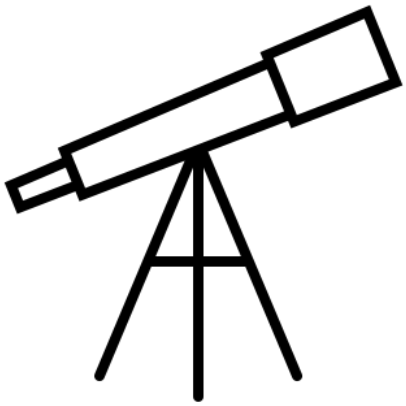
5G Observatory

Biannual Report

April 2023

Study on "European 5G Observatory phase III" (CNECT/2021/OP/0008).



EUROPEAN COMMISSION

Directorate-General for Communications Networks, Content and Technology

NOTE

This is the 18th edition of an independent, biannual summary of developments in the deployment of 5G in the EU, assessing progress towards EU policy goals. Quarterly publications of the European 5G Observatory have been issued since September 2018, under a contract with the European Union and the opinions expressed are those of (the contractor) and do not represent the official position of the European Commission. Since 2021, the 5G Observatory is run by a consortium of three companies VVA, Policytracker and LS. Since March 2023 the Reports became biannual.

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1 What has happened in the past 6 months

In the past 6 months, a total of four 5G spectrum auctions have taken place concerning licenses in the 700 MHz, 1500 MHz, 1800 MHz, 2.1 GHz, 2.3 GHz, 2.6 GHz, 3.6 GHz and 26 GHz bands. These auctions have been conducted in Estonia, Romania, Ireland, and Croatia and Spain.

Furthermore, several EU funding initiatives designed to bolster 5G infrastructure are well underway, such as the Connecting Europe Facility Digital programme (CEF Digital), which has awarded its first call winners, and the Smart Networks and Services Joint Undertaking (SNS JU), which is currently in its second funding cycle. In addition, several individual Member States have now awarded funds for 5G & 6G projects.

On the commercial side, mobile operators are making significant strides in enhancing 5G network coverage in rural areas while investing in emerging technologies like 5G standalone (5G SA), which is in its nascent stages of implementation. Moreover, there is growing interest in private local networks (PLN), with several ambitious projects being announced.

1.1 5G spectrum awards

In the past six months, four additional 5G spectrum auctions have taken place in EU Member States. Estonia completed its 700 MHz auction in November 2022, following its successful auction of the 3.6 GHz band which took place four months earlier in July 2022. The Consumer Protection and Technical Regulatory Authority (TTJA) of Estonia confirmed that Elisa, Tele2 and Telia Estonia were all awarded with two 2 x 5 MHz licences in the 700 MHz band which is a vital band for wide area and indoor 5G coverage, raising a total of €6.12 million.[1]

During the last quarter of 2022, Romania successfully completed its multi-band 5G spectrum auction. Romanian regulator Ancom announced that it had sold licences in the 700 MHz, 1500 MHz, 2.6 GHz and 3.6 GHz bands, raising a total of €432.6 million. The country's three major mobile operators Orange, Vodafone and Digi all won licences.[2]

Ireland also completed a multi-band 5G spectrum auction in the 700 MHz, 2.1 GHz, 2.3 GHz, and 2.6 GHz bands. A total of 470 MHz of spectrum was awarded to mobile operators Eir, Imagine, Three and Vodafone, increasing the total amount of spectrum available to mobile services in the country by 46%. In total, the auction raised €448 million.[3]

Spain awarded the 26 GHz band to mobile operators in late 2022. The regulator awarded a total of 1800 MHz to Movistar, Vodafone and Orange. The auction brought in a total of €36.2 million.[4]

Finally, Croatia completed its multi-band auction in March 2023. Croatia's regulator HAKOM has awarded spectrum at national level in the 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, and 2600 MHz bands, and at regional level in the 3.6 GHz band. The country's three major operators Hrvatski Telekom, A1 and Telemach all won licences, raising a total of €339 million. Licences run for 15 years, with a possible five-year renewal.[5]

[1] https://5gobservatory.eu/estonia-completes-700-mhz-spectrum-auction/

[2] https://5gobservatory.eu/romania-completes-multi-band-auction/

[3] https://www.policytracker.com/ireland-completes-multi-band-auction/

[4] https://www.policytracker.com/spain-bumps-up-5g-spectrum-provision-as-26-ghz-auction-concludes/

[5] https://5gobservatory.eu/croatian-5g-auction-concluded/

1.2 Public initiatives

The public funding of 5G and 6G projects continue both at EU and Member State levels.

5G corridors along transport paths identified in the Digital Decade Policy Programme as one of the strategic Multi-Country Projects (MCPs) for European recovery.

Pan-European 5G infrastructure for Connected and Automated Mobility (CAM) is already a prime example for European cooperation that will pave the way for the provision of CAM services, both safety and non-safety, for road, rail, inland waterways, or multimodal transport. The newly adopted Digital Decade Policy Programme 2030 (DDPP) will enable an even closer coordination between the European Commission and Member States programmes, in particular under the Connecting Europe Facility, Digital part, Programme (CEF Digital) and the Recovery and Resilience Facility (RRF), in order to build up a competitive new pan-European ecosystem in such an area where no Member State can have sufficient impact alone.

The MCP is being implemented under the leadership of the newly established Smart Networks and Services Joint Undertaking[6], where industry stakeholders and public authorities meet to provide the strategic input and coordinate the overall investment financing.

Under the recent CEF Digital instrument, Call 1, an EU funding of €42 million has already been allocated to 15 projects (inception studies and deployment works), contributing to a total combined budget of €98 million**. Seven of these projects will start deploying** infrastructure straightaway, both active and/or passive, to enable CAM services to develop in the coming years. At the same time, **eight inception studies will prepare the groundwork** for future large-scale 5G infrastructure deployment projects in view of upcoming CEF Digital Calls.

A second 5G Corridors call for some further deployment works and studies closed on **21 March 2023 and will fund additional projects for a planned complementary EU investment of €30 million, including** a Coordination Support Action aiming at integrating 5G connectivity infrastructure with edge nodes and European Federated Cloud infrastructure.

However, the first "big wave" of projects is foreseen in Call 3, which is planned for the second half of 2023, and will be linked to a total EU investment in the order of €150-200 million, where scaled up initiatives from a variety of players are expected including from Mobile Network Operators (MNOs), tower companies, automotive industry players and others. Inception studies to prepare the groundwork for some of these flagship corridors are under way, i.e., the Via & Rail Baltica, France-Luxembourg and France-Germany, Austria-Italy, Benelux/North Sea, and Munich-Prague.

The early projects feature an interesting range of emerging stakeholder cooperation models which can provide some indication on future ecosystems.

In some projects, tower companies are taking the lead and engage in cooperating across borders. The Spain-France and Spain-Portugal Corridor projects focus on deploying passive infrastructure over significant corridor lengths in cooperation with MNOs and road operators.

The Scandinavian project started along an MNO-led cooperation model focusing on advanced 5G coverage along extensive main roads. The lead is taken by MNOs with strong interest from automotive companies.

Finally, yet importantly, we are seeing a seamless cross-border roaming solution develop. The Luxembourg-Germany and Bulgaria-Greece projects are focusing on inter-operator seamless roaming and address cross-border roaming issues, thus attempting to ensure uninterrupted 5G coverage

[6]The SNS JU is a public-private partnership that aims to facilitate and develop industrial leadership in Europe in 5G and 6G networks and services

throughout cross-border corridors. Results will serve as model for other seamless roaming implementations throughout the EU, which will hopefully make minutes without connectivity when driving through border sections a thing of the past.

Other 5G-related projects, albeit with more limited 5G funding, have also been announced in other programmes at a European Union level. In January 2023, the European Defence Fund (EDF) launched a new project called 5G COMPAD (5G Communications for Peacekeeping and Defence). The project aims to provide European armed forces with resilient communications systems. It will develop new and improved functionalities and improve lifecycle costs. The overall project budget is €37.1 million, of which €27 million is co-funded by the EDF.[7]

Individual EU Member States have also announced important 5G and 6G projects and funding calls. In particular, major developments are taking place in Spain where the government has launched the second phase of its 5G and 6G R&D fund.[8] The government is also granting an additional €116 million for new projects in 2022 and 2023. The funding is split up into two programmes; one for the financing of 6G research infrastructures and the acquisition of scientific-technical equipment and another for the development of 5G+ R&D projects.[9]

The German Federal Ministry of Education and Research (BMBF) launched a €14.9 million 6G project called KOMSENS-6G which hopes to integrate sensing capabilities into wireless networks. Nokia has been selected to lead this project.[10] Germany plans to fund up to €700 million in research into 6G technologies by 2025[11].

France has launched a €750 million call for 5G and 6G projects part of President Macron's €54 billion investment plan called France 2030. The plan aims to transform key economic sectors in the country including energy, automotive, aeronautics and space.[12]

Finally, Belgium has announced it would fund 21 pilot 5G projects[13]. A total of €20 million will be distributed to projects in various fields such as healthcare, emergency services, logistics and defence. Mobile operator Orange has been selected to carry out a total of 12 of these projects. Private networking company Citymesh was awarded five projects, while Proximus was awarded with two projects. Finally, Telenet and NRB were both awarded with one project.[14]

1.3 Commercial developments

The deployment and expansion of public 5G networks continues across the European Union, as mobile operators drive to improve their networks and expand coverage to rural areas. The overall 5G population coverage in Europe now reaches 81%. This is a relatively high coverage rate. However, most of this 5G coverage is achieved using shared spectrum with 4G and/or lower bands such as the 700 MHz band which do not allow to ensure consistent high quality/high throughput 5G services to the end users. In fact, 5G coverage by the 3.6 GHz pioneer band which is the band that offer the largest bandwidths and hence enables the most advanced 5G based applications is still limited to 41% population coverage on average in the EU. Therefore, more emphasis should be put in the months and years to come to deploy a high quality 5G coverage that triggers the disruptive innovation based on 5G that has been anticipated

[7] https://5gobservatory.eu/european-commission-to-fund-5g-research-for-defence-applications/

[8] https://5gobservatory.eu/spain-announces-second-phase-of-5g-and-6g-rd-fund/

[9] https://5gobservatory.eu/spain-announces-second-phase-of-5g-and-6g-rd-fund/

[10] https://5gobservatory.eu/nokia-to-lead-german-6g-sensing-project/

[11] https://www.rcrwireless.com/20210412/5g/german-government-announces-financing-for-6g-technologies

[12] https://5gobservatory.eu/france-issues-e750-million-call-for-5g-and-6g-projects/

[13] https://5gobservatory.eu/belgian-government-to-fund-21-pilot-5g-projects/

[14] https://5gobservatory.eu/belgian-government-to-fund-21-pilot-5g-projects/

for some time. This will require massive investments in mid band infrastructures and possibly also later in millimetre spectrum connectivity.

As regards to overall 5G coverage, Deutsche Telekom says its network now reaches 95% of Germany's population with 5G.[15] In Portugal, operators have been expanding their 5G coverage, with the regulator confirming that operators have launched nearly 6000 5G base stations, which is a 30% increase since the last quarter.[16]

We are also observing improvements in networks and the introduction of new technologies, including the gradual roll out of 5G Stand Alone (SA) networks. Standalone 5G is a network architecture that operates independently of existing LTE networks, allowing for various improvements over non-standalone networks. Mobile operators have promised that 5G SA will delivery higher throughput, lower latency and improved coverage. These benefits will also be important for the development on private networks, which often have stringent performance requirements. While 5G SA is still in its early deployment phase, some operators have already begun rolling out their SA networks. In February of 2023, Orange Spain launched its 5G SA network in select cities, promising various benefits over non-standalone including better indoor 5G coverage, lower latency and greater security.[17]

German operator Telefónica, meanwhile, announced that it would migrate its 5G core network to the cloud. The mobile operator says this move will allow it to quickly deploy and make updates to its network.[18]

There have also been significant developments in the private local 5G network market which continues to grow worldwide. In December 2022, Global Mobile Suppliers Association (GSA) reports that it estimates that 955 companies have now deployed at least one LTE or 5G network (SA and NSA). Notably, nearly half of these deployments (406) are found in Europe.[19]

Several unique private local 5G deployments have occurred amongst Member States. Vodafone and Porsche announced the launch of a new private local 5G network at a test track in Italy[20], while a Latvian government has expended its 5G defence testbed site with the involvement of Nokia and Ericsson[21]. Deutsche Telekom has launched a 5G test site at a German port in Duisburg[22].

On the Spanish-Portuguese border, a high-traffic cross border corridor connecting the cities of Vigo and Porto was trialled. The EU-funded 5G-MOBIX project used a private local 5G network to connect autonomous vehicles and improve traffic, navigation, service demand and other social aspects to public transport.[23]

[15] https://5gobservatory.eu/deutsche-telekom-says-its-5g-network-reaches-95-of-the-population/

[16] https://5gobservatory.eu/portugal-sees-35-rise-in-number-of-5g-base-stations/

[17] https://5gobservatory.eu/orange-spain-launches-standalone-5g/

[18] https://5gobservatory.eu/telefonica-germany-to-move-5g-core-network-to-the-cloud/

[19] https://5gobservatory.eu/nearly-1000-organisations-now-deploying-private-networks/

[20] https://5gobservatory.eu/vodafone-and-porsche-build-hybrid-private-5g-network/

[21] https://5gobservatory.eu/latvian-5g-defence-testbed-expands/

[22] https://5gobservatory.eu/deutsche-telekom-launches-5g-test-site-at-german-port/

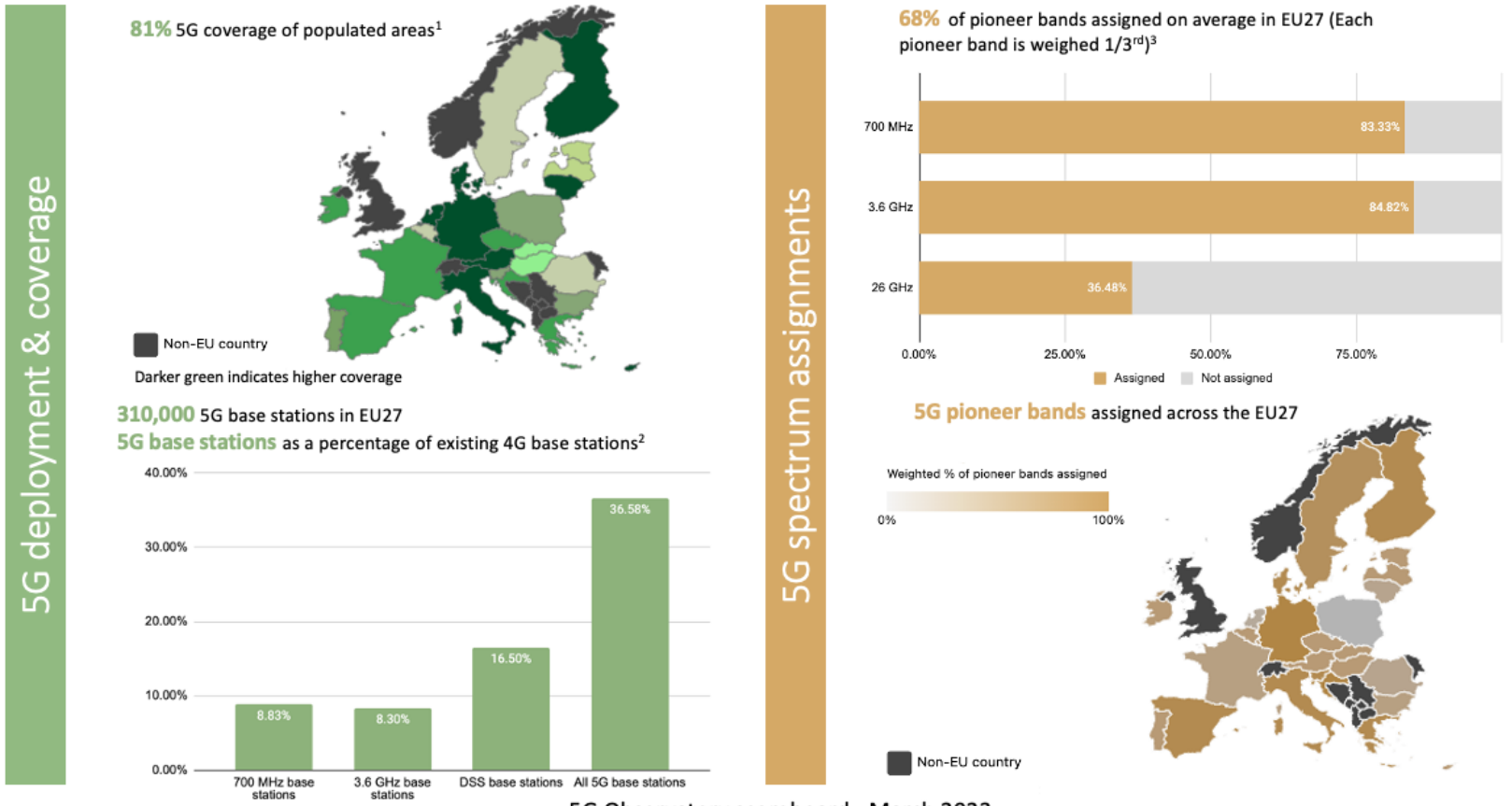
[23] https://5gobservatory.eu/spain-and-portugal-trail-first-5g-autonomous-public-transport/

2 5G scoreboard

2.1 EU27 progress so far

The 5G scoreboard summarises the status of 5G commercial launches, spectrum assignments and 5G corridors in EU-27. To date:

- All EU countries have now commercial 5G service available at least in a part of the country (please see the section on Latest Commercial Developments).
- A total of close to 310,000 5G base stations are now active in the EU.
- The most common type of 5G base station makes use of 4G bands in a Dynamic Spectrum Sharing (DSS) configuration.
- Approximately 81% of EU's population is covered by at least one basic 5G network.



5G Observatory scoreboard - March 2023

(Source: 5G coverage of populated areas and spectrum assignment data is sourced from the DESI index; Base station data is from the European Commission, via the Digital Decade Committee which is the successor of the Communications Committee (COCOM))

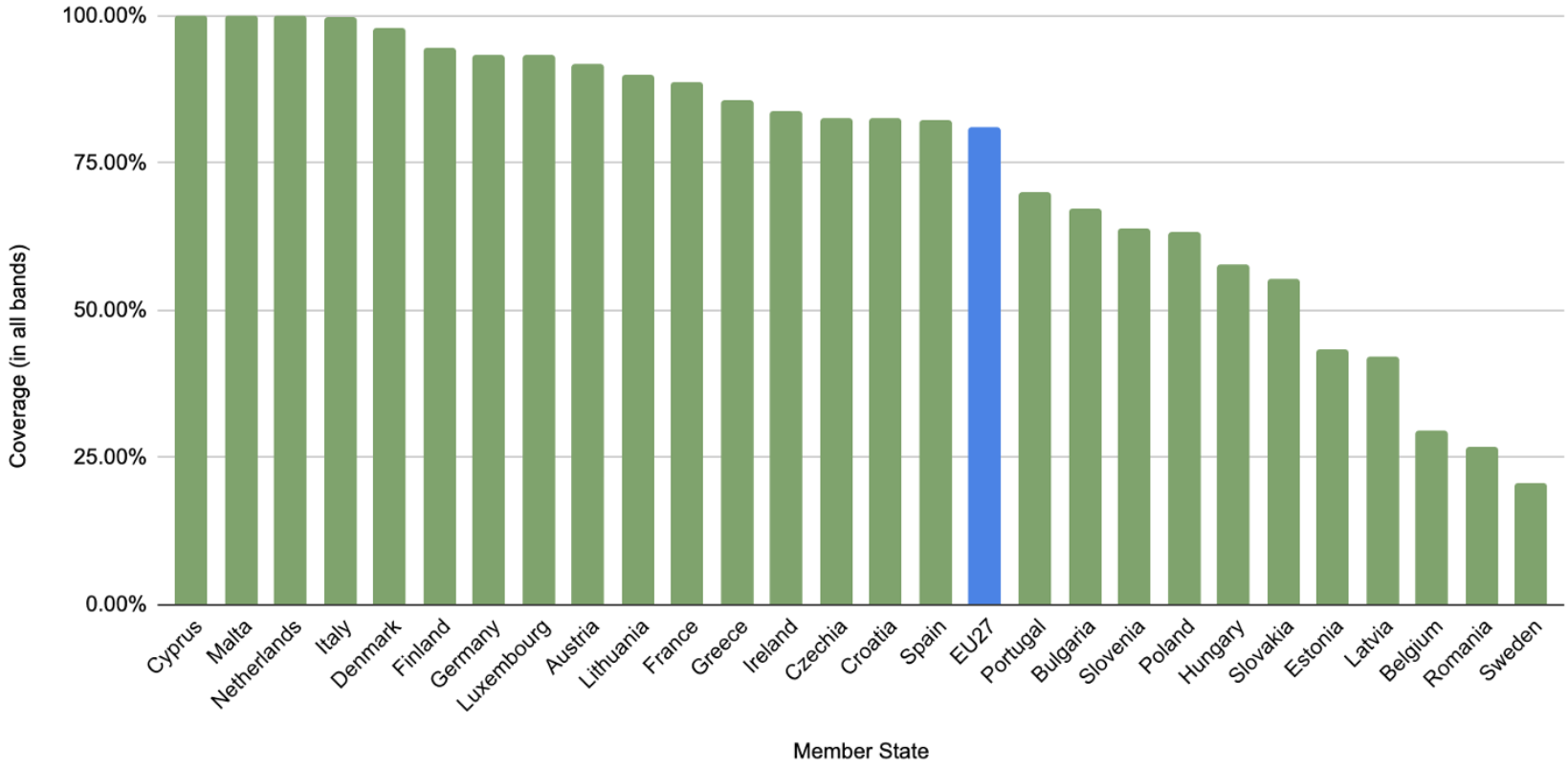
1 – Data was last updated in July 2022; this is a general indicator that does not presume any particular quality of service measures. All 5G coverage is included, including that using DSS. Location covered by at least one operator.

2 - For some EU countries, only the total number of 5G base stations is known. This means the true total number of base stations in the EU in 700 MHz, 3.6 GHz or DSS bands may be higher. Excludes Italy, Estonia, and Sweden as there was no base station data available. Additionally, some countries use bands that are not included in this chart and do no operate using a DSS configuration. In addition, the reference periods and number of base stations may vary for Member States due to the different timing of the provided data (e.g., end of 2022, Q1 of 2023)

3 – Data was last updated in March 2023; Countries need to assign 60 MHz in 700 MHz; 400 MHz in 3.6 GHz and at least 1000 MHz in 26 GHz to receive a 100% score.

EU 5G progress

5G coverage of populated areas (All frequency bands combined)[4]

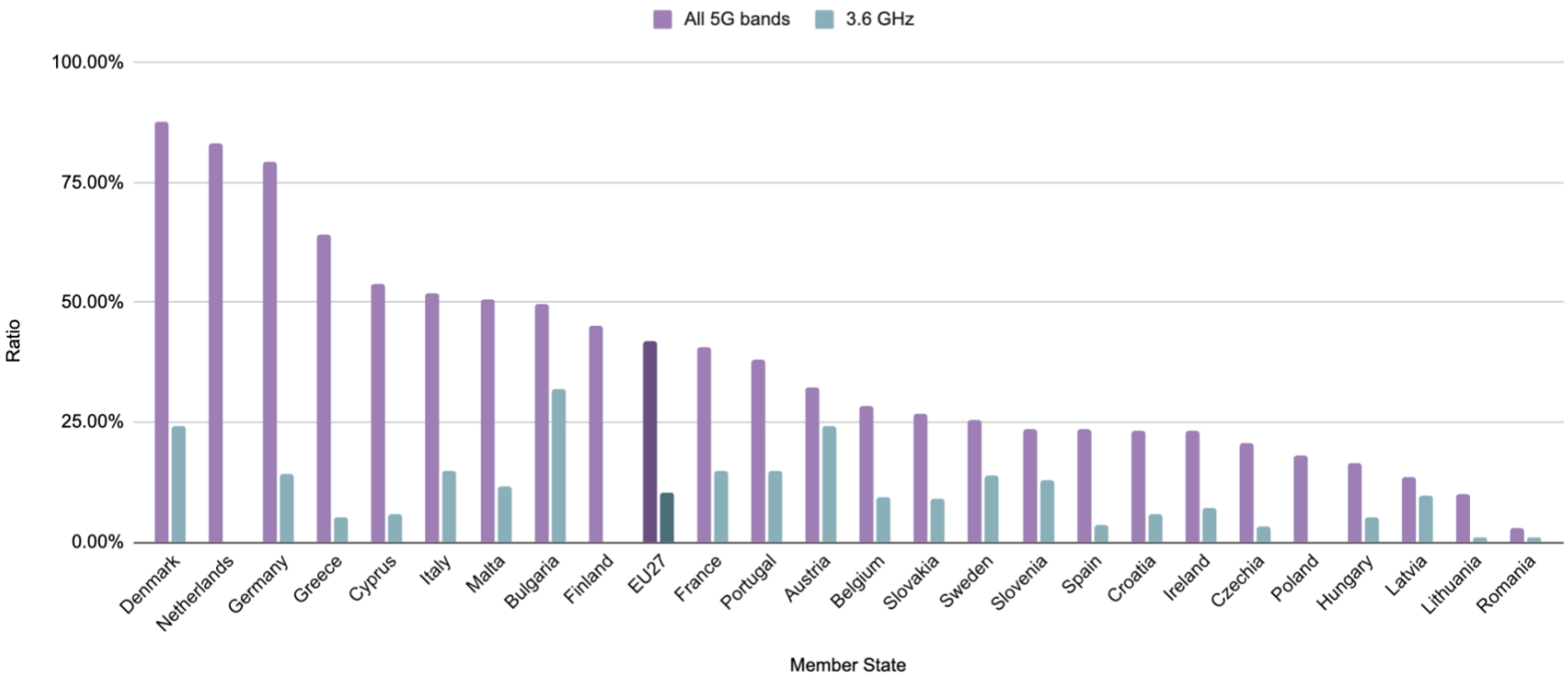


5G Observatory scoreboard - March 2023

4 – Data was last updated in July 2022; Percentage represents households covered by at least one 5G network.

EU 5G progress

5G base stations as a percentage of existing 4G base stations in Member States



5G Observatory scoreboard - March 2023

2.2 International developments

The international version of the scoreboard details the current status for 5G commercial launches and spectrum plans worldwide, including metrics such as "5G base stations per 100,000 inhabitants" which represents the extent of deployment of 5G is in each country. The following developments can be highlighted[24]:

- South Korea has the highest number of 5G base stations per 100,000 inhabitants: six times more than the EU and nearly 14 times more than the US. Meanwhile, China has the second most 5G base stations per 100,000 inhabitants.
- The United States has awarded the largest amount of high-band spectrum in the mmWave range (28 GHz) with a total of 4950 MHz assigned to operators. South Korea meanwhile has assigned 2400 MHz of mmWave spectrum to operators. The average spectrum assignment in the EU27 is 365 MHz out of 3250 MHz of harmonised spectrum in the 26 GHz frequency band.
- The largest amount of 5G spectrum already awarded in Europe is located in the mid-band (3.6 GHz), followed by the low band of 700 MHz.

[24] Please notice that there may be discrepancies between the reported figures, as the method for calculating the number of base stations is not standardised between regions

5G rollout

Comparison of 5G rollout in international markets[5]

	China	South Korea	Japan	USA	EU
Approximate number of 5G base stations	2,290,000	215,000	50,000	100,000	309,342
Total country population	1,402,000,000	51,780,000	125,800,000	329,500,000	447,706,000
5G base stations per 100,000 inhabitants	163	415	40	30	69
Indicative 5G subscribers	357,000,000	25,000,000	14,190,000	79,000,000	31,000,000
Indicative 5G subscribers per 100,000 inhabitants	25,464	48,281	11,280	23,976	6,924

5G Observatory scoreboard - March 2023

(Source: Data on subscriber numbers and base stations was collected from various sources including regulator announcements.)

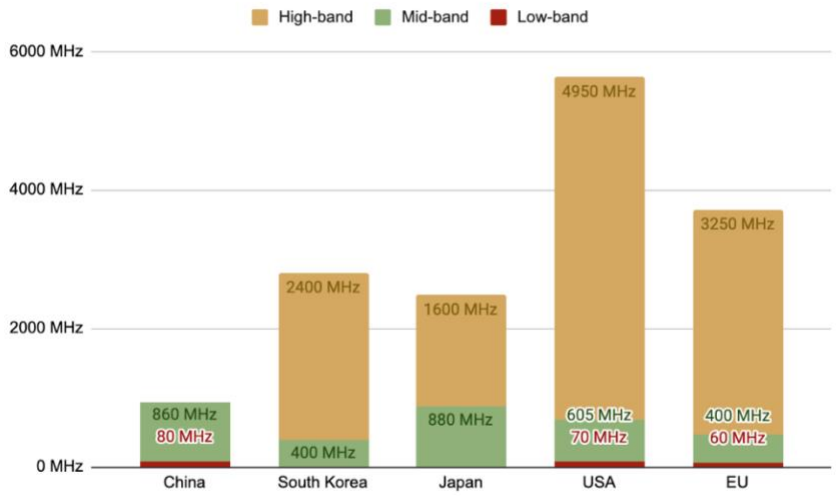
5 - There may be discrepancies between the reported figures, as the method for calculating the number of base stations is not standardised between regions

5G spectrum

Main bands authorised for 5G in international markets[6]

Country	Low-band (<1 GHz)	Mid-band (1 - 6 GHz)	High-band (>6 GHz)
China	700 MHz	2.6 GHz 3.6 GHz 4.9 GHz	-
South Korea	-	3.6 GHz	28 GHz
Japan	-	3.6 GHz 3.7 GHz 4 GHz 4.5 GHz	28 GHz
USA	600 MHz	2.5 GHz 3.45 - 3.55GHz 3.5 - 3.7 GHz 3.7 - 3.98 GHz	24 GHz 28 GHz 39 GHz 47 GHz
EU	700 MHz	3.6 GHz	26 GHz

Authorised 5G spectrum in international markets[6]



5G Observatory scoreboard - March 2023

(Source: Data on international spectrum assignments is sourced from the Policy Tracker database, the DESI index as well as FCC data.)

6 - US data shows all spectrum made available to mobile operators by the FCC. Not all of this spectrum will have been sold to operators so the final amount of spectrum assigned to operators may be slightly lower. For a more detailed explanation of the methodology used see section on *5G Spectrum comparison between EU and other world regions*. For the EU, the data represents spectrum that is harmonized across the EU27. Some individual countries may have more spectrum assigned for 5G, while some may have less or none. For a full breakdown see section A1.4.

3 Progress against monitored targets and strategic implications

The table below outlines major strategic implications referring to the overall performance of EU27 against relevant targets. 5G-related targets to be monitored throughout the publications have been sourced from EU Policy programmes, including the 5G Action Plan[25]; the DDPP[26, 27] as well as the EU 5G Cybersecurity Toolbox[28]. This monitoring exercise will be the basis of a full strategic progress assessment, including relevant roadmaps, to be included in the final report:

[25] https://digital-strategy.ec.europa.eu/en/library/communication-5g-europe-action-plan-and-accompanying-staff-working-document

[26] https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

[27] https://eur-lex.europa.eu/eli/dec/2022/2481/oj

[28] https://digital-strategy.ec.europa.eu/en/library/eu-toolbox-5g-security

Table 1: Progress against monitored targets and strategic implications

Targets: 5G AP; Digital Decade; Cybersecurity Toolbox	Performance/status	Bottlenecks identified	Solution/recommendation
Commercial launch of 5G services at least in one major city in all EU countries	Since January 2022, commercial 5G is now available in all 27 EU Member States.[29] All deployments to date cover major cities and urban areas.	None	This EU target for end of 2020 is now fully achieved. Therefore, there will be no subsequent reporting on this target.
All populated areas covered by next-generation wireless high-speed networks with performance at least equivalent to that of 5G.	Based on data collected by the Commission and operator announcements, the population coverage in the EU is estimated at 81%.[30]	As a result of research performed at Member State level, the study team identified a lack of consistent reporting at MS level (for example coverage of major roads and railways is only reported in Finland).	Reporting is expected to improve based on the DDPP decision. It includes a common EU monitoring mechanism for the attainment of the 2030 targets based on key performance indicators, reported by the Commission in the DESI on a yearly basis[31, 32].
"Digital technologies including 5G at the core of new products, new manufacturing processes and new business models"	The roll out of private local 5G networks is still in a relatively early growth phase but will be an important contributor to the continued productivity of Member States and adoption of new technologies for enterprises that will support the ongoing development of the 5G ecosystem.	A potential bottleneck may be the lack of consistent spectrum policies regarding private local networks. Some countries such as Germany offer local 5G spectrum licences for verticals while other	A recommendation regarding the optimal licensing regime for local 5G authorisation regimes could help harmonising deployment and cross-border 5G projects. With regard to spectrum consistency, in November 2020, the European Commission mandated CEPT to develop technical conditions regarding the shared use of the 3.8-4.2 GHz band for wireless broadband systems providing local-area network connectivity[33]. While CEPT's studies are still ongoing, this

[29] Final launch in Lithuania announced in January 2020 by Telia
[30] DESI 2022
[31] Source: https://eur-lex.europa.eu/eli/dec/2022/2481/oj
[32] For more information regarding 5G targets in the digital decade see: https://digital-strategy.ec.europa.eu/en/policies/5g-digital-decade
[33] https://digital-strategy.ec.europa.eu/en/library/radio-spectrum-cept-mandates

Targets: 5G AP; Digital Decade; Cybersecurity Toolbox	Performance/status	Bottlenecks identified	Solution/recommendation
	5G verticals appear to be particularly developed in ports, whereas in other industries they are at an earlier stage. Most vertical industry trials appear to be occurring within private local networks.	Countries such as Ireland do not offer local licenses. Additionally, there is a lack of consistency in which bands are available for 5G verticals. For instance, Germany offers the upper part of the 3.6 GHz band (3.7-3.8 GHz), while France is awarding licences in the 3.8-4.0 GHz.	Mandate may help resolving the existing lack of spectrum consistency as more Member States may choose to adopt the 3.8-4.2 GHz band for private local network licenses.
Authorising 5G spectrum bands	The 3.6 GHz band has been most widely assigned. 25 out of 27 Member States have assigned at least 50% of targeted spectrum in this band. The second most popular band is the 700 MHz band, which has been assigned in 24 out of 27 Member States. The least popular band is the 26 GHz band, which has only been assigned in 10 Member States. Finally, 1 Member State has failed to assign any of the pioneer bands.	Lack of demand for the 26 GHz band. Further development of harmonised approach to spectrum sharing for local networks	Referring specifically to the 26 GHz band, there have been differences in the way the band has been made available suggesting there is no *"universal formula"*. Most approaches, such as Germany's local licenses or Finland's licenses, take into account the use of the band for industrial applications and 5G verticals.[34] The identification of additional band/capacity for 5G should be initiated in a timely fashion to anticipate the expected growing business demand. The current planned review of the RSPP programme by the European Commission[35] may provide more guidance for spectrum assignment procedures. With regard to local 5G networks, the European Commission has mandated CEPT to assess technical conditions for the 3.8-

[34] From a technical perspective this is very much a band used to serve congestion in high capacity density networks as well which implies the need for a balanced approach.
[35] https://commission.europa.eu/system/files/2022-10/com_2022_548_1_annexe_en.pdf

Targets: 5G AP; Digital Decade; Cybersecurity Toolbox	Performance/status	Bottlenecks identified	Solution/recommendation
			4.2 GHz band. While CEPT's studies are still ongoing, this mandate may help resolve the existing lack of spectrum consistency.[36]
Promoting pan-European multi-stakeholder trials[37]/ Developing Pan-European deployment of 5G corridors	Twelve "digital cross-border corridors" have been established to accommodate live tests of 5G for Cooperative Connected and Automated Mobility (CCAM). In addition, at least eight Member States refer to the European deployment of 5G corridors along TEN-T networks in the interest of Single Market and cohesion in their recovery plans.[38]	17 of 27 Member States are involved in the existing 12 cross-border corridors trials, and 18 in large-scale deployment projects funded under CEF Digital	Upcoming projects (including the support of CEF Digital framework) and commitments of Member States in their recovery and resilience plans are expected to bridge existing gaps. Following the 1st call under CEF2 Digital in 2022, 15 projects (studies and works) will start shortly. Following a second call that was published in 2022 and closed in March 2023, evaluations are ongoing to assess submissions and additional projects are expected to launch.
5G toolbox implementation	A large number of Member States (such as Austria, Belgium, Croatia, Cyprus, Estonia, France, Ireland, Italy, Netherlands, Spain, and Sweden) have already taken concrete steps to implement the various strategic measures.	Based on the latest NIS report (2020), there are visible differences in terms of implementation maturity for different types of individual measures.[39]	The analysis presented in the report by the NIS Directive provides specific recommendations (next steps) based on identified findings for each of the Toolbox measures, highlighting areas requiring special attention in the next phases of the Toolbox implementation and monitoring (both at EU and MS level).

[36] https://digital-strategy.ec.europa.eu/en/library/radio-spectrum-cept-mandates

[37] The original 5G AP target Source: https://digital-strategy.ec.europa.eu/en/policies/5g-action-plan can be linked to the Digital Decade reference to Multi-Country Projects (MCPs): large scale projects facilitating the achievement of the targets for digital transformation of the Union and industrial recovery.

[38] CZ, ES, IT, LV, EL, LT plans. Source: Commission Staff Working Document

[39] https://digital-strategy.ec.europa.eu/en/library/report-member-states-progress-implementing-eu-toolbox-5g-cybersecurity

Targets: 5G AP; Digital Decade; Cybersecurity Toolbox	Performance/status	Bottlenecks identified	Solution/recommendation
			A specific NIS report[40] on open RAN architecture was published in May 2022 and is the subject of implementation discussions with Member States.

The table below represents the most recent data[41,42,43] on the number of base stations per Member State and band type. When it is reported "n/a" it means that no recent updated numbers are available. Please, note that the Annex II features the general number of 5G base stations per country while this section only reports recent updates on the numbers.

Table 2: Number of base stations per Member State and band type

Indicator	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LV	LU	MT	NL	PL	PT	RO	SE	SI	SK
Number of operating 5G base stations	4,287	2,266.5	3,628	979	8,550	79,061	8,553	n/a	3,187	18,844	9,000	39,502	3,533	2,169	3,098	53,863	1,610	449	887	440	12,858	23,943	4,634	1,276	4,012	906 + 12[44]	2,470
700 MHz band	917	688	0	570	1,803	16,537	6,819	n/a	483	13,790		14,826	1,963	883	107	8,573	1,317	132	0	0	n/a	15	2,622	0	2,157	375	62

[40] Cybersecurity of Open Radio Access Networks | Shaping Europe's digital future (europa.eu)

[41] The data for Austria, Bulgaria, Denmark, Estonia, Croatia, Italy, Malta, Poland, Slovenia, Slovakia and Sweden was based on the latest available data. The data for Belgium, Cyprus, Czechia, Germany, Greece, Hungary, Latvia, Lithuania, the Netherlands and Romania was taken from the end of February 2023. The data for Luxembourg was taken from the end of December 2022. The data for Spain, Finland, France, Ireland, and Portugal was taken from the end of August 2022. The figures are indicative and do not engage responsibility of the 5G Observatory nor any other parties.

[42] Please note that when there are empty cells, it means it was not possible to gather the data per band type but only as a total number of base stations.

[43] Please note that the calculated total of the 5G base stations may differ from the summing of the indicators for each considered band. That is because both 700 MHz and 3.5 GHz can be used in one 5G base station. Consequently, summing these indicators, including the use of DSS, might give inaccurate results.

[44] In 2300 MHz band

Indicator	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LV	LU	MT	NL	PL	PT	RO	SE	SI	SK
3.4-3.8 GHz band	4,015	834.5	2,735	108	1,289	14,272	2,580	n/a	257	4,619		14,457	907	697	1,088	15,444	155	352	164	102	0	26	1,811	437	2,515	501	823
in 4G spectrum bands (using dynamic spectrum sharing, DSS)	462	1,024	1,499	63	5,458	48,252		n/a	n/a	11,788		10,219	663	589	1,903	29,846	138	15	723	338	n/a	23,902	201	839		30	1,585

The graph below presents an analysis of the data on 5G base stations previously presented. It shows the prevalence of 5G base stations as a percentage of existing 4G base stations in each Member State. Since most Member States have achieved nearly 100% population coverage with 4G, the number of 4G base stations already deployed can be considered as a proxy for the amount of 5G base stations that might be needed to achieve total population coverage. This information provides an indication of the progress made in the rollout of 5G networks in each country. However, it should be noted that this is an indicative measure and should not be considered a definitive indicator of 5G rollout.

4 5G perspectives: Commentary and observations on the need for further public initiatives

4.1 How does direct to handset connectivity from the sky fit 5G in the European Union?

In this editorial we focus on the recent trend in provision of mobile connectivity 'from the skies' via satellite. Startups and well-established satellite companies have been developing solutions and launching either Low Earth Orbit (LEO) satellites[45] or High Altitude Platforms[46] (HAPs) to connect directly to users' mobile handsets.

Some of these companies are proposing to use mobile operator's existing spectrum (e.g., US-based companies AST SpaceMobile and Lynk) which means there is no need for subscribers to upgrade or change their handset. Others (e.g., US-based companies Globalstar/Apple and Iridium/Qualcomm) are offering basic connectivity to users from incumbent satellite operators using existing satellite spectrum but which need some additional frequenc(ies) in handsets.

The growing number and variety of different solutions and approaches to providing connectivity from the sky indicates the level of market interest for addressing unserved or underserved areas, regardless of the type of service. The majority of the solutions will provide, or are already providing, basic low data rate, emergency location services or simple messaging. However, there are others (e.g., US based Omnispace) keen to offer mobile broadband everywhere including the use of 5G technology.

These solutions provide coverage to very wide geographical areas (over 100's of kilometres), however in Europe, where urban coverage from mobile operators is already well served, these solutions could potentially serve remote and rural areas with 5G coverage. It is not yet clear from the proposed deployments how soon 5G technology will be available in these areas because the initial deployments only support messaging and basic voice services.

There are some technical challenges to overcome before these firms can deliver 5G broadband-like services to users' existing mobile handsets. For instance, Lynk and AST SpaceMobile are aiming to replicate base stations in space which means there are very long paths (~550km) between a handset and the satellite. Traditionally, handsets require strong signals to support high megabit and gigabit data rates, thus should be close (1-2 km) to the base station. This implies high throughput services between normal handsets (with small integrated antennas suited to terrestrial environments) and satellites will be somewhat challenging to overcome due to these long distances.

The main benefits to consumers and businesses from utilising sky-based infrastructure is the provision of wider area coverage of difficult to reach spots and use of existing handsets. This in turn could at least help address limited or no connectivity in rural areas in the short term with the possibility of providing 5G like services in future.

In terms of EU policy and impact to wider availability and use of 5G across the EU, it will be important to understand the challenges and complexities related to providing 5G from the sky, so that administrations can make informed decisions on adoption. In Europe, there are geographic limitations and many borders, so trying to avoid causing interference in those countries not willing to permit the use of the satellite direct to handset systems that wish to use the mobile bands, could be difficult.

[45] LEOs are deployed in low earth orbit at around 500 to 600km above the earth's surface

[46] HAPs are unmanned flying vehicles usually travelling in the stratosphere around 20 – 25 km above the earth's surface

4.1.1 What are the merits of connectivity from the sky for the EU?

The merits of a satellite-based 5G solution are yet to be determined for the EU. The goal as proposed by the satellite operators building these networks, is to provide universal coverage with a focus on remote yet populated areas rather than capacity in urban areas, at this early stage of development. For example, these solutions can provide extensive coverage for hundreds of rural communities with no/little cellular coverage but also for a number of practical and critical services, including emergency services in areas where coverage doesn't already exist but also provide essential connectivity during power cuts to support incidents and disasters.

There are some indications that these services will be deployed in European countries. In Switzerland (albeit not in the EU), mobile operator Salt has already announced plans to supplement its mobile coverage in the country using Starlink's LEO network. Salt says it expects a commercial launch of the service by 2024 to support SMS, with plans to expand this to support voice and data in 2025.

However, today there is very good 4G coverage in the majority of EU Member States and, as shown by the 5G Observatory, there is continued coverage expansion of 5G networks across all of them. It is possible that by the time these direct to handset satellite services are launched and available in the EU, 5G coverage will be much more widely deployed in Member States, meaning such a solution would be unnecessary.

Furthermore, the costs for building and launching satellites are very high. For example, Starlink, which is a new LEO constellation launched by Space X has so far spent $600 million[47] (€545 million) on launching 2000 satellites. The return on such an investment, however, is expected to be quite short (two years) for Starlink, based on its current customer base (250,000). The companies involved (presented later in the document) are investing significantly. For example, AST SpaceMobile has so far raised $358 million[48] (€325 million) in funding for development, build and launch of the constellations that will provide global coverage with the aim for revenue coming from partner companies (mobile operators) and subscribers. Likewise, Apple invested $450 million[49] (€409 million) in the infrastructure needed to support its Emergency SOS via satellite feature for the iPhone 14.

The whole direct to handset from the sky model might be challenging to solve in Europe, especially with the likes of Lynk and AST Space Mobile utilising mobile operator frequencies because of the current regulatory uncertainties. One particular legal uncertainty is whether the satellite operators are legally permitted to transmit in mobile frequencies from space, as they are essentially terrestrial frequencies i.e. not permitted to be used from space as specified in the Radio Regulations[50]. This will be something regulators, satellite incumbents and other mobile operators will need to start examining before allowing the services to commence, potentially causing delays to uptake. Furthermore, the systems are yet to be proved particularly if there is a risk of causing interference across multiple borders in Europe. However, one of the startup satellite companies, Lynk (see below for more details), says it can operate without interference, but this remains yet to be proved. Nevertheless, the solution has the potential to provide coverage where it is difficult and more expensive to serve, such as the remote mountainous regions and large rural areas which could be useful over the long term.

The driver for such systems appears to be market-led with the satellite operators offering to provide mobile operators potentially more cost-effective alternative for delivering connectivity. Therefore, the overall viability will be proved on the basis that this approach will actually deliver more extensive and robust wide area coverage (with more connectivity in more areas) at a much lower cost to existing

[47] Starlink Hits 250,000 Customers, Elon Musk Hints: SpaceX Booking Over $300 Million/Year, Forbes Feb 2022, https://www.forbes.com/sites/johnkoetsier/2022/02/14/starlink-hits-250000-customers-elon-musk-hints-spacex-booking-over-300-millionyear/?sh=10283f807063

[48] Crunchbase web site sear for AST SpaceMobile, accessed April 2023 https://www.crunchbase.com/organization/ast-spacemobile/company_financials

[49] https://www.apple.com/newsroom/2022/11/emergency-sos-via-satellite-made-possible-by-450m-apple-investment/

[50] The Radio Regulations are treaty bound regulations which all countries must adhere to

terrestrial approaches. In Europe, the satellite solutions would need to offer more cost-effective services for mobile operators compared to utilizing conventional terrestrial infrastructure to enhance coverage.

4.1.2 Industry players adopting direct to handset connectivity from a satellite

There are several industry players including start-ups and established companies that are adopting different approaches to handset connectivity from satellite constellation. For example, start-up companies, such as Lynk[51] and AST SpaceMobile[52] plan to connect their satellites by re-using terrestrial spectrum already licenced to MNOs, others such as Omnispace[53], Iridium[54] and Globalstar[55] either building new 5G-based platforms or using their existing satellite infrastructure to provide specific mobile services.

The table below summarises the key attributes of direct to phone LEO satellite systems under development or already in service today. It shows each of the companies introduced and what partner is being used, if any, the type of service provided, technology supported (e.g., 5G), state of maturity of the system, type of satellite orbit being used, number of satellites in operation, the spectrum bands used to connect to handsets, if they are re-using existing terrestrial spectrum and if an MNO partnership is required. The subsequent sections elaborate more on the various players, distinguishing between established operators and start-ups.

Summary table of satellite direct to handset companies

Satellite company	Globalstar (established, US)	AST SpaceMobile (start-up, US)	Lynk (start-up, US)	Omnispace[56] (established, US)	Iridium (established, US)	Starlink (start-up, US)
Telco partner	Apple	Various MNOs including Vodafone & AT&T	Various MNOs	n/a	Qualcomm	T-Mobile
Type of service	Emergency messaging use only	Broadband	SMS with plans to expand to voice and data in future	Voice and data	SMS with possible support for other messaging apps	SMS and "select messaging apps"

[51] https://lynk.world/

[52] https://ast-science.com/

[53] https://omnispace.com/

[54] https://www.iridium.com/

[55] https://www.globalstar.com/en-gb/

[56] Omnispace holds 2 GHz licences globally in countries such as South Africa and Mexico

Technology supported	Satellite communications technology[57]	3GPP[58] based terrestrial 4G and 5G	3GPP based terrestrial 2G and 4G (5G in future)	3GPP Terrestrial 5G	Satellite communications-technology	Existing terrestrial 4G
Maturity	Available in France, Germany, Ireland, UK and US	Testing with MNOs to begin Q1 2023	Plans to launch commercial service in April 2023	Commercial service expected to start in 2025	Commercial services expected in H2 2023	Testing to begin H2 2023
Number of satellites in operation which support Direct to Device service	24	1	7	2	66	0
Spectrum bands used to connect to handsets	S-band (2.4 GHz)	Low band spectrum (exact frequencies unknown)	617—960 MHz and 663—915 MHz	1980-2010 MHz (Uplink)/ 2170-2200 MHz (downlink)[59]	L-band (1616 - 1626.5 MHz)	1800 MHz
MNO partnership required?	No	Yes	Yes	Maybe	Maybe	Yes

Established satellite operators' LEO solutions

Globalstar (US) and Apple (US)

[57] Satellite communications technology means it does not use 4G or 5G technologies typically available in handsets but instead use other standard satellite communications methods for multiplexing, modulating and coding the signals.

[58] 3GPP is the Third Generation Partnership Project the organisation responsible for developing standard cellular technologies such as 5G

[59] For example, Omnispace owns spectrum licences in the S band in the US and Canada: https://ligado.com/press/omnispace-ligado-networks-join-forces-create-largest-portfolio-licensed-satellite-spectrum-global-direct-device-voice-text-data-connectivity/

Apple has developed a solution in its latest iPhone 14[60] enabling connectivity to the emergency services through Globalstar's satellite network. Apple has embedded a chip that operates on Globalstar's spectrum and once enabled can connect to the satellite network providing positioning information to the relevant emergency services. The service is quite limited due the high latency and narrow channel bandwidths but it is sufficient to provide the necessary emergency capabilities.

The novelty lies in the integration of a non-mobile band spectrum (it uses Globalstar's L-band spectrum) embedded into a smartphone and enabling connectivity to a satellite without significant changes to handset design or usage. This service will use GlobalStar's existing Mobile Satellite Spectrum (MSS) (see details in the table below).

Iridium (US), Qualcomm (US) and Alphabet (US)

Iridium is a global satellite connectivity provider for worldwide voice and data communication from handheld satellite phones, satellite messenger communication devices and other two-way devices. Together with US chip manufacturer Qualcomm, Iridium has enabled a satellite messaging and emergency services feature in smartphones, in a similar approach to Apple and Globalstar. This recently launched service (Jan '23) will be embedded into Alphabet's Android-based smartphones with commercial services becoming available later in 2023. Iridium's existing L-band holdings will be used for this service.

Start-up companies using LEO satellites

Starlink (Space X)[61] (US) [62]

Space X plans to use its next generation of Starlink's LEO satellites called Gen2 to provide cellular services to T-Mobile customers in the United States. The satellites will use T-Mobile's existing 1850 MHz spectrum to connect directly to subscribers existing handsets, providing basic messaging applications. The service will be called "Coverage Above and Beyond"[63] and is due to begin testing some time in 2023. The collaboration aims to address large areas of no cellular coverage across the US initially for messaging services.

AST SpaceMobile

AST SpaceMobile is a relatively new company founded in 2017 in the US. The company is currently developing small LEO satellites to connect directly to subscriber's handsets using spectrum already owned by mobile operators. Its business plan is to establish partnerships, such as the one already made with Vodafone[64] (and is an investor along with Japanese mobile operator Rakuten Mobile[65]), to provide very widespread connectivity to serve both areas of no coverage but also currently poorly served areas. The goal of AST SpaceMobile is to provide mobile broadband regardless of where you live or work in the world. The company is building its first satellites and looking to launch its first five commercial satellites in late 2023.

Lynk

Lynk is a US based start-up company, using a model similar to AST SpaceMobile, developing LEO satellites to connect to subscribers' existing smartphones using mobile operators' technology (2G and 4G) and spectrum. Its initial service offering will be messaging but it plans to expand into voice and data

[60] https://www.apple.com/uk/newsroom/2022/12/emergency-sos-via-satellite-available-in-france-germany-ireland-and-the-uk/

[61] https://www.starlink.com/

[62] https://www.t-mobile.com/

[63] https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex

[64] https://www.vodafone.com/news/inclusion/rakuten-and-vodafone-invest-in-ast-and-sciences-space-venture

[65] https://network.mobile.rakuten.co.jp/

services. Lynk deployed a test satellite in December 2022 with an experimental payload that can transmit a 5G radio signal. An article on the UK 5G web site said "*This test will demonstrate the ability to send a 5G signal from space to standard mobile devices on Earth*"[66].

It has already launched trial satellites into space operating GSM and LTE technologies, meanwhile AST SpaceMobile is still developing its satellite constellation. Furthermore, Lynk has secured a licence issued by the FCC[67] in the US and commenced its first commercial satellite direct to phone service[68].

Omnispace

Omnispace was founded in the US in 2012 and provides satellite connectivity around the world to a range of private and public sector customers. It now plans to build a satellite-based mobile network using its Mobile Satellite Service (MSS) spectrum in the 2 GHz range to provide connectivity to mobile users on earth. It also plans to integrate its system with ground based 5G networks. There is quite some work to do for Omnispace particularly around development of the Non-Terrestrial Networks (NTN)[69] features being adopted into the 3GPP standards, so that new devices can connect to its network. The company holds spectrum licences in the 2 GHz band (see table below for more details) in countries such as US, Mexico and South Africa where it plans to initially launch its service. This is a slightly different approach to the other examples as it not only plans to use dedicated satellite spectrum but also to deliver broadband type 5G services.

4.1.3 Other direct to handset connectivity

Companies using High Altitude Platforms (HAPS)

There are a number of companies that have been developing HAPs to provide terrestrial connectivity and this is potentially more cost effective than satellites and promises better performance (e.g. latency). Companies such as the already established company Airbus Zephyr[70] based in France, Japanese based start-up HAPSMobile[71] and UK based start-up Stratospheric Platforms[72] to name a few. The use of HAPs adds a layer of complexity as the vehicles do not orbit the Earth like satellites, but are unmanned autonomous flying vehicles that circumnavigate the earth at altitudes of around 20km and powered by a mix of solar and batteries. However, the approach and recent developments suggest the technology could offer reliable and high speed connectivity including 5G. Stratospheric Platforms call their system a 'mast in the sky' for operators that would be interested in being able to provide coverage to wide areas maintaining high connectivity speeds and low latency.

Current work on satellite developments in the EU: IRIS²

The European Commission has allocated €2.4 billion in the Infrastructure for Resilience, Interconnectivity and Security by Satellite (IRIS²) system,[73] which aims to build and operate an EU satellite constellation to provide "sovereign, autonomous and secured connectivity infrastructure". Its objective is to provide

[66] https://uk5g.org/updates/read-articles/spacex-competitor-lynk-testing-5g-cell-phone-service-from-space/

[67] https://lynk.world/news/lynk-to-launch-worlds-first-cellular-5g-from-space-payload/

[68] https://urgentcomm.com/2023/01/14/lynk-announces-deployments-plans-for-spring-satellite-direct-to-phone-commercial-service/

[69] Non-Terrestrial Networks (NTN) refer to communication networks that utilize satellites, high-altitude platforms, or other non-terrestrial systems to provide connectivity and communication services (e.g. voice and data). These networks are particularly useful in areas where traditional terrestrial networks may not be available or practical, such as in remote locations, during disasters or emergencies, or in situations where infrastructure is damaged

[70] https://www.airbus.com/en/products-services/defence/uas/uas-solutions/zephyr

[71] https://www.hapsmobile.com/en/

[72] https://www.stratosphericplatforms.com/

[73] https://defence-industry-space.ec.europa.eu/eu-space-policy/eu-space-programme/iriss_en

secure satellite connectivity to government users and businesses to support critical applications and critically not rely on third-country infrastructure.

The system will be built complementing existing satellite capabilities and know-how utilising multi-orbit constellations and as such creating synergies with the Galileo and Copernicus constellations. Although primarily focused on government services, it plans to enable connectivity to unserved areas of Europe, adopting the most sophisticated technology and taking a lead in aspects such as quantum encryption[74].

IRIS^2 will provide Europe with an independent and autonomous satellite capability, also involving EU new space actors. However, the project in its current form is not targeting direct-to-device connectivity and this type of service is currently not included in the portfolio.

4.1.4 Summary

Direct to handset connectivity from satellite or HAP infrastructure is still in the early stages of development and roll out. The solutions are highly innovative but at present cannot deliver benefits to specific EU policy goals such as providing 5G to all populated areas. It is likely to be some years away before it can be more realistically assessed to what extent 5G from satellites direct to handsets could help to meet the EU's Digital Decade targets. Further efforts are needed in addressing some of the regulatory uncertainties and technical aspects, notably the services using MNO spectrum, which could enable deployments in different Member State countries but will require assessment of the impact of interference and determine the legality of transmitting in mobile spectrum from space. It remains uncertain when these services will become commercially available in Europe and to what extent they help deliver the policy goals. These solutions are an encouraging innovation but to overcome the technical challenges and regulatory uncertainties may mean that 5G-like commercial satellite to phone services will not be available in Europe until late in the decade.

Furthermore, it is not clear the extent to which the European Commission and other European institutions should be involved in supporting, promoting or protecting users from the deployment of satellite/HAP direct to handset systems, unless there is a regulatory challenge and therefore EU legislation would be required to use satellite or HAP to connect to users' handsets. It could be worth exploring the issues around the use of terrestrial mobile operator (MNO) spectrum from satellites. For example, if mobile operators in certain Member States want to introduce a satellite direct to handset device and a neighbouring country could be affected by harmful interference, then there could be merit in exploring (by CEPT for example) the prevention of potential interference caused by these satellite deployments.

Satellite direct to handset technology is still an emerging and nascent technology. However, it has already attracted significant interest from various companies and regulators. While it remains to be seen how viable satellite direct to device is, it is important for policymakers to keep an eye on its development going forward.

4.2 5G Outlook on deployment forecasting for the intermediate 2025 perspective

This chapter features a summary of existing projections for the forecasting towards 2025 5G-related targets and in some cases even later.

[74] Quantum encryption is a method of secure communication that uses the principles of quantum mechanics to ensure that messages cannot be intercepted or read by unauthorised parties. This is achieved using Quantum Key Distribution (QKD), which is a method of generating and distributing encryption keys.

4.2.1 Ericsson, Mobility Report[75], 2022. Scope: Global

Methodological framework/approach

The forecast on mobile subscription and network traffic is based on historical data from several sources, which are then corroborated with internal data from Ericsson. Since the forecast is scoped for a five-year interval, future developments are approximated via technological advances, market maturity, and user and macroeconomic trends.

Outcome summary

In the November 2022 update, 4G technology is reported to be still dominant in Western Europe[76], with an expected subscription penetration of 82% by the end of 2022, while 5G subscriptions experienced a strong growth moving from 32 million in 2021 to 63 million (11% subscription penetration rate) by the end of 2022. 5G uptake is expected to significantly surge from 2023 onwards. Indeed, 5G subscriptions are expected to reach almost 150 million by the end of 2023, with a subscription penetration projected to reach 88% by 2028. Differently, in Central and Eastern Europe,[77] the uptake is slower due to both the reluctance of consumers to switch to more expensive options and slower spectrum allocation processes. As of yet, 4G subscriptions still account for 75% of the market and are expected to grow up to 2025. Nevertheless, from then onwards, only 5G subscriptions are projected to experience growth.

4.2.2 GSMA, "The Mobile Economy"[78], 2023. Scope: Global

Methodological framework/approach

Representing the interests of mobile operators worldwide, the GSMA is considered an industry reference point of global mobile operator data, analysis, and forecasts, publishing annually industry reports and research. GSMA's annual state of mobile economy reports (global and regional versions) provide market intelligence (technology, socio-economic and financial datasets) through their in-house research team (i.e. proprietary models/forecasting methodology and datasets).

Outcome summary

According to the latest Mobile Economy report[79], in 2022, 5G technology comprised 11% of the market in Europe, representing an increase from the 4% figure in 2021, whereas 4G still accounts for 75% of the market. By 2030, 5G uptake is projected to grow to 87% with a reduced 4G market share of 13%. Furthermore, overall mobile subscriber penetration is expected to only marginally increase from 90% in 2022 to 92% by 2030, accompanied by a moderate rise in smartphone adoption from 81% in 2022 to 91% by 2030.

[75] Ericsson, Mobility Report, November 2022

[76] Ericsson, Mobility Report, November 2022. According to the Ericsson Mobility Visualizer, Western Europe comprises of Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Iceland, Italy, Luxembourg, Malta, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

[77] Ericsson, Mobility Report, November 2022. According to the Ericsson Mobility Visualizer, Central and Eastern Europe comprises of Albania, Armenia, Azerbaijan, Belarus, Bulgaria, Bosnia and Herzegovina, Croatia, Czechia, Estonia, Georgia, Hungary, Kosovo, Kyrgyzstan, Latvia, Lithuania, Moldova, Montenegro, North Macedonia, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

[78] GSMA, The Mobile Economy, 2023

[79] Ibid.

Annex I: Latest developments per country

A1.1 Latest commercial developments

Since January 2022, commercial 5G is now available in all 27 Member States[80]. The full overview of commercial launches per operators offering 5G services across EU-27, detailing their frequency usage and where applicable, highlighting use of DSS technology, network configuration i.e. 5G NSA vs. SA implementations and announced coverage targets is available on the European 5G Observatory website. This information is updated regularly. Below is a summary of the main changes compared to the previous edition of the report:

- Austria:
  - Austrian telco Three announced the launch of its 5G Standalone network, named 5G+, available for 1.3 million households and companies across the country. In addition, the operator specified it will use network slicing to provide 5G home broadband.
- Denmark:
  - Hi3G Denmark (3) announced of having deployed a total of 1,000 5G mobile sites in the 3500MHz C-band, bringing its 5G population footprint to 70%. The company is aiming to provide 5G services with download speeds of 1Gbps to 100% of the population by the end of 2023.
- Germany:
  - Telefónica Deutschland, providing services under the brand name O2, announced on November 2022 that its 5G network now reaches 75% of the population via more than 18,000 antennas. The operator is focusing on the deployment of 5G in the 3.5GHz band in densely populated regions, while in more rural areas it is using 700MHz frequencies. By the end of 2025 the operator is aiming to cover the entire population with 5G.
  - In January 2023, Vodafone Germany announced plans to roll out 5G services at more than 2,700 additional locations in the first six months of this year. The firm's 5G network currently covers 80% of the population and is active at 12,000 locations via over 36,000 antennas. By mid-2023 a further 8,000 antennas will be added to the network.
  - In January 2023, Telekom Deutschland, the domestic fixed and mobile unit of Deutsche Telekom (DT), said it expanded the capacity and coverage of its mobile network at 3,096 locations nationwide since October last year. The firm rolled out 618 new sites using 4G and 5G frequencies and increased capacity at 2,478 existing LTE and 5G network sites. The carrier reported that 94% of the population are now covered by 5G services, with around 8,000 antennas transmitting in the 3.7GHz band. In addition, the 5G coverage is expected to reach 99% of homes by 2025.
  - Deutsche Telekom stated its 5G network currently reaches 95% of the country's population, with the aim of reaching 99% of the population by 2025. The carrier also highlighted that more than 80,000 antennas are currently transmitting 5G, of which around 8,200 antennas are already providing the technology via the 3.6 GHz band.

[80] The first commercial 5G service has been launched in Lithuania in January 2022 at the time of this report publication, completing EU27 deployment in 2022
Source: Telia

- Latvia:
    - Tele 2 Latvia announced the deployment if 25 new base stations since the beginning of 2023, extending coverage to Bervirtsava, Bene, Kapsede, Kronauce, Ķekava, Launkalne, Madon, Namiķi Rujien and Vilce. Additional 5G cell sites have been deployed in markets such as Riga, Daugavpils, Jelgava, Salacgriva, Saldus, Sigulda and Tukum, boosting coverage in those locations. In total, 5G services are now available in 64 populated areas across Latvia.
- Lithuania:
    - In February 2023, after the launch of its 5G services for mobile customers with compatible handsets and devices, Bite Lithuania said it plans to increase its coverage to 60% of the population by Spring 2023.
    - Telia Lietuva announced the expansion of its 5G network to the cities of Utena, Ignalina and Moletai, all located in the east of the country. Last year, the firm rolled out more than 1,200 5G base stations operating in the 700MHz and 3.5GHz bands and covering 85% of the population. Telia planned to achieve 99% coverage by the end of the summer 2023.
- Slovenia:
    - In January 2023, A1 Slovenia confirmed that its 5G mobile network reached 66% of the country's population, with plans to boost it to 98% by 2025.
- Spain:
    - In February 2023, Orange España announced the commercial launch of its 5G Standalone (SA) network, with the cities of Madrid, Barcelona, Valencia and Seville the first to enjoy its '5G+' offering. The company stated that the coverage in the four cities will exceed 90% of their respective populations, and that other cities/towns will be added to its 5G+ footprint during 2023.
    - Vodafone Spain announced plans to expand its 5G network to reach 65% of the population on the 700 MHz and 3.7 GHz bands to a total of 2,000 cities, towns and smaller localities by the end of 2023. The deployment means customers will be able to access 5G SA networks in municipalities spread throughout all of Spain's autonomous communities, including 238 digital divide localities with less than 1,000 inhabitants.

A1.2 Population coverage

As already introduced in previous editions of this report, according to data collected by the Commission in 2020, the baseline for 5G coverage in the EU was 14% of populated areas at the time when the Digital Decade announcement was first made in March 2020 (with the breakdown per member state).

Following a change of methodology compared to previous reports, currently all reports use data collected by the Commission for the DESI when available, ensuring consistency going forward. When possible, the data are also integrated with information based on operators' announcements.

The estimated coverage figure for EU27 (**81%**) in the table below is based on the sum of total number of people covered in each country (computed based on the percentage of population covered, obtained from operator/regulator reports where data was available) divided by the total EU27 population[81,82].

[81] Population statistics for 2022 accessed via Eurostat

[82] This figure can be contextualised based on the latest population coverage figure estimated by ETNO, although not directly comparable, the latter one also covering non-EU countries, e.g., UK, Switzerland, Norway, Iceland and Western Balkans (73% by the end of 2022). Source: ETNO State of Digital Communications 2023

Table 3: Population coverage

Country	Population coverage (March 2023 figures)	People covered (March 2023 figures)	Note (March 2023 figures)
Austria	91.7%	8,191,700	EC
Belgium	29.6%	3,426,858	EC
Bulgaria	67.2%	4,649,407	EC
Croatia	82.5%	3,329,449	EC
Cyprus	100.0%	896,005	EC
Czechia	82.6%	8,839,460	EC
Denmark	97.8%	5,713,996	EC
Estonia	43.3%	575,973	EC
Finland	94.7%	5,238,231	EC
France	88.8%	59,908,390	EC
Germany	93.2%	77,489,249	EC
Greece	85.7%	9,152,325	EC
Hungary	57.9%	5,634,074	EC
Ireland	83.9%	4,201,969	EC
Italy	99.7%	59,091,464	EC
Latvia	42.0%	795,187	EC
Lithuania	90.1%	2,517,677	EC
Luxembourg	93.2%	591,632	EC
Malta	100.0%	516,100	EC
Netherlands	100.0%	17,473,449	EC
Poland	63.4%	24,002,992	EC
Portugal	70.1%	7,216,870	EC
Romania	26.8%	5,132,939	EC
Slovakia	55.3%	3,021,669	EC
Slovenia	63.9%	1,348,045	EC
Spain	82.3%	39,003,604	EC
Sweden	20.5%	2,123,803	EC
EU 27	**81%**	**447,007,596**	

A1.3 5G sector comparison between EU and other world regions

Although the 5G Observatory primarily tracks developments in EU countries, it also follows significant international developments in the 5G sector. It is important to note that most of the figures collected on the number of 5G base stations are provided by governments, but in some cases such as the US and Japan, they are based on market research estimates. It is possible that some market-based estimates are not entirely up to date or accurate. However, they allow for an indicative overview of the state of 5G deployment internationally.

Globally, South Korea is the clear leader in 5G deployment. According to the country's Communication Agency, it now has 215,000 5G base stations[83]. If the country's population is taken into account, this

[83] Source: Korea Communications Agency https://en.yna.co.kr/view/AEN20210927001500320

equals to 415 5G base stations per 100,000 inhabitants. Following South Korea's lead is China, which has now deployed 2,290,000 base stations. Despite China's significant population size, this works out to 163 5G base stations per 100,000 inhabitants. The EU ranks just ahead of the US, with 296,091 base stations. This works out to 59 5G base stations per 100,000 inhabitants.

In terms of assigned 5G spectrum, the 3.6 GHz band has proved to be the most used 5G band globally. All four regions in this comparison have assigned this valuable mid-band spectrum. The 28 GHz band is also well adopted, and it has been assigned in South Korea, Japan, and the US. In the EU, the situation is more complex as each country assigns their own spectrum. However, most countries have assigned at least the 3.6 GHz band for 5G deployment, while only 10 EU MS have assigned the 26 GHz band, for which the demand has been lowest so far. See the spectrum assignment chart in 2.1.

A1.4 5G Spectrum comparison between EU and other world regions

In this section we compare 5G spectrum use by first introducing the "pioneer bands" identified at EU level for the initial launch of 5G service, providing an overview of current spectrum assignment trends in the EU and contextualising these by introducing international developments.

Since the last 5G Observatory Report, published in October 2022[84], several spectrum auctions have been completed, further increasing the number of pioneer bands assigned in the European Union. On average 68% of pioneer bands have now been assigned in European Member States.

Estonia has completed its 700 MHz band auction, while Spain awarded the 26 GHz band. Romania awarded the 700 MHz, 1500 MHz and 2.6 GHz bands and Ireland has completed its auction of the 700 MHz, 2.1 GHz, 2.3 GHz, and 2.6 GHz bands. Finally, Croatia awarded spectrum in the 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz, and 2.6 GHz bands. These awards showcase the importance of low-band spectrum in the sub 1 GHz range such as the 700 MHz band for wide area and indoor 5G coverage.

Overview of pioneer bands

In 2016, with the release of the 5G Action Plan, the EU Commission proposed establishing a list of pioneer spectrum bands for the initial launch of 5G services. It proposed bands in three categories: below 1 GHz, between 1 GHz and 6 GHz and above 6 GHz.

The 5G pioneer bands identified at EU level (Article 54 of the European Electronic Communications Code (EECC)) are as follows:

- 700 MHz (703-733 MHz and 758-788 MHz)
- 3.6 GHz (3400-3800 MHz)
- 26 GHz (at least 1000 MHz within 24250-27500 MHz)

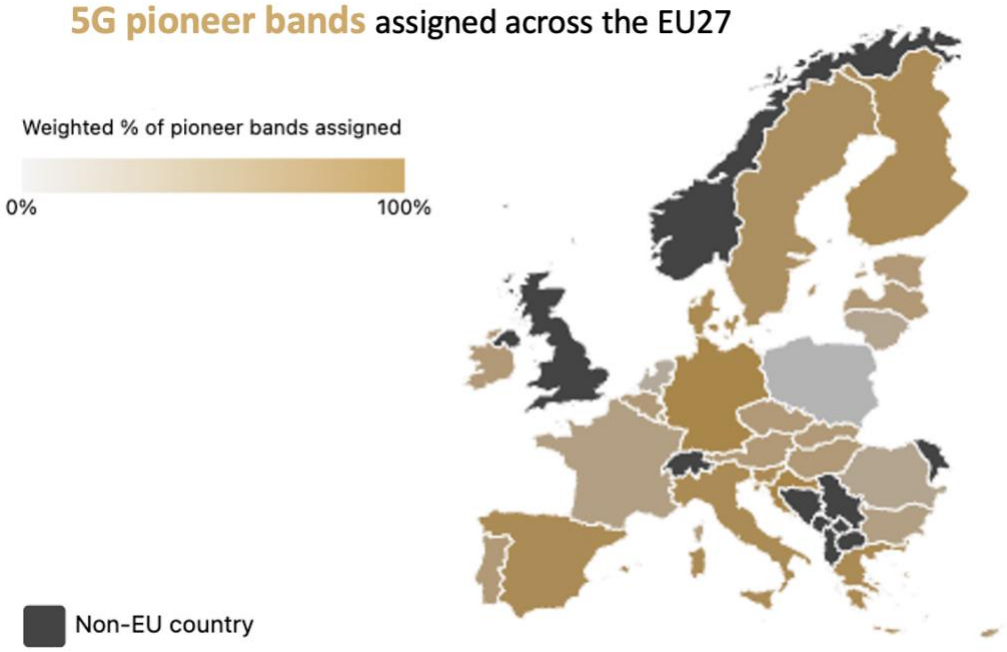
In the years following the release of the 5G Action Plan and the adoption of the EECC, the Commission successfully harmonised the frequencies in these bands. The 26 GHz band was the final frequency band to be harmonised. This occurred in May 2019 with a Commission Implementing Decision (EU) 2019/784[85]. Although the technical conditions for these three bands have been harmonised at EU level, not all Member States have assigned the pioneer bands, despite the deadlines set out in the EECC stating

[84] https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf

[85] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019D0784

that they should assign 700 MHz, 3.6 GHz, and 26 GHz by the 31 December 2020, provided that there is market demand for the latter and there are no significant constrains to clearing the bands.

EU27 trends



Source: Spectrum assignment data is based on the results of a European Commission survey of all 27 EU countries.

Pioneer bands assigned

The table below outlines how much spectrum each Member State has assigned in the pioneer bands. According to the 700 MHz Decision[86] and related Commission Implementing Decision[87] and the EECC a country must assign 60 MHz in the 700 MHz band; 400 MHz in the 3.6 GHz band and at least 1000 MHz in the 26 GHz band to achieve 100%. The percentages displayed present how much spectrum has been assigned to operators compared to these numbers.

Amongst Member States, the 3.6 GHz band has been most widely assigned. 25 out of 27 Member States have assigned at least 50% of the targeted spectrum in this band (meaning at least 200 MHz out of 400 MHz). The second most assigned band is the 700 MHz band, where 24 out of 27 Member States have assigned at least 50% of the targeted spectrum (meaning at least 30 MHz out of 60 MHz). The least assigned band is the 26 GHz band. The 26 GHz band has only been majority-assigned in 10 Member States, meaning only 10 Member States have assigned at least 50% (500 MHz) of the targeted 1000 MHz Finally, one Member State has failed to assign any of the pioneer bands.

[86] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32017D0899

[87] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.118.01.0004.01.ENG

Table 4: Pioneer bands assigned in the EU

Country	% of band assigned		
	700 MHz	3.6 GHz	26 GHz
Total harmonised spectrum (100%)	60 MHz	400 MHz	1000 MHz
Austria	100.00%	97.50%	0.00%
Belgium	100.00%	97.50%	0.00%
Bulgaria	0.00%	75.00%	100.00%
Croatia	100.00%	100.00%	100.00%
Cyprus	100.00%	100.00%	0.00%
Czechia	100.00%	100.00%	0.00%
Denmark	100.00%	97.50%	100.00%
Estonia	100.00%	97.50%	0.00%
Finland	100.00%	97.50%	100.00%
France	100.00%	77.50%	0.00%
Germany	100.00%	100.00%	100.00%
Greece	100.00%	97.50%	100.00%
Hungary	83.33%	97.50%	0.00%
Ireland	100.00%	87.50%	0.00%
Italy	100.00%	80.00%	100.00%
Latvia	100.00%	87.50%	0.00%
Lithuania	66.67%	75.00%	0.00%
Luxembourg	100.00%	82.50%	0.00%
Malta	0.00%	75.00%	0.00%
Netherlands	100.00%	0.00%	0.00%
Poland	0.00%	0.00%	0.00%
Portugal	83.33%	100.00%	0.00%
Romania	50.00%	77.50%	0.00%
Slovakia	100.00%	100.00%	0.00%
Slovenia	100.00%	95.00%	100.00%
Spain	100.00%	95.00%	100.00%
Sweden	66.67%	100.00%	85.00%
Number of countries that have assigned at least 50% of the band	23	25	10

International trends in spectrum allocation

The three pioneer bands harmonised by the EU Commission roughly fit into the three categories of 5G frequencies often used by spectrum policy makers: mid-band, low-band, and high-band.

Although there are international discrepancies on which bands are used in each category, classifying the spectrum in this way allows for an easier international comparison of the state of 5G spectrum harmonisation and assignment. The following table provides an overview of which spectrum bands are assigned for 5G in various international markets.

Table 5: Overview of which spectrum bands are assigned for 5G in various international markets[88]

Country	Low-band (<1 GHz)	Mid-band (1 - 6 GHz)	High-band (>6 GHz)
China	700 MHz	2.6 GHz 3.6 GHz 4.9 GHz	-
South Korea	-	3.6 GHz	28 GHz
Japan	-	3.6 GHz 3.7 GHz 4 GHz 4.5 GHz	28 GHz
USA	600 MHz	2.5 GHz 3.45 - 3.55GHz 3.5 - 3.7 GHz 3.7 - 3.98 GHz	24 GHz 28 GHz 39 GHz 47 GHz
EU	700 MHz	3.6 GHz	26 GHz

Internationally, mid-band 5G spectrum has been established as the workhorse band for 5G. It has been assigned in most major markets including China, South Korea, Japan, and the US. Japan is leading with mid-band 5G assignments. The country has allocated 880 MHz of spectrum in the band for 5G services. China comes in second with 860 MHz assigned. On average, an EU Member State has 339 MHz of mid-band spectrum assigned.

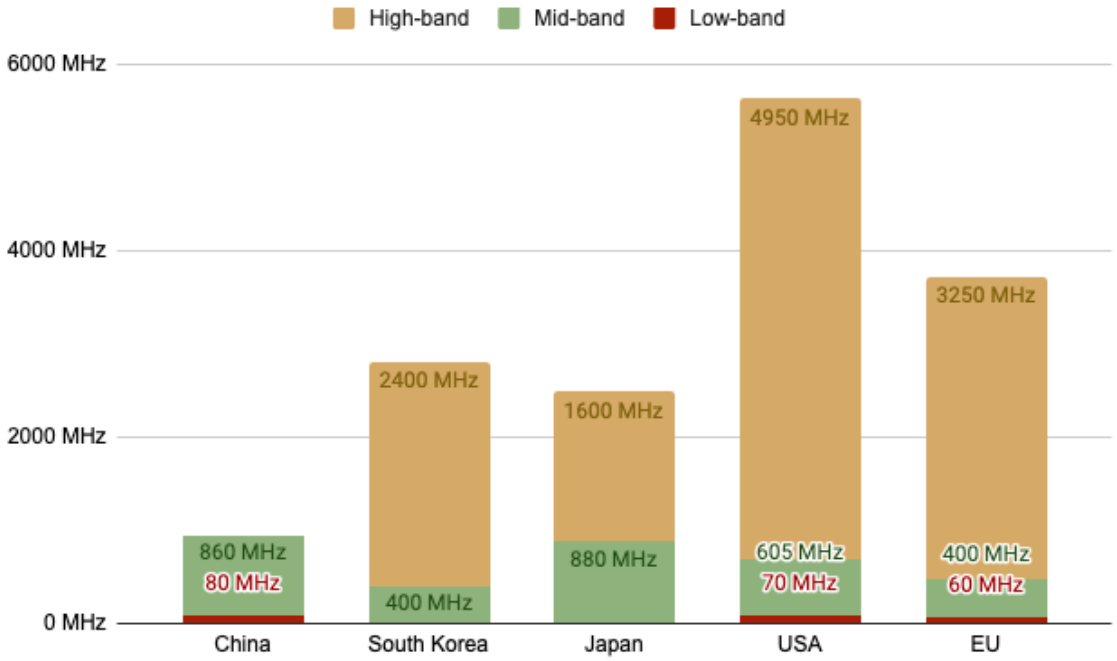
Low-band spectrum has proven to be slightly less popular, as both South Korea and Japan have yet to assign frequencies in this range. In fact, in South Korea's initial 5G auction in 2016, the 700 MHz low-band spectrum remained entirely unsold.

[88] Source: Data on international spectrum assignments is sourced from the Policy Tracker database.

A recent development in China however could indicate low-band spectrum becoming more popular. A new telecom player called China Broadcasting Network (CBN) recently struck a deal with China Mobile to begin deploying 5G using its 700 MHz spectrum. This is notable as the country previously relied entirely on mid-band spectrum for its 5G deployment.

Initially, 5G frequencies in the high bands proved to be very popular. The US led the world in making the high bands available for 5G and Japan and South Korea quickly followed. The United States leads with 4950 MHz of spectrum assigned in the high-band. However, it appears that there is less demand for this band in Europe, with only one country (Spain) assigning the band in 2022.

Figure 1: Authorised 5G spectrum in international markets[89]



[89] Note: Due to the nature of spectrum assignments in the US being regional, only the three big national operators were included: T-Mobile; AT&T and Verizon. The final spectrum amount was divided by the number of licenses to give a picture of how much spectrum is assigned in an average licensing area. For the EU, the data on spectrum assigned has been averaged across all EU27. Some individual countries may have more spectrum assigned for 5G, while some may have less or none.
Source: Data on international spectrum assignments is sourced from the Policy Tracker database.

A note on methodology:

China, South Korea, Japan

The source of data for China, South Korea and Japan is the PolicyTracker spectrum database. This is a comprehensive database of spectrum assignments.

All national spectrum licences were added up to find the total amount of spectrum that was assigned to mobile operators in each country. Only bands shown on the left side of the scoreboard were included in this. All of these bands are used to provide 5G services in their respective country.

US

In the United States, licences are usually awarded regionally, a common example being the use of PEAs (partial economic areas) of which there are 406.[90] This makes it difficult to know how much spectrum mobile operators hold on a national level, as they hold different amounts of each band in each licence area.

Because of this, we have chosen to instead use the amount of spectrum that was initially made available to mobile operators by the country's spectrum regulator, the Federal Communications Commission (FCC) at auction. This data comes directly from the FCC and the list of awards can be found the table below.

In the 2.6 GHz band spectrum licenses are held by educational institutions. These are called Educational Broadband Service (EBS) licenses. T-Mobile leases a majority of these licences and has purchased some.[91] The total number of spectrum that T-Mobile holds in these licences is unknown, however an estimate made by the FCC suggests the operator holds 155 MHz of spectrum in this band. [92] This is the estimate used in our data.

Regarding the CBRS auction, we have only counted the priority access licences (PAL) and the other spectrum made available is on an unlicensed basis.

Not all spectrum made available at these auctions will have been sold to operators. However, the amount of unsold spectrum licenses in these auctions is small. Furthermore, the amount of spectrum was cross-checked with the PolicyTracker spectrum database. This is a comprehensive database of spectrum assignments in over 100 countries.

[90] https://www.fcc.gov/oet/maps/areas
[91] https://www.lightreading.com/5g/inside-the-messy-world-of-t-mobiles-midband-5g-spectrum-licenses/d/d-id/774745
[92] https://www.fcc.gov/reports-research/reports/consolidated-communications-marketplace-reports/CMR-2020

Low-band spectrum	MHz	Source URL
600 MHz (Incentive auction)	70	https://auctiondata.fcc.gov/public/projects/1000

Mid-band spectrum	MHz	Source URL	Comments
CBRS (PAL licences)	70	https://www.fcc.gov/auction/105/factsheet	70 MHz was awarded as priority licences. However, operators may be able to use the entire CBRS range of 100 MHz in some circumstances.
3.45 - 3.55 GHz (Auction 110)	100	https://www.fcc.gov/auction/110/factsheet	
3.7 - 4.2 GHz (Auction 107) (C-band auction)	280	https://www.fcc.gov/auction/107/factsheet	
2.6 GHz (T-Mobile's holdings of education spectrum)	155	https://www.fcc.gov/reports-research/reports/consolidated-communications-marketplace-reports/CMR-2020	FCC estimate from 2020 marketplace report (p.24)
Total	605		

High-band spectrum	MHz	Source URL
28 GHz (Auction 101)	850	https://www.fcc.gov/auction/101/factsheet
24 GHz (Auction 102)	700	https://www.fcc.gov/auction/102/factsheet
37 GHz and 39 GHz (Auction 103)	2400	https://www.fcc.gov/auction/103/factsheet
47 GHz (Auction 103)	1000	https://www.fcc.gov/auction/103/factsheet
Total	4950	

European Union

Because spectrum assignments differ amongst EU Member States, the number used in the scoreboard is an average. To calculate this average, the total amount of spectrum assigned in each of the 5G pioneer bands for each country was added up and then divided by the total number of Member States.

Spectrum assignment data was retrieved from the 5G readiness indicator which is produced for the Digital Economy and Society Index (DESI).

This data represents an average but the situation in individual countries may be very different. To see a full breakdown of spectrum assignments in the EU, please refer to section A 1.4: 5G Spectrum comparison between EU and other world regions.

A1.5 5G verticals and trials

Overview

Whereas previous generations of mobile technologies primarily focused on human communication, including voice, data, and the internet, 5G has the ability to provide services for a range of industries where mobile telecoms has so far had little purchase. Because 5G features low latency and high speeds, it is well suited to enter the so-called "vertical" markets such as industrial and agricultural automation, the automotive industry, transport and healthcare. Early in the development of 5G/IMT-2020, the ITU identified 5G as a "key driver" for industrial and societal changes.

The 3GPP standardisation body released the first 5G specification in 2017 (Release 15). After the release of Release 15, focus quickly turned to optimising 5G for vertical domains in Release 16, which is informally referred to as '5G Phase 2'.

In June 2020, Release 16 was published, focussing on the verticals' needs. Enhancements were made to 5G System enablers for verticals including industrial automation, including time sensitive communication (TSC), Ultra Reliable and Low Latency Communication (URLLC) and Non-Public Networks (NPNs). Enhancements were also made to Cellular Internet of Things (CIoT) and support for 5G system Vehicle-to-Everything (V2X) communication.

Release 17, which was frozen in early 2022 included more features for 5G verticals, including a new IoT standard called NR-light and support for non-terrestrial networks (NTNs). Furthermore, more spectrum frequencies are now supported in the 52.6-71 GHz range.

5G verticals in the EU

With the announcement of the EU Digital Decade Communication, the European Commission has put emphasis on the importance of the digital transformation of business. The Communication outlined that 5G will play an important part in this transformation. It states, *"digital technologies including 5G, the Internet of Things, edge computing, Artificial Intelligence, robotics and augmented reality will be at the core of new products, new manufacturing processes and new business models based on fair sharing of data in the data economy."*

In Europe, trials of 5G verticals have been encouraged through the 5G Public Private Partnership project (5G PPP) which is funded by European Union research funding grants totalling €700m matched by €3.5bn of private investment between the period 2014-2020.

Furthermore, the 5G-PPP Vertical Engagement Task Force (VTF) has been established to coordinate and monitor activities related to working with vertical sector. The vertical sectors considered by 5G-PPP VTF are:

- Automotive
- Manufacturing
- Media
- Energy
- E-Health
- Public safety
- Smart cities

5G vertical spectrum: Is there a need for dedicated spectrum?

The licensing model (or model***s***) needed for 5G verticals is on an ongoing debate in spectrum management circles. 5G verticals can either use spectrum already assigned to mobile operators, or they can rely on dedicated spectrum licences issued by governments.

Some stakeholders argue in favour of dedicated spectrum. They say that dedicated spectrum access regimes enable innovation and competition, as they provide a new spectrum access option for industries[93]. It is also argued that dedicated spectrum better suited from some applications which have particularly demanding quality of service (QoS) requirements, such as utilities.

There are also arguments against dedicated spectrum. The mobile industry association, the GSMA, says[94] that doing may cause fragmentation. The organisation says that this could make it harder for operators to achieve contiguous blocs – which will then have a result in reduced speeds and QoS.

Despite this ongoing debate, an increasing number of countries are adopting a local licensing model that use dedicated spectrum for 5G verticals. Germany was the first country to decide to reserve the 3700-3800 MHz band for verticals. This may be because of the potential benefits for industrial companies, which account for about 20% of the country's GDP.[95]

In total 10 EU countries have proposed or implemented a local licensing model. These countries are as follows:

- Austria
- Belgium
- Croatia
- Denmark
- Finland
- France
- Germany
- Netherlands
- Poland
- Portugal
- Sweden

Although many European countries have adopted the approach of dedicating spectrum for verticals, the exact portions of spectrum used for these licences varies across Europe. This can cause issues when it comes to harmonisation efforts or standardising equipment. However, the 3.8-4.2 GHz band is emerging as a potential solution for this problem. The band has the potential to become the de-facto vertical band for Europe.

[93] https://www.rcrwireless.com/20221118/5g/americas-inventive-spirit-at-its-finest-cbrs-model-must-be-extended-says-cbrs-industry

[94] https://www.gsma.com/spectrum/resources/mobile-networks-for-verticals/

[95] https://www.statista.com/statistics/295519/germany-share-of-economic-sectors-in-gross-domestic-product/

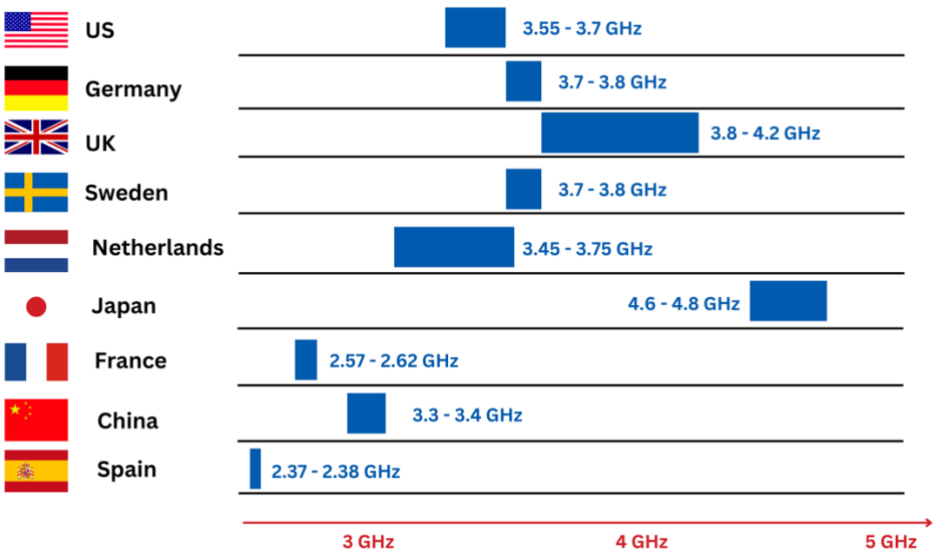


Figure 2: A graphic showing the variation of spectrum frequencies for 5G verticals in different countries (Source: Variation of original graphic from ARCEP[96])

The UK was the first European country to release[97] the band in 2019 exclusively for local private and shared networks. France has also followed in the UK's footsteps by opening up the 3.8-4.0 GHz band for 5G verticals licences.[98] Norway has also begun offering free trial licences in the 3.8-4.2 GHz range.[99] Meanwhile, the Belgian regulator BIPT is considering opening up the band. It launched a consultation on the issue in September 2022.[100]

The European Radio Spectrum Policy Group (RSPG) has previously published a consultation recommending Member States to explore the use of the 3.8 – 4.2 GHz band for 5G verticals.[101] In 2021, the European Union's Radio Spectrum Committee (RSC) mandated CEPT to develop harmonised technical conditions for the shared use of 3.8-4.2 GHz, however the work on these efforts is still ongoing within the technical body.

In Asia, the notion of 5G private networks has some traction. In Japan[102] a significant number of major companies have already acquired a spectrum licence.[103] The country's communications ministry started to issue licences for the deployment of local 5G networks in 3.7 GHz, 26 GHz and 28 GHz frequency bands as early as December 2019. In South Korea, the Ministry will offer 100 MHz in the 4.7 GHz band and 600 MHz in the 28 GHz band for campus networks at a fee of up to USD 88 per block. [104]

In China, The Ministry of Industry and Information Technology (MIIT) granted its first 5G private network licence in December 2022 to a domestic aeroplane manufacturer. The company will receive spectrum in the 5925-6125MHz and 24.750-25.15 GHz bands. The Chinese government is trying to promote industrial 5G networks which it says is key to "boosting manufacturing prowess".[105]

[96] https://www.lesnumeriques.com/pro/5g-industrielle-la-france-est-encore-loin-du-compte-n177861.html
[97] https://www.policytracker.com/ofcom-makes-3-8-4-2-ghz-available-for-private-networks/
[98] https://www.policytracker.com/france-seeks-to-expand-industrial-5g/
[99] https://www.policytracker.com/norway-offers-free-3-8-4-2-ghz-private-network-test-licences-to-businesses/
[100] https://5gobservatory.eu/belgian-regulator-considers-spectrum-for-private-5g-networks/
[101] https://www.policytracker.com/3-8-4-2-ghz-gains-momentum-after-rspg-backing/
[102] https://www.policytracker.com/japan-awards-its-first-commercial-licences-for-local-5g/
[103] https://www.policytracker.com/japan-awards-its-first-commercial-licences-for-local-5g/
[104] https://www.policytracker.com/south-korea-to-allocate-local-5g-spectrum-for-the-first-time/
[105] https://5gobservatory.eu/china-grants-first-5g-private-network-licence/

In the US, the FCC is hoping that it's three tier CBRS (Citizens Broadband Radio Service) approach will allow enterprises to deploy private 4G and 5G networks and verticals. Agricultural equipment manufacturer John Deere has already announced plans to use its CBRS spectrum to install a private 5G network in its factories.[106]

Nevertheless, internationally the vast majority of the countries have not yet reserved frequencies for enterprises. In these markets, verticals will have to rely either on unlicensed spectrum, services provided by MNOs or secondary access to mobile spectrum. Unlicensed spectrum may prove to be successful for certain private network scenarios, but mission critical applications are wary of unlicensed spectrum, which could have severe interference issues from other users.

Trends related to vertical trials

The 5G Observatory has been tracking the announcements of 5G trials in Europe and Internationally since 2018. The initial purpose of this was to monitor progress toward the 5G Action Plan. However, as commercial 5G networks have now launched in all EU-27 countries and the EU Digital Decade has realigned policy priorities the 5G Observatory will now focus on vertical trials.

5G verticals are still in the early growth phase. 3GPP Release 16, which specifically focused on 5G vertical needs was only finalised in early 2020. Work on Release 17, which will also introduce new features for 5G verticals, only recently concluded in March 2022. Some industry stakeholders have referenced this as a potential reason for the slow development of 5G verticals, particularly when compared to the rollout of commercial 5G. Furthermore, the covid-19 pandemic may have also contributed to delays.

5G verticals appear to be particularly developed in ports and has been extensively tested in several countries. Notable examples include:

- **Germany**: The Hamburg Port Authority, Deutsche Telekom and Nokia have conducted an 18-month field test at the 'smart seaport' in Hamburg, Germany. This test focussed on the integration of 5G in traffic and infrastructure control.[107]
- **Belgium**: Proximus and the Port of Antwerp have announced a 6-month trial of a private 5G network.[108]
- **Belgium**: Port of Zeebrugge and Citymesh have launched a private 5G network in the Port of Zeebrugge. In the first phase, this involved connectivity for tugboats, air pollution detectors and cameras and quay sensors.[109]
- **Estonia**: Tallinn, Telia, Ericsson and Intel have created a 5G test and exploration area in the Port of Tallinn. This trial enabled internet connectivity for commercial cruise ship passengers while in port.[110]
- **Spain**: Telefónica and APM Terminals have trialled 5G at the port of Barcelona. This test included connecting cranes, vehicles and people.[111]

[106] https://www.fiercewireless.com/private-wireless/john-deere-foresees-private-5g-at-its-factories-worldwide
[107] https://www.telekom.com/en/media/media-information/archive/port-of-hamburg-is-ready-for-5g-574536
[108] https://www.proximus.com/news/2020/20200205-Proximus-and-Port-of-Antwerp-are-preparing-for-the-port-s-digital-transformation-by-developing-a-private-5G-network-.html
[109] https://citymesh.com/en/news/port-of-zeebrugge-accelerates-innovation-by-investing-in-a-5g-network
[110] https://www.ericsson.com/en/cases/2017/5g-telia-tallink
[111] https://enterpriseiotinsights.com/20210311/channels/news/telefonica-apm-terminals-to-deploy-5g-and-c-v2x-port-of-barcelona?utm_campaign=20210311%20Enterprise%20IoT%20NewsletterThurs&utm_medium=email&utm_source=Eloqua

5G verticals in other industries appear to be in an earlier stage. Various trials are taking place in the transport and automotive sector, although these are mostly early-stage tests and demonstrations. Examples include:

- **Germany**: Nokia and Deutsche Bahn are testing 5G for autonomous trains and rail operations.[112]
- **Norway**: Ericsson, Telia and the Norwegian University of Science and Technology have carried out a demonstration of a 5G autonomous ferry.[113]
- **Germany:** Sony and Vodafone have conducted remote 5G car trials in Aldenhoven, Germany.[114]
- **Germany**: Volkswagen and Nokia trial private 5G network at manufacturing plant.[115]
- **Finland**: Nokia to build private 5G network in Finnish goldmine.[116]
- **Germany**: Vodafone Germany launches standalone 5G network at a University Hospital in Kiel.[117]

From the verticals the 5G Observatory has been tracking, most appear to be occurring within private networks. See the private network subchapter for more on this, including country by country examples of private networks and their associated vertical trials.

A1.6 5G private local networks

Deployment of 5G private local networks is growing across EU countries. These networks are not typically utilised by consumers (for mobile voice and data services) but use network elements and resources to provide dedicated secure services to private enterprises such as factories, plants, large campuses, ports and airports.

The Observatory has produced a non-exhaustive list of private 5G networks which is based on research of publicly available information. The Observatory team endeavour to obtain as much information on published private 5G network deployments as possible.

An overview of 5G private networks featuring a searchable table of major private network projects in the EU can be found here.

A1.7 Supply market trends (vendors): Major procurements, Open RAN, multivendor deployments

There have been a number of major procurements by large operators across EU countries in recent months. The table of which vendors have won contracts for the provision of 5G network builds across Member State countries is available to search and extract on the 5G Observatory website.

A1.8 EMF developments related to 5G policy goals

An EMF explainer is available online here.

Key highlights:

- Application of EMF limits remains inconsistent across Member States

[112] https://www.nokia.com/about-us/news/releases/2019/12/12/nokia-wins-deutsche-bahn-tender-to-deliver-and-test-the-worlds-first-5g-based-network-for-automated-rail-operation/
[113] https://www.teliacompany.com/en/news/news-articles/2019/telia-tests-5g-powered-autonomous-vessels/
[114] https://5gobservatory.eu/sony-and-vodafone-conduct-remote-5g-car-trial-in-germany/
[115] https://5gobservatory.eu/volkswagen-and-nokia-trial-private-5g-network-at-manufacturing-plant/
[116] https://5gobservatory.eu/nokia-to-build-private-5g-network-in-finnish-goldmine/
[117] https://5gobservatory.eu/vodafone-germany-launches-5g-standalone-network-at-university-hospital/

- The Commission mandated[118] in June 2021 the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER)[119] to provide an opinion on the need for a technical revision of the annexes to the Council Recommendation 1999/519/EC[120] and Directive 2013/35/EU[121] for the frequency range 100 kHz to 300 GHz in view of the latest scientific evidence available, in particular the ICNIRP guidelines updated in 2020. This mandate further tasks SCHEER to update the SCENIHR Opinion of 2015 in the light of the latest scientific evidence with regard to frequencies between 1 Hz and 100 kHz. The SCHEER Committee will adopt its first Opinion on the frequency range from 100 kHz to 300 GHz in the coming months, while the second opinion is scheduled to be issued within 2023.

The EECC recommends setting limits on exposure to electromagnetic fields (EMF) in line with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, which are about 50 times less than the level where there has been substantiated evidence of health damage. However, these limits are not binding on Member States and there is inconsistency in how they are applied, and this can restrict the economic and social benefits of including 5G. Current EMF policies in the Member States are shown in the table below.

Table 6: Current EMF policies in the Member States

Countries	ICNIRP limits used?	Details
Austria	Yes	
Belgium	No	More restrictive than ICNIRP. Each region has its own limits, but those in Brussels were relaxed in August 2021
Bulgaria	No	Public exposure limit of 0.1 W/m^2 (300 MHz to 30 GHz)
Croatia	No	Power density limits are 16% of the ICNIRP guidelines
Cyprus	Yes	ICNIRP limits adopted in 2004
Czech Republic	Yes	ICNIRP limits adopted in 2000
Denmark	Yes	
Estonia	Yes	ICNIRP limits adopted in 2002. No permit for ERP power <100W
Finland	Yes	
France	Yes	ICNIRP limits adopted in 2002
Germany	Yes	
Greece	No	60% of ICNIRP guidelines for base stations located less than 300 m from schools, hospitals... 70% of ICNIRP guidelines in other areas
Hungary	Yes	ICNIRP limits adopted in 2004
Italy	No	20 V/m as a general limit in open areas. 6 V/m inside buildings used for more than four hours a day
Ireland	Yes	
Latvia	Yes	

118 https://health.ec.europa.eu/system/files/2021-07/scheer_q_023_0.pdf

119 https://ec.europa.eu/health/system/files/2021-07/scheer_q_023_0.pdf

120 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:31999H0519

121 Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013L0035

Countries	ICNIRP limits used?	Details
Lithuania	Yes	
Luxembourg	No	Limit at 3 V/m per operator and per antenna system. About 0.2% of ICNIRP limit above 2 GHz
Malta	Yes	
Netherlands	Yes	
Poland	Yes	ICNIRP limits adopted in 2020
Portugal	Yes	ICNIRP limits adopted in 2004
Romania	Yes	
Slovakia	Yes	ICNIRP limits adopted in 2007
Slovenia	No	For sensitive and protected areas limits are lower
Spain	Yes	ICNIRP limits adopted in 2001
Sweden	Yes	
UK	Yes	ICNIRP limits adopted 2000

A1.9 5G corridors

Highlights (past 3 months):

- A total of 15 corridor deployment projects consisting in 7 Works projects and 8 Inception were kick-started at the beginning of 2023. A description of these projects can be found in an EC news item[122].

The analysis from the last quarterly report can be found here.

A1.10 5G cybersecurity toolbox implementation

Cybersecurity has been an important priority in the context of 5G development. The EU toolbox for 5G security is a set of robust and comprehensive measures for an EU coordinated approach to secure 5G networks. The full paper providing an overview of the toolbox as well as measures already taken by Member States can be found here.

Below are some highlights summarising the latest developments.

Since the publication of the last report, there have been no new developments in the implementation of 5G security toolbox amongst Member States.

A1.11 Next generation networks contribution to reaching Green Deal targets and addressing sustainability issues

Sustainability is another key topic accompanying 5G development. The full paper providing an overview of commitments taken up by the industry (telecom operators) to reduce emissions and the role of 5G in the context of the targets set by the Green Deal can be found in here.

- As a part of the chapter on sustainability in their latest State of Digital Communications 2023, ETNO emphasised the focus on the greening of telecoms networks through the transition toward

[122] 5G Coverage along Transport Corridors: first wave of projects selected for co-funding 5G corridor infrastructures | Shaping Europe's digital future (europa.eu)

next-generation networks. Indeed, 4G and 5G networks are more energy efficient and, thus, their rollout is crucial for reducing energy usage. Most ETNO members are planning to shut off their 3G networks by 2028 and 2G networks will follow thereafter due to their importance for IoT functions and basic voice services. Five decommissioning dates per year were announced for legacy networks (PSTN) in 2017. This is due to increase to 10 in 2023 and 2024 and 11 in 2025–2030.

- According to Analysis Mason, mobile network operators who are operating a full suite of 2G, 3G, 4G and 5G networks would be able to lower energy consumption by 40% by decommissioning 2G and 3G networks. Similarly, transitioning from legacy fixed networks (PSTN, copper, local exchanges, FTTC and HFC) to an all-FTTP access network could reduce operators' energy usage by up to 80%. The upgrading process varies across fixed networks operators, featuring A1 Telekom Austria and Deutsche Telekom who has switched off PSTN, Telenor and Telefónica who will switch off their copper-based networks by 2025, and Proximus and KPN who are beginning to shut down their FTTC networks.

- From the private sector, and in companion with the 2023 Mobile World Congress (MWC), several major telecommunication companies announced initiatives toward more sustainable 5G networks. For example, Huawei launched their Eco series antennas, aiming to reduce site power consumption by 15%, as well as improving network energy efficiency, reducing OPEX and reducing carbon emissions. These antennas are supposed to bolster the development of green and high-performance 5G networks.[123] Similarly, ZTE is pursuing a higher 5G network energy efficiency by the way of their AAU hibernation or zero-load zero-carbon technology, which reduces the energy consumption of their zero-load equipment.[124] Another example is Ericsson who showcased several new solutions in accordance with meeting their Net Zero ambitions during the MWC. The solutions focus on sustainability, energy saving and capacity expansion, and include portfolios such as new remote radios for 4G and 5G capacity, new mobile transport offerings and a new range of wideband Massive MIMO radios. All of which put an emphasis on lowering carbon emissions and site footprint.[125]

[123] https://www.huawei.com/en/news/2023/3/mwc2023-eco-5g-antenna

[124] https://www.zte.com.cn/global/about/news/zte-brings-new-wireless-products-and-solutions-at-mwc-2023.html

[125] https://www.ericsson.com/en/press-releases/2023/2/strengthened-networks-portfolio-boosts-ericssons-drive-towards-net-zero-emissions

Annex II: Detailed country situation

The detailed country situation is available online via this link.