only react adequately to ever increasing consumer expectations of network quality, but also to augment networks in anticipation of rising data demands.

Time-to-content and consistency for web browsing and video streaming have a significant effect on how users perceive their network

MASSIVE IOT COVERAGE IN THE CITY

A wide range of Internet of Things (IoT) services are being embraced in cities. Deep indoor connectivity is a requirement for many of these services. Simulation of a realistic large-scale IoT service scenario in a city showed that up to 99 percent of devices located deep indoors could be reached with new cellular technologies for the IoT

Cellular networks are well-suited to providing connectivity for emerging IoT applications due to their ubiquitous deployments, as well as their inherent characteristics, which include security and reliability. Currently, the main role of cellular networks is to provide mobile broadband coverage. Connectivity for IoT devices poses new coverage challenges for a variety of use cases. The newly standardized 3GPP Low-Power Wide-Area (LPWA) cellular technologies, Cat-M1 and NB-IoT, can be deployed on existing LTE networks, and are helping to overcome these challenges. The technologies meet massive IoT coverage requirements and support a wide range of low-cost devices.
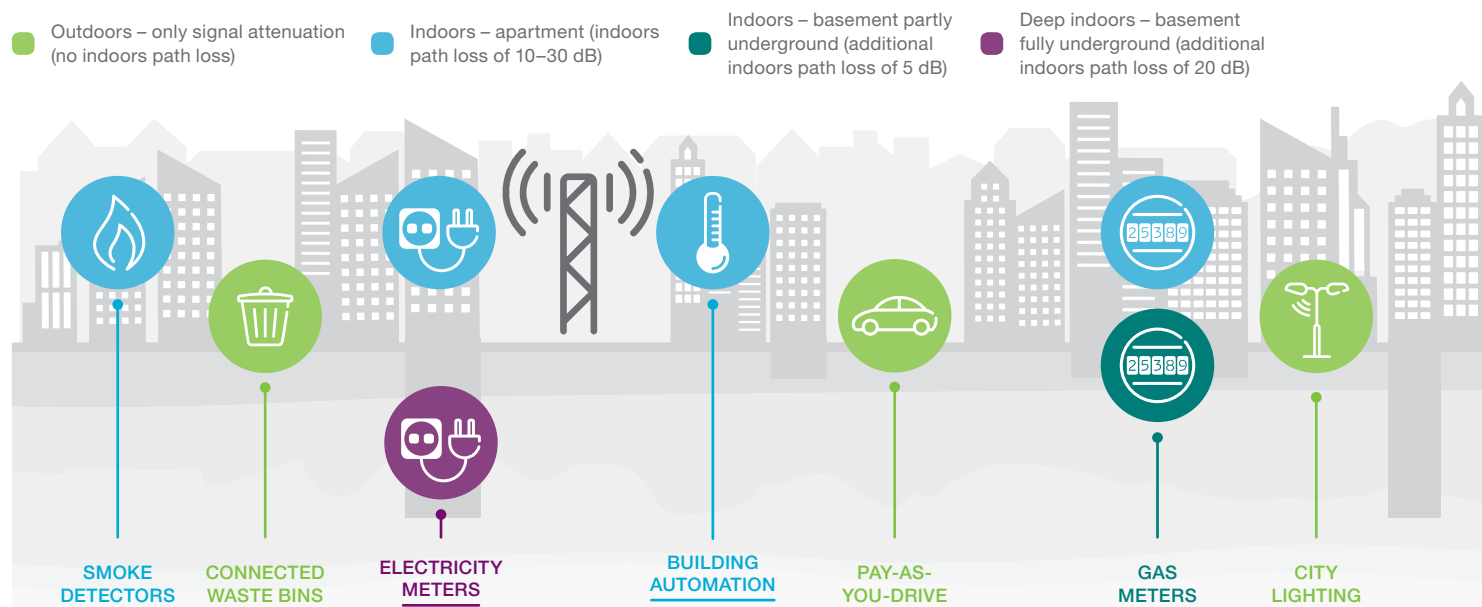
Supporting diverse use cases

Cat-M1 is a solution designed to support a wide range of IoT applications, from simple to rich content. This includes such applications as connected waste bins through to alarms incorporating emergency voice assistance and

fleet management. Cat-M1 provides theoretical peak uplink data throughput of around 1 Mbps. However, there is a compromise between the data throughput and coverage: the lower bitrate the application requires, the further the coverage is extended for the application. The minimum connectivity target has been set to a maximum coupling loss (MCL)[1] of 160 dB where the achievable uplink data rate is around 1 kbps.[2] This can be compared to an MCL of 144 dB for broadband LTE with up to 1 Mbps in downlink and a few 10s of kbps in uplink.

NB-IoT is a narrowband solution, which is designed to provide even better coverage and enables deployment of devices with an even lower cost than Cat-M1. It targets ultra-low-throughput IoT applications, such as smoke detectors and utility meters. The minimum connectivity target has been set to an MCL of 164 dB where the achievable uplink data rate is around 300–400 bps.[3] Both technologies support the massive IoT use cases exemplified in the figure below.

Massive IoT connected devices in a city scenario

- ● Outdoors – only signal attenuation (no indoors path loss)
- ● Indoors – apartment (indoors path loss of 10–30 dB)
- ● Indoors – basement partly underground (additional indoors path loss of 5 dB)
- ● Deep indoors – basement fully underground (additional indoors path loss of 20 dB)

SMOKE DETECTORS CONNECTED WASTE BINS ELECTRICITY METERS BUILDING AUTOMATION PAY-AS-YOU-DRIVE GAS METERS CITY LIGHTING

[1] Maximum coupling loss (MCL): Coupling loss is a measure of the attenuation of the radio signal between the transmitter and receiver. MCL is the largest attenuation the system can support with a defined level of service. This can also be used to define the coverage of the service
[2] An MCL of 159.7 dB is a 3GPP target that has been evaluated and exceeded by the industry. See also industry white paper "Coverage Analysis of LTE-M Category-M1, Version 1.0, January 2017"
[3] An MCL of 164 dB is a 3GPP target that has been evaluated and exceeded by the industry

Percentage of devices reached in the massive IoT city scenario

	800 MHz band			2.6 GHz band		
	LTE MBB (144 dB)	Cat-M1 (160 dB)	NB-IoT (164 dB)	LTE MBB (144 dB)	Cat-M1 (160 dB)	NB-IoT (164 dB)[4]
Outdoors	100	100	100	100	100	100
Indoors – apartment	100	100	100	97	100	100
Indoors – basement partly underground	99	100	100	83	99	99
Deep indoors – basement fully underground	77	99	99	32	86	92

Massive IoT city model

Network coverage for massive IoT applications in a metropolitan area was analyzed. Measurements from a commercially deployed LTE network[5] for broadband services were used to calibrate a model for simulating broadband LTE, Cat-M1 and NB-IoT coverage. A three-dimensional model of a city was used, with close to 1,000 buildings per square kilometer with an average of 5 floors per building. Both line-of-sight and non-line-of-sight characteristics, including outdoor-to-indoor and indoor radio propagation models, were considered. Typical radio base station site characteristics were assumed, with inter-site distances of approximately 500 meters.

IoT devices, with a density of around 20,000 per square kilometer, were uniformly distributed across the city, both outdoors and indoors, and corresponding signal strength attributed to the different environments. For example, basements located partly underground were modelled with an additional path loss[6] of 5 dB in addition to the signal attenuation indoors (10–30 dB), and those fully underground (deep indoors) with 20 dB.

The coverage was simulated for an IoT application on broadband LTE, Cat-M1 and NB-IoT. The same cell layout was used to calculate coverage for each technology. Network coverage was analyzed in two frequency bands: one lower band (800 MHz) that has the advantage of stronger signal propagation for further coverage, and one higher band (2.6 GHz) offering greater capacity. The table above shows the percentage of devices reached for each technology.

Extending the LTE coverage for IoT

The 800 MHz band modelling showed that in challenging radio signal propagation environments, such as deep indoors, both Cat-M1 and NB-IoT can reach up to 99 percent of the devices. This can be compared to broadband LTE that would reach 77 percent of mobile broadband devices. In the 2.6 GHz capacity band, the coverage of both Cat-M1 and NB-IoT is also substantially better than the broadband LTE coverage of only 32 percent.

Coverage is enhanced for low-data-rate IoT devices by reducing the data rate to provide additional coverage. With 3GPP targets already exceeded in evaluations, the enhancements will enable massive IoT city deployments with up to 99 percent coverage of devices using cellular networks for connectivity.

BIKE FLEET MANAGEMENT   SMART PARKING   ENVIRONMENTAL MONITORING   WATER METERS   VENDING MACHINES
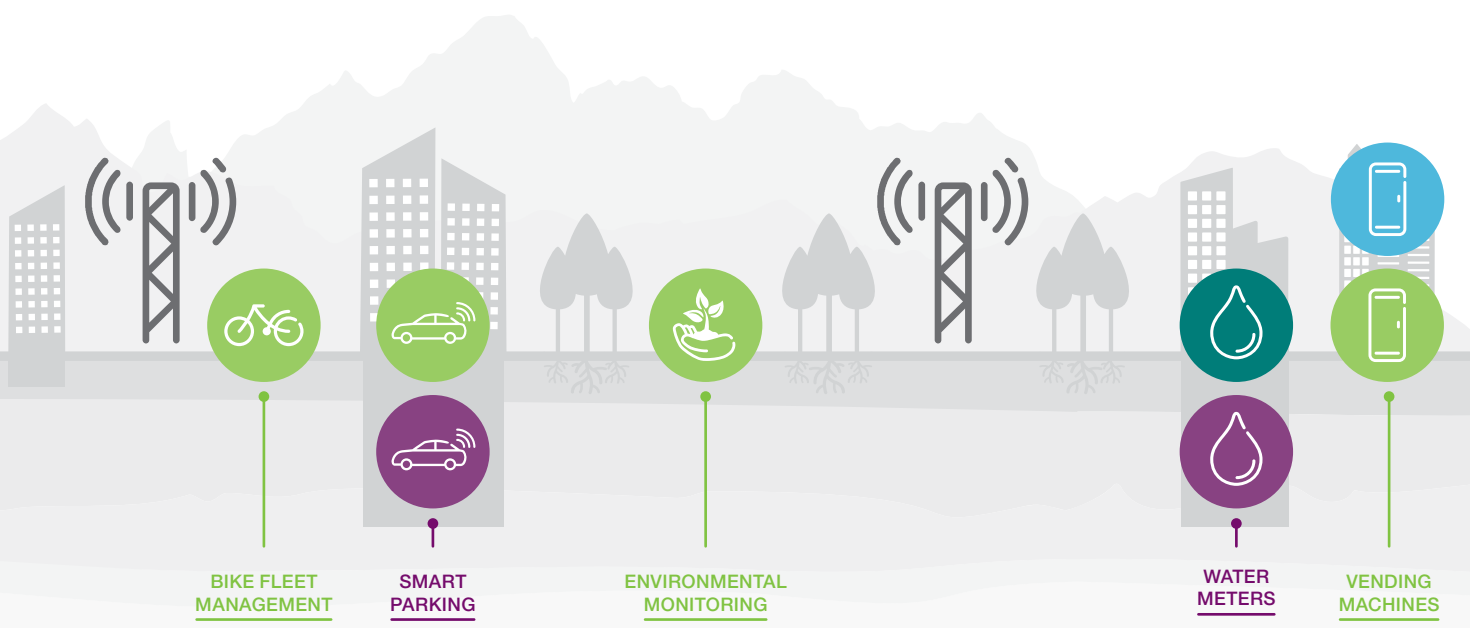
[4] Radio Frequency (RF) requirements for NB-IoT have not yet been formally defined for the 2.6 GHz band
[5] Mobile network of a major European operator in a metropolitan area
[6] Path loss is the signal decrease that occurs as the radio waves travel through the air or through obstacles

REMOTE OPERATION OF VEHICLES WITH 5G

In the near future it will be a common occurrence to see driverless buses on city streets. A key step towards introducing autonomously driven buses into the public transport system is the development of remote monitoring and control capabilities, which will help to ensure safety

While autonomous vehicles could revolutionize mass transportation as we know it, their safety has been widely debated. To address this concern, remote operation brings a safety mechanism that allows public buses to be monitored and controlled by a remote operator from a distance, if needed. The vision of operators scanning screens and on-hand to intervene if necessary, should contribute to public acceptance of autonomous vehicles.

Network requirements for remote operation include broad coverage, high data throughput and low latency to enable continuous video streaming and to send commands between a remote operations center and a vehicle. 5G will bring a number of benefits to remote control systems, including core network slicing that will enable priority service provisioning, and radio access to bring ultra-low latency and beamforming for high throughput and capacity.

At its headquarters in Södertälje, Sweden, Scania has a 5G proof-of-concept test network devoted to controlling a bus remotely from a vehicle operations center. Work at the site is focused on two important areas: total system response time for remote monitoring and control, and the automated tools required to provision prioritized network services.[1]

The tests involve a remote operator driving a bus around the test track, as well as to and from the parking facilities. Sensor data from the bus, including a high-resolution video feed, is streamed to the remote operations center over LTE radio access with an evolved 5G core network. The testbed features automated service ordering and provisioning, allowing the set-up and take-down of prioritized network resources needed for the remote monitoring and operation.

The 5G proof-of-concept network is not the biggest source of latency in the complete remote operation system. Additional factors that cause delays include servo-driven mechanics, as well as video encoding and decoding

Isolating and measuring contributors to system response time

A key objective is to isolate and measure the different contributors to the remote control system response time, including network latency. Response time is measured in milliseconds (ms) – for example, from when an operator sees an obstacle on the road and reacts by using the remote controls to apply the brakes, to the point when the result (the bus slowing) is visible in the video presented to the operator. During the tests, total system response times of around 185 ms were achieved. The most significant contributors to the response time and its variation were mechanical delays (physical actuators controlling the bus), followed by the video processing delay and, finally, the network delay (round trip time (RTT)).

Network RTT mostly stayed under 50 ms during the study, although some areas with obstacles along the test route increased the latency beyond this value. Uplink throughput, which is critical for remote operation, was also measured. In good coverage areas, the uplink throughput was between 10–20 Mbps.

[1] Ericsson Research, "5G teleoperated vehicles for future public transport" (2017), Rafia Inam, Keven (Qi) Wang, Nicolas Schrammar, Athanasios Karapantelakis, Leonid Mokrushin, Aneta Vulgarakis Feljan, Viktor Berggren and Elena Fersman: www.ericsson.com/research-blog/5g/5g-teleoperated-vehicles-future-public-transport

Illustration of system response time and its components

Remotely operated vehicle

Remote controlled bus

Video encoding

Mechanical controls

5G test network

LTE radio

Evolved Packet Core

Remote operations center

Video decoding

Screen rendering

Remote control rig

Remote operator
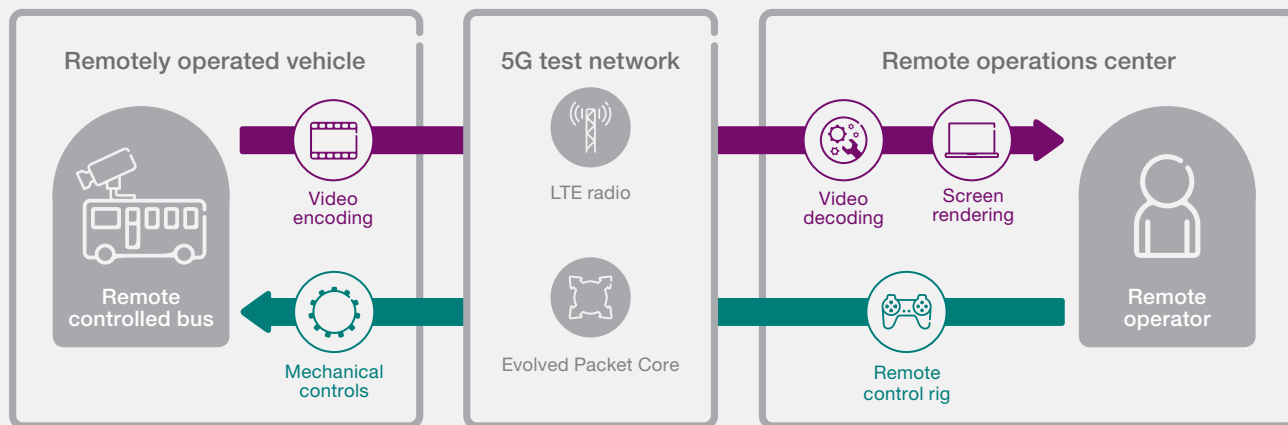
5G radio access lowers round trip time to under 4 ms

Reducing system response time

Improvements are being made in all areas affecting system response time. Network latency improves significantly with 5G radio access, lowering network RTT to under 4 ms. Video encoding and decoding are on a track to continuously improve, with advances in both codecs and adaptive streaming mechanisms. Mechanical delays will decline as the buses themselves are specially designed for autonomy and remote operation is deployed – rather than being converted from today's driver-controlled buses.

Automated network resource prioritization

A critical requirement for a remote vehicle control center is the ability to prioritize network services if remote operation is required, through a service ordering API to a mobile telecom operator. In the testbed, an interface based on the Open Mobile Alliance candidate standard is used for network resource prioritization.

Technology is being developed to enable a self-service portal, allowing network customers, such as public transport companies, to specify quality of service (QoS) requirements on their own terms; for example, to prioritize 4K video traffic for 40 buses. The software will then translate this specification into instructions for network resource prioritization.

Mechanical delays will decline as the buses themselves are specially designed for autonomy and remote operation is deployed – rather than being converted from today's driver-controlled buses

The remote operation of a research concept vehicle (RCV), using a 5G testbed radio, was demonstrated at Mobile World Congress 2017

Research concept vehicle

Parallel to the Scania activities, the remote operation of a research concept vehicle (RCV) – developed and custom-built by the Integrated Transport Research Lab at KTH Royal Institute of Technology – was demonstrated at Mobile World Congress 2017. A 5G testbed radio, using a 15 GHz carrier frequency, provided sufficient bandwidth for remotely operating multiple vehicles in the same cell. Delivering the throughput on 15 GHz is accomplished using beamforming; that is, tracking the moving vehicle and focusing the radio power for maximum effect. Due to the low latency of the 5G radio access, RTT was under 4 ms.

The work on remotely controlled buses and the RCV are making safe, autonomous vehicles a reality. Additionally, the insights from these activities can be applied to other industrial use cases that require high uplink throughput, low network latency and automated service provisioning.

Attributes of 5G – including network slicing and low latency – will make safe public transport using autonomous vehicles a reality

Integrated Transport Research Lab

The Integrated Transport Research Lab (ITRL), a collaboration between the Swedish Royal Institute of Technology (KTH), Scania and Ericsson, is actively exploring intelligent transport systems. Recent studies illustrate the use of emerging 5G cellular technologies in testbed environments.

Illustration of the remote control system

Network service ordering

Scania remote operations center

Testbed network management

Over-the-top services

Network resource prioritization

5G PoC test network

Evolved Packet Core

LTE radio

Remote control bus
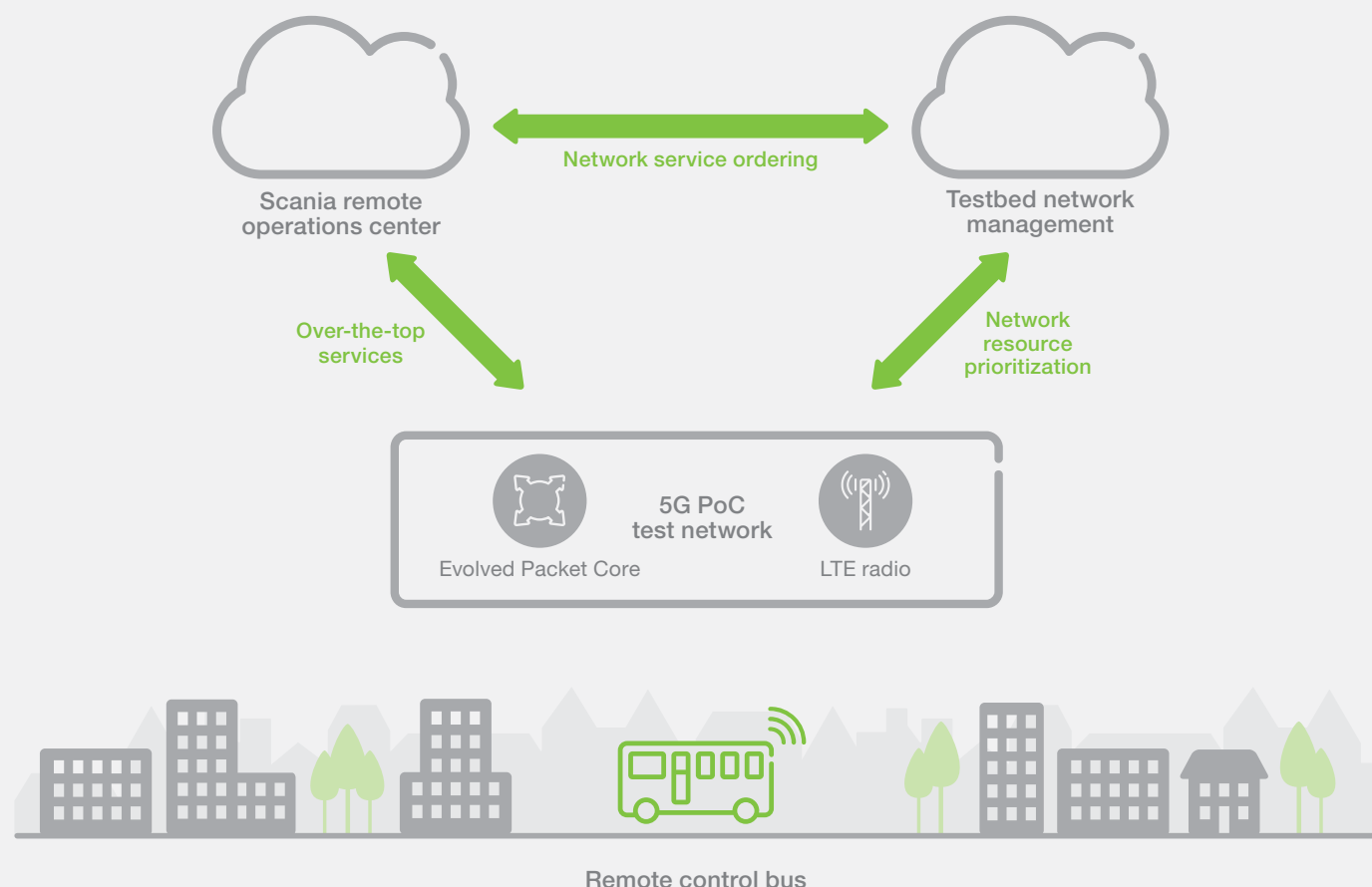
Testbed and methodology

Testbed network

The Scania testbed network uses LTE radio access on band 40 (2.3 GHz TDD) to provide data connectivity to the bus. Throughput and RTT were measured between the remotely operated bus and the network provisioning system. RTT was measured from the remote operations center to the vehicle and back, along with covered radio and network transport (both uplink and downlink). RTT measurements were collected at a rate of one per second, resulting in hundreds of measurements collected from different areas of the test track.

Video link

A single camera at the front of the bus requires an uplink throughput of 8 Mbps to stream a 1080p 60-frames-per-second video from the bus to the operations center. An industrialized solution will include cameras to capture video from the front, back and sides of the bus, requiring about 24 Mbps bandwidth using current codecs. The video latency was measured using two GPS-synchronized clocks. Each clock displayed time in binary format as a line of LEDs, allowing sub-millisecond resolution. One clock was placed on the bus in view of the camera, while the second clock was attached to the video display at the control center. Photos showing both clocks were taken at one-second intervals. The difference between the clocks indicated the video latency, measured to a high degree of accuracy.

> In 5G radio, uplink/downlink allocation will be more flexible and able to meet the demands of uplink critical use-cases

Mechanical controls

The latency of the remote control rig can be reduced to under 1 ms by using optimized equipment. On the other hand, the vehicle latency, including mechanical controls, has a wide variation.

Automated network service prioritization

A cloud-hosted application function (AF) dynamically sets up virtual connections between vehicles and the 5G Evolved Packet Core (EPC) network, with specific QoS attributes such as designated latency levels and guaranteed throughput. This application functionality can be securely opened to third parties through an API. In the use case described here, the testbed uses this API to set up priority virtual connections for vehicles in need of remote operator assistance.

METHODOLOGY

Forecast methodology

Ericsson makes forecasts on a regular basis to support internal decisions and planning, as well as market communication. 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 ConsumerLab), 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 of a 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, 69 GB/month or 8.5 GB/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 coverage: App coverage is the geographical area within which an app works as expected by the user. This means that each app has its own coverage map. App coverage can be measured as the probability that a mobile broadband network delivers sufficient performance for a good user experience for that app

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 easily sum up total signal gains or losses from a transmitter to a receiver through the media a signal passes through

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

Gpbs: Gigabits per second

GSA: Global Supplier 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

MIMO: Multiple Input Multiple Output

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 standalone solution, targeting ultra-low-throughput IoT applications

NFV: Network Functions Virtualization

OS: Operating System

PB: PetaByte, 10^{15} bytes

QAM: Quadrature Amplitude Modulation

SDN: Software-Defined Networking

Smartphone: Mobile phones with open OS, e.g. iPhones, Android OS phones, Windows phones but 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

GLOBAL AND REGIONAL KEY FIGURES

In this edition of the Ericsson Mobility Report, we have included the regional key figures in addition to the global figures

To find out more, scan the QR code, or visit **www.ericsson.com/mobility-report**

Traffic Exploration Tool:

Create your own graphs, tables and data using the Ericsson Traffic Exploration Tool. The information available here can be filtered by region, subscription, technology, traffic and device type. You may use charts generated from this tool in your own publications as long as Ericsson is stated as the source.

Regional appendices:

This year we have provided five versions of the report: a standalone global version as well as four variations of this, each containing a section for a different region of the world.
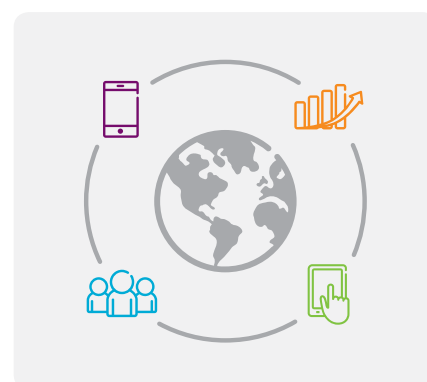
GLOBAL KEY FIGURES

	2015	2016	2022 forecast	CAGR** 2016–2022	Unit
Mobile subscriptions					
Worldwide mobile subscriptions	7,260	7,520	8,980	3%	million
> Smartphone subscriptions	3,280	3,860	6,830	10%	million
> Mobile PC, tablet and mobile router subscriptions	240	240	320	5%	million
> Mobile broadband subscriptions	3,530	4,390	8,280	11%	million
> Mobile subscriptions, GSM/EDGE-only	3,600	3,050	670	-22%	million
> Mobile subscriptions, WCDMA/HSPA	2,080	2,280	2,780	3%	million
> Mobile subscriptions, LTE	1,090	1,860	4,960	18%	million
> Mobile subscriptions, 5G			530		million
Mobile traffic*					
> Data traffic per smartphone	1.4	2.1	12	33%	GB/month
> Data traffic per mobile PC	5.8	7.7	23	20%	GB/month
> Data traffic per tablet	2.5	3.6	11	20%	GB/month
Total traffic					
Total mobile data traffic	5.3	8.8	71	42%	EB/month
> Smartphones	4.1	7.2	66	45%	EB/month
> Mobile PCs	0.4	0.5	1.3	17%	EB/month
> Tablets	0.2	0.3	1.5	30%	EB/month
> Total fixed data traffic	60	70	170	15%	EB/month

* Active devices
** CAGR is calculated on unrounded figures
[1] These figures are also included in the figures for North East Asia

[2] These figures are also included in the figures for Middle East and Africa
[3] Category introduced as part sum of all regions do not sum up to total figure due to the definition of regions used here

REGIONAL KEY FIGURES

	2015	2016	2022 forecast	CAGR** 2016–2022	Unit
Mobile subscriptions					
North America	370	380	430	2%	million
Latin America	690	690	770	2%	million
Western Europe	520	520	550	1%	million
Central and Eastern Europe	580	580	640	1%	million
North East Asia	1,550	1,570	1,840	3%	million
China[1]	1,310	1,320	1,580	3%	million
South East Asia and Oceania	1,010	1,070	1,280	3%	million
India, Nepal and Bhutan	1,040	1,160	1,480	4%	million
Middle East and Africa	1,370	1,400	1,770	4%	million
Sub-Saharan Africa[2]	660	660	950	6%	million
Other[3]	130	150	220	7%	million
Smartphone subscriptions					
North America	280	310	370	3%	million
Latin America	340	410	590	7%	million
Western Europe	350	380	480	4%	million
Central and Eastern Europe	200	240	440	11%	million
North East Asia	1,120	1,250	1,750	6%	million
China[1]	930	1,050	1,520	6%	million
South East Asia and Oceania	370	480	1,000	13%	million
India, Nepal and Bhutan	210	270	890	22%	million
Middle East and Africa	350	470	1,220	17%	million
Sub-Saharan Africa[2]	180	250	770	20%	million
Other[3]	60	50	90	10%	million
Data traffic per smartphone*					
North America	3.7	5.0	26	31%	GB/month
Latin America	1.3	1.7	10	35%	GB/month
Western Europe	1.9	2.7	22	42%	GB/month
Central and Eastern Europe	1.8	2.6	14	33%	GB/month
North East Asia	0.8	1.2	8.4	38%	GB/month
China[1]	0.4	0.8	6.5	41%	GB/month
South East Asia and Oceania	1.3	1.8	12	36%	GB/month
India, Nepal and Bhutan	1.5	4.1	11	18%	GB/month
Middle East and Africa	1.0	1.3	8.2	36%	GB/month
Sub-Saharan Africa[2]	0.8	1.0	5.3	31%	GB/month
Total mobile traffic					
North America	1.2	1.8	9.8	33%	EB/month
Latin America	0.4	0.7	5.6	42%	EB/month
Western Europe	0.8	1.2	9.5	42%	EB/month
Central and Eastern Europe	0.5	0.7	6.3	43%	EB/month
North East Asia	1.2	1.9	15	40%	EB/month
China[1]	0.5	1.0	9.8	47%	EB/month
South East Asia and Oceania	0.5	0.8	9.0	50%	EB/month
India, Nepal and Bhutan	0.3	1.0	7.8	41%	EB/month
Middle East and Africa	0.4	0.6	8.4	55%	EB/month
Sub-Saharan Africa[2]	0.1	0.2	3.2	53%	EB/month
Other[3]	0.0	0.1	0.1	0%	EB/month

Ericsson is a world leader in communications technology and services with headquarters in Stockholm, Sweden. Our organization consists of more than 111,000 experts who provide customers in 180 countries with innovative solutions and services. Together we are building a more connected future where anyone and any industry is empowered to reach their full potential. Net sales in 2016 were SEK 222.6 billion (USD 24.5 billion). The Ericsson stock is listed on Nasdaq Stockholm and on NASDAQ in New York. Read more on www.ericsson.com