European Commission

5G Observatory Quarterly Report 12

Up to June 2021

European 5G Observatory

A study prepared for the European Commission
DG Communications Networks, Content & Technology by:

IDATE DIGIWORLD

This study was carried out for the European Commission by IDATE DigiWorld

Authors: Frédéric PUJOL, Carole MANERO, Basile CARLE and Santiago REMIS

90013 – July 2021

Internal identification

Contract number: LC-00838363

SMART number 2019/009

DISCLAIMER

By the European Commission, Directorate-General of Communications Networks, Content & Technology.

The information and views set out in this publication are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

Contents

Tables & Figures

***

1. Executive summary

This is the twelfth quarterly report of the European 5G Observatory for the second quarter of 2021.

At the end of June 2021, 5G commercial services were available in twenty-five of the EU-27 countries.

The level of spectrum assignments in the pioneer bands has not yet reached the 5G Action Plan objectives regarding the assignment of the three pioneer bands in all Member States. At the end of 2020, only three Member States had made available and assigned spectrum in all three pioneer bands, and six months later there were five Member States in the same situation.

Beyond the dramatic health and socio-economic impact of the COVID-19 pandemic affecting all of us, there are also many impacts on the 5G ecosystem today. During the lockdown, cellular networks have coped with increased traffic requirements and been proven reliable. The first 5G networks deployed in Europe have only a limited number of users, so there have been no congestion issues yet.

During 2020, many 5G spectrum auctions were delayed in Europe due to the pandemic situation. However, most of these delayed auction processes finally took place in the last months of 2020.

In the medium to longer term, this crisis will probably have increased awareness regarding the need for digital solutions, e.g. telehealth, increased teleworking (which also calls for higher network capacity and speeds), fixed wireless access and many other functionalities supported by 5G networks.

1.1. Status of 5G deployment in Europe and assessment against the 5G Action Plan

On 14 September 2016, the Commission launched the 5G Action Plan to boost EU efforts for the deployment of 5G infrastructures and services across the Digital Single Market by 2020, and ensure to achieve a comprehensive coverage by 2025. The action plan sets out a clear roadmap for public and private investments in 5G infrastructure in the EU.

The European 5G Observatory provides updates on key market developments in EU-27 and a number of other relevant countries, including actions undertaken by the private and public sectors, in the field of 5G. It also presents an analysis of the strategic implications of the 5G Action Plan and other public policy objectives.

On 9 March 2021, the Commission set out an ambitious European approach to a digitalised economy and society, which is presented in the 2030 Digital Compass Communication “The European way for the Digital Decade” (COM (2021) 118). The proposed approach takes full account of the increasing strategic importance of the digital transformation and paves the way for a comprehensive investment and regulatory agenda. In this approach, 5G is a key element to reach one of the so-called “cardinal points”, the one concerning secure and performant sustainable digital infrastructures. In particular, the Commission proposes to raise the level of EU ambition for 2030 in order to ensure that all European households will be covered by a Gigabit network, with all populated areas covered by 5G. There is also a target for deploying at least 10,000 energy-efficient edge cloud nodes by 2030.

In the context of the Digital Compass Communication, the Commission will be reviewing the targets and actions of the 5G Action Plan (5GAP) and conduct relevant stakeholder consultations. This will be done with the aim to integrate the new requirements resulting from the Digital Decade strategy.

As far as commercial developments are concerned, many European mobile operators were preparing the commercial phase during 2019, as the first 5G smartphones became available in the second or third quarter, and now commercial services are already available in a large number of cities throughout Europe. Deployments are on-going with generally hundreds to thousands of base stations operational in many European cities. In Germany alone, there are already more than 10,000 5G base stations in operation.

At the end of June 2021, 25 EU-27 countries do enjoy 5G services: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, and Sweden.

In several countries there are more than one 5G service provider: all four mobile operators in Denmark (TDC, Telenor, Telia, 3), France (Bouygues Telecom, Free Mobile, Orange and SFR), Italy (TIM, Illiad, WindTre and Vodafone), Spain (Orange, Masmovil, Telefonica and Vodafone) and Sweden (Tele2, Telenor, Tre and Telia) offer commercial 5G services. Three players provide 5G services (mobile and/or FWA) in Austria (T-Mobile, A1 and Hutchison), Bulgaria, Czech Republic (Telefonica, T-Mobile and Vodafone), in Finland (DNA, Elisa and Telia), Germany (T-Mobile, Telefonica and Vodafone), Greece (Vodafone, Cosmote and Wind Hellas), Ireland (Eir, Three and Vodafone), Luxembourg (Post, Tango and Orange), Netherlands (KPN, T-Mobile and VodafoneZiggo), Poland (Orange, Plus and Play) and Romania (Digi, Vodafone and Orange). New commercial service launches took place during Q2 2021 with Orange Slovakia and Melita becoming in May 2021 Malta's first nationwide 5G network.

Key trends related to the 5G Action Plan measures, covering commercial 5G launches, early deployments and pan-European multi-stakeholder trials, are presented in Table 1:

Table 1: Key trends related to 5G Action Plan measures

5G AP measures	Key trends
Announcements by operators, service providers or users	At the end of June 2021, 5G commercial services had been deployed in 25 EU-27 countries: Austria (3 operators with 5G commercial service), Belgium (1), Bulgaria (3), Croatia (1), Cyprus (1), Czech Republic (3), Denmark (4), Estonia (1), Finland (3), France (4), Germany (3), Greece (3), Hungary (2), Ireland (3), Italy (4), Latvia (2), Luxembourg (3), Malta (1), Netherlands (3), Poland (3), Romania (3), Slovakia (2), Slovenia (1), Spain (4), and Sweden (4). 5G commercial launches in the USA: Verizon (October 2018 for FWA and April 2019 for mobile services), AT&T (December 2018 for network and June 2019 for mobile services), Sprint in May 2019, T-Mobile in July 2019. Dish Mobile is expected to launch 5G services in Q3 2021. 5G commercial launches were launched in South Korea in December 2018 for enterprise customers, and in April 2019 for residential customers. 5G commercial services in China were launched in November 2019. 5G commercial services available in Japan since April 2020.
Promote early deployment in major urban areas and along major transport paths	209 trials announced in EU-27. 49 trials identified in the UK, Russia, Turkey, San Marino, Switzerland and Norway. Twelve "digital cross-border corridors" established inter alia accommodating live tests of 5G for Cooperative Connected and Automated Mobility. Three large-scale projects were initially selected on these corridors (5G-CARMEN, 5GCroCo, 5G-MOBIX). Between September and November 2020, four new projects (5GMed, 5G-Routes, 5G-Blueprint and 5GRail) were launched; they will provide applications in the domain of cross-border connected and automated mobility, rail, inland waterways, ferry and ports.
Promote pan-European multi-stakeholder trials as catalysts to turn technological innovation into full business solutions	Large trials are part of H2020 Phase 3 projects. Three projects (5G EVE, 5G-VINNI, 5GENESIS) started in July 2018. They are implementing and testing advanced 5G infrastructures in Europe (EUR 15 to 20 million investment). Seven additional projects (5G-SOLUTIONS, 5G-TOURS, 5GDrones, 5G-HEART, 5GROWTH, 5G-SMART, 5G-VICTORI) focussed on trialling 5G across vertical industries started in June 2019. Eight projects (ARIADNE, 5G-CLARITY, 5G-COMPLETE, INSPIRE-5Gplus, LOCUS, MonB5G, TERAWAY and 5GZORRO) started in November 2019 on the longer term vision. Eleven new Horizon 2020 projects under the European 5G Public-Private Partnership (5G PPP), kicked off in September 2020 with the objective to seize opportunities in 5G hardware innovation and to validate 5G ecosystems for connected and automated mobility (CAM) along three new European cross-border corridors.

Source: IDATE DigiWorld – July 2021

1.2. 5G deployment outside Europe

In other regions of the world, 5G has been progressing at a rapid pace as well. We estimate that there are close to 180 operators providing commercial 5G services worldwide at the end of June 2021. It should be noted that mobile 5G-ready devices were available quite early in 2019, and that in the end of June 2021, more than 600 5G devices had been announced.

In the USA, the four major mobile players launched 5G services in 2018 and 2019. Verizon launched its fixed wireless access service based on a proprietary standard in October 2018 in four cities. AT&T also

announced the launch of a mobile 5G service based on the 3GPP standard in December 2018. The service was restricted to friendly[1] customers until the first quarter of 2019, and it was extended to additional cities during the first quarter of 2019. Verizon also launched a mobile service in Chicago and Minneapolis in April 2019. Sprint launched its 5G service at 2.5 GHz in May 2019, and T-Mobile USA did the same two months later in July 2019. Following the T-Mobile/Sprint merger, only three national mobile operators are operating 5G services at the end of June 2021. Dish Mobile is expected to launch its 5G service during Q3 2021.

After the announcement of limited commercial services targeting the enterprise market in early December 2018, the three South Korean operators launched 5G services on the same day in April 2019. In South Korea, 5G deployment has been massive with more than 115,000 live 5G base stations at mid-2020.

In China, the three mobile operators - China Mobile, China Telecom and China Unicom - launched 5G services on November 1st, 2019.

Japan has also been very active in the 5G field, and three operators (NTT Docomo, KDDI and Softbank) launched commercial 5G services in March 2020. The newcomer, Rakuten, launched 5G in September 2020.

Other commercial 5G launches were also reported in many countries, mainly using the 3.5 GHz band (non-exhaustive list): Australia (Telstra in 2018, Optus in January 2019), Bahrain (Viva in February 2019), Brazil (Telefonica in July 2020), Canada (Rogers, Bell Canada and Telus in early 2020), Hong Kong (HKT, Hutchison 3 and China Mobile Hong Kong in April 2020), Kuwait (Viva, Zain and Ooredoo in June 2019), Lesotho (Vodacom in August 2018), New Zealand (Vodafone New Zealand in December 2019), Oman (Omantel in December 2019), Philippines (Globe Telecom), Qatar (Ooredoo in May 2018 and Vodafone in August 2018), Saudi Arabia (STC and Zain in June 2019), South Africa (Vodacom in May 2020), Taiwan (Taiwan Star in August 2020), Thailand (Advanced Info Service in March 2020), UAE (Etisalat in September 2018, Du in June 2019). Other recent launches took place for example in EMEA (Monaco, San Marino), Safaricom (Kenya), APAC (Maldives) and South America (Suriname, Trinidad & Tobago and Uruguay).

1.3. Framework conditions and public measures in the context of the 5G Action Plan

National administrations in the EU have taken measures to facilitate the introduction of 5G since the past three years. This has been ranging from national 5G strategies to the completion or preparation of 5G spectrum assignments.

The European Electronic Communications Code, which entered into force on 21 December 2018, set important framework conditions as regards 5G investment in the EU. In particular, the EU MS were required to make 5G pioneer bands available by end of 2020 with investment certainty and predictability for at least 20 years in terms of spectrum individual licensing. Moreover, it established a voluntary peer review for the consistent assignment of spectrum across the EU.

[1] Friendly customers are employees of the mobile operator or people using the service for no charge in exchange for reports on the service

The 5G Action Plan also set out key targets to be achieved by Member States on the roadmap to 5G. The first one aims at unlocking bottlenecks including identification of spectrum for the initial launch of 5G (the three pioneer spectrum bands identified by RSPG). The second target was the identification of a full set of spectrum bands for 5G by the end of 2017 and working toward an approach for the authorisation of specific bands above 6 GHz.

At the end of March 2021, the Commission published a Connectivity toolbox including 39 cases of best practices proposed by Member States. By 30 April 2021, every EU Member State should have provided the Commission with a roadmap for the implementation of the Toolbox and, by 30 April 2022, all Member States will have to report on the implementation of the Toolbox. This initiative should facilitate the deployment of 5G infrastructure by reducing costs and the regulatory burden.

At the end of June 2021, the most tested frequency band in Europe has been by far the 3.6 GHz band (69% of the tests), the spectrum assignment percentage of which is almost 55%, whereas 46% of the spectrum in the 700 MHz band has been assigned in the EU. The 26 GHz band is still gaining traction very slowly.

Table 2: Assessment of 5G AP analysis criteria

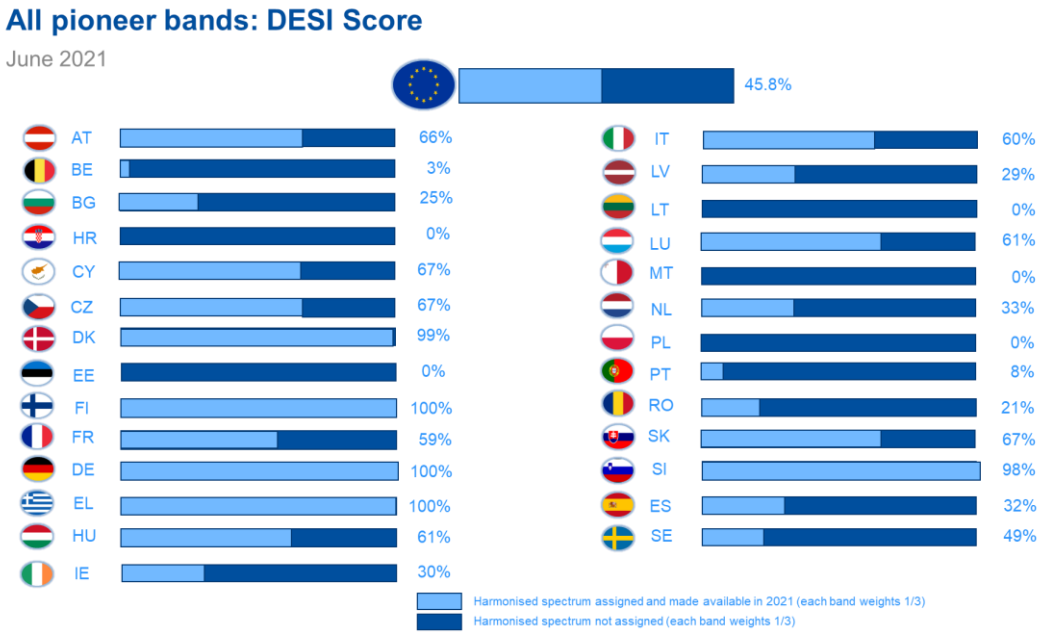
5G AP analysis criteria	Assessment
Roadmaps and priorities for a coordinated 5G deployment	The European Commission published a guidance document for national 5G strategies and roadmaps. Fourteen MSs published fully-fledged national 5G roadmaps including spectrum strategies (Austria, Czechia, Denmark, Estonia, Finland, France, Germany, Lithuania, Luxembourg, Portugal, Romania, Spain, Sweden, and the Netherlands). All EU-27 Member States have launched public consultations on 5G spectrum/strategy.
Make pioneer spectrum bands available for 5G **use ahead of WRC-19**	Member States were required to authorise the 700 MHz band by 2020, unless there are justified reasons for delaying it until mid-2022 at the latest. • The 700 MHz band has been assigned in fourteen EU-27 countries: Austria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Slovakia and Sweden. • Spectrum within 3.4-3.8 GHz frequency band has already been assigned in accordance with 5G technical conditions in 18 EU-27 countries: Austria, Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Romania, Romania, Slovenia, Slovakia, Spain and Sweden. • 26 GHz spectrum has been assigned in Italy, Finland and Greece, and available for local licences in Germany. In 20 Member States, at least one spectrum auction has been completed. The latest spectrum auction ended in April 2021 in Slovenia, where the 700 MHz spectrum was assigned.
Spectrum: usage of 5G pioneer bands and/or of other bands identified by the RSPG	Commercial usage of 5G spectrum in EU-27: 5G-compatible devices appeared in the European market in March 2019 and 5G infrastructure building started early 2019 in many countries.
Service verticals: feasibility of vertical use cases based on deals inked with key vertical players	Media & Entertainment: 39 trials Transport: 34 trials Automotive: 24 trials

5G AP analysis criteria	Assessment
	Other verticals: Industry 4.0, Agriculture, Smart cities, smart buildings, eHealth, Public Safety…
Top 10 countries (EU-27 plus the UK) in terms of 5**G trials organised**	Spain, Germany, Italy, France, UK, Finland, Netherlands, Portugal, Estonia, Poland
Technologies (Non-Stand Alone, Stand Alone…)	Non-Stand Alone 5G (3GPP Release 15) for all mobile operators. Many MNOs are starting to test and to implement Stand Alone 5G networks.
Functionalities tested: virtual networks/edge computing, broadcast/streaming, Heterogeneous Networks…	Mainly throughput and latency have been tested in the first trials in Europe. The media and entertainment vertical has been the most popular one amongst the reported trials.

Source: IDATE DigiWorld – July 2021

The Digital Economy and Society Index (DESI) score for each Member State for the three pioneer bands is presented in Figure 1.

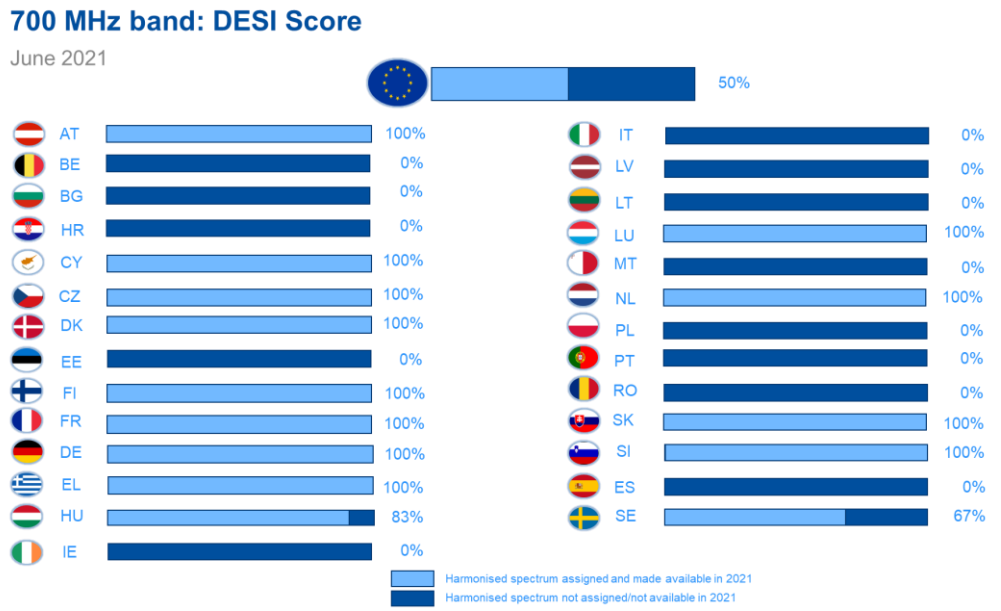
Figure 1: DESI score for the three pioneer bands



Source: IDATE DigiWorld – July 2021

The Digital Economy and Society Index (DESI) score for each Member State for the 700 MHz band is presented in Figure 2.

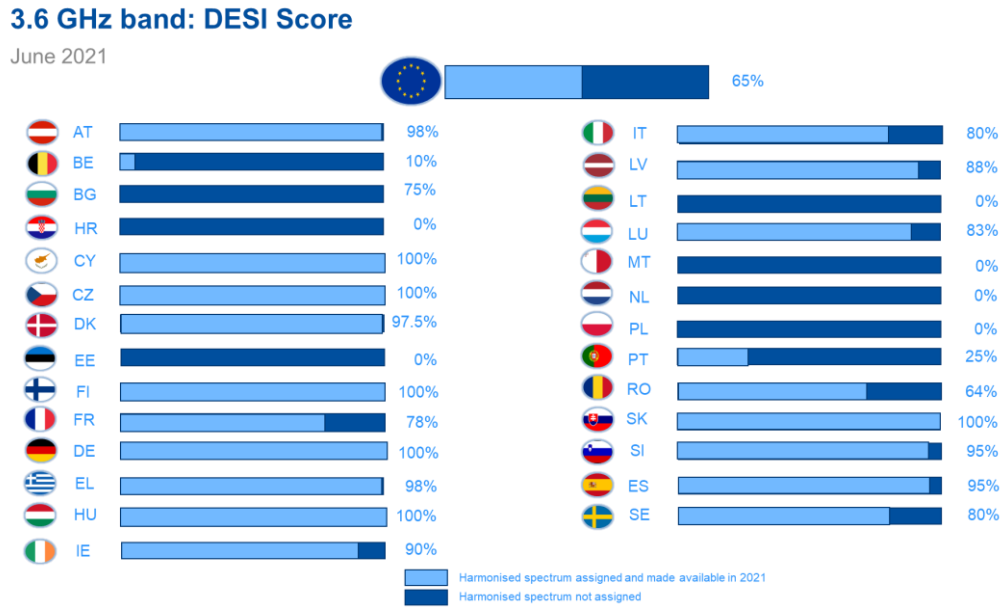
Figure 2: DESI score for the 700 MHz band



Source: IDATE DigiWorld – July 2021

The Digital Economy and Society Index (DESI) score for each Member State for the 3.6 GHz band is presented in Figure 3.

Figure 3: DESI score for the 3.6 GHz band



Source: IDATE DigiWorld – July 2021

2. Recent major developments

2.1. Latest developments at EU level

5G keeps progressing well in Europe, and the process has significantly accelerated during the past year. The European Commission's 5G Action Plan (COM (2016) 588) has ensured the timely commercial launch of 5G by targeting at least one major city in every Member State by the end of 2020, and has paved the way to having uninterrupted 5G coverage in all urban areas and major terrestrial transport paths by 2025.

The European Union regulatory framework for electronic communications has been modernised and gave birth to the new European Electronic Communications Code (EECC), which entered into force on 21 December 2018. Member States had to transpose the EECC into national law by 31 December 2020, which is expected to give a strong push to 5G and high-speed broadband networks as a whole.

The EECC is foreseen to greatly facilitate investments and entry into the market for wireless communications operators by:

- enhancing the deployment of 5G networks by ensuring the availability of pioneer 5G radio spectrum by the end of 2020 in the EU;
- providing operators with investment certainty and predictability for at least 20 years in terms of spectrum individual licensing;
- ensuring better coordination of planned radio spectrum assignments;
- supporting the entry of new spectrum users and economic operators through increased recourse to shared use of radio spectrum and general authorisation where possible, as well as easier spectrum trading and leasing;
- facilitating the deployment of 5G networks by introducing a light authorisation regime for small-area wireless access points;
- facilitating the roll-out of new, very high capacity fixed networks by making rules for co-investment more predictable and promoting risk sharing in the deployment of very high capacity networks;
- promoting sustainable competition for the benefit of consumers, with a regulatory emphasis on the real bottlenecks, such as wiring, ducts and cables inside buildings; and a specific regulatory regime for wholesale only operators.
- ensuring close cooperation between the Commission and the Body of European Regulators for Electronic Communications (BEREC), including in supervising measures related to the new access provisions on co-investment and symmetric regulation.

According to the UHF Decision of 2017 ((EU) 2017/899), all Member States were required to adopt national roadmaps regarding the licensing of the 700 MHz band.

Seven 5G PPP projects (5G-SOLUTIONS, 5G-TOURS, 5GDrones, 5G-HEART, 5GROWTH, 5G-SMART, 5G-VICTORI) were launched on 1 June 2019, closely involving vertical industries.

Eight "longer term vision" H2020 projects started in November 2019: ARIADNE, 5G-CLARITY, 5G-COMPLETE, INSPIRE-5Gplus, LOCUS, MonB5G, TERAWAY and 5GZORRO.

In June 2020, the European Commission adopted the Implementing Regulation[2] on small-area wireless access points, or small antennas. It aims to help simplify and accelerate 5G network installations, which should be facilitated through a permit-exempt deployment regime, while ensuring that national authorities keep oversight.

Eleven new Horizon 2020 projects under the European 5G Public-Private Partnership (5G PPP), have been kicked off in September 2020 with the objective to seize opportunities in 5G hardware innovation and to validate 5G ecosystems for connected and automated mobility (CAM) along three new European cross-border corridors.

On 9 March 2021, the Commission set out an ambitious European approach to a digitalised economy and society, which is presented in the 2030 Digital Compass Communication "The European way for the Digital Decade" (COM (2021) 118). The proposed approach takes full account of the increasing strategic importance of the digital transformation and paves the way for a comprehensive investment and regulatory agenda. In this approach, 5G is a key element to reach one of the so-called "cardinal points", the one concerning secure and performant sustainable digital infrastructures. In particular, the Commission proposes to raise the level of EU ambition for 2030 in order to ensure that all European households will be covered by a Gigabit network, with all populated areas covered by 5G. There is also a target for deploying at least 10,000 energy-efficient edge cloud nodes by 2030.

In the context of the Digital Compass Communication, the Commission will be reviewing the targets and actions of the 5G Action Plan (5GAP) and conduct relevant stakeholder consultations. This will be done with the aim to integrate the new requirements resulting from the Digital Decade strategy.

2.2. Progress of national strategies and plans

Most EU MSs have examined 5G strategic issues through public consultations, often followed by 5G strategy documents in 2016 or 2017. The 5G strategies generally resulted from national broadband strategies defined in 2015 or 2016 and lasting up to 2020. These strategies are being extended or renewed for the 2021-2023 or 2021-2025 period.

In order to facilitate a consistent approach across Europe, the European Commission published in November 2018 a Report[3] summarising the best practices and common elements that could be considered for national 5G strategies. The work done with experts from EU Member States covered key issues ranging from deployment targets, spectrum and small cells to public financing programmes and 5G innovation support.

Most EU MSs have examined 5G strategic issues through public consultations, often followed by 5G strategy documents in 2016 or 2017. The 5G strategies generally resulted from national broadband strategies defined in 2015 or 2016 and lasting up to 2020. These strategies are being extended or renewed for the 2021-2023 or 2021-2025 period.

In order to facilitate a consistent approach across Europe, the European Commission published in November 2018 a Report[4] summarising the best practices and common elements that could be

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2020.234.01.0011.01.ENG&toc=OJ:L:2020:234:TOC

[3] https://circabc.europa.eu/ui/group/7da1d333-3dda-4a40-9d7c-0013e0c51c98/library/3179b0e0-061d-4eac-9742-e391d63b5cc6/details

[4] https://circabc.europa.eu/ui/group/7da1d333-3dda-4a40-9d7c-0013e0c51c98/library/3179b0e0-061d-4eac-9742-e391d63b5cc6/details

considered for national 5G strategies. The work done with experts from EU Member States covered key issues ranging from deployment targets, spectrum and small cells to public financing programmes and 5G innovation support.

2.2.1. Consultations: all MSs have launched public consultations on 5G

By end June 2021, all the MSs had finalised public consultations on 5G spectrum/strategy: Austria (2017, 2019, 2021), Belgium (2018, January 2020, December 2020, April 2021), Bulgaria (December 2018), Croatia (2019, September 2020, April 2021), Cyprus (September 2019), Czech Republic (early 2019, July 2019, February 2020, August 2020), Denmark (March 2018), Estonia (October 2019, May 2020) Finland (2018, February 2021), France (December 2017, October 2018, May 2019, July 2019, September 2019, December 2019, October 2020, May 2021), Germany (2018), Greece (2018, 2019, February 2020, July 2020), Hungary (2019), Ireland (2019, June 2020, July 2020, September 2020, January 2021), Italy (2017, February 2021), Latvia (April 2020, July 2020), Lithuania (2018), Luxembourg (2018, May 2019, March 2020), Malta (2018, February and April 2021), Netherlands (first half 2019, January 2020, June 2021), Poland (2018, 2019, January 2020, August 2020), Portugal (2018, 2019, February-May 2020, April 2021), Romania (December 2018, July 2019, December 2020), Slovakia (2017, August and December 2019, March 2021), Slovenia (2017, 2019, August 2020, December 2020), Spain (2018, July 2021), Sweden (2017, June 2019, December 2019, February 2020, August 2020, May 2021).

The UK has also released a number of consultations on 5G or on subjects related to 5G (2017, 2019, February 2020 on EMF, May 2020 on modelling and technical matters for the 700 MHz and 3.6-3.8 GHz bands).

5G strategies and plans by Member States are detailed in section 3.1 of the report.

2.2.2. National strategies

National administrations in the EU have taken measures to facilitate the introduction of 5G since the past three years. This has been ranging from national 5G strategies to the completion or preparation of 5G spectrum assignments.

The European Electronic Communications Code, which entered into force on 21 December 2018, set important framework conditions as regards 5G investment in the EU. In particular, the EU MS were required to make 5G pioneer bands available by end of 2020 with investment certainty and predictability for at least 20 years in terms of spectrum individual licensing. Moreover, it established a voluntary peer review for the consistent assignment of spectrum across the EU.

The 5G Action Plan also set out key targets to be achieved by Member States on the roadmap to 5G. The first one aims at unlocking bottlenecks including identification of spectrum for the initial launch of 5G (the three pioneer spectrum bands identified by RSPG). The second target was the identification of a full set of spectrum bands for 5G by the end of 2017 and working toward an approach for the authorisation of specific bands above 6 GHz.

At the end of March 2021, the Commission published a Connectivity toolbox including 39 cases of best practices proposed by Member States. By 30 April 2021, every EU Member State had to provide the Commission with a roadmap for the implementation of the Toolbox. Toolbox roadmaps were available for 25 Member States as at June 21st, 2021. All Member States will have to report on the

implementation of the Toolbox by 30 April 2022. This initiative should facilitate the deployment of 5G infrastructure by reducing costs and the regulatory burden.

The national 5G strategies adopted to date have a number of facets as the 5G roadmaps set concrete targets, define priority areas and milestones. A spectrum section provides details on 5G potential auctions to be held in different 5G pioneer bands, and trial licences are often considered. Funding methods are presented and discussed, and measures to stimulate and mobilise key players from the telecom and vertical industries are also considered.

The review of progress made towards 5G market introduction shows various stages. Fourteen MSs have published fully-fledged national 5G roadmaps including spectrum strategies (Austria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Lithuania, Luxembourg, Portugal, Romania, Spain, Sweden and the Netherlands).

Lithuania approved the Guidelines for the Development of 5G over the 2020-2025 period in June 2020. Late in 2020, Romania published its 2021 5G Action Plan with three priorities including the organisation of the 5G multi-band spectrum auction.

Portugal adopted its strategy and calendar for 5G rollout in February 2020. In March 2019, Croatia adopted a new plan with 5G as a priority and started consultations on spectrum auction processes. They also published a document as a result of consultation. In May 2020, Ireland revised its national roadmap on the use of 700 MHz frequencies initially published in March 2019.

Other countries have not published fully-fledged 5G strategies, but instead organised successful 5G auctions or released strategies on spectrum (Cyprus, Malta, Hungary, Portugal, Romania, and Slovenia).

In 2020, 5G auction plans were significantly impacted by the pandemic. A number of Member States decided to postpone or put on hold their spectrum auction processes due to the covid-19 pandemic. The Hungarian 5G spectrum auction was, on the contrary, upheld due to heavy market interest. The auction took place one time one day before tight restrictions on movements and activities were imposed. In Finland, the 26 GHz auction was not disrupted either by the pandemic, and it took place in June 2020. However, a number of countries could complete their scheduled auctions in 2020:

- In Austria, the multi-band auction for 700/1500/2100 MHz spectrum ended in August 2020.
- In Cyprus, the 700 MHz/3.5 GHz auction was completed in December 2020.
- In Czech Republic, spectrum auctions in the 700 MHz and 3.5 GHz frequencies ended in November 2020
- In France, the 3.4-3.8 GHz auction which was initially planned for end April 2020 started late in September 2020. It ended on October 1st, 2020. The positioning auction followed quickly.
- In Greece, the multi-band (700 MHz, 3.5 GHz, and 26 GHz) auction ended in December 2020.
- In Luxembourg, the multi-band 700 MHz/3.4-3.8 GHz auction was completed in July 2020.
- In the Netherlands, the multi-band auction ended in July 2020.
- In Slovakia, the 700/900/1800 MHz auction ended in November 2020.

The first half 2021 showed intense activity around 5G auctions:

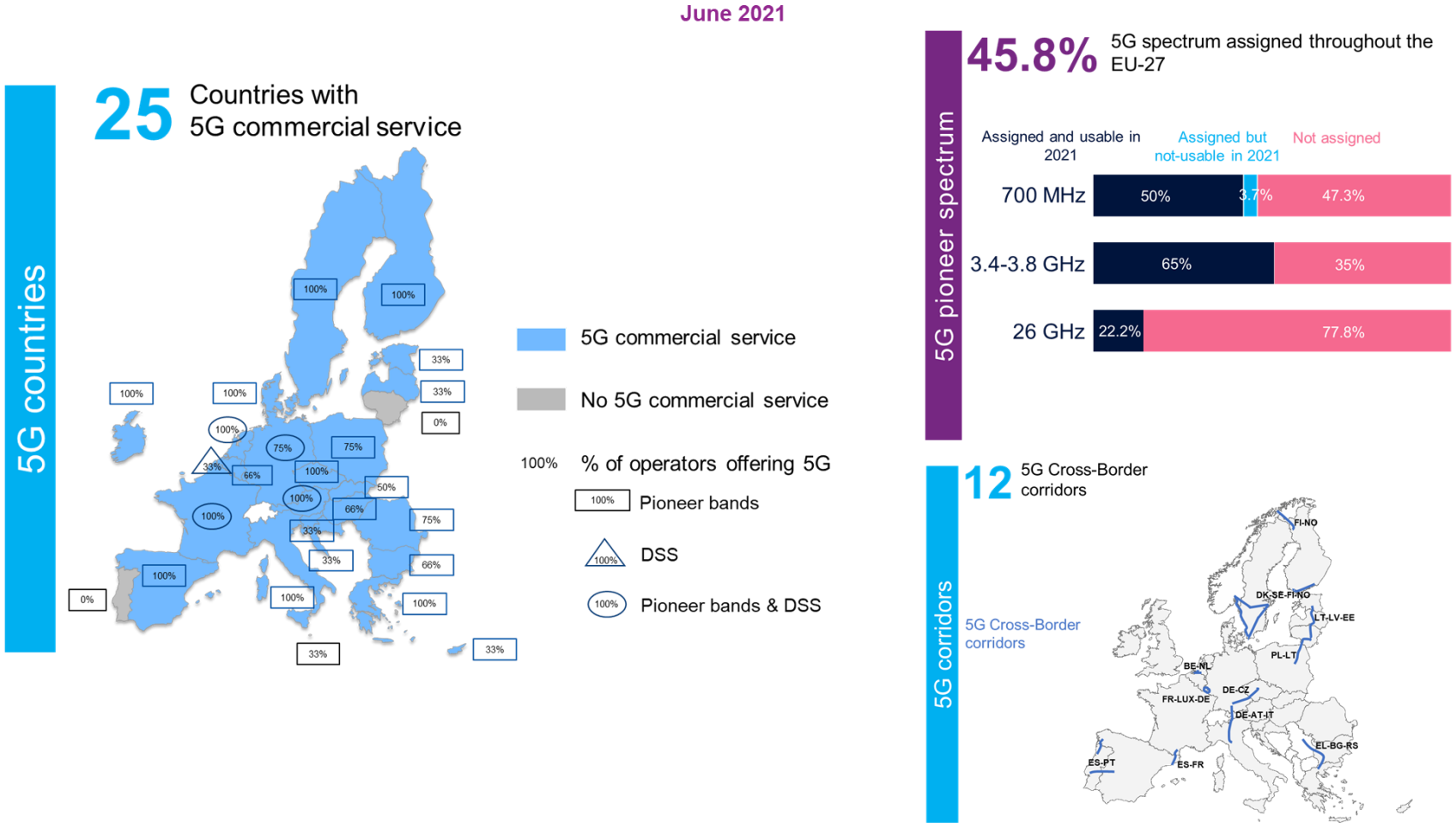
- In Bulgaria, the 3.5 GHz auction was completed in April 2021.
- In Denmark, the multi-band (1500/2100/2300/3500 MHz and 26 GHz) auction also ended in April 2021.
- In Portugal, the multi-band auction (700/900/1800/2100/2600/3600 MHz) which was postponed three times has started in March 2021 and is still ongoing. ANACOM tries to speed up the process after 100 rounds of bidding (as of June 4th, 2021).
- In Spain, the remaining 2 slots of 10 MHz of 3.5 GHz spectrum have been assigned late in February 2021.
- In Slovenia, the multi-band spectrum auction (700 MHz/3.5 GHz/26 GHz) successfully ended in April 2021.
- In Sweden, the first stage of the 2.3 GHz and 3.5 GHz auction which was initially scheduled for March 2020 and was postponed twice, ended in January 2021.

2.3. 5G scoreboard

2.3.1. 5G scoreboard – EU-27

The 5G scoreboard summarizes the status of 5G trials, spectrum assignments, and measures on coverage, roadmaps and national plans in EU-27.

Figure 4: 5G scoreboard – EU-27 (June 2021)

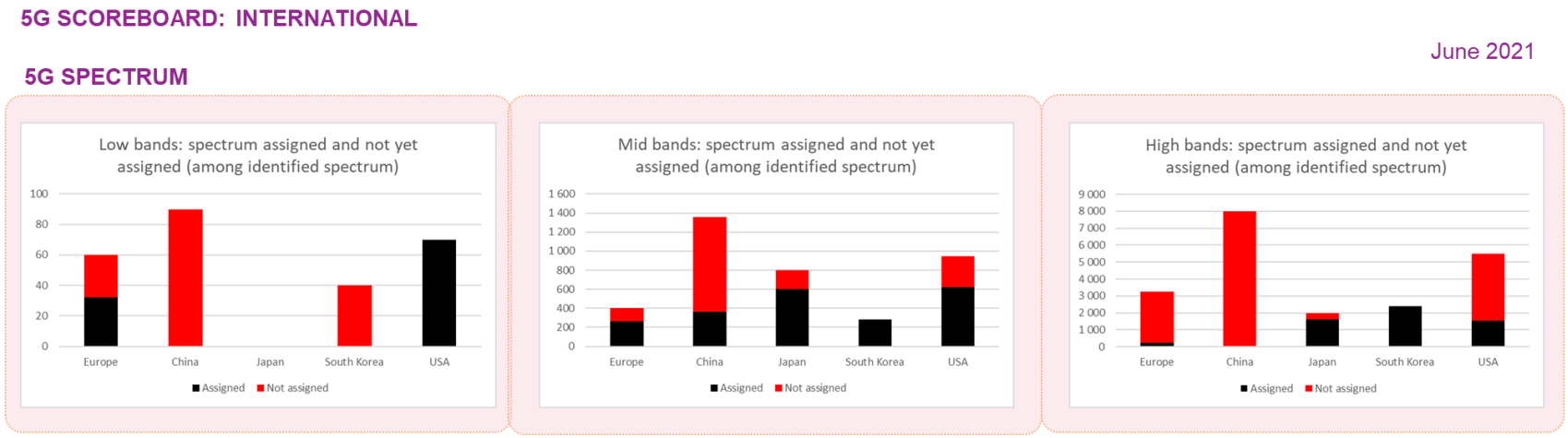


Source: IDATE DigiWorld

2.3.2. 5G scoreboard – International

The international version of the scoreboard details trials and timelines for 5G commercial launches and spectrum plans worldwide.

Figure 5: 5G Scoreboard – International markets (June 2021)



5G NETWORKS				
5G mode (NSA/SA[1])	NSA	NSA	NSA	NSA
Number of 5G base stations	700,000+	150,000+	~50,000	~40,000
Use of DSS[2]	Limited	Limited	Limited	Yes
Use of mmWave bands	No	No	Planned in 2021	Yes

[1]: Non Stand Alone / Standalone
[2]: Dynamic Spectrum Sharing

Source: IDATE DigiWorld

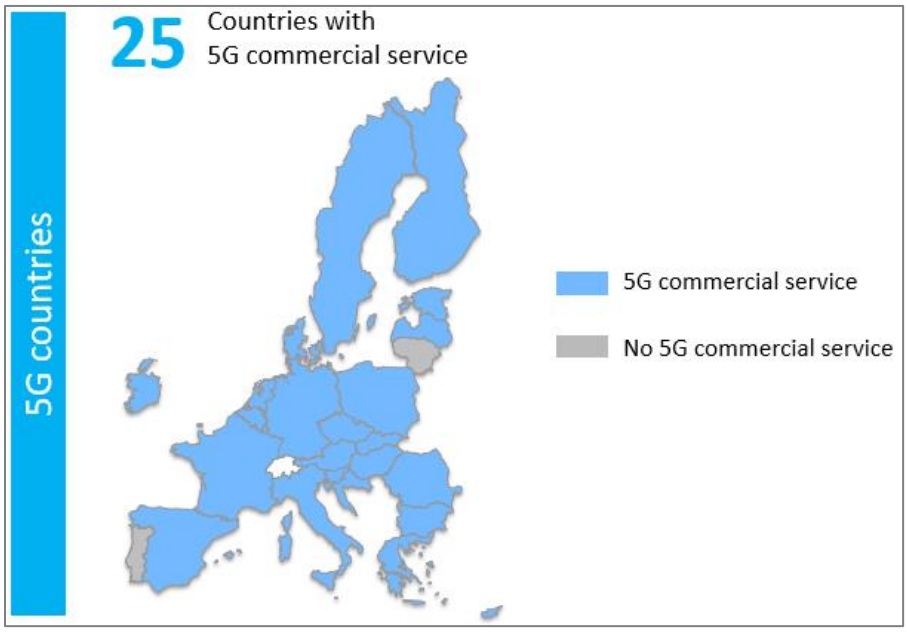
2.4. Announcements of commercial launches

Global 5G race is heating up. The number of live 5G networks increased significantly in Europe and outside Europe since the beginning of 2019. Only Lithuania and Portugal have not launched 5G services in the EU as at the end of June 2021.

2.4.1. Europe

By end June 2021, 5G commercial services had been deployed in 25 EU-27 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, and Sweden.

Figure 6: EU-27 countries with 5G commercial service – June 2021



Source: IDATE DigiWorld

Austria

T-Mobile

T-Mobile announced in March 2019 commercial launch with friendly customers using the 3.7 GHz band. The operator announced it had deployed 25 base stations for this launch in rural areas. The first 5G smartphones were available at the end of 2019.

The operator announced in July 2020 that its 5G network was active at 600 locations across the country, covering 25% of Austrian homes and businesses. By the end of 2020, the player reached 1,200 locations, representing almost 40% of homes and businesses. The company noted that it is implementing Dynamic Spectrum Sharing technology.

In May 2021, the company announced it began the rollout of the 700 MHz band for 5G services in rural areas. More than a third of the Austrian population was covered by the operator's 5G service, which also uses the 2100 MHz and 3.7 GHz bands.

Three

Three Austria announced a 5G pre-launch after activating its 5G network in the city of Linz in June 2019. The operator activated more 5G base stations in Worgl and Vienna in September 2019, and started offering 5G tariffs and devices. In December 2019, the company revealed that around 100 5G locations were going to be live across the country by the end of 2019. The operator has worked with Chinese vendor ZTE in its commercial 5G deployment.

A1 Telekom

A1 launched its 5G network in January 2020 using the 3.5 GHz band. The operator announced in April 2021 that its 5G network covered 3.8 million people in both urban and rural parts of the country, with about 1,500 5G base stations. A1 had previously signed a commercial contract with Finnish vendor Nokia for the deployment of its 5G network across the country. The contract includes both Nokia's 5G radio access and cloud-native 5G core technology.

Belgium

Proximus

Proximus launched Belgium's first commercial 5G services on April 1, 2020, using spectrum in its existing spectrum holdings (2.1 GHz) and within current EMF norms. Coverage was available in about 30 cities and towns. In June 2020, the operator expanded the network coverage to an additional 26 locations in Flanders, including central areas of Ghent and Antwerp. The network was not deployed in the Brussels region due to its stricter EMF radiation standards. By end 2020, the network covered more than 100 sites in 62 cities and municipalities, mainly in Flanders.

Bulgaria

Vivacom

In September 2020, Vivacom launched the first Bulgarian 5G network in all 27 district centers of the country. The operator gave 30 GB per month to its customers free of charge to test the new technology until the end of 2020. Vivacom is using Dynamic Spectrum Sharing (DSS) in the 1800 MHz and 2.1 GHz bands.

A1

A1 Bulgaria switched on its 3.6 GHz 5G network in capital city Sofia in November 2020. The operator said that the network supports coverage of Sofia's main residential and business districts and can deliver 1 Gbps download speeds.

Telenor

Telenor Bulgaria officially launched its 5G network in more than 60 locations across the country in early June 2021. The capital city of Sofia is one of the first locations to receive the new 5G services, as well as cities of Burgas and Varna and several other big cities and seaside resorts.

Croatia

Hrvatski Telekom

Hrvatski Telekom (HT) switched on Croatia's first commercial 5G network in late October 2020 in parts of six major cities: Zagreb, Rijeka, Split, Osijek, Samobor and Sveta Nedelja. At launch, 18% of the Croatian population was covered with the 5G network. In April 2021, the operator launched 5G services in 15 new markets.

In December 2020, the operator announced its 5G network covered one million people in 14 cities, reaching 25% of the country's population.

The Hrvatski Telekom's 5G network is based on Dynamic Spectrum Sharing (DSS) technology, which enables the current use of existing frequencies for 5G. Hrvatski Telekom has launched on 2100 MHz bands while awaiting the upcoming 3.5 GHz auction rescheduled for 2021.

Cyprus

Cytamobile-Vodafone
In February 2021, Cypriot mobile operator Cyta launched 5G services capable of providing speeds of 1 Gbps. The company advertised population footprint of 70% at launch, with plans to extend the coverage to 98% of the population within twelve months.

Czech Republic

Telefonica

O2 (Telefonica) Czech Republic launched 5G services in July 2020 in selected parts of Prague. The network is also available in the city of Koline. In December 2020, the operator announced its network was available in two more cities: Pilsen and Bilina. O2 plans to cover at least three more cities in early 2021.

Vodafone

Vodafone Czech Republic announced in early October 2020 the launch of its NSA 5G network in the cities of Prague, Brno, Usti nad Labem, Jesenik, and Karlovy Vary, using Dynamic Spectrum Sharing technology. In February 2021, the operator communicated that its 5G network was available in more than 130 cities and smaller municipalities, covering approximately two million people, more than 20% of the population.

T-Mobile

T-Mobile launched 5G commercial services in November 2020 in the cities of Prague and Brno. The operator said that by the end 2020, more than a quarter of the population in both cities will be covered

by its 5G network, targeting having around 360 base transceiver stations online. In December 2020, T-Mobile announced its 5G network covered one million people in 14 cities.

Operators count on the coming 5G auction for a truly nationwide expansion of the network.

Denmark

TDC

TDC launched commercial 5G services in the 3.5 GHz band in Copenhagen, Odense, Aarhus and Helsingør in early September 2020. The company claimed that by December 2020, 3,800 base stations had been equipped with Ericsson's 5G technology throughout Denmark, with a coverage of 90% of the population.

Telenor Denmark

Telenor Denmark activated its 5G network in November 2020 using the 3.5 GHz band, covering around 600,000 potential customers in Copenhagen and Aalborg. Cities of Aarhus and Odense are next in line for rollouts.

Telia Denmark

The operator launched commercial 5G services in November 2020 using the 3.5 GHz band. By January 2021, 30% of the population was covered by its 5G network.

TT-Netvaerket

Telenor Denmark and Telia Denmark have announced that their Danish joint venture TT-Netvaerket has activated 5G on the 3.5 GHz band, using equipment provided by Finnish vendor Nokia. The operators expect to cover the vast majority the Danish population with 5G technology during 2022.

Hi3G Access

Danish mobile network operator Hi3G Access announced the official switch-on of its new 5G network in Copenhagen and Roskilde in mid-December 2020. The operator launched 5G using frequencies in the 700 MHz and 1800 MHz bands. In March 2021, it is expected that the Danish Energy Agency will hold an auction to award spectrum in the 3.5 GHz band. That additional spectrum and further 5G development will enable speeds of around 1 Gbps, 3 Denmark said. The operator announced that it expects to cover one-third of its network by mid-2021 and to complete its nationwide network by mid-2022.

Estonia

Telia

Telia Eesti switched on Estonia's first commercial 5G network in November 2020 in the centres of the country's three largest cities, Tallinn, Tartu and Pärnu. The network uses Ericsson's Dynamic Spectrum

Sharing technology, enabling Telia to utilise its existing frequencies since the government has not yet auctioned off the 3.5 GHz licences for 5G.

Finland

Elisa

Elisa reported its 5G network carried a 5G phone call on 27 June 2018 between the Estonian minister of Economy and her Finnish colleague in Finland. Tests performed showed data speeds of 2.2 Gbps. That said, the first 5G licences were made available in the 3.6 GHz band frequencies in autumn 2018. The operator started offering 5G mobile devices and plans in June 2019 in Tampere, Jyväskylä, Turku and Helsinki.

Elisa revealed in June 2020 that its 5G network had been switched on in a total of 30 cities and towns across the country, with more than one million people within its service area. In March 2021, Elisa confirmed that its network covered some 2.5 million Finns and about 40% of the population, while 5G subscriptions had risen to close to 200,000 by the end of 2020.

Telia

Telia Finland launched 5G services in seven cities at the end of 2019 using its 3.5 GHz spectrum. The operator also promotes Fixed Wireless Access for homes, besides mobile subscriptions. In March 2021, the operator stated that its 5G network was covering about 60 locations, reaching approximately 40% of the population.

DNA

DNA started selling mobile 5G subscriptions in January 2020 using its 3.5 GHz band, having previously launched its 'DNA Home 5G' offering in December 2019. In November 2020, the network was available in 76 municipalities, covering more than 1.5 million people and representing 27% of the population. The operator announced in June 2021 that its 5G network covered 42% of the population or 103 towns and cities.

France

Orange

Orange France launched its commercial 5G mobile network on 3 December 2020 in 15 municipalities including Nice, Marseille, Le Mans, Angers, and Clermont Ferrand. By March 2021, about 200 municipalities were covered with the 3.5 GHz 5G network, providing data speeds up to three-to-four times faster than 4G LTE. According to Orange, each municipality will be added to the official coverage list when its 5G outdoor population coverage rate reaches 80% or more.

Bouygues Telecom

Bouygues Telecom switched on its 5G network in 20 major cities the 1st of December 2020. The network was available in Lyon, Nice, Montpellier, Reims, Le Havre, Toulon, Dijon, Villeurbanne, Le Mans, Aix-en-Provence, Boulogne-Billancourt, Metz, Saint-Denis, Argenteuil, Rouen, Versailles, Montreuil, Nancy, Avignon, and Cannes. In January 2021, Bouygues announced its 5G rollout reached

over 1,000 municipalities across the country via 2,407 base stations. The French operator has also confirmed the goal of achieving nationwide coverage by the end of 2021. The current roll-out phase will rely on the 3.5 GHz and 2.1 GHz bands. In March 2021, the Bouygues had 2,500 active 5G base stations.

SFR

SFR announced in late November 2020 the launch of its 5G service using the 2.6 GHz and 3.5 GHz in the city of Nice. 50% of the population of the city was covered by 5G, and within several weeks, 80% was planned to be covered. The company confirmed plans to extend its coverage to more than 120 municipalities throughout December 2020. The rollouts will take place at selected locations in the agglomerations of Bordeaux, Marseille-Aix-en-Provence, Montpellier, Nantes, Nice, and Paris-Ile-de-France.

Free

Free Mobile became in December 2020 the fourth French operator to launch commercial 5G services. At launch, for the same data volume, consumers had to pay more than three times at Orange or at SFR.

The 5G network covered about 40% of the population and had good indoor reception thanks to the 5,255 active 700 MHz cell sites. Free Mobile also activated 220 cell sites equipped with 3.6 GHz frequencies to offer ultra-fast speeds in selected locations. By February 2021, the operator had activated 6,274 base stations. In May 2021, Free announced it covered 52% of the population, 8,700 municipalities within its 5G footprint.

France's spectrum agency ANFR said that the number of cell sites authorized for 5G services amounted to 26,000 as of July 1, 2021.

Germany

Deutsche Telekom

Deutsche Telekom switched on its 5G network in September 2019, in five German cities: Berlin, Bonn, Cologne, Darmstadt, and Munich. Hamburg, Frankfurt, and Leipzig followed.

In July 2020, the operator announced that its 5G network covered 40 million Germans, representing half of the population. Services were available in over 3,000 towns and municipalities, after a further 18,000 antennas were upgraded for 5G and integrated into the live network. The company announced in May 2021 that it covered 80% of Germans, via a total of 50,000 antennas in over 5,000 towns and communities across the country. DT plans to cover 90% of Germans by the end of 2021.

Telekom uses spectrum in the 2.1 GHz band to provide customers with 5G coverage in less densely populated areas, while the 3.6 GHz band is being used in large cities. Dynamic Spectrum Sharing is also being deployed.

Vodafone Germany

Vodafone Germany started its 5G network in July 2019. In February 2021, the operator announced that it switched on a further 2,200 5G antennas at around 800 locations across Germany. In total, more

than 7,000 5G antennas were active at almost 2,500 locations, providing coverage to more than 20 million Germans, with this set to rise to 30 million by the end of 2021. In May 2021, Vodafone announced its network reached 25 million people, with 10,000 active 5G base stations at 3,000 locations.

Vodafone is using the 1800 MHz band to provide 5G in densely populated cities with speeds of more than 500 Mbps, while the 700 MHz range is being deployed in rural areas to offer data rates of up to 200 Mbps and the 3.5 GHz band is being rolled out in high traffic areas such as stadiums and train stations, where it can support speeds of 1 Gbps. In May 2021, Vodafone announced the launched of its 5G SA network in 170 cities. Customers can book a free '5G core network option' for all post-paid 5G tariffs to use the new technology.

Telefonica

Telefonica became Germany's third mobile network operator to introduce 5G services in October 2020, when the network was activated in ten cities: Berlin, Hamburg, Munich, Frankfurt, Cologne, Dusseldorf, Stuttgart, Essen and Potsdam. By May 2021, the 5G network was available in 60 cities. Telefonica's 5G network in the 3.6 GHz band will have grown from 450 antennas to over 6,000 to cover more than 30% of the population by the end of 2021. The operator expects to reach around 50% by the end of 2022 and the whole country by 2025. Telefonica also plans to utilise the 700 MHz and 1800 MHz bands to expand its coverage. In rural areas, the company will use Dynamic Spectrum Sharing. In May 2021, the 5G network was available in 60 cities.

Greece

Wind Hellas

Greek mobile operator Wind Hellas announced in December 2020 that it switched on its 5G mobile network a few days after winning frequencies in the country's multi-band 5G spectrum auction. The network was initially covering Athens and Thessaloniki, while coverage of other major cities is expected in 2021. The operator said that 5G population coverage is expected to exceed 60% within three years.

Cosmote

Cosmote launched its commercial 5G services in December 2020 in Athens, Thessaloniki and other Greek cities, with speeds exceeding 1 Gbps in certain areas. In March 2021, the operator expanded its 5G network to cover 17 cities, including 90% of the populations of the country's two largest cities, Athens, and Thessaloniki. The company is aiming to increase coverage to over 50% of the population by the end of 2021.

Vodafone Greece

In January 2021, Vodafone Greece became country's third mobile operator to switch on its 5G network. The services were available in parts of Athens and Thessaloniki, with 40% of the population expected to be covered by March 2022.

Hungary

Vodafone Hungary

In October 2019, Vodafone Hungary launched a commercial 5G service limited to Budapest, using its existing 3.5 GHz spectrum and ahead of Hungary's March 2020 licence auction where it won additional 3.5 GHz frequencies plus a 700 MHz licence. In March 2021, the operator announced that its 5G network was available 'in most of Budapest'.

In late June 2020, the operator announced plans to roll-out 5G services in six cities, focusing on the busiest parts of inner cities and around universities. The rollouts will increase the number of Vodafone 5G base stations to about 300.

Magyar Telekom

The operator launched commercial 5G mobile network services in April 2020 in partnership with Ericsson. The network was available in limited areas of Budapest and Puskas Ferenc stadium. By September 2020, the network was available in parts 18 cities and towns including Zalaegerszeg, Szombathely, Debrecen, Szeged and Kecskemét.

Ireland

Vodafone

Vodafone Ireland launched 5G services in August 2019 in selected areas of five Irish cities, including Dublin and Waterford using the 3.5 GHz band. In May 2020, the operator communicated that the 5G network was live in Cork, Dublin, Galway, Limerick and Waterford.

Eir

In early December 2019, Eir launched its 5G service in 10 towns and cities using the 3.5 GHz band. By January 2020, 5G services were available in 20 towns and cities. In February 2021, Eir confirmed that its 5G network covered 55% of the population, with infrastructure available in 239 towns and cities via more than 800 base stations. The operator covered 57% of Irish and 260 cities via more than 900 5G base stations by April 2021.

Three Ireland

In late September 2020, Three Ireland started offering 5G commercial services with Ericsson's equipment in a total of 315 sites across Ireland, reaching 35% of population coverage using the 3.7 GHz band. The operator expects to add a further 500 5G-capable sites in 2021. Ericsson announced that the 5G network is powered by the vendor's fully virtualised 5G Core and the latest products and solutions from its Radio System portfolio.

Italy

Vodafone

Vodafone Italy launched its commercial 5G services in 5 cities on 6 June 2019 (Milan, Rome, Turin, Bologna and Naples). In Turin, the Vodafone network covered 80% of the city with 120 cell sites. The number of cities with 5G availability is meant to increase up to 100 by the end of 2021. The operator inked a network sharing 5G deal with Telecom Italia early 2019.

Telecom Italia

TIM launched its 5G service on June 24th, 2019 in parts of Rome and Turin, Naples followed in July 2019. As of late March 2020, 5G services were available in Bologna, Brescia, Florence, Genoa, Milan, Naples, Turin, and Rome. In August 2020, the network was available in a total of ten cities. The company announced plans to reach 20 cities by the end of 2021.

Windtre

Wind Tre launched its 5G network in around ten regional capitals in October 2020. The operator announced in January 2021 it had rolled out 5G networks in 59 Italian provinces and eight additional provincial capitals, covering around 73.7% of the population. By March 2021, the 5G network covered 86% of the population.

Iliad Italia

Iliad Italia switched on its 5G network in 27 Italian cities in December 2020. The operator launched what it could be a highly disruptive offer in Italia, a 5G called Flash 70 for under 10 EUR for a limited period only, until January 21, 2021. In July 2021, the operator was offering 120 GB for the same monthly fee.

Fastweb

Fastweb became the fourth operator in the country to launch 5G services in December 2020. By May 2021, the 5G network reached more than 460 municipalities.

Latvia

LMT

Latvian Mobile Telephone launched 5G network in July 2019, with limited availability. In January 2020, commercial 5G services were extended to the cities of Jelgava and Daugavpils.

Tele2

Tele2 Latvia commercially launched 5G services in Daugavpils and Jelgava in January 2020. The operator said any customer with a compatible device could use the 5G network. By September 2020, the network was available in Riga, Jurmala, and Valmiera. In January 2021, the operator announced plans to expand its 5G network with the deployment of base stations in 13 more cities over the course of 2021.

Luxembourg

Orange

The operator confirmed the network was activated in November 2020 covering Luxembourg City and surrounding areas, such as Bertrange, Strassen, Kirchberg and the airport. Orange subscribers can access 5G services at no extra charge as part of their existing mobile plans.

Tango

Luxembourg mobile network operator Tango launched 5G services in November 2020. The 5G network was initially available in Luxembourg City before being deployed in other larger towns from early 2021.

All customers can benefit from the new 5G network with their current mobile subscription, reaching speeds of up to 1 Gbps.

Malta

Melita

The operator launched in May 2021 country's first nationwide 5G network. Melita is using existing spectrum for its 5G service ahead of an auction of 5G-capable licences in the 700 MHz, 3.5 GHz and 26 GHz bands later this year.

Netherlands

VodafoneZiggo

The operator activated its 5G network in late April 2020 across more than half of the Netherlands. VodafoneZiggo annouced plans to cover all the Netherlands by late 2020. In partnership with Ericsson, the operator implemented 5G services via its existing antennas and Dynamic Spectrum Sharing technology which allows operators to dynamically allocate some of their existing 4G LTE spectrum to 5G. More specifically, the company is using 800/1800/2100/2600 MHz bands.

The company notes that the mobile data download speeds that 5G can offer using its existing spectrum reach a maximum of 1 Gbps, although it adds that in practice the 5G data rates experienced by initial customers will be on average 10% higher than the 4G speeds (maximum of 350 Mbps) they were previously getting.

T-Mobile

In late July 2020, T-Mobile Netherlands launched its 5G mobile network in The Hague and 'most of the Netherlands'. The operator confirmed that its initial 5G network is based on its new 700 MHz spectrum, with existing subscribers to its Unlimited and Unlimited Plus subscriptions automatically receiving 5G access on suitable devices. The company announced in January 2021 that it reached 90% 5G population coverage.

KPN

KPN launched commercial 5G services the same day than T-Mobile, in late July 2020 using its 700 MHz spectrum band. The network covered over 90% of the top five Dutch cities, Amsterdam, Rotterdam, The Hague, Utrecht, and Eindhoven, reaching approximately half of the Netherlands' population. The operator plans to offer nationwide 5G coverage by the end of 2021. KPN announced that B2B customers will be able to purchase special 5G-only services including coverage-on-demand, application priority and guaranteed bandwidth.

Poland

Polkomtel (Plus)

Polish operator launched the country's first commercial 5G mobile network in May 2020. The network used 100 base stations in the 2.6 GHz band, providing 5G services in seven cities and to about 900 000 people: Warsaw, Gdansk, Katowice, Lodz, Poznan, Szczecin and Wroclaw. Polkomtel communicated

there were 5.2 million people covered by its 5G networks at the end of November 2020. The company is planning to have coverage of eleven million Poles in 150 cities and towns with 1,700 base stations by the end of 2021.

Orange Poland

The operator launched 5G services via 1,600 base stations, using the 2.1 GHz band and covering up to six million people in July 2020. T-Mobile aimed to cover by the end of June 2020, Warsaw, Lodz, Krakow, Poznan, Wroclaw, Plock, Opole, Czestochowa, Rzeszow, Bielsko-Biala and Kielce. The network uses the 2.1 GHz band.

Play

The operator announced the launch of its commercial 5G services in June 2020 over 50 base stations in 16 cities using the 2.1 GHz band.

Romania

Vodafone

Vodafone launched 5G services in Romania on 26 June 2019 in areas of three cities. Customers could choose two 5G plans: The Red Infinity 17 with unlimited 5G data at EUR 17 per month and Red Infinity 25 with unlimited 5G data and more services at EUR 25 per month.

Digi

RCS&RDS (Digi) announced its first 5G commercial service in June 2019, in areas of six cities. The company offered two 5G compatible smartphones: the Xiaomi Mi Mix 3 5G and the Huawei Mate 20x 5G.

Orange

In November 2019, Orange Romania launched 5G in Bucharest, Cluj-Napoca and Iasi. The operator announced in January 2020 the expansion of its 5G network to Brasov and Poiana Brasov.

In late August 2020, Orange Romania announced its 5G network in Bucharest had been expanded to cover the entire city, enabling 100% of its population to access download speeds of up to 1.2 Gbps. The network was also expanded to Mamaia and Timisoara.

Slovakia

Slovak Telekom

Slovak Telekom became the country's first operator to launch commercial 5G services in December 2020. Services were available in eight districts of Bratislava. ST announced that customers can expect download speeds of between 300 Mbps and 600 Mbps, and between 60 Mbps and 80 Mbps for upload. The operator is utilizing 15 MHz of frequencies in the 2.1 GHz band, in combination with LTE spectrum.

Orange

In May 2021, Orange Slovensko launched its 5G network in areas of Bratislava and Banska Bystrica using 3.5 GHz spectrum and Massive MIMO equipment.

Slovenia

Telekom Slovenije

Telekom Slovenije launched the first commercial 5G network in Slovenia in July 2020. The mobile operator upgraded 150 4G base stations to support 5G and announced that it provided coverage to approximately 25% of the population. By the end of 2020, Telekom Slovenije expected to surpass 33% coverage.

Ericsson announced that Telekom Slovenije is using its Radio Access Network (RAN) and Cloud Core solutions for its 5G commercial rollout. Ericsson also assisted with a software installation to existing Ericsson Radio System and packet core equipment, which enables spectrum sharing between 4G and 5G on 2.6 GHz FDD spectrum.

Spain

Vodafone

Vodafone Spain launched its commercial 5G services at 3.7 GHz in 15 cities in June 2019 with initial speeds of up to 1 Gbps. At launch, the service was reaching approximately 50% coverage in each of the 15 cities.

Vodafone Spain activated in June 2020 its 5G network in a total of 21 cities. The company had previously said that it was working with Huawei and Ericsson in the deployment of the 5G network. By April 2021, the 5G network covered a total of 25 markets, representing about 50% of the population.

Telefonica

Telefonica announced in September 2020 the switched on of its 5G network in unspecified Spanish locations. The network utilises 3.5 GHz spectrum, alongside with refarmed 1800 MHz and 2.1 GHz frequencies. Telefonica announced it awarded Finnish vendor Nokia the contract to increase 5G coverage up to 75% of the Spanish population by year-end 2020. By March 2021, its 5G network covered 80% of the population. Nokia is the only vendor to supply 5G radio technology to all of Telefonica's 5G operations across Europe.

Orange

In September 2020, Orange Spain launched 5G mobile services using the 3.5 GHz band in selected parts of five cities, namely: Madrid, Barcelona, Valencia, Seville and Malaga, predominantly in central areas. Orange covered around 30% of each city. The operator announced in March 2021 that its 5G network covered 295 municipalities across 38 provinces, equivalent to population coverage of 23%. The telco expects its 5G service to reach more than 400 cities by the end of 2021, providing coverage of over 51% of the population. In 2022, coverage is expected to reach 90%, via a combination of NSA 5G architecture and Dynamic Spectrum Sharing technology.

The Ericsson Radio System, delivering Massive MIMO, powers the 3.6 GHz 5G network in Madrid and Barcelona. Ericsson also supplies Orange Spain with a 5G Evolved Packet Core to support the 5G New Radio non-standalone 5G network.

MASMOVIL

In September 2020, Grupo MASMOVIL became the fourth Spanish operator to launch 5G services, after switching on connectivity in 15 cities. The carrier said that the 5G service is being offered via a combination of own infrastructure and an agreement with rival operator Orange. In April 2021, its 5G network covered more than 200 cities and municipalities across 35 Spanish provinces.

Sweden

Tele2

Tele2 switched on 5G networks in Stockholm, Gothenburg and Malmö on May 24, using 80 MHz of the 3.6 GHz spectrum band. The operator communicated in November 2020 that it expanded its 5G network to 30 new locations, and that speeds of up to 1 Gbps are available at most 5G-enabled locations.

Telia Sweden

Telia Sweden announced in May 2020 that its 5G network was active through 15 base stations in Stockholm, using its existing 700 MHz spectrum, boosted by LTE and New Radio carrier aggregation. In December 2020, the operator announced that its 5G network was available in 20 cities. Telia is working with local partner Ericsson, which has confirmed it is providing radio access network products and solutions. Certified by the Swedish Society for Nature Conservation, the 5G network is powered by 100 % renewable energy.

Tre

In late June 2020, Tre Sweden announced the commercial launch of 5G services in Malmö, Lund, Uppsala, Helsingborg, Vasteras and large parts of Stockholm. Tre has activated 385 5G base stations, 200 of which are in Stockholm, and is expected to cover most of the centre of the capital by the end of August.

Telenor

Telenor Sweden launched commercial 5G services in central Stockholm in October 2020, becoming the fourth 5G network in the country. The operator said its network will provide internet access at 1 Gbps to customers with a compatible handset and a Telenor 5G-ready 30 GB, 75 GB, or unlimited subscription. 5G network coverage is available in at least half of the city centre. Telenor intends to widen its footprint in the capital while also adding connectivity in Malmö and Gothenburg before expanding the rollout to towns with a population of over 50,000. It expects the 5G network to cover 99% of Sweden’s population by 2023.

2.4.2. Rest of Europe

Norway

Telenor Norge begun offering a commercial 5G service in March 2020, becoming the first operator in the country to do so. The 5G network initially available in nine locations across the country: Kongsberg, Elverum, Bodo, Askvoll, Fornebu, Kvitfjell, Spikersuppa, Oslo and Trondheim. In November 2020, Telenor launched a FWA 5G service, and announced in March 2021 that it had more than 200,000 5G subscribers.

In May 2020, *Telia Norge* launched 5G for its customers in Lillestrøm and parts of Groruddalen in Oslo, with plans to expand to other areas during 2020. In November 2020, Telia launched a FWA 5G service.

Switzerland

In Switzerland, *Sunrise* announced partial 5G commercial launch in March 2019 and full launch in September 2019.

Swisscom launched in April 2019, its network encompassing at launch 100 sites in 50 cities and villages. Swisscom was targeting more than 90 per cent population coverage by the end of 2019.

United Kingdom

EE

EE launched 5G services in May 2019 across six cities, including some areas of London, Edinburgh, Cardiff, Belfast, Birmingham, and Manchester. It had targeted to bring 5G connectivity in 45 cities and large towns by the end of 2019.

As of June 2020, EE's 5G service was live in 80 towns and cities across the country, using a Non-standalone 5G New Radio deployment focused on using the combined power of 4G and 5G technologies. In a second phase from 2022, it will introduce the full 5G core network, enhanced device chipset capabilities, and increased availability of 5G-ready spectrum. A third phase, beginning in 2023, will introduce Ultra-Reliable Low Latency Communications (URLLC), network slicing and multi-gigabit-per-second speeds.

In January 2021, EE announced that it was offering 5G connectivity in a total of 125 towns and cities across the country. By April 2021, its 5G network covered 160 locations in Britain with almost 1 million 5G customers.

Three UK (FWA)

Three UK launched its 5G network for smartphone users in February 2020 in 65 locations, including parts of London, Cardiff, Glasgow, Manchester, Birmingham, Coventry and Nottingham. The 5G network went live earlier in August 2019, but it was available in central London and to Three Broadband service users only.

In May 2021, Three UK had 1,300 5G sites in operation across 193 towns and cities, up from around 1,000 at the end of 2020. Furthermore, it expects 'hundreds more sites' online before the end of 2021, noting that its 5G home broadband services now cover 1.6 million premises.

Vodafone

Vodafone UK launched 5G services in July 2019 in seven cities, planning to offer 5G services in twelve additional UK cities by year-end 2019.

Vodafone confirmed in July 2020 that its 5G network covered a total of 44 locations, while also claiming to have 'massively expanded' coverage in the seven launch cities. By November 2020, its 5G network was available in 57 towns and cities.

Telefonica (O2)

In October 2019, Telefonica (O2) became the latest mobile operator to switch on its 5G network in the UK. Services were made available in six cities and towns: Cardiff, Belfast, Edinburgh, Leeds, London, and Slough. As of June 2020, the 5G network was live across parts of 60 towns and cities in the country, up from 20 at the start of 2020.

The company revealed in January 2021 that it was offering 5G services in over 150 towns and cities nationwide. Telefonica also noted that it had increased its 5G coverage 'significantly' in bigger cities such as London, Birmingham, Glasgow, Bristol, Liverpool, and Manchester.

2.4.3. South Korea

SK Telecom, LGU+ and KT launched 5G services in December 2018 for business customers and in April 2019 for residential users. The Korean government announced that operators had deployed in early 2020 a total of 115,000 5G base stations across the country.

There were 15.15 million 5G subscribers in South Korea in the end of April 2021, representing about 21 % of the total 71.27 million mobile subscriptions, according to the data from the Ministry of Science and ICT. The country's largest operator, SK Telecom, had a total of 7.07 million subscribers in the 5G segment, followed by KT with 4.6 million and LG Uplus with 3.47 million.

South Korean telcos are expecting a big surge in 5G adoption in 2021, with SK Telecom aiming to have 9 million 5G users by the end of 2021, and smaller rival LG Uplus targeting 4 million.

South Korean telecom operators provide 5G services via NSA 5G networks in most of country's large cities. The companies are preparing to commercialize new technology, such as Standalone versions of the 5G networks and millimeter-wave 5G.

2.4.4. Australia

Telstra Australia

The operator launched its 5G service on the 3.6 GHz band at the end of May 2019 as it had switched on over 200 5G sites since August 2018. The 5G service was available in over 10 cities and twenty-five additional cities were expected to be covered before end-June 2020. The operator announced it was ahead of its target and 5G services were available in 47 cities across the country by summer 2020.

Telstra and Swedish vendor Ericsson announced collaboration agreements to provide 5G equipment and upgrade Telstra's network.

In September 2020, the operator announced that it had more than 1,500 5G sites in operation across selected areas of 53 cities and towns covering around ten million people.

In January 2021, the Australian operator announced that its 5G network covered 50% of the country's population and that it plans to increase coverage to 75% before the end of June 2021.

Telstra previously acquired spectrum in the 3.6 GHz auction for AUD 386 million (EUR 240 million), giving it 60 MHz of contiguous 5G spectrum in all major capital cities and between 50 MHz and 80 MHz in regional areas.

Optus

Rival mobile network operator Optus announced the commercial launch of 5G mobile and 5G residential fixed broadband services covering selected areas in November 2019. 290 5G base stations went live in Sydney, Canberra, Adelaide, Brisbane, Melbourne, Perth and other locations in New South Wales, Victoria and Queensland, noting that 1,200 sites were planned by March 2020. The telco failed to achieve that target and announced in January 2021 it had 1,000 active 5G base stations.

Optus is using equipment from both Ericsson and Nokia in its rollout of 5G. The company secured spectrum in the 3.6 GHz spectrum auction for AUD 185 million (EUR 110 million) in late 2018.

The operator announced in May 2021 the switching on of its first six 5G mmWave commercial sites in Sydney, Melbourne, and Brisbane. Optus communicated that the new sites are equipped with 800 MHz of spectrum in the 26 GHz band.

Vodafone Australia

The telco switched on, in March 2020, its first 5G sites in Parramatta and confirmed plans to expand its network in Sydney, Melbourne, Brisbane, Adelaide, Canberra and Perth in summer 2020.

2.4.5. Japan

NTT DOCOMO

NTT DOCOMO launched Japan's first 5G smartphone service on March 25, 2020. The network was live in 150 areas in the country covering 29 of Japan's 47 prefectures. By March 2021, more than 500 cities were expected to have access to the next-generation network. The operator expects to reach 10,000 5G sites by June 2021 and 20,000 by March 2022. NTT DOCOMO announced it had 3 million 5G subscribers by March 2021.

KDDI

KDDI launched 5G mobile services in 15 of Japan's 47 prefectures on March 26, 2020. The operator said it aimed to install 10,000 base transceiver stations by March 2021 and another 10,000 BTS by the end of March 2022. By 2025, the company plans to cover 93% of the populated areas of the country, as well as install 30,107 base stations in the 3.7 GHz and 4.5 GHz spectrum bands and 12,756 base stations in the 28 GHz band.

SoftBank

SoftBank turned on its 5G network in March 27, 2020. 5G mobile services were available in selected areas in seven prefectures across Japan. The operator aims to install over 10,000 5G base stations by the end of March 2023. By 2025, the company plans to expand its network to roughly 64% of the populated areas of the country and install 7,355 base stations in the 3.7 GHz and 4.5 GHz spectrum bands and 3,855 base stations in the 28 GHz band.

SoftBank and KDDI teamed together to speed up their 5G rollout in rural areas. To this end, they announced on April 1st, 2020, the setup of a joint venture, 5G JAPAN. The joint venture's goal is to promote infrastructure sharing based on the mutual use of base station assets held by the two companies. The initial capital of the joint venture will be 500 million JPY (4.24 million EUR) and each operator will own 50% of the stakes.

Rakuten

Greenfield operator Rakuten launched commercial 5G services in late September 2020 in certain areas across six prefectures of the country. The service, initially offered via Non-Stand Alone (NSA) 5G architecture, was available in parts of Tokyo, Kanagawa, Saitama, Hokkaido, Osaka and Hyogo. Rakuten Mobile's President Yoshihisa Yamada said that the operator was expecting the 5G network to be available in Japan's all 47 prefectures by end-March 2021, with a coverage of 70% of the population. The operator planned to cover 96% by summer 2021. Rakuten claims to have launched the world's first fully virtualized mobile network that uses lower-cost and more up-to-date cloud and software technologies. The operator expects to launch a Stand-Alone 5G network in the second quarter of 2021.

2.4.6. China

In December 2018, China issued test licences to players for national 5G trials until June 2020 (China Telecom: 3.4-3.5 GHz, China Unicom: 3.5-3.6 GHz, 260 MHz on 2515-2675 MHz and 4800-4900 MHz). 5G licences were awarded to China Mobile, China Unicom, China Telecom and China Broadcasting Network earlier in June 2019.

China Mobile, *China Telecom* and *China Unicom* launched 5G services on November 1st, 2019. Each player activated their network in 50 cities at launch, including Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou, Nanjing, Tianjin, Wuhan, Jinan, and Zhengzhou. In early October 2019, the three major mobile operators had already registered almost 9 million 5G users before the official launch. China Mobile announced 5.32 million subscribers, China Telecom hit 1.76 million subs, and China Unicom was right in line with 1.75 million users.

In April 2021, China Mobile had a total of 205.3 million 5G subscribers, compared to 43.74 million 5G customers in March 2020. The Chinese operator had deployed over 385,000 5G base stations nationwide. Rival operator, China Telecom, added 6.54 million 5G subscribers in April 2021 to take its total 5G subscribers base to 117.77 million. China Unicom started to provide 5G statistics in 2021. The telco announced it ended April with 98.56 million 5G subscribers. China Unicom and China Telecom had deployed about 380,000 active 5G base stations by May 2021.

It should be noted that not all "5G package subscribers" announced by the players are in possession of a 5G-capable handset. This overstates the actual 5G user numbers.

The Ministry of Industry and Information Technology announced that by April 2020, telecommunications companies had built more than 250,000 5G base stations across the country. By September 2020, the number of base stations was 500,000. The tech hub, often referred to as China's answer to Silicon Valley, was home to about 46,000 5G cell sites as of September 2020.

China's vice-minister of industry and information technology communicated in early 2021 that a total of 718,000 5G base stations were built in China in 2020, accounting for 'nearly 70% of the world's total 5G sites'. About 100,000 5G base stations were built in 2019. In 2021, local carriers are expected to deploy approximately another 600,000 5G base stations. The Chinese government has been encouraging 5G partnerships to boost efficiency and accelerate network rollouts.

In September 2019, China Telecom and China Unicom agreed to share their 5G SA infrastructure. The deal could save about 9 billion EUR in construction investment by preliminary estimate.

In May 2020, China Mobile signed a 5G network sharing agreement with China Broadcasting Network, which jointly fund and deploy a network over the 700 MHz frequency.

2.4.7. USA

Verizon

Verizon's 5G Home service was launched in October 2018 in limited areas of four US cities (Houston, Sacramento, Indianapolis, Los Angeles). The telco noted that the platform can deliver peak speeds of up to 1 Gbps, although users could expect 'typical' speeds of around 300 Mbps. In early October 2020, the service was also available in Chicago, Detroit, Saint Paul and Minneapolis and by the end of 2020, the technology was available in ten cities nationwide.

The operator launched its 5G mobile services in selected areas of Chicago and Minneapolis in April 2019 using millimetre-wave spectrum. As of September 2020, the 5G mobile network was available in about 35 cities across the country and 61 cities in December 2020. In October 2020, the company switched on its 5G network utilizing Dynamic Spectrum Sharing (DSS) technology, allowing 5G to run simultaneously on the same spectrum band as 4G. Verizon total footprint increased to 230 million people and covered 2,700 towns and cities.

AT&T

The company launched its '5G E' mobile services in certain parts of selected cities in December 2018, using the 39 GHz frequency range. In April 2020, the company had rolled out its 5G network in the 850 MHz band in over 190 markets, covering about 120 million people. By March 2021, AT&T's 850 MHz 5G network reached more than 230 million people in about '14,000 cities and towns across the U.S.'.

AT&T's faster mm-wave network branded '5G+' was launched for consumer access in March 2020, offering coverage in parts of 35 cities. By March 2021, the network covered 38 cities.

T-Mobile USA

In July 2019, T-Mobile USA pre-launched its 5G services in selected parts of six US cities (Atlanta, Cleveland, New York City, Los Angeles, Dallas, and Las Vegas) using the 28 GHz band.

In December 2019, T-Mobile switched on its 600 MHz frequency band 5G network. The deployment covered more than 200 million people and more than 5 000 cities and towns across the country. In March 2021, the operator announced its 5G network covered 287 million people, equivalent to more than 87% of the population. The operator announced the same month it reached the ten million milestone of 5G users. Also, T-Mobile launched its 5G Home Internet services with more than 30 million households eligible.

T-Mobile partnered with Cisco and Nokia to build its 5G core, and Ericsson and Nokia for its 5G radio infrastructure.

T-Mobile USA and Sprint Merger

Sprint and T-Mobile officially merged into one company in April 2020. T-Mobile started to expand its network with spectrum refarmed from Sprint in the 2.5 GHz band and opened nationwide 5G access for Sprint customers in the 600 MHz and mm-wave bands.

Sprint

Sprint had launched 5G services in May 2019 in three cities (Atlanta, Dallas Fort Worth, and Kansas City). In July 2019, it extended services to Chicago and in September 2019 to selected parts of Los Angeles, New York City, Phoenix and Washington DC. The Sprint 5G Non-Standalone network in the 2.5 GHz band was using massive 128-antenna MIMO equipment to be able to operate 4G at the same time.

Dish Mobile

Dish Mobile is currently performing tests of its 5G fully virtualised network in Las Vegas and is expecting to start 5G commercial services in Autumn 2021.

2.4.8. Other countries

Argentina

Telecom Personal launched 5G services in February 2021 using DSS technology via five base stations in Buenos Aires and five others in Rosario.

Bahrain

Batelco and *STC* announced that they had launched 5G services in June 2019. Batelco announced in October 2020 that its 5G network covered 95% of the Kingdom's population across all four governorates. In January 2020, STC's 5G network was expanded to cover 50% of Bahrain's territory.

Brazil

Telefonica

In July 2020, Telefonica launched its 5G network in selected parts of eight state capitals, namely: Sao Paulo, Salvador, Brasilia, Rio de Janeiro, Porto Alegre, Goiania, Curitiba, and Belo Horizonte. The operator planned to activate its 5G network in a total of 12 cities by March 2021.

Claro

Claro launched its 5G network in July 2020 using a combination of 700 MHz, 1800 MHz and 2.5 GHz spectrum in areas in Sao Paulo and Rio de Janeiro. The operator had covered selected parts of 14 cities by February 2021.

Canada

Rogers Communications

The operator started offering 5G services in March 2020 in parts of Vancouver, Toronto, Ottawa, and Montreal using equipment from Ericsson. In October 2020, the company announced the expansion of its 5G network to a total of 130 towns and cities. Rogers also disclosed that it added 600 MHz and AWS (1700 MHz) band frequencies to its original 2.5 GHz 5G commercial spectrum, having switched on Dynamic Spectrum Sharing (DSS) technology in several new and existing 5G locations. By March 2021, the network was available in about 170 cities across the country.

In December 2020, Rogers announced that it was starting to roll out Canada's first 5G standalone (SA) core network, in partnership with Ericsson, initially to serve Montreal, Ottawa, Toronto and Vancouver, aiming to support future devices and chipsets as they become available.

Bell Canada

Bell started the construction of its 5G network in February 2020, using equipment from Finnish vendor Nokia. The carrier also selected Ericsson 5G Radio Access Network (RAN) technology to support its nationwide 5G mobile and fixed wireless access deployment. The operator launched commercial 5G services in Montreal, The Greater Toronto Area, Calgary, Edmonton, and Vancouver. In February 2021, the operator reported that the 5G network was available in more than 150 centres (cities and smaller communities) covering 24% of the Canadian population. Bell is targeting 5G population coverage of roughly 50% by end-2021.

Telus

Third largest mobile operator, *Telus*, announced the selection of European vendors Ericsson and Nokia in June 2020 to build its 5G network. Telus then also announced the roll-out of its 5G network in Vancouver, Montreal, Calgary, Edmonton, and the Greater Toronto Area, planning to expanding to additional 26 markets across Canada throughout the remainder of 2020. As of February 2021, Telus' 5G presence reached over 75 towns and cities across the country. The mobile operator also revealed that it selected South Korea's Samsung as a network infrastructure partner to provide 'transformational 5G mobile services'. The operator aims to cover 70% of the Canadian population with 5G mobile services by end-2021

Hong Kong

HKT, *Hutchison 3* and *China Mobile Hong Kong* (CMHK) launched 5G services on April 1, 2020, and *SmarTone* joined the 5G market the following month. CMHK has announced that its 5G network covers over 90% of the main areas of Hong Kong Island and HKT has said its coverage will initially reach 11 of the territory's 18 districts.

India

The Indian government is strongly backing 5G deployment, but 5G is still in early stages of reflection. The Department of Telecom (DoT) is harmonizing spectrum in the 3.3-3.6 GHz and 26 GHz bands, along with the 71-76 GHz, the 81-86 GHz and the 57-64 GHz frequency ranges as 5G candidate bands.

A reasonable target for 5G launch is 2022.

Israel

Pelephone announced the launch of its commercial 5G services in 150 locations October 2020, including Tel Aviv, Haifa, Ra'anana, Dimona and Kiryat Shmona.

Kuwait

All the three MNOs in Kuwait launched 5G services in July 2019.

New Zealand

Vodafone New Zealand launched 5G services in parts of Auckland, Wellington, Christchurch and Queenstown in December 2019. In March 2021, Vodafone New Zealand announced 5G mobile and broadband services were available in parts of Tauranga.

Spark launched 5G service in July 2020 in Palmerston North and promised that four more locations will be added before the end of the year. By March 2021, its 5G services were available in six cities.

Oman

Omantel launched 5G home services in December 2019, its network covering parts of about 17 cities and towns. *Ooredoo* followed and launch 5G services in May 2020 in over 6 cities and towns. Omantel launched 5G mobile services in February 2021 in parts of over 7 locations.

Philippines

Globe Telecom launched 5G FWA services in June 2019 in parts of Bulacan, Cavite City, and Rizal. In March 2021, the network covered 1,300 cities.

PLDT launched its 5G mobile network in the main business districts of Metropolitan Manila in late July 2020. By June 2021, the company had 5,000 active 5G base stations in 17 cities.

Smart Communications launches its 5G network in September 2020.

Mislatel launched 5G services in March 2021.

Qatar

Ooredoo in Qatar claimed in May 2018 to be the first world player to launch 5G nationally with 50 sites registered late in July 2018. Ooredoo seemed to be providing 5G wTTH (wireless To The Home) services in the 3.5 GHz spectrum range domestically with very few compatible devices available. In July 2019, the operator launched its 5G mobile network and by September 2020 the coverage reached 'more than 90% of populated areas' in Qatar. In February 2021, the 5G network covered 95% of the population.

Vodafone Qatar launched 5G services in August 2019. In February 2021, its 5G network covered about 70% of the population.

Saudi Arabia

The SA Kingdom set up a national 5G task force to prepare the foundations for a large scale 5G rollout before the end of 2019.

Zain and *STC* launched 5G services in June 2019. By February 2021, Zain's 5G network covered 50 cities across the country and STC 5G services were available in 22 cities.

Etisalat launched 5G services in Q1 2020 and by December 2020 the 5G network covered 21 cities.

Singapore

M1 announced that it switched on its 5G non-standalone network in Singapore in September 2020. Coverage was available in Singapore's central business district, and other selected areas. The operator announced plans to extend coverage to the rest of the country's key urban areas/towns by end-2020.

Singtel launched 5G services in September 2020, and it had covered about 50 locations by March 2021.

South Africa

In May 2020, *Vodacom* turned on 5G in Johannesburg, Pretoria, and Cape Town. *MTN* rolled out 5G services in areas of Bloemfontein, Cape Town, Edenvale, Johannesburg, Hopetown, Queenstown, Port Elizabeth and Port Alfred in July 2020. Also *Rain* launched 5G services in areas of Cape Town, Johannesburg & Tshwane in July 2020.

Thailand

In March 2020, *Advanced Info Service* (AIS) launched 5G services on the 2.6 GHz range it acquired from auction concluded the same month. By February 2021, the network covered 200 locations and had 5,400 base stations.

True launched commercial 5G services in March 2020 via 400 BTS in the 2.6 GHz band, while the 700 MHz band was enabled in January 2021 and 5G in the 26 GHz range was added in February 2021. By March 2021, True offered 5G connectivity in 355 locations in all 77 provinces.

DTAC commenced commercial 5G services in the 700 MHz band in December 2020. As of February 2021, 5G has been offered in six provinces.

Taiwan

Taiwan Mobile launched 5G services in July 2020 in major cities via 2,000 base stations. *Taiwan Star* launched its commercial 5G services in August 2020. 5G coverage in Taiwan's major metropolitan areas reached 50% and was expected to top 80% by the end of 2020. *Chunghwa Telecom* launched 5G services in June 2020, and by September its 5G network covered 22 major cities. *APT* launched 5G commercial services in October 2020 in 'parts of densely populated areas'.

UAE

Du announced the rollout of a limited 5G network in 2018. In June 2019, it launched 5G services using the 3.5 GHz and 2.6 GHz bands, and by February 2021 it had 700 base stations in main urban areas. *Etisalat* planned to roll out 5G commercial fixed devices in September 2018; its 5G mobile services were made available in May 2019 and the network was available in main urban areas by February 2021.

Uruguay

Antel launched a commercial 5G network in April 2019 in Manantiales, though limited in reach.

2.5. 5G corridors

Twelve "digital cross-border corridors" established inter alia accommodating live tests of 5G for Cooperative Connected and Automated Mobility

Within the European 5G vertical strategy, Connected and Automated Mobility (CAM) is considered as a flagship use case for 5G deployment along European transport paths, in view of creating complete ecosystems around vehicles, from road-safety or digital rail operations to high-value commercial services for road users and train passengers, e.g. mobile office or infotainment. In order to prepare for the deployment of 5G cross-border corridors for CAM, the MSs signed, in March 2017 in Rome, a Letter of Intent (LoI) with the view to intensify cross-border cooperation for large-scale testing and pre-deployment. This agreement was preceded by bilateral initiatives between Luxembourg, France and Germany, and among the Nordic countries, and has been followed since then by a number of agreements between Spain and Portugal, between Bulgaria, Greece and Serbia, and between Estonia, Latvia, Lithuania and Poland over the "Via Baltica", with an extension between Lithuania and Poland. More recently, two agreements - between France and Spain and between the Netherlands and Flanders - were signed, respectively in September 2020 and in May 2020, in the form of MoU. The Netherlands-Flanders agreement concerns the Antwerpen-Rotterdam corridor encompassing road, harbours and inland waterways. The table below presents the situation regarding the on-going initiatives.

Table 3: 5G CAM cross-border corridors

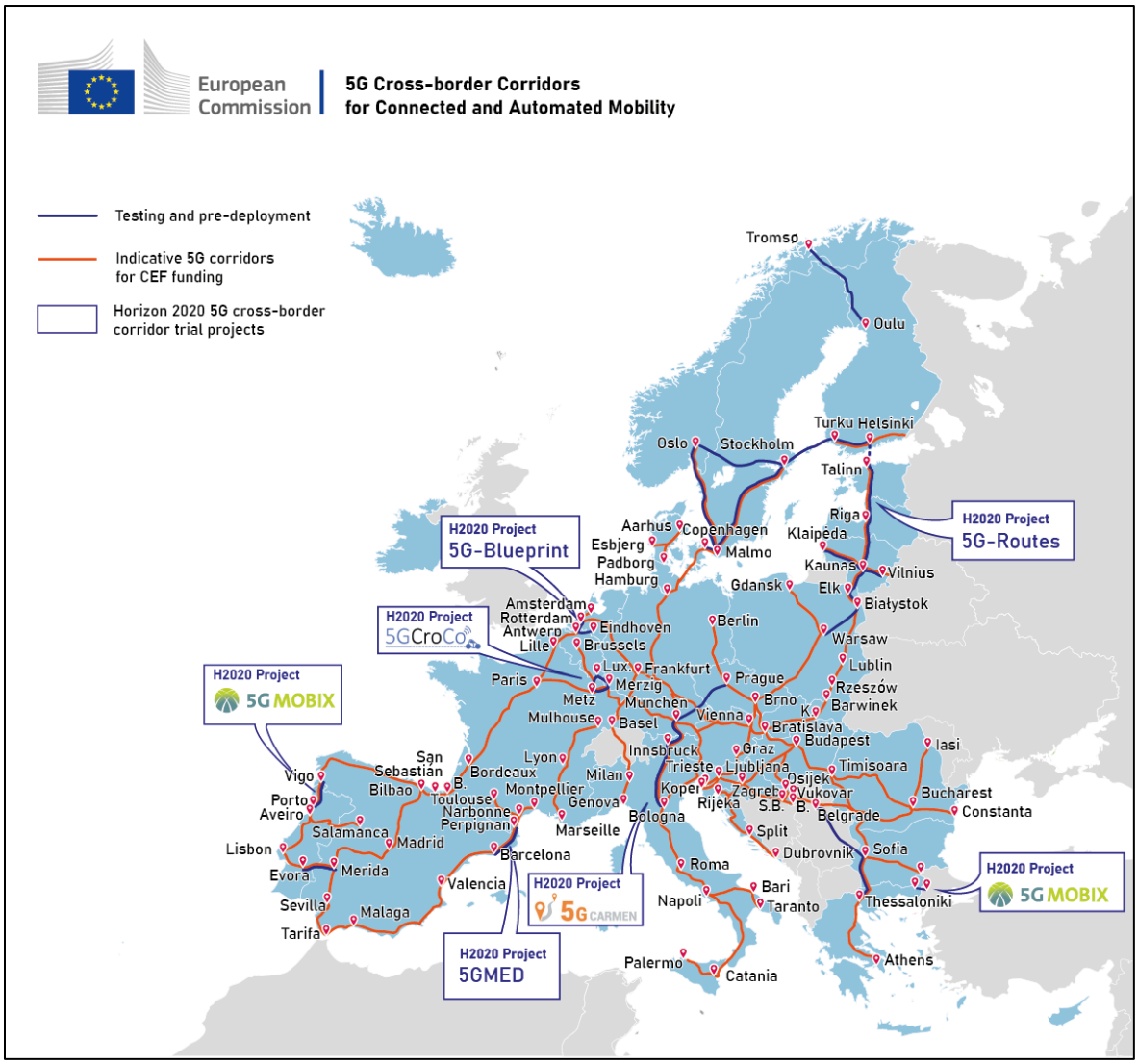
5G Corridors	Political Commitment	H2020 cross-border corridor projects

Metz-Merzig-Luxembourg: FR-DE-LU	LoI between FR and DE in Sept. 2016. LU joined in Sept. 2017. Industry consultation in March 2018. Agreement for testbed signed.	**5G CROCO:** €17.2M Budget (€12.9M H2020 funded). Coord: CTTC (ES). Consortium: DT, PTLU, Orange PSA, Renault, Volkswagen, Volvo + Bosch, SANEF (FR Highways) Ericsson, Huawei, Nokia, i2Cat
Rotterdam-Antwerpen: NL-BE	MoU signed in May 2020 by NL and Flemish authorities	**5G-Blueprint** will trial 5G for road, harbours and inland waterways between Antwerpen and Vlissingen, as of Sept. 2020, with a total budget of €13.6M
Porto-Vigo, Evora-Merida: PT-ES	LoI signed on Digital Day 2018, 10 April 2018	**5G Mobix:** a fraction of €27M budget (€21.4M H2020 funded Coord: ERTICO (BE). Consortium: Cosmote, KPN, Telefonica, Turkcell, Ford Otomotiv, National Electric Vehicle Sweden, Auto-Estradas Norte Litoral, Brisa, Ericsson, NSN, Nokia, Siemens, Fraunhofer, TNO, VTT
E8 "Aurora Borealis": NO-FI	C-ITS-TEN-T legacy. First 10km Aurora open in FI for testing since Nov. 2017. LoI not yet signed	None
Nordic Way2: NO-SE-FI-DK	Follows-on Nordic Way 1, funded under C-ITS/CEF, which demonstrated that providing C-ITS services over cellular networks works.	None
Brenner Corridor: IT-AT-DE	Ahead of DD2, Italy and the three presidents of Euroregion Tirol-Südtirol-Trentino have confirmed their intention to work, in cooperation with other interested Member States, on the development of the 5G Corridor on the Brenner pass motorway However, no LoI signed yet.	**5G-Carmen:** €18M budget (€ 15M H2020 funded). Consortium: DT, TIM, T-Mobile AT, BMW, FIAT Autostrade del Brennero (Brenner-Autobahn) NEC, Nokia, Qualcomm, CEA, IMEC. Support from IT Ministry of Transport, Euregio Tirol-SüdTirol-Trentino, Bavarian Road Administration.
Thessaloniki, Sofia-Belgrade: EL-BG-RS	Letter of Intent signed in June 2018 during Digital Assembly in Sofia.	None
EE-LV-LT Via Baltica (E67) Tallinn (EE) – Riga (LV) – Kaunas (LT) – Lithuanian/Polish border	MoU signed on 28 Sept. 2018 in Riga at the 5G Techritory event. Although focused on C-V2X, elements of the Riga-Tallinn	**5G-Routes** will test 5G for road, rail and maritime over the Via Baltica-North through LV-EE-FI, including cross-border locations. The project, with a budget of €11.7M, will start in Sept. 2020, for a three year period.

	segment builds upon Smart E67 project (ITS).	
LT-PL Via Baltica Kaunas-Warsaw, and further a national extension between Kaunas and Vilnius (LV)	LoI signed on 5 Sept. 2018. Goal is to cooperate in V2X, C-ITS, 4G LTE, LTE Advanced and 5G with the view to promote CAD. EE-LV-LT-PL consolidated MoU signed on 14 Sept. 2020.	
Barcelona (ES) - Perpignan (FR), Santander (ES) - Biarritz	MoU signed on 24 Sept. 2020 between ES and FR.	**5GMED**, will trials 5G-enabled use cases for road and rail across the border between FR and ES. The project, with a budget of €15.7M, will start in Sept. 2020, for three years.
CZ-Bavaria: Prague-Munich	MoU signed on 18 July 2019 in the perspective of CEF Digital.	
Greece-Turkey (8 km segment across the border)	The Greek Ministry of Transport and the Greek Ministry for Digital policies, and the Turkish ICT Authority (BTK) have expressed support to the proposal from 5G-Mobix (see 3rd column)	**5G Mobix:** a *small* fraction of €27M budget (€21.4M H2020 funded). Coord: ERTICO (BE). Consortium: Cosmote, KPN, Telefonica, Turkcell, Ford Otomotiv, National Electric Vehicle Sweden, Auto-Estradas Norte Litoral, Brisa, Ericsson, NSN, Nokia, Siemens, Fraunhofer, TNO, VTT

Source: European Commission

The following map displays all the main public-private initiatives in Europe.



Source: European Commission, September 2020

In addition to these initiatives, three Horizon 2020 projects were launched in November 2018 for the conduct of large-scale testing and trials of 5G connectivity for CAM over cross-border corridors, under the umbrella of 5G Public-Private Partnership (5G PPP). Benefiting from a nearly €50 million funding, for a combined total budget of €63 million, the three projects cover three 5G cross-border corridors: Metz-Merzig-Luxembourg (5GCroCo), Porto-Vigo between Spain and Portugal (5G-Mobix), and Bologna-Munich via the Brenner Path (5G-CARMEN). In addition, a small 8 km cross-border segment between Greece and Turkey will be deployed for testing as well.

Between September and November , 4 new new projects were launched and will provide applications in cross-border connected and automated mobility over road, rail and inland waterway.

- 5GMed will test use cases for connected and automated mobility (CAM), including road and rail, on the basis of the same 5G network infrastructure along the Figueras-Perpignan cross-border corridor.
- 5G-Routes will test and validate over 150 km of the Via Baltica corridor, with a ferry extension to Helsinki, including ports and maritime routes.

- 5G-Blueprint will design and validate a technical architecture, business model and governance model for uninterrupted cross-border teleoperated transport for roads and maritime based on 5G connectivity in the ports of Antwerp (Belgium) and Vlissingen (Netherlands).
- 5G-Rail will validate the first set of FRMCS specifications (which will replace GSM-R) by developing and testing prototypes of the FRMCS ecosystem, for both trackside infrastructure and on-board operations, across different locations in France, Germany and Hungary.
- Moreover, the forthcoming EU financial support to a large-scale deployment of 5G corridors in the perspective of CEF Digital (2021-2027) and the Resilience and Recovery Facility (RRF) has further strengthened the momentum, and the first CEF calls should be launched by October-November 2021 (inception studies and early wave of deployment work). The recent publication by the industry, on 2 October 2020, of a 5G Strategic Deployment Agenda for CAM, with the support of leading European industry associations, and of a 5G SDA on 5G connectivity and spectrum for rail, in April 2020, by European rail associations, will contribute to provide strategic guidance to public and private investment projects in the field in the framework of the new European Partnership for Smart Networks and Services (SNS) that will be set up by the second half of 2021.

2.6. 5G spectrum assignments in EU-27

The 5G pioneer bands identified at EU level are the 700 MHz (694-790 MHz), the 3.6 GHz (3.4-3.8 GHz) and the 26 GHz (24.25-27.5 GHz) frequency bands. The technical conditions of the three 5G pioneer bands have been harmonised through Commission Implementing Decisions (EU) 2016(687) of 28 April 2016, 2019/235 of 24 January 2019 and 2019/784 of 14 May 2019 respectively. The last one, which concerns the 26 GHz band, has been amended by Commission Implementing Decision (EU) 2020/590 of 24 April 2020 to take due account of the developments at the last ITU World Radiocommunication Conference in 2019.

Member States have adopted a common deadline for the effective usability of pioneer spectrum in the European Electronic Communications Code, namely the 3.6 GHz band and at least 1 GHz within the 26 GHz band had to be assigned in all Member States by end of 2020. As for the 700 MHz band, Member States should have allowed its use by 30 June 2020, in accordance with Decision (EU) 2017/899 ("UHF Decision").

All Member States have recognised the need for timely availability of the harmonised spectrum for 5G. Work is on-going. Spectrum assignments per EU MS are detailed in the Annex section.

A number of auction processes scheduled for H1 2020 were postponed due to the covid-19 pandemic. Some were rescheduled and ended in the last months, others are expected later in 2021.

2.6.1. Overview of spectrum assignment progress

In 20 MSs, spectrum has been auctioned in at least one pioneer band for 5G. In some of these MSs, auctions are ongoing or planned for the coming months. At the end of June 2021, 53.7% (50% assigned and usable in 2021) of spectrum in the 700 MHz band, 65.4% (65.4%) in the 3.4-3.8 GHz band and 22.2% (22.2%) in the 26 GHz band have been assigned in the EU-27. However, not all assignments have been usable by end of June 2021, which has been taken into account in the EU scoreboard, as marked in the values in parenthesis.

The 700 MHz band has been assigned in fifteen Member States: Austria (2020), Cyprus (2020), Czech Republic (2020), Denmark (2019), Finland (November 2016), France (2015), Germany (2015), Greece (2020), Hungary (March 2020), Italy (October 2018), Luxembourg (2020), Netherlands (2020), Slovakia (2020), Slovenia (2021) and Sweden (December 2018). All in all, assignment of 700 MHz accelerated in 2020 and the first months of 2021 with more than half of the global count to date. Other 700 MHz assignments will take place later in 2021.

In the mmWave bands, Denmark, Finland, Greece, Italy and Slovenia have so far assigned spectrum in the 26 GHz band. Additional auctions in 26 GHz frequencies are expected. In Germany, local licences are available in the 26 GHz: "*local licences available on demand subject to co-ordination*". Some assignments processes in the 26 GHz frequencies are put on hold or rescheduled for 2022 or 2023 due to a lack of demand.

Spectrum auctions scheduled in 2021

- Croatia, 700 MHz/3.6 GHz/26 GHz, expected to start on 12 July 2021
- Estonia, 700 MHz/3.6 GHz/26 GHz, likely in 2021
- Ireland, 700/2100/2300/2600 MHz, expected during summer 2021
- Lithuania, 700 MHz/3.6 GHz, likely in 2021
- Malta, 700 MHz, June 2021 and 3.6/26 GHz likely in 2021
- Poland, 3.6 GHz, by 27 August 2021
- Portugal, 700/900/1800/2100/2600 MHz & 3.6 GHz, ongoing auction
- Romania, 700 MHz/800 MHz/1500 MHz SDL/2600 MHz TDD/3.6 GHz, auction expected in the third quarter 2021
- Spain, 700 MHz, ongoing auction (launched on 21 July 2021)

Spectrum auctions scheduled/planned as from 2022

- Austria, 26 GHz, by the third quarter 2022
- Belgium, 700 MHz/3.6-3.8 GHz/1.5 GHz, early 2022
- Latvia, 700 MHz, award expected in 2022
- Luxembourg, 26 GHz, on hold due to lack of demand
- Netherlands: 26 GHz
- Poland, 700 MHz by July 30, 2022, 26 GHz by December 31, 2022
- Romania, 26 GHz, likely in 2022
- Spain, 26 GHz, expected at year-end 2021

Spectrum auctions scheduled/planned after 2022

- Belgium, 26 GHz in 2023, 31.8-33.4 GHz and 40.5-43.5 GHz from 2022 to 2027
- Latvia, 26 GHz before 2024
- Netherlands, 3450-3750 MHz to be auctioned for 5G nationwide in 2022 and 3400-3450 and 3750-3800 MHz reserved for local use
- Portugal, 26 GHz auction expected in 2023
- Slovakia, 26 GHz, not before 2023

2.6.2. Allowing spectrum use for 5G

Allowing use of spectrum in low, mid and high bands is key for 5G. Effective usability of spectrum will highly contribute to the position of EU Member States in the 5G race.

Mid-band spectrum is defined as the baseline capacity layer, in favour of flexibility for many use cases with higher throughputs, wider spectrum and potential refarming of LTE spectrum. The 3.4-3.8 GHz band is the primary band in Europe with early availability.

High-band spectrum is known as the extreme capacity layer with large amounts of spectrum potentially available for very high capacity, very high data rates but limited coverage, partially offset by massive MIMO. The 26 GHz band (24.25 – 27.5 GHz) is the pioneer high band for 5G in Europe.

Italy was the first Member State that allowed the use of all the 5G pioneer bands, finishing out the spectrum awards in September 2018, followed by Finland which completed the 26 GHz band award process in June 2020. Greece ranked third in assigning 26 GHz spectrum in Europe in December 2020. Slovenia appears to be the fourth MSS to have auctioned 26 GHz spectrum, closely followed by Denmark.

Usability of low-band (700 MHz) spectrum

700 MHz spectrum already assigned in fifteen EU-27 countries: Austria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Slovakia, Slovenia and Sweden.

Table 4: Availability of 700 MHz spectrum in EU-27 (as of end June 2021)

Member State	Frequencies	Tentative/Expected assignment date. Date of completion	Comments
Austria	703-733/758-788 MHz	August 2020	Licences include coverage conditions
Belgium	703-733/758-788 MHz	Expected early 2022	Domestic administrative issues at federal/regional level
Bulgaria	703-723/758-778 MHz	2021?	new consultation expected by June 2021
Croatia	703-733/758-788 MHz	Expected to start on 12 July 2021	EC issued a decision on 8 November 2018 to initiate proceedings against Croatia
Cyprus	703-733/758-788 MHz	December 2020	Started and ended on December 17, 2020
Czech Rep.	703-733/758-788 MHz	November 2020	Auction rescheduled in February 2020 and further rescheduled in May 2020 and further delayed to November 2020
Denmark	703-733/758-788 MHz	March 2019	
Estonia	703-733/758-788 MHz	Likely in 2021	
Finland	703-733/758-788 MHz	November 2016	5G services in 2019
France	703-733/758-788 MHz	November 2015	5G services in 2019/2020
Germany	703-733/758-788 MHz	June 2015	Spectrum approved for use in July 2019
Greece	703-733/758-788 MHz	December 2020	Spectrum available in December 2020 Auction ended on December 16, 2020
Hungary	703-733/758-788 MHz	March 2020	
Ireland	703-733/758-788 MHz	Expected during summer 2021	
Italy	703-733/758-788 MHz	October 2018	5G services possible in 2022 due to TV use
Latvia	703-733/758-788 MHz	Expected in 2022	Unresolved cross-border issues
Lithuania	703-733/758-788 MHz	Expected in 2021	
Luxembourg	703-733/758-788 MHz	July 2020	Public consultation in Q3 2018, Q3 2019, March 2020
Malta	703-733/758-788 MHz	Expected in June 2021	Availability date for 5G commercial use
Netherlands	703-733/758-788 MHz	July 2020	
Poland	703-733/758-788 MHz	Expected by 30 July 2022	
Portugal	703-733/758-788 MHz	Started in December 2020 Ongoing	Auction was scheduled to begin in April 2020, rescheduled. Six lots of 2x5 MHz, €19.20 million per lot Rights of use: January/February 2021 Auction stopped in December 2020 and resumed in March 2021.
Romania	703-733/758-788 MHz	Expected in the third quarter 2021	"National Strategy for the Implementation of 5G in Romania" between November 20th and December 21st, 2018.
Slovakia	703-733/758-788 MHz	November 2020	Primarily for 5G
Slovenia	703-733/758-788 MHz	19 April 2021	Public consultation issued in May 2019. Auction delayed to YE2020 in December 2019 and further delayed in 2020
Spain	703-733/758-788 MHz	Expected to start on 21 July 2021	Initially planned for Q1 2020, delayed until May 2020. Further delayed due to the outbreak of the novel coronavirus in the country.
Sweden	703-733/758-788 MHz	December 2018	40 MHz assigned, available as from Jan. 1st, 2019 till Dec. 31st, 2040

Source: IDATE DigiWorld, based on NRA information

Table 5 : Availability of 700 MHz spectrum in the UK (as of end March 2021)

Country	Frequencies	Tentative/Expected assignment date. Date of completion	Comments
UK	703-733/758-788 MHz	March 2021	80 MHz

Source: IDATE DigiWorld, based on NRA information

Usability of mid-band (3.4-3.8 GHz) spectrum

Spectrum within 3.4-3.8 GHz frequency band has already been assigned in accordance with 5G technical conditions[5] in 20 EU-27 countries: Austria, Belgium (only 40 MHz) Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Portugal (only 100 MHz), Romania, Slovenia, Spain and Sweden.

Spain auctioned two additional 10 MHz lots in February 2021. In Portugal, the process is still ongoing at the time of writing.3.4-3.8 GHz spectrum has been assigned[6] in 2016 and 2020 in Hungary, in May 2017 in Ireland, in Czech Republic in 2017, in July 2018 in Spain and (the upper half of the band) in September 2018 in Italy. Parts of 3.4-3.8 GHz spectrum were awarded in Latvia in November 2017 and September 2018. Finland assigned the 3.6 GHz band in September 2018. In March 2019, Austria assigned 3.6 GHz spectrum. The 3.6 GHz auctions ended in June 2019 in Germany raising unprecedented amounts. In Slovakia, the 3.4-3.8 GHz (400 MHz) had been previously assigned for 4G usage and the conditions of the existing licences (valid until 2025) were modified into 5G-compatible ones. The auctions in Bulgaria, Denmark and Slovenia were completed in April 2021.

Outside Europe, the USA is progressively catching up in this spectrum range. The FCC established a three-tier spectrum sharing system for spectrum at 3.5 GHz in 2015. In 2017, the FCC started to analyse how 3.7-4.2 GHz spectrum could be relevant for mobile broadband. Earlier in 2018, the FCC identified spectrum at 3.4 GHz as a government band for a potential reallocation for mobile broadband. In September 2020, the FCC announced winning bidders of 3.5 GHz (3550-3650 MHz) in auction 105. In December 2020, the 3.7-3.8 GHz started. The auction ended on January 15, 2021 for the clock phase and on February 17, 2021 for the assignment phase. It raised 81.167 billion USD (68.362 billion EUR) in gross proceeds.

[5] Harmonised technical conditions in line with Commission Decision (EU) 2019/235 of 24 January 2019 on amending decision 2008/411/EC as regards an update of relevant technical conditions applicable to the 3400-3800 MHz frequency band

[6] Parts of this frequency band are used for 4G fixed wireless access

Table 6: Availability of 3.4-3.8 GHz spectrum in EU-27 (as of end June 2021)

Member State	Frequencies	Tentative/Expected assignment date Date of completion	Comments
Austria	3410-3800 MHz	March 2019	Four months after approval of the May 2018 tender document (period of approval not limited by law)
Belgium	3400-3800 MHz	Expected early 2022	Administrative issues at federal/regional level 40 MHz have been assigned for local use (port)
Bulgaria	3400-3800 MHz	7 April 2021	
Croatia	3400-3600 MHz 3600-3800 MHz	2022 Expected to start on 12 July 2021	
Cyprus	3400-3800 MHz	December 2020	Started and ended on December 17, 2020
Czech Rep.	3600-3800 MHz 3400-3600 MHz	2017 November 2020	 Auction rescheduled in February 2020 and in November 2020
Denmark	3410-3800 MHz	21 April 2021	Delayed to 2021 on 8 December 2020 Started in March 2021 Licences expected to be valid from 1 June 2021 to 31 January 2042
Estonia	3400-3800 MHz	Expected in 2021	Auction for 390 MHz of spectrum suspended in April 2019. New consultation held in October 2019
Finland	3400-3800 MHz	October 2018	
France	3400-3800 MHz	October 2020	Public consultation in October 2018. Auction ended in October 2020.
Germany	3400-3700 MHz 3700-3800 MHz	June 2019 December 2019	Full availability in 2022, early stage in 2019 100 MHz dedicated to vertical sites, applications opened on November 21st, 2019
Greece	3400-3600 MHz	December 2020	Public consultation issued in Q1 2019 Another public consultation expected by YE2019 Ended on December 16, 2020
Hungary	3400-3800 MHz	March 2020	400 MHz assigned
Ireland	3410-3435 MHz and 3475-3800 MHz	May 2017	Available from January 2019
Italy	3600-3800 MHz	October 2018	
Latvia	3400-3800 MHz	November 2017 September 2018	 Remaining 50 MHz
Lithuania	3400-3800 MHz	Expected in 2021	Public consultation in Q2 2018 including the 3800-4200 MHz band. New public consultation in Q3 2018. Another public consultation closed (04/2019) Temporary allocation to Telia
Luxembourg	3420-3750 MHz	July 2020	Public consultations in Q3 2018, May 2019, March 2020. 280 MHz + 50 MHz announced in December 2019 by the Prime Minister
Malta	n/a	Expected in 2021	Public consultation in Q2 2018
Netherlands	3500-3700 MHz 3400-3450/3750-3800 MHz	Expected at year-end of 2021/beginning of 2022	Final recommendations disclosed. Spectrum available from September 2022 Spectrum available from 2026
Poland	3400-3800 MHz	Expected by 27 August 2021	Public consultation in Q3 2018. Four blocks of 80 MHz
Portugal	3400-3800 MHz	Ongoing	Auction initially scheduled to begin in October 2020. Six lots of 10 MHz, 840 000 EUR per lot Rights of use valid as from January/February 2021. Auction stopped in December 2020 and resumed in March 2021. 100 MHz have been assigned under 5G conditions.
Romania	3400-3800 MHz	Expected in the third quarter 2021 2015	110 MHz FDD and 145 TDD spectrum valid from 2020 to 2025. 400 MHz available from 2026

Member State	Frequencies	Tentative/Expected assignment date Date of completion	Comments
	3700 MHz		3700 MHz licence granted in October 2015 valid for a period of 9 years starting from January 1st, 2016
Slovakia	3400-3800 MHz	Expected in 2021	Licences valid until 2025.
Slovenia	3500-3800 MHz	19 April 2021	Public consultation issued in May 2019. Auction delayed to YE2020 in December 2019
Spain	3400-3600 MHz	2016	160 MHz assigned for 4G (and usable for 5G)
	3600-3800 MHz	July 2018	For 5G
		February 2021	2 remaining 10 MHz lots assigned
Sweden	3400-3720 MHz	January 2021	Initially scheduled for March 2020, rescheduled to November 2020. Resumed and ended on 19 January 2021

Source: IDATE DigiWorld, based on NRA information

Table 7: Availability of 3.4-3.8 GHz spectrum in the UK (as of end March 2021)

Country	Frequencies	Tentative/Expected assignment date Date of completion	Comments
UK	3400-3600 MHz	April 2018	150 MHz assigned in the 3.4-3.6 GHz band
	3680-3800 MHz	March 2021	120 MHz assigned

Source: IDATE DigiWorld, based on NRA information

Usability of high-band (24.25-27.5 GHz) spectrum

26 GHz spectrum has been assigned in five Member States: Denmark, Italy, Finland, Greece and Slovenia, and is available for local licences in Germany.

Italy was the first Member State to auction 1 GHz of the 26 GHz band; at world level, it ranks second, after South Korea, which already awarded 2400 MHz spectrum at 28 GHz in June 2018. The USA ranks third globally with 1550 MHz of such spectrum. Finland is the second country to have auctioned 26 GHz spectrum at European level and the fourth country at world level. Greece is the third European country to auction 26 GHz spectrum. Slovenia and Denmark which assigned 26 GHz in April 2021 follow.

A number of countries decided to put 26 GHz auction processes on hold due to a lack of demand.

Table 8: Availability of 26 GHz spectrum in EU-27 (as of end June 2021)

Member State	Frequencies	Tentative/Expected assignment date Date of completion	Comments
Austria	24.25-27.5 GHz	Expected by the third quarter 2022	Public consultation on plans for 26 GHz in June 2019
Belgium	n/a	No award planned	Consultation launched
Bulgaria	24.25-27.5 GHz	n/a	Consultation launched
Croatia	24.25-27.5 GHz	Expected to start on 12 July 2021	
Cyprus	24.25-27.5 GHz	n/a	
Czech Rep.	24.25-27.5 GHz	n/a	Earmarked for 5G in 2019
Denmark	24.65-27.5 GHz	21 April 2021	Usage requirements Started in March 2021
Estonia	24.25-27.5 GHz	Expected in 2021	
Finland	25.1-27.5 GHz[7]	8 June 2020	Parts of the range are already available for shared use
France	26.5-27.5 GHz	n/a	Public consultation in Q2 2018
Germany	24.25 GHz to 27.5 GHz	2020	General authorisations in 2H 2020 Application procedure for local/regional use
Greece	24.25-27.5 GHz	December 2020	Ended on December 16, 2020
Hungary	26.5-27.5 GHz	n/a	Public consultation in July 2019, limited demand for 5G. Auction put on hold
Ireland	n/a	n/a	Spectrum assigned in 2017 but restricted to point-to-point (P2P) links. Study year-end 2020 Study concluded on lack of market demand
Italy	26.5-27.5 GHz	October 2018	
Latvia	n/a	Expected before 2024	
Lithuania	n/a	n/a	Depending on market demand, on hold
Luxembourg	24.5-27.5 GHz	2022 ?	Consultation on use of 26 GHz spectrum ended on 8 December 2020 On hold due to lack of demand
Malta	n/a	2021	
Netherlands	24.5-27.5 GHz	Expected from 2022	Ongoing consultations
Poland	26.5-27.5 GHz	Expected by year-end 2022 (subject to market demand)	Band reorganisation envisioned
Portugal	n/a	2023	
Romania	24.25-27.5 GHz	Likely in 2022	
Slovakia	24.5-27.5 GHz	Expected after 2023	Lack of market demand
Slovenia	26 GHz	January 2018	Two blocks (56 and 112 MHz) awarded, but not available for 5G
	26 GHz	19 April 2021	Public consultation issued in May 2019 for 5G
Spain	n/a	Expected at year-end 2021	1.4 GHz of spectrum could be assigned
Sweden	24.25-27.5 GHz	2022 ?	Auction process considered and consultations launched Local licences in 2021

Table 9: Availability of 26 GHz spectrum in the UK (as of end June 2021)

Country	Frequencies	Tentative/Expected assignment date Date of completion	Comments
UK	24.25-26.5 GHz	2020	Local licences available on demand subject to co-ordination

Source: IDATE DigiWorld, based on NRA information

[7] The lower range will be reserved for local/regional (vertical) players and research/development/educational usage.

2.7. Product/market developments

2.7.1. Overview of the 5G baseband market as of end of March 2021

Now 4 generations of (high-end) 5G chipset and an expansion into lower tier and new categories

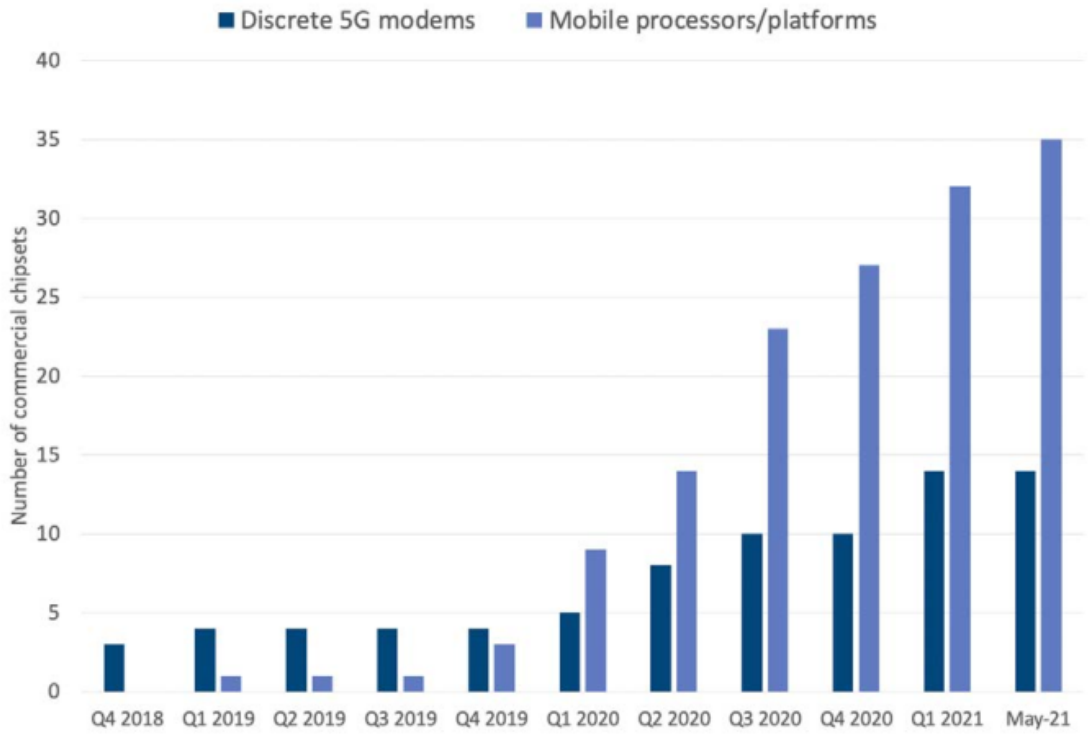
In 2019 and 2020, the 5G chipset market has seen several announcements that points to both an increased maturity and competition on the market and in February 2021, when Qualcomm announced the 4th generation of its flagship 5G baseband, the X65, the previous generation was only starting to be available in commercial end-user devices.

In the meantime several mid-end 5G chipsets have been announced, not only by Qualcomm, but also its competitors and the end of the year has even seen the release of even lower end chipsets such as the Mediatek Dimensity 720 that is powering the cheapest 5G phone, the Oppo Realme v3, at 146 USD (in China) or the Snapdragon 480 (announced at the beginning of 2021).

While first integrated 5G SoC announced can be dated back to September 2019 with the Samsung Exynos 980, followed by Huawei/HiSilicon Kirin 990 5G, all targeting the high end market, the end of 2019, 2020 and the course of 2021 has seen several other 5G SoC announced and launched by Qualcomm, Huawei, Samsung, Mediatek, but also the lower profile UniSOC (previously known as Spreadtrum and focused on the lowend Chinese market. Since that date of September 2019, not only have we watched high-end 5G SoC released but also a proliferation of mid-end chipsets and to a lower extent low-end chipset. More recently, as first standalone 5G network have been commercially launched, more specific IoT 5G chipsets have been announced, from Qualcomm notably but other players such as Sequans with its Taurus 5G chipset are known to be developing a proposition too.

The fact that most 5G chipsets are integrated SoC is not anecdotal as it reveals the increased maturity of the market and the capability to address more and more targets. Discrete 5G modem are developed and then integrated into SoC with different capabilities depending on the price tear targeted. The figure below highlights this fact. What is notable also is the increased number of chipsets released each quarter, as a result of this increased competition.

Figure 7: Evolution in the number of commercial 5G chipset



Source: gsacom

While those new lower tier chipset have initially had in common the fact that they only supported the sub-6 GHz frequency range, this has started to change with the introduction of Qualcomm Snapdragon 480 a further indication of the ever evolving market. Indeed, limiting 5G chipset to sub-6 GHz is a way to reduce the Bill of Material (BOM) and make it more adapted to both lower tier segments and markets where mmWave is not yet available. However, as mmWave is slowly being introduced in more markets than just in the US (South Korea, Japan, Russia, Italy, Singapore…) limited support for mmWave in lower end 5G chipset now can be seen, the SD480 being the first to feature this capability. Announced on the 4th of January 2021, the SD480 support both sub 6 GHz frequency bands and mmWave, albeit with some limitations:

- Bandwidth limited to 200 MHz in the mmWave for 2.5 Gbps maximum 5G throughput
- No cross carrier aggregation between mmWave and Sub 6 GHz spectrum

As of mid-June 2021, around 54 5G chipsets had been in development or released but at the same time, only 35 chipsets could be considered as commercially available (11 from Qualcomm, 7 from Huawei, 6 from Samsung 13 from Mediatek and 2 from UniSoc). As of end of September 2019, we reported only 5 of them and only 8 at the end of December 2019.

It is to be noted here that in this count of 5G chipset. Discrete 5G modem that are not sold separately, such as the X52, X51, X52, X53 Qualcomm modems are not included, even though, as such they could be considered as modems.

Table 10: Presentation of announced 5G chipsets

Vendor	Product name	Announ-cement	Availability	Throughputs	Comments
Qualcomm	X50 (baseband)	First announced in 2016	End of 2018	Up to 5 Gbps	Discrete baseband, need to be implemented with 2G/3G/4G baseband. 18 OEM announced to use X50
Qualcomm	X55 (basebands)	February 2019	Expected to ship in 2H 2019	Up to 7 Gbps in the DL, 3 Gbps in the UL	Now support FDD in sub 6 GHz with up to 200 MHz bandwidth
Qualcomm	X60 (basebands)	February 2020	Sampling in Q1 2020 for 1st commercial smartphone early 2021	Up to 7,5 Gbps in the DL, 3 Gbps in the UL	5nm baseband, support Sub6 GHz and mmWaves, NSA and SA, 2CCA, mmwave + Sub6 CA, DSS, VoNR
Qualcomm	X52 (basebands)	December 2019		up to 3.2 Gbps / 1.6 Gbps	Unclear if sold separately or only to be used in mid range 5G SoC from Qualcomm
Qualcomm	Snapdragon 765 and 765G	December 2019	Q1 2020	up to 3.2 Gbps / 1.6 Gbps	based on Qualcomm x52 5G modem
Qualcomm	Snapdragon 768G	May 2020	NA	up to 3.7 / 1.6 Gbps	An updated version of the SD 765G to keep up with Mediatek competition
Qualcomm	X51			up to 2.5 / 1.2 Gbps (support for up to 100 MHz)	Does not support mmWaves, will not be sold separately but integrated in future Qualcomm SoC
Qualcomm	Snapdragon 690	June 2020	H2 2020	up to 2.5 / 1.2 Gbps (support for up to 100 MHz)	based on x51 5G modem, aimed at lower range 5G modem. It doesn't support mmWave, only sub 6 GHz
Qualcomm	RB5	June 2020	products based on RB5 expected by the end of 2020	Sub 6 and mmWave support	Qualcomm Robotic platform based on x55
Qualcomm	Snapdragon 750G	September 2020	available by the end of 2020	up to 3.2 Gbps / 1.6 Gbps	based on x52 modem, support sub 6 GHz and mmwaves
Qualcomm	Snapdragon 888	December 2020		Up to 7,5 Gbps in the DL, 3 Gbps in the UL	integrate the x60 modem, support Sub6 GHz and mmWaves, NSA and SA, 2CCA, mmwave + Sub6 CA, DSS, VoNR
Qualcomm	Snapdragon 480	January 2021	First devices to be launched "early 2021"	Up to 2.5 Gbps (5G)/660 Mbps (5G) vs 800/210 Mbps (4G)	based on x51 5G modem, aimed at lower range 5G modem. Support for mmWave (up to 200MHz BW) and Sub-6 GHz (up to 100 MHz), SA and NSA modes, TDD, FDD, and Dual Spectrum Sharing (DDS)
Qualcomm	Snapdragon 870	January 2021	First phones to be announed in Q1 2021	Up to 7.5 Gbps in the DL, 3 Gbps in the UL	based on x55 modem, 800 MHz in mmWaves, support FDD in sub 6 GHz with up to 200 MHz bandwidth
Qualcomm	x65	February 2021		Up to 10 Gbps	up to 1GHz aggregated (10x100 MHz) bandwidth in the mmWaves and up to 300 in the sub 6 GHz, support 3GPP Rel 16, based on 4nm process
Qualcomm	x62	February 2021		Up to 4.6 Gbps	Up to 400 MHz bandwidth (4x100) in mmWaves, up to 120 MHz in sub 6 GHz, same upgradable architecture as x65
Qualcomm	x53	March 2021		up to 3.3 Gbps	Sub 6 GHz only ?
Qualcomm	Snapdragon 780G	March 2021		up to 3.3 Gbps	based on x53 5G modem RF System

Vendor	Product name	Announ-cement	Availability	Throughputs	Comments
Qualcomm	Snapdragon 778	May 2021		up to 3.7 Gbps	based on x53 5G modem RF System, support 400 MHz bandwidth in mmWave and 100 MHz in sub 6 GHz
Qualcomm	315 5G IoT modem	May 2021		up to 1.54 Gbps (DL) & 330 Mbps (UL)	IoT chipsetv, support sub 6 GHz only, SA mode only, TDD only, up to 100 MHz bandwidth
Qualcomm	QCS8250	June 2021		up to 7.5 Gbps	5G (sub 6 GHz and mmwave support) + Wifi (802.11ax) + support for 2.4 GHz, 5 GHz and 60 GHz Wifi
Qualcomm	QCS6490 & QCM6490	June 2021		up to 3,7 (DL) / 2.5 Gbps (UL) with up to 400 MHz bandwidth support in mmwave + up to 100 MHz in sub 6 GHz	chipset for ruggedized devices, support for sub 6 GHz and mmwave support 5G + Wifi 6 and 6E+ support for 2.4 GHz, 5 GHz
Samsung	Exynos 5100	August 2018	End of 2018	up to 2 Gbps in sub 6 GHz and 6 Gbps in mmWaves	Integrated multimode 2G/3G/4G/5G chipset, built on 10nm process, fully compatible with 3GPP Rel 15
Samsung	Exynos 5123	October 2019	mass production expected to begin by the end of 2019	up to 7.35 in mmWave and 5.1 GHz in sub 6GHz. In LTE: 3 Gbps/422 Mbps	built using a 7nm EUV process. It also support 1024 QAM in 4G
Samsung	Exynos 980	September 2019	Mass production by the end of 2019 and devices available in the begining of 2020	Up to 2,5 Gbps/1,28 Gbps and up to 3,55 Gbps through LTE/5G Dual connectivity	SoC with integrated 5G baseband
Samsung	Exynos 880	May 2020	May 2020 (already shipped in Vivo Y70S in China)	Up to 3,55/1,28 Gbps. 3,55 can be reached with dual LTE/5G connectivity	SoC with integrated 5G baseband for mid range device. Only support sub 6 GHz
Samsung	Exynos 1080	November 2020	NA	up to 5.1 Gbps (sub 6) and 3.67 Gbps (mmWaves)	SoC only meant for Chines market at the begining. A mid range solution competing with the SD 765. Support Sub 6 and mmWaves will debut with the Vivo X60 series
Samsung	Exynos 2100	announced on the 12th of January 2021	NA	mmWave; Up to 7,35 Gbps/3.67 Gbps, Sub 6 GHz: 5,1 Gbps / 1.92 Gbps	build on 5nm process
Hi-Silicon	Balong 5G01	February 2018	End of 2018	Up to 2.3 Gbps	Only for Huawei products, designed for fixed 5G devices. 5G only
Hi-Silicon	Balong 5000	January 2019	NA	Up to 4,6 Gbps at sub 6GHz and 6,5 Gbps on mmWaves	Dubbed as the first single chip multi mode modem (2G/3G/4G/5G) and first to support 2CC of 100MHz

Vendor	Product name	Announ-cement	Availability	Throughputs	Comments
Hi-Silicon	Kirin 990 5G	sept-19	End of Q4 2019/2020	Up to 2,3 Gbps/1,5 Gbps	mass production thought to start in Q3 2019, along the introduction of the Huawei Mate 30 model
Hi-Silicon	Kirin 820 5G	March 2020	sampling in Q1 2020, available mid 2020 in devices	Up to 2,3 /1,5 Gbps	Sub 6 GHz only, based on Balong 5000 modem
Hi-Silicon	Kirin 985 5G	April 2020		Up to 1.277 Gbps / 173 Mbps	Sub 6 GHz only,
Hi-Silicon	Kirin 9000	October 2020	November 2020	Up to 6.5 Gbps	SoC integratingBalong 5000 modem, support sub 6 and mmWave
Hi-Silicon	Kirin 9000E	January 2021			reduced number of GPU and NPU cores, and the same CPU, modem processor, and ISP. Support SA&NSA, sub 6 GHz and mmWave
Hi-Silicon	Kirin 9000L	March 2021			built on Samsung 5nm EUV process to circunvene US ban on huaweir, but still a rumor
Hi-Silicon	Kirin 9010	2022 ?	NA	NA	built on a 3nm process, still a rumor and dependent on the capability to use still unready 3nm process from TSMC
Mediatek	Helio M70 (MT6885)	June 2018	2019-2020	Up to 4,7 Gbps (DL) / 2,5 Gbps (UL)	Standalone modem. Devices powered by Helio M70 to be available in early 2020 while being sampled in Q3 2019. Partnership with China Mobile. It will use 7 nm EUV process from TSMC
Mediatek	Dimensity 1000L SoC / MT6885 based on Helio M70	May 2019	sampling in Q3 2019, availabke in devices in Q1 2020	Up to 4,6 Gbps (DL) / 2,5 Gbps (UL), support for 2x100 MHz CA	5G SoC with an Helio M70 integrated. Support mmwaves and sub 6GHz, 2CCA , SA and NSA
Mediatek	Dimensity 1000+ SoC	May 2020			5G SoC with higher performance than Dimensity 1000L but same connectivity
Mediatek	Dimensity 800 SoC	January 2020	First devices to be launched during H1 2020 but may slip in H2 with COVID-19	unanounced throughput	multimode 5G SoC to power Premium mid-range devices. Support 2 carrier aggregation, NSA and standalone, only sub 6 GHz, DSS, VoNR
Mediatek	Dimensity 820 SoC	May 2020	1st devices in June 2020	2CC aggregation up to 100 MHz, sub 6GHz only, VoNR, up to 4.7 /2.5 Gbps	
Mediatek	Dimensity 800U			up to 2,3 Gbps	up to 100 MHz BW, 2 CC Aggregation, SA, NSA, Sub 6 only
Mediatek	Dimensity 720 SoC	July 2020		up to 2,77 Gbps in the DL	SA&NSA, 2 CC aggregation up to 120 MHz, Sub 6 GHz only
Mediatek	Dimensity 700 SoC			up to 2,77 Gbps in the DL	2CC 5G-CA, SA&NSA, DSS
Mediatek	Dimensity 1000C SoC			up to 2,3/1,2 Gbps	SA&NSA, 2 CC aggregation up to 120 MHz, Sub 6 GHz only
Mediatek	T700	announced in August 2020	will be found in PCs in 2021	NA	Developped in collaboration with Intel for 5G PCs, probably based on Helio M70, with support limited to sub 6 GHz

Vendor	Product name	Announ-cement	Availability	Throughputs	Comments
Mediatek	T750	Announced in September 2020	sampling in September 2020	NA	Baseband for FWA and mobile routeurs, built with a 7 nm process and probably based on Helio M70, support for up to 200 MHz BW
Mediatek	Dimensity 1200 SoC	January 2021		up to 4.7 Gbps / 2.5 Gbps	based on Helio M75, Support for Sub 6 GHz only, full dual SIM 5G SA support (claimed as a first)built on 6nm process, up to 200 MHz bandwidth
Mediatek	Dimensity 1100 SoC	January 2021		up to 4.7 Gbps / 2.5 Gbps	based on Helio M75, Support for Sub 6 GHz only, full dual SIM 5G SA support (claimed as a first)built on 6nm process, up to 200 MHz bandwidth
Mediatek	Helio M80 (baseband)	February 2021	to be sampled in 2021	up to 7.67 Gbps / 3.76 Gbps	support for both mmWave and Sub 6 GHz frequencies, dual 5G SIM, sub 6 (up to 200 MHz BW) and mmWave (up to 800 MHz) carrier aggregation
Mediatek	Dimensity 900	May 2021	Q2 2021	up to 2.7 Gbps DL	Support up to 120 MHz bandwidth through 2 Carrier Component aggregation, support SA and NSA, TDD-FDD CA and dual 5G SIM
UniSOC (Spreadtrum)	Makalu Ivy510	February 2019	2020	up to 2.3 Gbps	Support SA and NSA, To be found in mid range smartphones in China in 2020. It will also be found in CPEs and modules
UniSOC (Spreadtrum)	T7510				based on baseband ivy510, support SA/&NSA, sub 6 only, DSS, VoNR
UniSOC (Spreadtrum)	T7520	February 2020		up to 3.25 Gbps in SA	2nd gen 5G platform based on Makalu 5G platform, support DSS, support TDD+FDD carrier aggregation, sub 6 GHz only
UniSOC (Spreadtrum)	V8811	November 2020		The 1st 5G NB-IoT chipset, 3GPP Rel 16 compliant	**UniSOC (Spreadtrum)**
U-Blox	UBX-R5 IoT chipset	June 2019	5G software update realease date unkwon		Will support 5G through an OTA update
Sequans	Taurus 5G chipset	2022			5G IoT chipset (support for eMBB, mMTCa and URLLC) , will support 3GPP Rel 16 but not yet released. Will support sub 6 and mmwave

Source: IDATE DigiWorld

What differentiates those chipsets?

The number of feature sometimes makes it difficult to differentiate all those chipset and indeed a lot is shared on the paper. We used to mention the support for SA in addition to NSA as a differentiator, but all 5G baseband now support both modes, although probably the support for more specific implementation of SA and NSA mode could be discriminated. Below are the features where 5G chipset might differentiate:

- The number of carrier that can be aggregated both in the sub-6 GHz and in the mmWave bands: while early 5G basebands were capable of aggregating up to 100 MHz in the sub-6 GHz at the beginning and up to 800 MHz in the mmWave (even though no operator currently hold such among of spectrum), the increased technology and market maturity has enabled players

to largely differentiate with the maximum amount of bandwidth possible for each part of the spectrum. Recently announced x65 discrete modem from Qualcomm (February 2021) will for instance support the aggregation of up to 1000 MHz of spectrum in the mmWave bands and up to 300 MHz in the sub-6 GHz, something naturally associated with higher peak download speed. In lower price tier, different combination of maximum bandwidth are used to segment the market even further

- Capability to aggregate sub-6 GHz and mmWave spectrum for increased maximum throughput up to 10 Gbps (Qualcomm x65). This is especially important for increased coverage and will ease the transition for operator from NSA to SA. It also often requires the support for the aggregation of FDD and TDD spectrum, as sub 3.5 GHz spectrum is mostly FDD while it is mostly TDD above 3.5 GHz
- Support for mmWave bands: Because the deployment in those frequency band used to be limited, the absence of support for mmWave was not an issue and an opportunity to develop lower end / cheaper 5G chipset, while still providing and enhance user experience over 4G. MmWave bands however has started to be deployed outside the US in the 2nd half of 2020 and now continue their ramp up in Europe and in other parts of the world in 2021. Combined with reduced bandwidth support, mmWave support is now being introduced in lower tier. Even the Snapdragon 480 supports mmWave now, although with a support for only 200 MHz bandwaidth
- Support for DSS (Dynamic Spectrum Sharing) feature, which enable the dynamic deployment of 5G in 4G bands, as standardized within 3GPP (instead of dedicating fixed portion of spectrum to RAT as was usually done with refarming. While absent from early generations of 5G chipset, DSS is now commonly supported by every player on the market.

Those capabilities differentiate chipset between each other and often between the different generations of 5G chipsets.

State of the competition

The 5G baseband market is quite different from the 4G and earlier generation baseband market. Actually, each new generation of cellular technologies has seen a player leaving the market and a new one emerge. As an example, TI left the baseband market with 3G and Infineon sold its cellular asset to Intel. In 4G, several players left the baseband market, such as Broadcom, despite several acquisition or Fujitsu. With 5G, Intel was the first to leave the (device) baseband market by selling its cellular assets to Apple. Due to the economic war between the US and China, the future of Huawei chipsets, with the inability to rely on TSMC foundry 5nm process starting on 15th of September 2020 is also uncertain. Since our last update, Huawei is the only player for which we were not able to find a new 5G chip in its portfolio. The latest flagship device from Huawei use the Kirin 9000 chipset, which is reportedly based on the Balong 5000 modem that was announced in 2019. Since January 2021, we observed new variation of the Kirin 9000 chipsets (the 9000E, 9000L…) which likely points to Huawei attempts at producing its chipset with another process node than TSMC one.

In 5G Qualcomm is still considered the leader in market share but recently, the rise of Mediatek with its Dimensity range of 5G modem, now commercially available is somehow changing the competitive landscape and this is particularly true in China where tensions with the US put Huawei in a difficult situation regarding its chip design capabilities. While Counterpoint Research estimates Qualcomm market 5G smartphone market share to be around 39% of the sold in Q3 2020, Mediatek has been growing dynamically throughout 2020. In Q3 it even surpassed Qualcomm on the global smartphone

chipsets market, benefiting from the growth in China and India and the next step for Mediatek would be to surpass Qualcomm in volume for the whole 2021 year, something that Mediatek might very well accomplish if we look at the ever increasing number of 5G chipsets announced. With the announcement, of its x65 latest generation of 5G baseband, Qualcomm however is demonstrating it is still a little bit ahead in terms of technology development. X65 5G modem will support up to 10 Gbps throughputs and will be software upgradable. Supporting Rel 16, it will be able to support new capabilities to adapt to new use cases. In May 2021, Qualcomm announced that the X65 had been upgraded with the support of wider 200 MHz mmWave channel, a feature that will be required for the Chinese market where carriers will be able to deploy with such bandwidth. Later in May and June, Qualcomm announced the release of more specific 5G chipset aimed at supporting IoT and IIoT, an indication of the expansion of 5G applications worldwide.

As for Mediatek, It is only with the Helio M80 5G modem announced in February 2021 that Mediatek is supporting mmWave while Qualcomm has been supporting it from the beginning.

Samsung and Huawei

While Samsung and Huawei, number one and three in the smartphone market in 2020 have initially used their chipset internally, this situation has changed throughout the time, as both chipset manufacturers have been mentioned as selling their chipset to other device manufacturers, mostly Asian one. As mentioned earlier, the situation of Huawei is uncertain because of the political rivalries between the US and China and the difficulty for Huawei to source an efficient process node for its chipset (TSMC being considered to be the most advanced player in that field). Samsung is rumored to be helping Huawei to bring its chipset into the market with its 5nm EUV process. As for Samsung, its last update to its 5G chip portfolio dates back to January 2021 with the Exynos 2100, which notably power the Galaxy S21+, ultra and 5G in some geographic versions of its flagship device. This enable Samsung to manage its cost structure. According to Counterpoint Research, Samsung own ecosystem contributes as high as 63% of the total bill of material of the Galaxy S21.

In a not so distant future, they will both be joined by Apple, after the Cupertino company acquired Intel cellular assets for mobile devices. For now, Qualcomm is still benefiting from this situation, since Apple is not currently capable of using its own silicon for 5G connectivity and has inked a licensing deal with Qualcomm to use their 5G products. The new iPhone 12, which is powered by Qualcomm x55 5G modem has positively impacted latest financial results from Qualcomm in the last quarter and the iPhone 12 currently holds the number 1 market share as a 5G phone.

Mediatek is now challenging Qualcomm in 5G

After a slow 5G headstart, Mediatek has turned into a serious competitor in the recent months thanks to the growth in the very large Chinese market as well as thanks to the difficulties leading Huawei to partly rely on Mediatek 5G chipset in lieu of HiSilicon chipsets difficult to be produced in the context of US restriction on doing business with Huawei. In the recent months, Mediatek has been mainly competing on the mid-end and low end 5G chipset market, launching a host of different SoC. For various price range. The Dimensity 720 announced in July 2020 for instance power the cheapest 5G smartphone to date, the Oppo Realme v3 which can be found at around 120 EUR in China. Mediatek portfolio of 5G chipset is rich with several different SoC based on the same 5G baseband. In August and Sept 2020 it also announced specific 5G chipsets for PCs built in partnership with Intel and 5G

chipset for the FWA market. In February 2021, Mediatek announced its 2nd generation of 5G baseband, the M80, which is likely to be integrated in new SoC to be announced in 2021. M80 5G baseband marks the 1st 5G baseband from Mediatek to support mmWaves with maximum reachable throughput of 7.67 Gbps with a capacity to aggregated up to 800 MHz of spectrum in the mmWave. This set this baseband in the same ballpark as Qualcomm x60 announced one year ago. Mediatek M80 is to be sampled during 2021.

As for Unisoc which announced the Makalu Ivy510 at MWC 2019, it is targeting the (Chinese notably) mid-tier smartphone and IoT market. Unisoc was previously known as Spreadtrum and had development partnership with Intel for LTE chipset for Chinese device but the partnership over 5G has been dropped and Unisoc is now following its own route. In February 2020, it announced its 2nd generation 5G chipset, the T7520 SoC, which Unisoc claims as "the all-around leader in power consumption for both light-load and heavy-load scenarios and delivers a power consumption reduction of up to 35% for some data business scenarios.", a claim, which of course remains to be verified. Unisoc power smarphone commercially available from HiSense, CoolPad and AGM notably, smartphones that are targeting the Chinese market. Interestingly, Unisoc announced in November 2020, what it claims as the 1st 5G NB-IoT 3GPP Rel 16 compliant chipset. In April 2021, Unisoc revamped its portfolio of 5G chipset under the name Tanggula which is classified into four series – the Tanggula 6, Tanggula 7, Tanggula 8, and the Tanggula 9 where serie 6 will be the low-end 5G chipsets and the Serie 9 the highest end 5G device. As of mid-2021, only the Tanggula serie 7 has been unveiled. In the future, Unisoc said it was working on a solution for AR.

Apple to develop its own 5G modem for tighter control and integration

After Intel quitted the smartphone chipset market in April 2019, Apple purchased most of Intel 5G business for 1 billion USD with the intent to develop its own 5G baseband. In the meantime, Apple is using Qualcomm 5G modem after it reached a 6 year license agreement as a settlement for the litigation between Apple and Qualcomm. The reason for Apple to develop its own modem is above all the capability to better integrate connectivity capabilities to Apple global ecosystem of devices, not only in iPhones and iPad, for which a homegrown ARM based processor has already been available for many years but also for the rest of its line of computers. In mid-June 2020, Apple indeed announced its choice to transition from Intel x86 architecture to the ARM architecture, something which resulted in the commercial launch of first ARM based Mac computers in November 2020. By mastering and fully controlling the processors of Mac computers, Apple will be able to develop and integrate new features, of which of course 5G connectivity.

It is estimated that Apple own 5G modems could come to the market around 2023-2025. Such modems are very unlikely to be sold to other OEMs as they are meant to become a differentiating point for Apple. While designing a cellular modem is no easy task, Apple has proven in the past that it could acquire knowledge and competences in the design of new solutions, something that takes times to reach maturity but will in the end serve the interest of Apple.

In October 2020, Apple launched its line of 5G iPhones, using Qualcomm x55 modem and next iPhone in 2021 are likely to be powered by Qualcomm x60 generation. Being at the forefront of the cellular connectivity field has never been a focus for Apple, which has always had a conservative approach in that domain (remember, iPhone 1st generation was a 2.5G smartphone).

2.7.2. 822 5G devices announced at the end of May 2021

The release of 5G baseband and RF systems is the first step before commercial devices. Usually, when a new radio technology is released, basebands are developed and implemented in relatively simple devices such as mobile WiFi hotspots, before more complex devices such as smartphones, where integration is always more challenging. Before fully commercial devices can be made available, several steps are required.

Figure 8: The steps a device takes to market

Source: IDATE DigiWorld, September 2018

This time, with 5G, Fixed Wireless Access was one of the first use cases, rather than mobile usage and first commercial devices announced have been 5G home routers, such as the one announced by Huawei at MWC as soon as in 2018 in Barcelona, or the one by Samsung. Those early devices have been more specifically designed for carrier partners Verizon in the US and in South Korea, and have already received their approval by the FCC. Since then, many other routers and CPEs have been released for various usage and with newer 5G chipsets and capabilities.

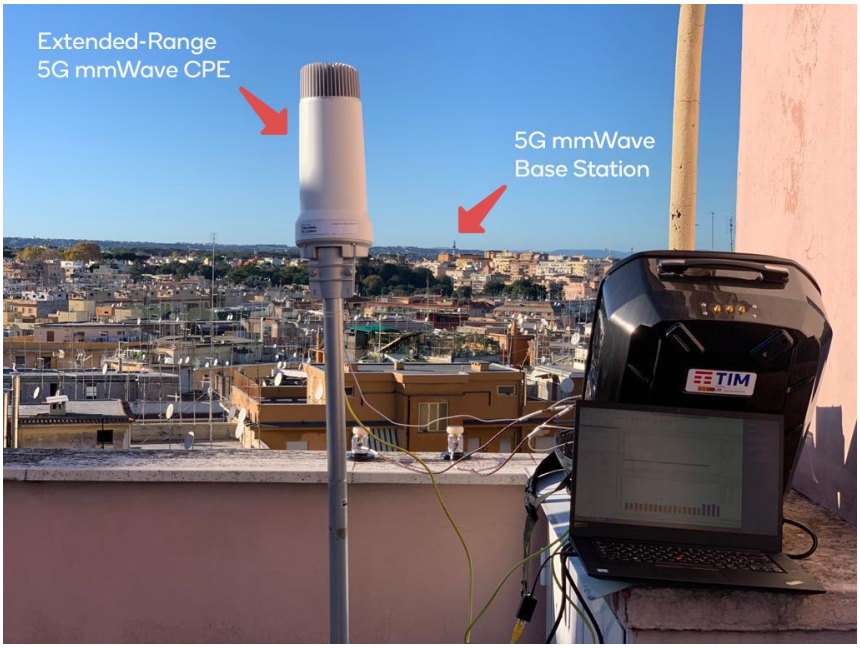
Figure 9: Example of routers based on Snapdragon 865 (based on 2nd gen x55 5G modem)

Source: Qualcomm

Since then however, the ecosystem has continued its expansion alongside that of the smartphone devices, which has now became the first category of 5G device. In addition to Huawei, Samsung and Qualcomm, Mediatek has also developed a 5G chipset specifically for 5G FWA. Some 5G FWA CPE support only sub 6 GHz frequency bands in order to better fulfil the needs of rural and indoor deployments while some other also support mmWave for deployments in Urban and sub Urban scenario where the business case enable denser deployments. In December 2020, TIM, Qualcomm and Ericsson have demonstrated a record 1Gbps throughput over a link of 6.5km on TIM commercial

network, highlighting the (evolving) capability of mmWave in FWA deployment beyond strict urban scenarios.

Figure 10: Demonstration of mmWave capabilities on TIM commercial network over a distance of 6.5 km

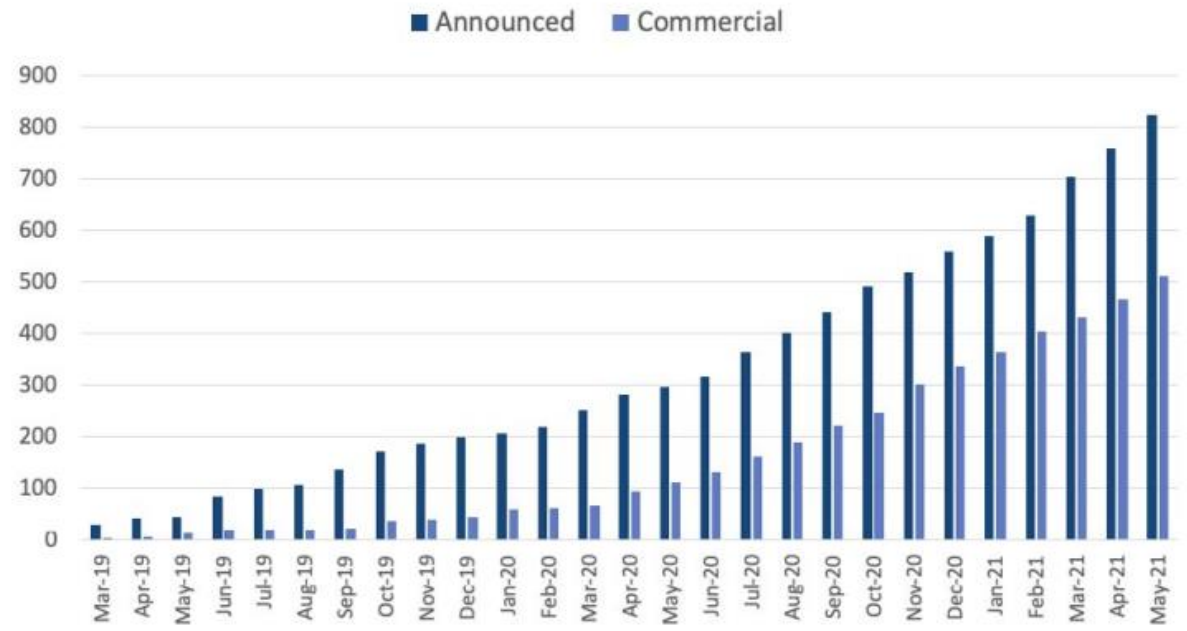


Source: Qualcomm

Smartphones and modules, most popular form factors indicates an already relatively rich ecosystem powered by 5g basebands

Since early 5G devices designed for fixed wireless usage, the first mobile 5G networks have been launched in the world and the device ecosystem, thanks to the enabling basebands, has "considerably" widened. As of end of May 2021, indeed, Gsacom reported 822 5G devices announced by 128 different vendors and 22 different categories of form factors, some of which are fairly similar. As a comparison, in December 2019, Gsacom reported around 15,000 different LTE devices. Of those 822 5G devices, at least, 511 are commercially available, which is a more than 3.5 multiplication as compared to May 2020 and a 42% increase in the last three month. It certainly indicates a continued momentum in the building of the ecosystem.

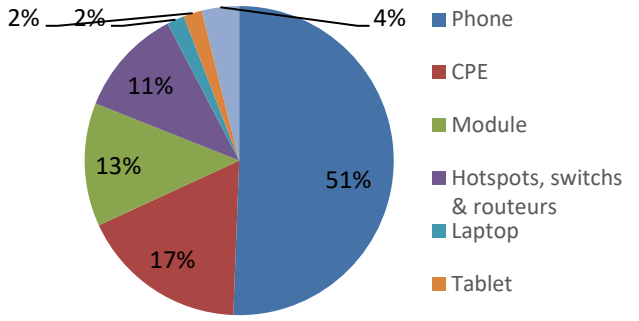
Figure 11: Growth of announced 5G devices (not all commercially available) as of end of May s2021



Source: Gsacom

Table 11: Simplified distribution of the 5G device ecosystem as of end of May 2021

Formfactors	# of devices announced	%AGR *
Phone	416	42%
CPE	144	0 %
Module	106	43%
Hotspots, switches & routeurs	93	232%**
Laptop	15	36%
Tablets	16	100,0%
Others	32	10,3%



Source: Gsacom, as of end of May 2021 * as compared to January 2021 ** change in methodology

In detail most of the devices launched in 2020 have been based on second generation 5G baseband and it is only one year after its announcement that 3rd generation 5G modem are going to take place in commercial devices, just as a new generations of basebands are being announced.

While initial 5G devices often had either sub 6 GHz, either mmWave RF system, 2020 has seen first mmWave+sub6 GHz devices. The reason for not including support for both frequencies was to be found in the different geographical/market choices regarding frequency bands for deployment, but also in the cost that those additional frequency bands incur. At this stage, the RF and antennas add a significant toll to the total Bill of Material (BOM) of 5G devices without even talking of power

consumption, time has not yet come for worldwide 5G devices supporting all the 5G frequency bands. As an illustration of the additional cost that RF represent in the total Bill of Material (BoM) of a 5G phone, Samsung notably decided to switch from three mmWave antenna modules in the Galaxy S20 to two only in the Galaxy S21. Because of the high capacity for obstacles (foliage, body…) to completely block mmWave signal, more than two mmWave antennas are often advised so as to be able to dynamically switch from one antenna to another one in case of blockage.

One important aspect though is that 5G devices that have been released in 2020 now support sub 6 GHz FDD and not just TDD. While TDD mode is important for mid and high frequency bands, FDD is key for lower frequency bands (those frequency bands used for 2G, 3G and 5G). While those band sport more limited throughput, they are key for 5G roaming, as operator will be vying for expanded coverage and SA deployments.

In 2020, as lower-tier 5G solutions have been released on the market thanks to a wider 5G baseband/SoC portfolio, the premium price for 5G device has continued to decrease. This decrease of price initially come principally from cost optimizations and "reduced" 5G performance as compared to high-end 5G solutions as exemplified by the difference between the Snapdragon 765 and the x55 modem that is found in the snapdragon 865. The 5G performance of the Snapdragon 765 is still far better than the best 4G possible performance, topping at a theoretical downlink throughput of 3.2 Gbps but is still below the 7.5 Gbps that the x55 is capable of. Likewise, the newly released Snapdragon 480, while supporting both sub 6 GHz and mmWave only support bandwidth up to 200 MHz, in the end "only" providing up to 2.5 Gbps downlink throughput in 5G (vs 660 Mbps in LTE). Of course, this differentiation doesn't really matter when the capabilities of the network do not even match this level of throughput.

The 3.5 GHz frequency band, still the most popular frequency bands for 5G

Despite much noise around mmWave bands deployment abroad, the sub-6 GHz device ecosystem is doing strong and especially the 3.5 GHz band which provides interesting capabilities with a mix of coverage and capacity when wide bandwidth configuration are used (100 MHz). More precisely, the n78 band (3.5 GHz) is the most popular frequency band in terms of devices announced mirroring the sizeable number of network believed to use this frequency band. As of end of November 2020, 57% of devices announced or in development supported this frequency band vs 30% for all mmWave bands. Given the wide availability of this frequency band worldwide, this is not a big surprise. While not providing as much bandwidth as mmWave bands (largest possible bandwidth configuration is 100 MHz) it is providing a much larger coverage. As compared to lower frequency bands, it still sports better capacity and is better suited to massive MIMO deployment in the field because of the much smaller antennas required.

Thanks to features such as Dynamic Spectrum Sharing (DSS), a 5G device ecosystem for "legacy frequencies" is also being built with devices announced supporting several of those bands (such as the much used 1800 MHz, 2100 MHz or 700 (APT) MHz) especially as operators in the US (AT&T and Verizon but also T-Mobile without DSS) have started to deploy in those low bands in 2020. During the last three quarters, the number of devices supporting those frequency bands has grown substantially indicating a clear interest from operators in those frequencies as they prepare to leverage their existing asset in complement to mid frequency band. In 2021, the support for sub-6 GHz carrier aggregation

should further drive the support for those bands including in Europe where DSS has also been deployed in the field with various strategies depending on the operators. In France for instance, Free Mobile (Iliad) has heavily relied on DSS on the 700 MHz (3GPP B28) to provide wide 5G coverage at the launch of 5G in the country in addition to a much less important number of 3.5 GHz sites, whereas competitors have focused initially on 3.5 GHz frequency band experience. Of course, the use of such low frequency bands for 5G comes with inferior throughput but from a marketing standpoint it enables operators to claim a coverage dominance over the competition.

While initial support for the mmWave device ecosystem was driven by the need to support US 5G networks this has started to change in 2020 as other mmWave deployments have taken place during the second half of 2020 in countries such as Korea and Japan but also in Russia, Singapore and Italy where usage for FWA has started. In Japan, where all operators have deployed mmWave , in six month, the number of mmWave base stations has increased 6 times from 2,300 in September 2020 to around 8,100 in March 2021. While no devices had been announced for n258 (26 GHz) band in December 2019, (the mmWave frequency of choice in Europe (and China) for latter deployments), this band has humbly jumped from 0 to 3 devices in March 2020 to 5 at the end of May 2020, and now 8 by the end of November which for now still remains anecdotal. In 2021, the ecosystem for mmWave devices should continue to build up as more countries, including in Europe start to deploy some mmWave networks. In the last two months, the growth dynamic for mmWave devices has come from the n261 bands used by Verizon Wireless.

Table 12: Distribution of announced 5G devices by range of frequency band*

Frequency band range	Number of 5G devices announced (November 2020)	Average progress in the category Nov 20 / Sept 20
39 GHz (mainly US)	37	37,0%
28 GHz (mainly US)	119	153,5%
n257 (JP, SK and US)	20	33,3%
n258 (Australia, China, Europe)	8	60,0%
n261 (Verizon)	91	237,6%
between 3.5 and 5 GHz (Global)	724	32,2%
between 1.8 and 2.6 GHz (Global)	1 080	43,7%
< 1.8 GHz (Global)	518	61,6%

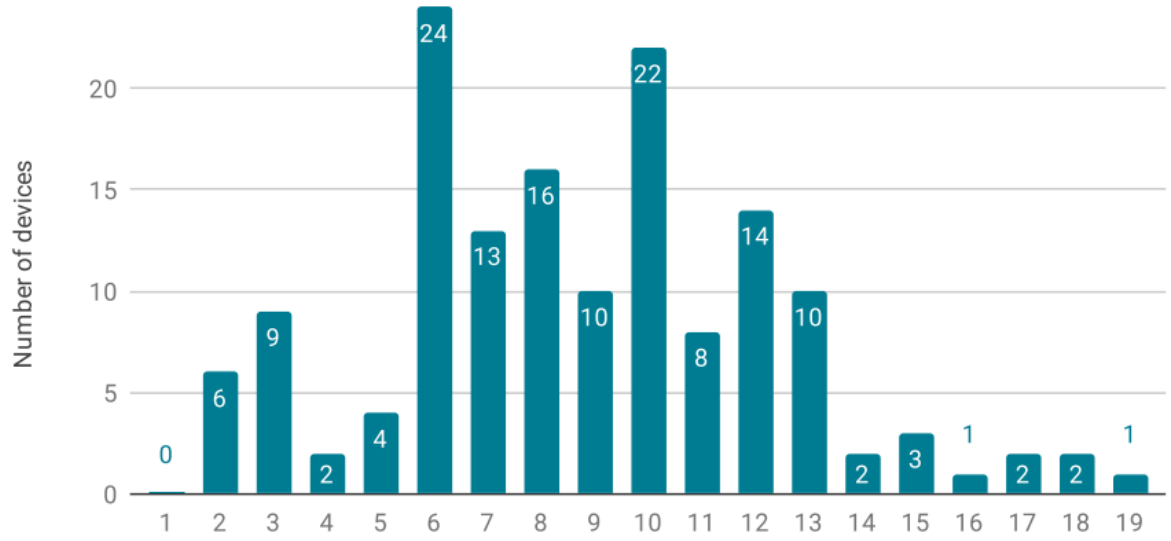
Source: gsacom, halberdbastion and IDATE * Note that one same device might be listed several times in different category when supporting several bands at the same time

A 5G smartphone supported on average 8.3 different 5G NR frequency bands in 2020

Starting with LTE the number of frequency bands in has increased significantly to support increased throughput thanks to carrier aggregation and availability of wider bandwidth in higher spectrum. This however has led to more RF complexity in our devices with the need to support an even bigger number of frequency bands in the same devices to cater to the situation of each market and reduce the variant of the same device for different market. As an example an iPhone 12 (model A2403) supports 30 different LTE and 5G NR frequency bands. This is an extreme example and such number of bands support is usually limited to higher end device that can support such an increase in the Bill of Material.

A report from the GCF, the certification stated that in 2020, certified 5G devices on average supported 8.3 different 5G NR bands, with the following repartition:

Figure 12: Multiband deployment of 5G NR: number of supported frequency bands



Source: GCF

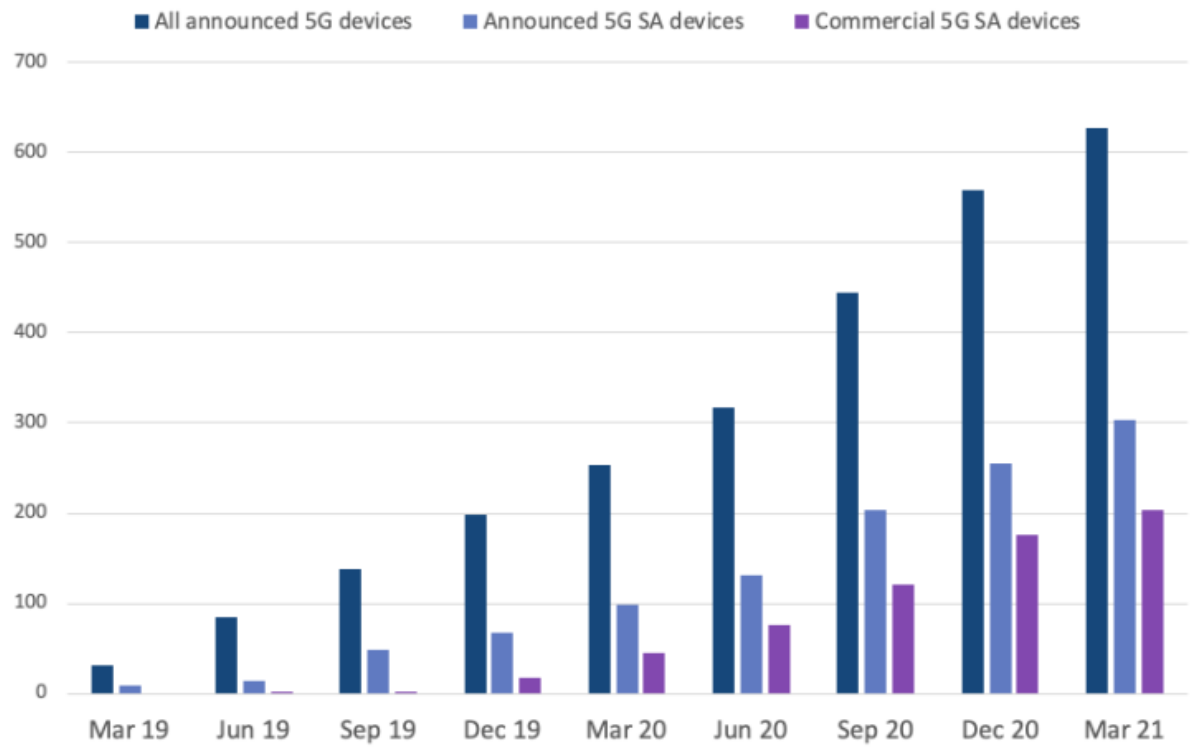
What comes out from this figure is the fact that 78% of 5G devices certified in 2020 had between six and thirteen different frequency bands.

The building up of a 5G device ecosystem

As 5G Standalone deployments have started in a few countries such as in China and in the US, the existence of devices supporting this mode is of paramount importance. According to Gsacom, at least seven operators in five countries/territories are understood to have launched public 5G SA and 68 operators in 38 countries worldwide have been more generally investing in public 5G SA networks.

While nearly all baseband now support SA modes, it was not the case in the beginning of the building up of the ecosystem. As of February 2021, Gsacom however reported 304 announced 5G devices with support for 5G standalone of which 204 were commercially available. This accounts for 47% of the total number of reported 5G devices. As an indication this amounted to only 28% in March 2019. This share could increase easily as network operators decide to start the deployment of native 5G Core required for SA deployment as a software update is possible to turn this capability on for devices with compatible basebands. 5G SA is key for the support of new features such as network slicing and all other use case envisioned for 5G such as massive Machine Type Communication or URLLC. It should be especially important for private 5G networks to be built in the future in the same way support for bands such as n77 (3.7 GHz) and n79 (4.5 GHz for use in China and Japan) or n48 (CBRS in the US) will pave the way for the creation of an ecosystem.

Figure 13: Number of announced and commercially available 5G devices with support for 5G Standalone mode



Source : Gsacom

For the consumer market, 5G SA compatible devices should be synonym with better coverage and improved latency as devices connected to a low frequency band in 5G but without connection to a 4G LTE (and thus EPC) could finally be covered directly in 5G. In NSA mode indeed, the control plane is handled by the 4G Core network. In the USA, where T-Mobile has launched SA on the 600 MHz frequency band, a 30% increase in coverage was observed and latency was reduced by 24% as compared to 5G NSA. Interestingly, as a result of 5G devices not supporting the aggregation between FDD and TDD in the sub 6 GHz, inferior throughputs on average was observed. Indeed, when connected in SA mode, devices were not capable of aggregating the FDD 600 MHz band with the TDD 2.5 GHz spectrum inherited from Sprint. With the arrival of devices capable of such carrier aggregation, the situation should change significantly (thanks to Qualcomm x60 modem or Mediatek M80).

In China, the three main MNOs have launched their SA network quite extensively. China Mobile for instance has deployed or upgraded 400 000 base stations to support SA mode and it plans to have 200 million of 5G SA devices on its network in 2021.

2.7.3. Infrastructure ecosystem

Infrastructure equipment is probably even more important than devices in the early building of an ecosystem, as they are used to test the technology features and concepts, even as the technology is being standardized within 3GPP. Equipment vendors were early in announcing their effort in building 5G technology, often by announcing trials efforts with Mobile Network Operators and/or chipset manufacturers. Those demonstrations were often focused on pieces of technologies or concepts, such as Massive MIMO, the use of mm-wave in different mobility scenarios…

Industry efforts have now resulted in early (and accelerated) standardization of the technologies and as more than 166 operators have commercially (as of end of May 2021) launched a 5G network throughout the world, most equipment vendors have completed their 5G portfolio to meet the various needs of the market. Those solutions share more or less the same features, although each vendor has designed its solution around its main strength. These baseline features are:

- 3GPP Release 15 compliance: Release 15 is the first official release of 5G. Before that, some equipment vendors have worked around unfinalized versions of the standard, or as is the case of network operators having built a pre-standard (such as Verizon with the 5GTF). Release 15 is considered as the phase 1 of 5G. Rel 16., which has been frozen in June 2020 will bring new capabilities
- End-to-end offering: in the race to being the most advanced vendor, it is important to show full end-to-end product portfolio, which means having a core network solution, a transport solution, a base-station adapted to different scenarios (e.g. such as indoor or outdoor), and a "front-end" solution with diverse antenna solutions.
- A (virtual) core network solution: this is built to be deployed in the cloud for maximum flexibility and to support the deployment of certain network functions at different places in the network, in a centralized or more or less distributed (up to the edge of the network) way.
- Support for massive MIMO: Massive MIMO, beam forming and beam tracking and beam steering are key features to attain increased spectrum efficiency in 5G. The support of this feature is thus key for equipment vendors to assert 5G ambitions. Since the early introduction of massive MIMO, new generations of equipment have been released that notably improve the size, wind drag and energy consumption of such a key element of 5G network. Energy consumption has indeed not been a focus initially and the requirement for increased processing power has caused energy consumption to rise significantly with massive MIMO to become a key topic for MNOs.
- Support for sub 6 GHz and mm-wave: While mm-wave has received much of the attention in the race to 5G because of all the challenges associated in operating a radio network in these frequency bands (the 26 and 28 GHz bands notably), but C band below 6 GHz has also seen traction because of its roaming capabilities for 5G. In Europe, nearly all 5G deployments that have already taken place have been in this band rather than in the 26 GHz band, because of its better coverage capabilities and the feeling of operators that they are not yet running out of capacity (as compared to the U.S. for instance).

As Release 15 is now fully supported by equipment vendors and as first 5G Standalone Network with a native 5G core have been launched by the end of 2020, Release 16 is now finalized. Initially supposed to be frozen in March 2020, the Release 16 has seen its frozen date postponed to June 2020 due to COVID-19 epidemic and compatible equipment have been launched on the market. Work on Release 17 has now already begun and should see its feature frozen in September 2021.

As for Release 16 is considered as the phase 2 of 5G and is aimed at complementing the previous release after the initial calendar was quicken to enable early 5G deployments. Release 16 brings the following capabilities:

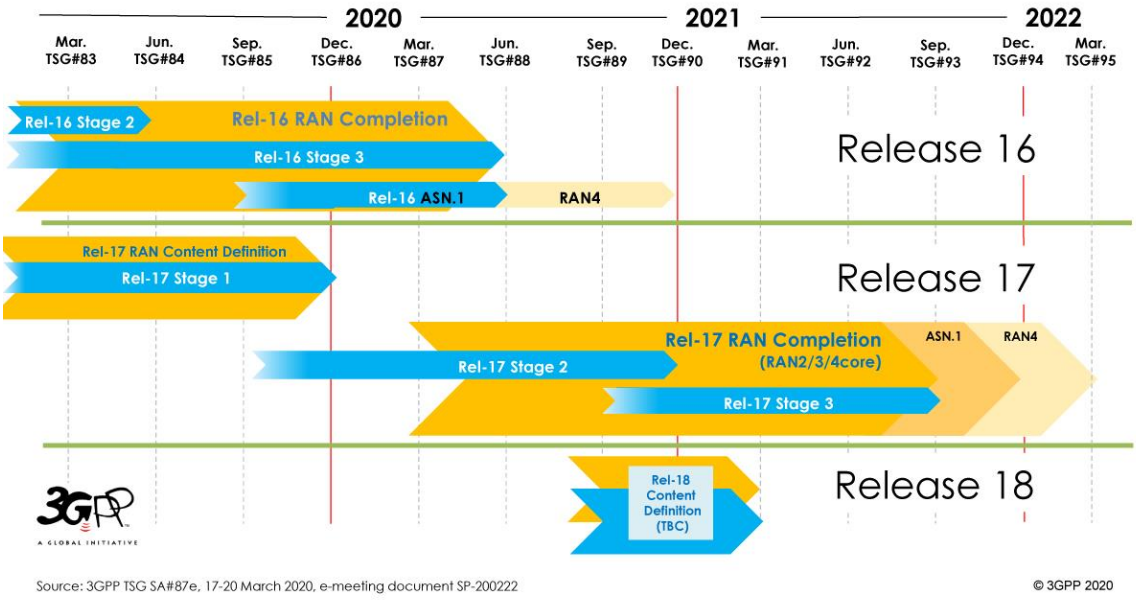
- NR-U: it will now be possible to deploy 5G NR in unlicensed spectrum, not only with an anchor in licensed spectrum but also as standalone. This is notably aimed at serving the development of 5G private networks. NR-U will also make it possible to have an anchor in unlicensed spectrum.
- URLLC: while Release 15 focused on eMBB use case, but nonetheless bringing improved latency, Release 16 will support Ultra-Reliable Low Latency communication for critical

applications, the main difference lying in the support for the Reliability in Rel 16. It is notably aimed at serving the needs of the Industrial IoT.

- Improvement to C-V2X communication with support of communication directly between the vehicles under and out of coverage thanks to PC5 interface.
- Integrated Access Backhaul: to support the densification of the network when fiber is not easily available, it will be possible to use a NR wireless link from central locations to distributed cell sites and between cell sites.
- Other enhancement to existing features: Massive MIMO, Dynamic Spectrum Sharing but importantly as well for devices energy saving features (Wake Up Signal, adaptive MIMO Layer reduction, low power carrier aggregation control …)

The figure below present the update roadmap for 5G standard development:

Figure 14: 5G standard development roadmap



Source: 3GPP

Presentation of the 5G portfolio of the main equipment manufacturers

Below, we present the 5G portfolio of each equipment manufacturer. Their claim is mostly similar and as for device baseband, those claims can be seen through different angles. Table 13 below summarizes what stands out from each vendor solution:

Table 13: Infrastructure equipment 5G solutions from major vendors

Equipment vendor	Most notable for	Device manufacturer
Huawei	3rd Gen Massive MIMO solution with support for up to 400 MHz bandwidth (for network sharing). Boast for having a unique lightweight integrated passive and active antenna system to facilitate deployment	Yes
Ericsson	With a complete portfolio, Ericsson advocate for a new way of building network with precision to deploy the appropriate capability at the right place. Recently, Ericsson has been very vocal about its Ericsson Dynamic Spectrum Sharing (DSS) solution, a field where Ericsson is leading. Recently, Ericsson announced its last generation of Massive MIMO system, as well as a new Private 4G and 5G platform for Industrial IoT and an enhanced indoor connectivity solution	No

Equipment vendor	Most notable for	Device manufacturer
Nokia	An Active Member of the ORAN Alliance, Nokia has been partnering with several new equipment vendors, as operators are pushing for a disaggregation of the RAN. After initial difficulties with its 1st generation of homegrown baseband chipset, Nokia is developing its portfolio of ReefShark base station with multiple partnership with silicon vendors. It is notably betting on the rise of Private 5G network	No
ZTE	Claims to have the lightest Massive MIMO solution at 22 kg for easier site deployment and support for 400 MHz bandwidth to support network sharing. It uniquely provide solution to dynamically deploy 3 RAN technologies in the same band (vs 2 for its competitors)	Yes
Samsung	With a strong experience in TDD, Samsung Networks boast the Massive MIMO capabilities of its Radio solution both in C-band and mmWave	Yes
NEC	Veteran supplier of telecoms infrastructures in the optical and backhaul segments, it is now positioned in 5G wireless through the development of vRAN solutions for the domestic market initially. Recently it made the headline through its development of Open RAN 5G Radio Equipment for Rakuten fully virtualized 5G network	No

Source: IDATE DigiWorld

Open RAN and the expected rise of new network vendors

As the native 5G core network will be fully virtualized, the virtualization of the Radio Access Network (RAN) and the development of new RAN architecture is paving the way for the implementation of open and interoperable solutions on the network.

Initially pushed by MNOs to end their dependency on one or two single equipment provider it has been seen as an opportunity for new players to enter the RAN market with software solution while traditional equipment vendors excepting Huawei have been forced to more or less timidly supporting the movement to continue working with some Tier 1 mobile operators.

Figure 15: Mapping of new equipment vendor

Source: IDATE DigiWorld

In support of the development of a standardized interface between the different equipment that make up the RAN, alliances have been formed such as the TIP (notably) or the ORAN Alliance. More recently and in a more political approach, the Open RAN Policy Coalition has been formed in the US. Indeed, in the country, with no more mobile infrastructure equipment vendor on the market, the move is seen as way to rebuild a presence for infrastructures also considered as strategic for the independence of the country.

While still relatively limited in its breadth this move should be seen as a solid trend for the years to come. While “legacy” equipment vendors have initially developed a virtualized RAN solution, those solutions remained proprietary and did not provide the openness that operators had been calling for.

Recently, certain move by both greenfield operators and legacy operators have shown that the ecosystem was moving in the right direction. If the launch of Rakuten fully virtualized 4G network in Japan is being observed carefully, massive testing by major telcos such as DoCoMo in Japan, Etisalat in UAE and Telefónica are also an indication that Open RAN is there to stay.

At this point of development, Open RAN solution still lack maturity as compared to more integrated and proprietary solution as it require new (IT) competencies that few operators have yet. One issue with Open RAN today lies in the fact that, as operators are deploying a new Radio Access Technology, they also need to have an end to end control of what is happening in the network (especially as network slicing is seen as a way for operators to transform their business model). The more vendors solutions are deployed in the network, the more difficult it is to identify where error come from when they arise. As of today, most of the Open RAN have thus been seen in greenfield networks as well as in rural or remote areas where the business case does not fit well with network deployments. One of the difficulty for Open RAN today is to support areas where high capacities are required as well areas where strong collaboration between cells are required. Rakuten and Altiostar is keen to highlight however how its massive MIMO Open RAN solution demonstrated the capability of Open RAN. The biggest challenge for Open RAN is thus to continue educate the market and persuade skeptical operators. Among brownfield operators however, things are slowly moving. Vodafone has committed to deploy Open RAN on 2,500 cell sites in rural areas in the UK. It recently selected Samsung for this Open RAN commitment, following the announcement a few days before that Verizon in the U.S. had selected Samsung for the deployment of vRAN base stations. In France, Orange CTO, at the end of April 2021 stated that starting in 2025, only equipment that conform with specifications developed by the ORAN Alliance will be deployed, which in a way is likely to prevent Huawei to participate to the game and might benefit to other vendors such as Nokia or Ericsson. The latter vendor, which was late to join the ORAN Alliance is often keen to claim the limits of Open RAN and only time will tell if this lukewarm support from Ericsson to Open RAN will play in its favor or not. Indeed, while Open RAN is vRAN by nature, not all virtualized RAN are open RAN and Ericsson is trying to push a virtualized RAN solution built on proprietary hardware of its own and that would remain ahead in terms of (processing and power efficiency) performance. At the end of the day, if Open RAN doesn't offer feature parity with "legacy" solutions, MNOs might have to temper their disaggregated ambitions.

In the years to come thus, new equipment vendors are going to continue to progress meanwhile on the market but biggest "legacy" vendors are not yet threaten, even though they need to rethink their positioning.

Table 14: Presentation of main new equipment vendors

Equipment suppliers	Background	RAN products
Accelleran (Belgium)	Company created in 2012, having acquired several companies specialised in radio equipment (Phazr, Teko and CSS Antenna), particularly active in Italy and the private networks market.	Open RAN-compatible vRAN hardware and software solutions
Airspan (USA)	Founded in 2005 and specialised in software solutions for networks operators. Pioneer in virtualised solutions for network operators (IMS, EPC). Acquired Brocade's vEPC business in 2017. Selected by Telefónica and Vodafone from among other Open RAN suppliers.	All open standards DU, RRH and vRAN hardware and software solutions, for outdoor and indoor small cells

Equipment suppliers	Background	RAN products
Altiostar (USA)	Company created in 2011. An Open RAN pioneer. Investors include: Telefónica, Rakuten, Qualcomm, Cisco, Tech Mahindra. Among the main Open RAN contributors and selected by Telefónica and Vodafone from among other Open RAN suppliers.	vRAN (virtualised distribution units and central offices) and MEC solutions
JMA Wireless (USA)	Company created in 2012, having acquired several companies specialised in radio equipment (Phazr, Teko and CSS Antenna), particularly active in Italy and the private networks market.	xRAN software solutions for mobile networks and CBRS
Mavenir (USA)	Founded in 2005 and specialised in software solutions for networks operators. Pioneer in virtualised solutions for network operators (IMS, EPC). Acquired Brocade's vEPC business in 2017. Selected by Telefónica and Vodafone from among other Open RAN suppliers.	End-to-end 5G network software solution (core and open vRAN)
Parallel Wireless (USA)	Company created in 2012, supplier of small cells positioned as the Open RAN leader; TIP member. Targets Tier 2 and 3 carriers in the US that are part of the Competitive Carriers Association (CCA) and employ virtualisation to reduce infrastructures costs. Also Tier 1 carriers in the US for Increasing network density in large cities. In Africa: supplying connectivity to unconnected regions.	End-to-end open vRAN solutions (unified 2G/3G/4G/5G mobile architecture)
Radisys (USA)	Company created in 1987, taking over by Indian carrier, Reliance Jio in 2018. Supplier of innovative hardware and software building blocks, notably for virtualisation and edge computing Involved in open source projects such as TIP, M-CORD and xRAN (main contributor to O-RAN). Also positioned as an integrator.	C-RAN software solution
Cisco (USA)	World's leading supplier of core network equipment (routers and switches), the company has positioned itself in virtualisation solutions for operators, and now targeting RAN solutions as well Founding member of the Open vRAN initiative	Open vRAN solution: a multi-vendor, modular and open RAN architecture
Commscope (USA)	Network infrastructure supplier, notably optical fibre Diversification of its solutions via acquisitions, including Airvana (mobile access networks) in 2015 Active member of the Open RAN alliance Main clients: carriers' carrier for companies and public property	C-RAN solution for small cells designed for private network deployments

Source: IDATE DigiWorld

5G expanding into lower frequency band for increased coverage (and capacity)

In 2020 and beyond, after early deployments, 5G has expanded its coverage thanks to lower frequency bands. This would not have been possible without flexible solution such as Dynamic Spectrum Sharing (DSS) which enable to seamlessly and dynamically "re-farm" 4G spectrum for 5G application. Instead of dedicating a fixed portion of a frequency band to 4G or 5G, the idea is to support both 4G and 5G users in the same frequency band. It is especially useful for sub-3.5 GHz bands used by 4G (the mid and low frequency bands of 5G) as it will expand 5G coverage outside the spotty area where "higher band 5G" has been deployed. This feature is part of 3GPP Release 15 and while its support has been announced first by Qualcomm with its x55 5G chipset at MWC 2019, it is supported by all the 5G baseband players as well as most equipment vendors which have announced support for this feature. Ericsson is today considered as a leader but Samsung, Nokia and ZTE have all released their solution. Quite uniquely, ZTE supports the deployment of a third radio access technology such as 2G or 3G together with 4G and 5G.

It should not be seen as a way to deploy 5G in a single band but as a way to increase throughput in low frequency bands where little bandwidth is available. DSS is thus meant at being used in carrier aggregation configuration. In the very low frequency bands such as in the 600 MHz or even in the 700-800 MHz band, the spectrum available is often quite limited and as such offer very limited performance. This however can be somehow mitigated by increasing the receive and transmit diversity with for instance 4x4 MIMO instead of 2x2 MIMO and the use of high gain antennas for instance in device such as CPE to be used in FWA in rural areas. At the beginning of March 2021, Ericsson and Unisoc demonstrated more than 600 Mbps throughput using the n28 (700 MHz) frequency band.

It is to be noted that while the solution seem interesting on the paper, as every new technology, it also needs some maturation. Indeed, it has been reported that some DSS solution could incur a reduced spectrum efficiency on the 4G part of the spectrum. As a result from this initial situation, some operators have decided to allocate fixed portion of their spectrum to 4G and 5G instead of dynamically managing the allocation of resource depending on the network load. In the US, T-Mobile is known to have raised concern on the performance of DSS, touting instead its strategy of dedicating the 600 MHz frequency band for its 5G expansion in complement to its 2.5 GHz spectrum inherited from its merger with Sprint. The 600 MHz band is used as an anchor for the deployment of T-Mobile 5G SA network.

Quite importantly indeed, the support for low frequency bands in 5G will be critical for the launch of Standalone 5G, where the native 5G Core network will be able to handle the control and signaling plane, thus paving the way for more advanced/transformational 5G capabilities such as network slicing.

Figure 16: Outlook for 5G features deployments worldwide

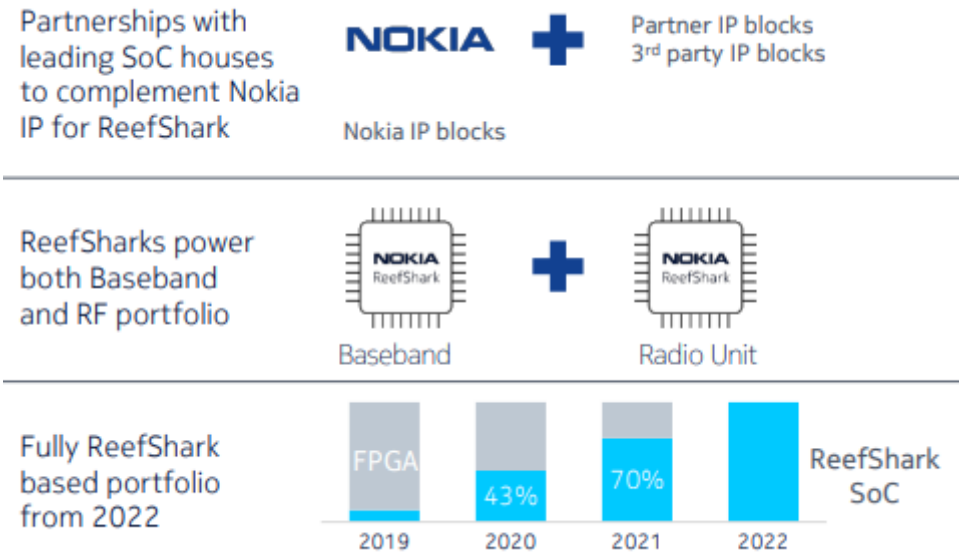
Source: Qualcomm

The critical importance of semiconductor in building a differentiated (more efficient) portfolio

With the ever complexification of radio technologies, and in a very competitive environment, the chipset within the infrastructure is increasingly becoming a matter of differentiation. But as most of the main equipment manufacturers are today claiming to somehow design their own chipset, making bad choice can decisively impact competitiveness as experienced by Nokia in the recent past.

Nokia indeed introduced its 1st generation of ReefShark chipset in January 2018 touting its capability to enable the reduction of massive MIMO antennas by a factor of two while reducing the power consumption of baseband unit by 64%, a key benefit as both size, weight and power consumption have a direct impact on operator OpEx. However, in order to achieve this prowess, Nokia made a chip design choice that put the Finnish vendor in a difficult position. Indeed, by making the decision to use FPGA, a programmable chipset, rather than a dedicated ASIC, Nokia actually quite negatively impacted its product margin. FPGAs indeed, provide flexibility by enabling to reconfigure the chip after it has been designed, something that Nokia believed to be an advantage. But that turned out to be a serious disadvantage as FPGAs are more expensive than ASICS and the time to market that this design choice was supposed to bring disappeared as one of its supplier experienced difficulties in the manufacturing of the chipset with its 10 nm foundry process. Nokia finally departed from this design choice by finally designing a more competitive SoC through partnership with silicon specialist such as Broadcom, Intel and Marvell for its range of product. This turn of event however quite negatively impacted Nokia's competitiveness. As of March 2020, Nokia indicated that 17% of its 5G products were powered by Reefshark with the objective of reaching 35% by the end of 2020, 70% by the end of 2021 and 100% by the end of 2022. At the end of Q1 2021, Nokia reported that it was on track to reach the 70% mark by end of 2021. ReefShark is used for both the baseband and the Radio Unit.

Figure 17: The critical importance of ReefShark for Nokia



Source: Nokia

Because of the limited margin in the industry and the pressure on price that Chinese vendor Huawei has been able to impose, every point of margin is key, either to reinvest in Research and Development, either to more aggressively compete on prices.

Meanwhile, Huawei launched its 1st generation of own 5G base station processor called Tiangang in 2019. According to the company, this chip bring several improvements in Active Antenna Units with 50% smaller, 23% lighter and 21% less power consuming base station. However because of the strengthened ban on making business with Huawei, the company is facing difficulties in producing its own chip, after TSMC was forced to stop producing Huawei chipset and the future of Huawei capability to design and produce new chips seem uncertain. In 2020, while Huawei managed to increase its market share in the Chinese market, it lost, according to Dell'Oro Group 2% points outside china. Outside the geopolitical pressure on not using Huawei, the uncertain capability of Huawei to have access to enough component is seen by MNOs as a risk

As a semiconductor company Samsung has also invested in the development of its own base station chipset whose 2nd gen was launched in 2019. In April 2020, it announced the selection of Xilinx FPGA to improve the beamforming capabilities of its equipment and more recently in March 2021, it announced a new Massive MIMO 5G SoC developed in collaboration with Marvell and that promises better coverage and importantly as well a 70% power efficiency improvement over the previous generation.

With all the surge of 5G networks and the need to support ever increasing capacity, Massive MIMO has a critical role to play especially in the mid band where it is particularly adapted and as well required to make up for the reduced coverage of higher bands. This new approach however, is causing an explosion of energy consumption in absolute value and explains why so much focus is being drawn on improving Massive MIMO antenna solutions energy consumption. Not surprisingly then, Ericsson announced in February 2021 that its new mid band 5G radios and suite of six RAN compute product would be powered by its next generation custom silicon called Ericsson Silicon. This new chip must increase performance of its Massive MIMO antennas while reducing energy consumption and physical footprint (size and weight). One of the radio is presented by Ericsson has being the lightest Massive MIMO Active Antenna Unit on the market with a 20 kg weight. Previous record was held by ZTE with its 22 kg AAU solution.

Last but not least, Qualcomm, already designing chipsets for small cells, announced in last November that it would also enter the 5G base station chipset market focusing on open vRAN solutions with base station to antenna chipset solutions. Leveraging on its expertise in 5G the company aims at competing with players such as Intel, Marvell, Broadcom but also Nokia and Ericsson.

5G infrastructure contracts announcements

In the race to 5G contracts for equipment manufacturers, it is sometimes difficult to say who is really winning so far because of not all the figures being released and made public, not at the same time and sometimes as well with no precision on the scale of the contracts. To make it worse, the situation seem to change quite rapidly as exemplified by Nokia figures. As of end of May 2021, Nokia had secured 220 5G commercial engagements and 66 live 5G networks contracts. More than one year ago, we stated that Nokia was considered to be trailing behind in terms of contracts, Nokia however stating that they

were leading in terms of the comprehensiveness of the 5G solution sold to operators: “More than half of the deals that we have signed actually include more than just radio”. It is to be noted here that those deals likely include enterprise customers, 5G Private networks being known has having been a particular focus for Nokia.

As of end of May 2021, Ericsson states that it currently has 139 5G commercial agreements or contracts with unique operators out of which 81 have been publicly announced and out of which 86 are live 5G networks. As for Huawei, as of February 2021, it claimed 140 commercial 5G networks deployed in 59 countries but Huawei is not updating this figure often. In Europe, Huawei says it has more than 46 commercial 5G contracts signed and to have shipped 120,000 5G base stations but this claim has not been updated for a long time now either.

While the American ban on Huawei has been seen as an opportunity for its competitors it has not prevented the Chinese infrastructure vendor to claim the leadership in the past but this is something that is difficult to follow over the time. Looking at overall market share of telecom equipment revenues, it is still considered globally that Huawei is leading, with, according to Dell’Oro a 31% market share during 2020, as compared to 15% for Nokia and 15% for Ericsson. Despite difficulties in Europe (it lost 2% market share in 2020), the market dynamic in China is helping Huawei to maintain its position. Together with ZTE, it is estimated that Chinese equipment manufacturers hold 40% of the market in revenues.

Table 15: Network contracts announcement by infrastructure vendors – Based on figures known as of December 2020

Vendor	5G contracts
Ericsson	More than 139 5G contracts with mobile operators. Durign Q2 of 2021, Ericsson was selected for its 5G core network by Vodafone in Germany and the UK, Mas Movil in Spain, Swisscom in Switzerland. As for 5G RAN win, Ericsson was selected by Siminn in Iceland and O2 Slovakia, In March 2021, Ericsson was selected by Telenet to deploy 5G RAN in Belgium and its 5G Core for 5G standalone and non-standalone was selected by Far EasTone in Taiwan. Previously, in January 2021, Ericson had been selected by APT for a first Multi Operator Core Network in Taiwan In January 2021, Ericsson is selected by T-Mobile in the US to for Massive MIMO equipment In September 2020, Proximus (Belgium) selected Ericsson for its core network. At the end of October 2020, BT selected Ericsson 5G radio equipment for a selection of major UK cities. In November it confirmed a win Czech republic with CETIN and in January 2021, it announced a comprehensive 5G contract with Ooredoo across 10 markets Main customers in: USA (AT&T, T-Mobile US, US Cellular, Verizon), Canada (Bell Canada, Telus, Rogers), Europe (Swisscom, TDC, Telenor, Vodafone UK, Wind, Deutsche Telekom, O2 UK, Orange France, Vodafone UK), Middle East (Etisalat, Optus, Ooredoo, STC), South Korea (KT, SK Telecom) China (China Mobile, China Unicom, China Telecom) and Australia (Telstra)
Huawei	140 5G contracts with mobile operators. (March 2021 : no update available so far) During Q2 2021, Huawei announced it had launch a 5G network in Moscow with MTS. Interestingly as well, the Vodafone-Huawei 5G deal was approved in Italy at the beginning of June 2021 China is the first market for Huawei. Huawei also provides 5G networks in South Korea, The Philippines, Thailand and other Southeast Asian countries, in Europe and Africa.
Nokia	220+ 5G contracts with mobile operators During Q2 2021, Nokia announced it had been selected: - In 5G FWA contracts with Mobily in Ryadh, Kuwait, Oman, - In 5G RAN contracts in Taiwan, Sweden with Net4mobility, Movistar in Chile, Telenor and Telia in Denmark and with Dito in the Philippines - 5G small cell deployment with LGU+ in South Korea, - In Core network contracts with Dish in the US, Veon in Georgia

Vendor	5G contracts
	In September 2020, Orange and Proximus in Belgium announced contracts with Nokia replacing Huawei. Nokia announced the same "swap" for BT in the UK. In December 2020, Nokia announced a win at Proximus Luxembourg in a replacement of Huawei equipment
	Main customers in: USA (AT&T, T-Mobile US, US Cellular, Verizon), Canada (Bell Canada), Japan (SoftBank), Europe (Swisscom, TDC, Telenor, Vodafone UK, O2 Germany, O2 UK, Wind , Etisalat, Optus, Orange France, Telia Company, Vodafone Italy), Middle East (Ooredoo, STC), South Korea (KT, SK Telecom), Australia (Telus and Telstra).
Samsung	In June 2021, Samsung announced it had been selected by Vodafone for the deployment of Open RAN solution in the UK, an interesting first for the South Korean vendor, which has been otherwise more focused on the US and Latam, outside South Korea.,
	In March 2021, Samsung was selected by Sasktel in Canada to provide 5G core and RAN. The same month it launched 5G network in New Zealand with Spark
	Contracts in the USA (AT&T, U.S. Cellular, Verizon Wireless), Canada, Japan, and in South Korea (KT, SK Telecom and LG U+)
	In September 2020, Samsung signed a major network deal with Verizon, worth USD 6.65 billion
ZTE	55 5G commercial contracts around the world in September 2020. China is the first market for ZTE.

Source: IDATE DigiWorld

3. Annexes

3.1. National strategies and plans by MS

3.1.1. Austria

Main points

- Between July 2017 and September 2017, RTR launched a public consultation on 5G spectrum auctions
- 3.4-3.8 GHz SCA (Simple Clock Auction) took place in March 2019
- 700 MHz/1500 MHz/2100 MHz completed in August 2020
- 5G Strategy for Austria, April 2018
- All MNOs launched 5G services between March 2019 and January 2020.

The 5G strategy for Austria

The Austrian Government set up a steering group for 5G in February 2017. The "5G strategy for Austria" document was approved in April 2018.

The document defines three phases:

- Pre-commercial 5G tests are expected to be held during the first phase by mid-2018
- By year-end 2020, nationwide availability of 100 Mbps connections should be almost reached. This creates the basis for a nationwide expansion of 5G. At the same time, the market launch of 5G in all provincial capitals should take place.
- In Phase 3, 5G should be accessible across the main traffic roads by year-end 2023, followed by nationwide coverage two years later.

It lists 24 actions in terms of spectrum, funding, research…, translating into ten concrete measures for 5G applications.

In August 2019, the Austrian Government announced the new national broadband strategy 'Breitbandstrategie 2030'. The strategy aimed to provide nationwide access to gigabit-capable broadband services by the end of 2030.

The goals were:

- Nationwide access to 100 Mbps speeds by end 2020
- Launch 5G in all federal state capitals by end 2020
- Becoming a '5G pilot country' by early 2021
- 5G coverage along all main traffic routes by end-2023
- Nationwide coverage of 5G by the end of 2025.

700 MHz

The auction was postponed from April to August 2020 due to covid-19. It consisted of eight blocks of 10 MHz in 700 and 1500 MHz and 12 blocks of 2x5 MHz on 2100 MHz spectrum granted under coverage obligations (traffic routes covered by year-end 2023, "virtually nationwide" 5G coverage by the end of 2025). 700 MHz licences will include coverage of 900 underserved communities with speeds of 30 Mbps download and 3 Mbps upload, 90% of federal and state roads – to enjoy at least 10 Mbps download and 1 Mbps upload. The minimum bid was set at 239.3 million EUR (+55 million EUR compared to previous conditions). The duration of the licences was set at 25 years, from 20 years previously.

The auction raised 202 million EUR. T-Mobile paid 86.7 million EUR for 2x20 MHz of spectrum in 700 MHz frequencies, 20 MHz of spectrum in 1500 MHz frequencies and 2x15 MHz of spectrum in 2100 MHz frequencies. The incumbent A1 got 30 MHz of 1500 MHz spectrum and 2x25 MHz of 2100 MHz spectrum for 65.6 million EUR. Hutchison Drei won 2x10 MHz of 700 MHz spectrum, 30 MHz of 1500 MHZ spectrum and 2x20 MHz of 2100 MHz spectrum at 49.6 million EUR. A1 did not win 700 MHz spectrum. Players benefitted from price reductions as they agreed to cover underserved areas.

Other aspects

Security measures for 5G networks

In April 2020, the draft regulation on security measures for 5G networks was debated. The draft ordinance proposed in Austria establishes (a) a common set of rules applicable to all telecommunications networks; and (b) particular obligations for operators to protect the security of 5G networks (for networks with more than 100,000 users). The rules established for operators include:

- the obligation to notify a security incident that has a significant impact on the security of the communications network;
- the obligation to design and implement a security policy that ensures an adequate level of security in relation to existing risks;
- a set of obligations for 5G network operators with more than 100,000 users, such as:
    - to regularly submit an audit report;
    - to submit a declaration of conformity attesting to the observance of international standards such as 3GPP, expressly mentioned in the annex of this order;
    - to ensure the operation of the network operations center and the security operations center in the European Union;
    - to effectively monitor all critical components and sensitive parts of 5G networks through the network operations center and the security operations center;
    - to prevent unauthorized change of networks or components;
    - to ensure the physical protection of the critical and sensitive components of 5G networks;
    - restrict access to competent and qualified personnel, previously subject to security checks;
    - use of appropriate tools to ensure software integrity when operating software updates;

- to establish a strategy to ensure the provision of infrastructure by several providers, including by taking into account technical constraints and interoperability requirements in different parts of other 5G networks.

Coverage increase

In May 2020, Vienna announced it plans to increase 5G coverage by subsidizing new sites deployment locally between July 2020 and June 2022. The city expects to spend 20 MEUR.

3.1.2. Belgium

Main points

- Royal Decrees adopted in July 2018 drafted plans regarding the 700 MHz, 1500 MHz and 3600 MHz bands. Final plans were released in September 2018
- Draft strategic plan 2020-2022 late in 2019 opened to public consultation including on information about the planned multi-band spectrum auction
- BIPT granted temporary 5G 3.6-3.8 GHz licences to five players (Entropia Investments, Telenet, Proximus and Orange Belgium) in April 2020. Licences are valid until a traditional auction procedure takes place. Entropia Investments failed to pay for the permit and lost it in October 2020
- Launch of "light" 5G services by Proximus on April 1st, 2020
- 700 MHz and 3.5 GHz auction expected early 2022.

In July 2018, Royal Decrees were adopted among which draft regarding the 700 MHz, 1500 MHz and 3600 MHz bands. In September 2018, the BIPT released its plans for the introduction of 5G in Belgium. 700 MHz, 3400-3800 MHz and 1500 MHz (SDL, or Supplementary Downlink) frequencies were expected to be auctioned in the autumn of 2019 at that time. The 26 GHz band auction will not take place before 2021. Upper frequencies (31.8-33.4 GHz and 40.5-43.5 GHz) should be auctioned as from 2022.

BIPT published its draft strategic plan 2020-2022 for public consultation until December 8, 2019. The document mentioned plans to award the 700 MHz, 1500 MHz, and 3.5 GHz bands, and to renew rights for the 900 MHz, 1800 MHz, and 2.1 GHz bands, which expire in March 2021. The auction was delayed due to a disagreement over how the amount raised by the sale should be distributed. The BIPT gave details on the 700 MHz auction in November 2018. Bids will start at a reserve price of 20 million EUR per 5 MHz block for 20-year licences.

Due to the delay in assigning 5G spectrum, BIPT decided to award temporary licensees. In April 2020, the BIPT granted temporary 5G 3.6-3.8 GHz licences to Proximus, Cegeka, Entropia Investments, Telenet and Orange Belgium. Licensing was followed by the launch of 5G services by Proximus as from April 1st. Orange Belgium started testing 5G. Entropia Investments failed to pay for the permit and lost it. BIPT started to redistribute spectrum to other temporary licensees while Cegeka did not ask for additional spectrum. As a result, Orange Belgium, Telenet and Proximus which got 40 MHz each in April 2020, received 50 MHz while Cegekia kept 40 MHz.

In January 2021, the Government approved the draft legislation on the multi-band spectrum auction for 5G. The auction is expected to take place early 2022. Coverage obligations will accompany licences. By one year after spectrum assignment, licensees should cover 70% of the population. Two years after assignment, population coverage should reach 99.5% and 99.8% after three years.

3.1.3. Bulgaria

Main points

- Cross-border cooperation agreement for testing and early deployment of 5G corridor between Bulgaria, Greece and Serbia
- 700 MHz and 3.6 GHz 5G auction scheduled for April 6, 2021
- 5G launch by A1 on November 20, 2020.

The Communications Regulation Commission (CRC) of Bulgaria closed a public consultation on frequency allocations in October 2017. It proposed to sell eight blocks of 5 MHz in the 1.5 GHz band (1452-1492 MHz), three paired blocks of 5 MHz in the 2 GHz band (1920-1935 MHz/2110-2125 MHz), 14 paired 5 MHz blocks of frequency division duplex (FDD) spectrum in the 2.6 GHz band (2500-2570 MHz/2620-2690 MHz), ten blocks of 5 MHz TDD spectrum in the 2.6 GHz band (2570-2620 MHz), 34 blocks of 5 MHz in the 3.6 GHz band (3430-3600 MHz) and further 22 blocks of 5 MHz TDD in the 3.6 GHz band (3645-3700 MHz and 3745-3800 MHz). The auction was initially scheduled for the second quarter 2020 and postponed to April 2021.

In a January 2021 decision, the Bulgarian regulator mentioned three 100 MHz-licences in the 3.5-3.8 GHz frequencies. All the 20-year licences will be granted with coverage obligations and sold at a reserve price of 4 million BGN (2 million EUR) per 100 MHz block. Under the auction terms defined in the January 2021 decision, bid increments are of 100,000 BGN (50,000 EUR) and players have to place deposits of 200,000 BGN (100,000 EUR). What is more, to be allowed to bid, companies must have provided mobile services (2G, 3G or 4G) and prove they have already made investments in mobile networks. The decision seems to exclude non-telecom players. The highest bidder will be given first choice.

3.1.4. Croatia

Main points

- 700 MHz, 3.6 GHz and 26 GHz 5G auction rescheduled for H1 2021
- 5G launch by Hrvatski Telekom on October 30, 2020 thanks to Dynamic Spectrum Sharing.

The Strategy for Broadband Development in Croatia for 2016-2020 was adopted in July 2016. It aims at achieving full broadband deployment by a technology neutral approach. The estimated budget for the implementation of the Strategy measures is ca. 770 MEUR.

In January 2020, the Government of the Republic of Croatia has adopted a resolution on Osijek as the Croatian 5G City and Slavonia as the first Croatian region to operate 5G networks commercially.

In June 2020, HAKOM postponed the multi-band auction (700 MHz, 3.6 GHz and 26 GHz) until the first half 2021 blaming the Covid-19 outbreak.

The regulator opened a new consultation in September 2020 into its plans to allocate spectrum in the 800MHz, 900MHz, 1800MHz, 2100MHz and 2600MHz bands. The spectrum, currently used for 2G, 3G and 4G services, has been harmonised at the European level for use in 5G networks.

3.1.5. Cyprus

Main points

- Updated Cyprus Broadband Plan 2016-2020[8]
- 700/3400-3800 MHz 5G spectrum auction completed on 17 December 2020. Four winners: Cyta, EPIC, Primetel and Cablenet Communications Systems
- 5G launch on January 31st, 2021 by Cyta.

In 2016, the Cyprus Broadband Plan 2016-2020 was published and updated in December 2018, in order to be aligned with the targets of the European Gigabit Society and the 5G Action Plan.

The document covers the strategic objectives, the broadband actions and the national roadmap for 5G. In the long term the objectives are 100% coverage with 30 Mbps and 50% household penetration with 100 Mbps by 2020. The Official procedure for licensing the 5G priorities bands (700 MHz, 3.6 GHz and 26 GHz) was initially expected in Q4 2019. It was postponed to December 2020.

700 MHz

Six 2x5 MHz blocks of 700 MHz spectrum were available. A spectrum cap has been set at 2x10 MHz. Licences are offered with coverage obligations of 70% of the population and highways by year-end 2025. Data throughputs will have to be above 100 Mbps. The reservation price for each 2x5 MHz was set at 6 million EUR. Licences will be valid 20 years. The auction took place on 17 December 2020, after several postponements.

The winners were Cyprus Telecommunications Authority (Cyta), Primetel, Epic and Cablenet. The auction raised 41.6 million EUR for spectrum in the two bands (700 MHz and 3.5 GHz).

3.4 -3.8 GHz band

In January 2019, before the auction, the government gave three (3) pilot (trial) national licences in 3.4 -3.8 GHz band to the three (3) existing mobile operators, with 100 MHz bandwidth each, in order to test the equipment and the relevant applications.

Eight 50 MHz blocks are available for sale. A spectrum cap has been set at 100 MHz. Licences are offered with coverage obligations of 70% of the population and highways by year-end 2025. Data

8 http://www.mcw.gov.cy/mcw/dec/dec.nsf/all/46C0AB062D81E9D7C225838600407D2A/$file/%CE%91%CE%BD%CE%B1%CE%B8%CE%B5%CF%89%CF%81%CE%B7%CE%BC%CE%AD%CE%BD%CE%BF%20%CE%95%CF%85%CF%81%CF%85%CE%B6%CF%89%CE%BD%CE%B9%CE%BA%CF%8C%20%CE%A0%CE%BB%CE%AC%CE%BD%CE%BF%20%CF%84%CE%B7%CF%82%20%CE%9A%CF%8D%CF%80%CF%81%CE%BF%CF%85.pdf?openelement

throughputs will have to be above 100 Mbps. The reservation price for each 50 MHz block was set at 2.5 million EUR. Licences will be valid 20 years. The auction ended on 17 December 2020, after several postponements.

The winners were Cyprus Telecommunications Authority (Cyta), Primetel, Epic and Cablenet. The auction raised 41.6 million EUR for spectrum in the two bands (700 MHz and 3.5 GHz).

26 GHz

Cyprus is planning to authorise this band according to the EU Decision.

3.1.6. Czech Republic

Main points

- Implementation and Development of 5G Networks in the Czech Republic – Towards the Digital Economy" approved by the Czech government on January 13, 2020
- National Plan for the Development of Next Generation Networks 2016-2020
- 3.7 GHz spectrum auctioned off
- O2 Czech Republic launched 5G in July 2020, Vodafone in October 2020 (3.5 GHz), T-Mobile Czech Rep. in November 2020 (1800/2100 MHz)
- Spectrum auctions in the 700 MHz and 3.5 GHz frequencies completed mid-November 2020 raising 5.6 billion CZK (212.9 million EUR).

3.7 GHz

The Czech Telecommunication Office (CTU) auctioned off 3.7 GHz spectrum in 2017 to four bidders, including two new players:

- Telecom 5G: two 40 MHz blocks 3720-3760 MHz and 3760-3800 MHz
- O2 Czech Republic: one block 3680-3720 MHz
- PODA: 3640-3680 MHz
- Vodafone Czech Republic: one block 3600-3640 MHz
- Each 40 MHz block was sold for CZK 203 million (9.2 million USD), for a total of CZK 1.015 billion.

This spectrum seems to be dedicated to "Geographically localised BWA with fixed, mobile or nomadic terminals" and not 5G (source: CTU - http://spektrum.ctu.cz/en/band/3400-3600-mhz?filter%5BfrequencyFrom%5D=3&filter%5BfrequencyFromUnit%5D=GHz&filter%5BfrequencyTo%5D=4&filter%5BfrequencyToUnit%5D=GHz).

700 MHz / 3.4-3.6 GHz

In March 2020, the auction was delayed later in 2020 by CTU. The regulator modified rules for the 5G auction twice. The auction was further delayed due to complaints against the auction terms.

- 700 MHz: two blocks of paired 10 MHz of spectrum and two blocks of paired 5 MHz spectrum are available of which 2x10 MHz were reserved for new players. The minimum prices for 700 MHz blocks were set at 700 million CZK (26.8 million EUR), 1.12 billion CZK (42.8 million EUR), and 1.4 billion CZK (53.5 million EUR)

- In the 3.4-3.6 GHz, 10 blocks of 20 MHz of spectrum were available with spectrum caps for incumbents of 60 MHz and 100 MHz for new players. It also decided to provide national roaming conditions to new players in the 700 MHz and the 3.5GHz frequencies; In addition, 40 MHz of spectrum was reserved for industry verticals (3400-3440 MHz)
- New players could buy up to 100 MHz.

The auction ended on November 13, 2020. In the 700 MHz band, O2 Czech Republic won the 2x10 MHz block with obligations to provide national roaming and PPDR services for public emergency and security bodies. The other 700 MHz 2x10 MHz blocks are acquired by T-Mobile Czech Republic and Vodafone Czech Republic. In the 3,400-3,600 MHz band, O2 Czech Republic and CentroNet gained blocks of 20 MHz connected with obligations to lease frequencies to support Industry 4.0. T-Mobile Czech Republic, Vodafone Czech Republic and Nordic Telecom 5G also won spectrum 20 MHz blocks.

All in all, the auction raised 5.6 billion CZK (211.9 million EUR). T-Mobile Czech Republic paid 1.89 billion CZK (71.8 million EUR), Vodafone Czech Republic 1.568 billion CZK (59.6 million EUR) and O2 Czech Republic 1.342 billion CZK (51 million EUR). CentroNet was charged 628 million CZK (23.9 million EUR), and Nordic Telecom 168 million CZK (6.4 million EUR). Poda and Sev.en Innovations participated but did not acquire any spectrum. The auction included conditions to encourage the entry of new players but none of the bidders acquired enough spectrum to be operational.

26 GHz

In August 2020, CTU launched a public consultation on draft spectrum utilisation plan for the 26 GHz band.

3.1.7. Denmark

Main points

- 700/900 MHz auction held in March 2019
- 3.5 GHz temporary licences issued
- 5G launch by TDC in September 2020, by Telia/Telenor mid-November 2020, by 3 in December 2020
- Multi-band auction (1500 MHz /2100 MHz/2300 MHz/3.5 GHz/26 GHz) started in March 2021.

The national 5G Action Plan for Denmark was published in February 2019. In March 2019, Denmark completed its auction of the 700, 900 and 2,300 MHz bands, TDC, Hi3G and TT-Netvaerket, raising total proceeds of DKK 2.21 billion (EUR 296 million). The licences are valid from April 2020.

- Hi3G Denmark ApS won 2 x 10 MHz in the 700 MHz band and 2 x 10 MHz in the 900 MHz band at a total cost of almost 65 million EUR
- DC A/S won 2x15 MHz in the 700 MHz band, 2x10 MHz in the 900 MHz-band, 60 MHz in the 2300 MHz band and 20 MHz for SDL in the 700 MHz-band at a total cost of almost 217 million EUR
- TT-Netvaerket P/S won 2x5 MHz in the 700 MHz band and 2x10 MHz in the 900 MHz band at a total cost of 14 million EUR

Multi-band auction (1500 MHz/2100 MHz/2300 MHz/3.5 GHz/26 GHz)

The multi-band auction started on March 12, 2021. The frequencies will be awarded nationwide on a service- and technology-neutral basis. TDC Net, Hi3G Denmark and TT-Netvaerket (Telenor and Telia Joint Venture) participate in the tender. The process is divided into five stages. In the first two phases, spectrum in 2100 and 3500 MHz will be assigned. The phase 3 is expected to start on March 22, 2021 focusing on spectrum in the other bands (1500/2300 MHz and parts of 26 GHz). The remaining 26 GHz spectrum will be assigned in phase 4. Phase 5 will be the allocation phase where successful bidders bid again for specific frequency lots.

In the 3.5 GHz frequencies, licensees will be subject to coverage obligations, or leasing obligations in the first four years of the licence period for licences in 3740-3800 MHz spectrum or usage requirements. The licensee shall install antennas as well transmitting and receiving equipment capable of using the frequencies specified in the licence not later than 31 December 2023 at a minimum of 100 mast positions. The equipment at the relevant mast positions shall be connected to the necessary telecommunications infrastructure in such a way as to enable the licensee, via the relevant mast positions, to offer at least one electronic communications service (at the licensee's own discretion) to end-users by using the frequencies specified in the licence. The coverage obligation does not require a specific technology to be used. Licensees shall ensure:

- not later than 31 December 2023, a population coverage of 60% when using the 3.5 GHz frequency band, ensure
- not later than 31 December 2025, a population coverage of 75% when using the 3.5 GHz frequency band.

Licensees in 2100 MHz frequencies will also be subject to coverage obligations. Licensees shall provide mobile voice and data services by February 1st, 2024 with at least 30 Mbps DL and at least 3 Mbps UL in outdoor locations. The coverage obligation applies in the coverage areas specified in the licence, and in each individual coverage area at least 90% of the area shall be covered. Licensees are not required to fulfil the coverage obligation only with the 2100 MHz frequencies included in their licence. The coverage obligation may also be fulfilled via national roaming agreements.

Frequencies in the 26 GHz band to be awarded in the auction comprise 2850 MHz unpaired frequencies (24.65 – 27.5 GHz). The licences are subject to usage requirements. The licensee shall install antennas as well transmitting and receiving equipment capable of using the frequencies specified in the licence not later than four years from the date of entry into force at a minimum of 100 mast positions. The equipment at the relevant mast positions shall be connected to the necessary telecommunications infrastructure in such a way as to enable the licensee, via the relevant mast positions, to offer at least one electronic communications service (at the licensee's own discretion) to end-users by using the frequencies specified in the licence.

3.1.8. Estonia

Main points

- 4 licences in 3.6 GHz frequencies postponed in 2021
- 700 MHz and 26 GHz tenders scheduled later in 2021
- 5G launch by Telia Estonia in November 2020 with DSS

In March 2019, a 5G spectrum roadmap was issued with plans to auction 700 MHz and 3.4-3.8 GHz spectrum. The potential of spectrum in the 40-44 GHz and 66-71 GHz ranges was mentioned.

700 MHz

In October 2019 the Ministry of Economic Affairs and Communications launched a consultation about a public tender of spectrum at 700 MHz and 26 GHz (24.25–27.5 GHz) for mobile broadband services. The consultation run until mid-December 2019.

In June 2020, a fourth licence was added in the forthcoming 5G auction.

3.6 GHz

The auction for 390 MHz of spectrum in the 3.6 GHz band was suspended in April 2019 following a complaint about the rules of the tender. Levikom Eesti, a provider of IoT and fixed-wireless internet services, said that auctioning only three licences in the 3.6 GHz band would favour the country's trio of incumbent cellcos, while also hampering competition. In the first months 2020, the IT ministry decided to offer a 4th 5G licence. Applications are due by June 18th, 2020.

3.1.9. Finland

Main points

- The 700 MHz band frequencies were assigned in November 2016
- In May 2018, the government launched a consultation to free spectrum in the 3.6 GHz band
- The 3.6 GHz band spectrum auctions took place in September 2018
- Elisa, first 5G network in Europe launched in June 2018. All players launched 5G since then
- Early award of trial licences to a large number of companies (October 2015-October 2017)
- Auction for the 26 GHz (25.1- 27.5 GHz) spectrum ended on June 8, 2020. The incumbent MNOs each got a 5G licence at 7 MEUR giving them the right to use 800 MHz of spectrum.

At the end of 2018, the Finnish Ministry of Transport and Communications published a new strategy for digital infrastructure called "Turning Finland into the world leader in communications networks – Digital infrastructure strategy 2025". It details the strategy for promoting the implementation of 5G and supporting optical fibre construction in Finland. The strategy contains Finland's 5G deployment plan and deals especially with the 3.6 GHz and 26 GHz bands.

26 GHz

In January 2020, Finland launched a consultation on the 26 GHz auction scheduled in the summer 2020. It included spectrum from 25.1 to 27.5 GHz, excluding the lowest 850 MHz part of the 26 GHz band that was reserved for local 5G networks and research & development or educational usage. The auction took place on June 8th, 2020, and the current MNOs - Elisa, Telia and DNA - were each assigned 800 MHz of spectrum at the starting price of 7 million EUR. Licences are national for mainland Finland. Elisa won the 25.1-25.9 GHz frequencies, Telia the 25.9-26.7 GHz and DNA got the 26.7-27.5 GHz

frequencies. The frequency band can be used for 5G networks as of 1 July 2020 and the licence is valid in mainland Finland until 31 December 2033.

3.1.10. France

Main points

- 700 MHz frequencies assigned in December 2015
- Consultation on 5G, 2016
- Trial licences and trial cities, 2017-2020
- 5G pilot window, Jan. 2018
- Provision of mid-band spectrum for trials in selected cities
- 5G roadmap, July 2018
- 3.5 GHz auction completed on October 1st, 2020. Results of the positioning auction published on October 20th, 2020
- 5G launch by SFR in November 2020, by Bouygues Telecom and Orange France in December 2020 (in March 2021 in Paris).

The 5G road began in 2016 when Arcep launched a public consultation on 5G. The process accelerated in 2017 when ARCEP consulted on its 5G roadmap and awarded trial licences. Arcep created a 5G pilot window 5G@arcep.fr in January 2018 aimed at assigning frequencies to stakeholders wanting to perform full-scale 5G pilot trials (ports, hospitals, connected roadways…). In 2017, 5G trial authorisations were provided in many cities in 3.5 and 26 GHz frequencies. Mid-July 2018, ARCEP disclosed the French 5G roadmap and announced the launch of four priority areas:

- Free up and assign 5G spectrum; ARCEP is currently working hard on future connectivity needs and on freeing-up and awarding 3.4-3.8 GHz spectrum
- Facilitate development of new uses and applications
- Support deployment of new infrastructures
- Ensure transparency and discussion on 5G deployments and on public exposure

In February 2019, the French government and the national regulatory authority, ARCEP, issued a call for 5G trials in the 26 GHz frequency band in France.

3.5 GHz (metropolitan)

In July 2019, ARCEP opened a public consultation on the terms and conditions for the allocation of 5G spectrum in the 3.4 GHz - 3.8 GHz band. The regulator was planning to release 31 TDD blocks (10MHz each) in the 3490 MHz – 3800 MHz band. The procedure was to include a first stage, in which operators can obtain frequency blocks for optional commitments, before a second stage (auction), which would allow candidates to obtain additional frequencies. Each bidder should be allowed to purchase a maximum of 100 MHz. Operators could be obliged to offer 5G in at least two cities before the end of 2020. The obligations to support the deployment of 5G equipment were the following: 3,000 sites by 2022, 8,000 (2024) and 12,000 (2025).

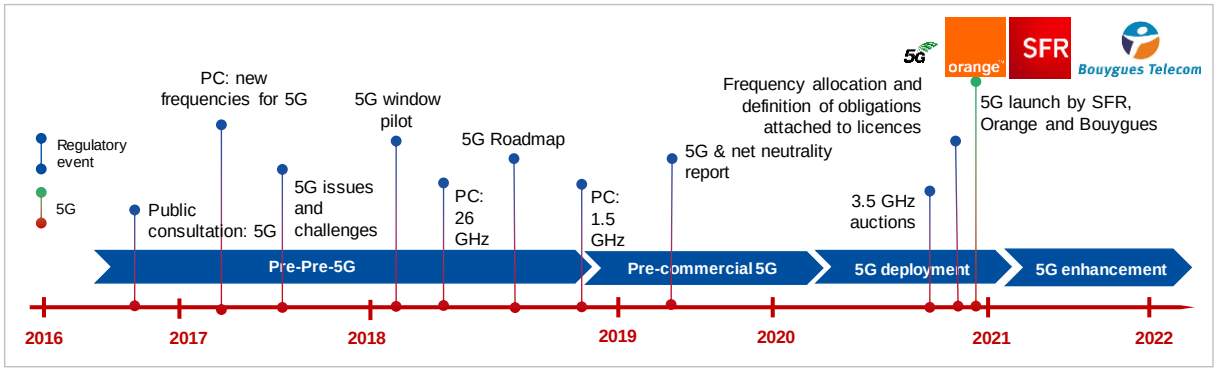
The auction was postponed twice from April 2020 to September/October 2020. The auction for eleven 10 MHz blocks started on September 29, 2020. The first round (bidding) was completed on October 1st, 2020. The four MNOs paid a total of 2.786 billion EUR for 310 MHz of spectrum, in addition to the previous 50 MHz block awarded earlier in 2020 to each player at 350 million EUR per block. Orange won 90 MHz of spectrum, SFR obtained 80 MHz and both Bouygues and Free got 70 MHz of spectrum. A spectrum cap had been set at 100 MHz of spectrum per MNO. The second round where players bid for "positioning" that spectrum in the band ended on October 20th, 2020. Allocations are as follows:

- SFR : 3490-3570 MHz
- Bouygues Telecom : 3570-3640 MHz
- Free Mobile : 3640-3710 MHz
- Orange : 3710-3800 MHz

700/3.5 GHz (overseas)

In December 2020, Arcep issued a consultation (18 December 2020-26 February 2021) on draft procedures for 700 MHz and 3.4-3.8 GHz frequencies in La Reunion and in 700 and 900 MHz frequencies in Mayotte.

Figure 18: 5G timeline in France



Source: IDATE DigiWorld, as of March 2021

3.1.11. Germany

Main points

- The 700 MHz frequencies assigned in June 2015
- "5G for Germany", autumn 2016
- 5G spectrum roadmap, 2018
- Update in mobile broadband strategy in 2019
- 3.4-3.7 GHz (300 MHz) and 2 GHz (2x60 MHz) 5G auction ended in June 2019, raising 6.55 billion EUR (of which 4.18 billion EUR for the 3.6 GHz spectrum). Licences include coverage obligations
- 100 MHz reserved for local and regional purposes in 3.7-3.8 GHz spectrum. Applications opened on November 21st, 2019

- 26 GHz spectrum expected to be potentially awarded upon application
- Vodafone and Deutsche Telekom launched 5G in July 2019, Telefonica in October 2020. The new player 1&1 Drillisch has not launched 5G yet.

5G initiatives

The Bundesnetzagentur published its "Frequency Compass" in July 2016 in a view to identify areas for regulatory action on spectrum for 5G. More detailed Points of Orientation were published in December 2016.

The Government launched in autumn 2016 its "5G Initiative for Germany". In a paper released in September 2017, the Federal Government describes the national 5G strategy (context, actions, rollouts) over the period to 2025. It defines five field of actions, key milestones and allocates 80 MEUR to 5G research initiatives in 5G research centres.

The BNetzA reserved 100 MHz in 3.7-3.8 GHz spectrum for verticals and started reservations in November 2019.

In the 2 GHz band, 2x40 MHz will be made available as from 1st, January 2021. An additional 2x20 MHz will be available as from 1st January 2026.

The Minister for transport and digital infrastructure in Germany updated the national mobile strategy in September 2019. A 5-point plan was announced and a 1.1 billion EUR plan to improve mobile coverage was agreed. The central topic raised deals with coverage issues (extending coverage) and especially with ways and means to reduce white spots in 4G and consequently in 5G.

National mobile operators agreed to i) provide reliable voice and data services in 99% of households nationwide by the end of 2020, and 99% of households in each state by 2021, especially in rural areas, ii) increase intra-cooperation and build at least 1,400 masts accessible to any operator, iii) meet a minimum of 100 Mbps speeds across major transport routes, iv) and install base stations in "white spots" unserved rural areas. Dedicated funds for Municipalities will be opened to help them actively contribute to improve mobile coverage. MNOs agreed to share 6,000 5G sites in rural areas and in transportation routes.

In the plan to counter the economic crisis caused by the covid-19, the German government decided to allocate 7 billion EUR to 5G.

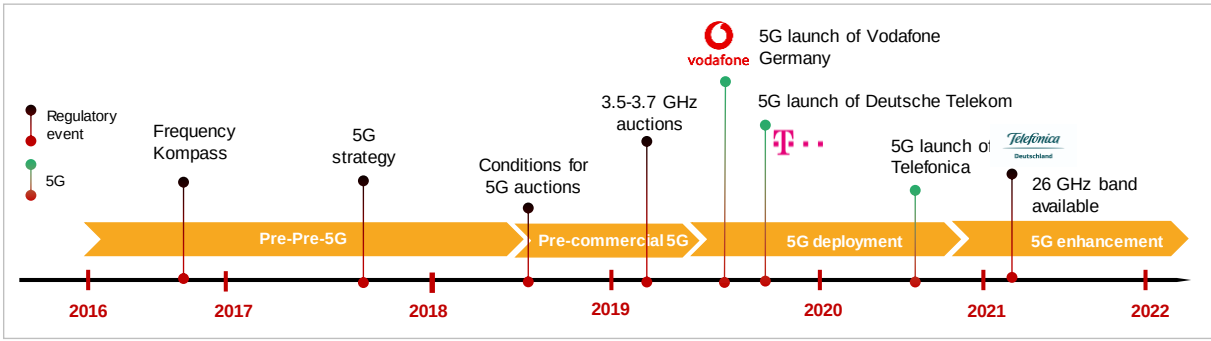
3.5 GHz

The 3.6 GHz band auctions started in March 2019. On June 5, 2019, the regulator ramped up minimum bids in an attempt to wrap up the 5G spectrum auction. The process ended on June 12, 2019 raising 6.55 billion EUR after 497 rounds. Deutsche Telekom bid 2.17 billion EUR for 130 MHz of the 420 MHz of spectrum allocated in the 2 and 3.6 GHz frequencies. Vodafone got 130 MHz for 1.88 billion EUR and Telefonica got 90 MHz for 1.42 billion EUR. Drillisch paid 1.07 billion EUR for 70 MHz. Frequencies will be available as from 2021 or 2026.

Coverage requirements:

- At least 100 Mbit/s for at least 98% of households in each federal state by the end of 2022
- At least 100 Mbit/s and a maximum latency of 10 ms for all German motorways by the end of 2022
- At least 100 Mbit/s and a maximum latency of 10 ms for all federal roads with connectivity function levels 0 or 1 by the end of 2022
- Of at least 100 Mbit/s and a maximum latency of 10 ms for all other federal roads by the end of 2024
- At least 50 Mbit/s for all state roads by the end of 2024
- At least 50 Mbit/s for seaports and the inland waterways core network by the end of 2024
- At least 100 Mbit/s for rail routes with more than 2,000 passengers daily by the end of 2022, at least 50 Mbit/s for all other rail routes by the end of 2024
- And, by the end of 2022:
- Operation of 1,000 "5G base stations", and
- Operation of 500 base stations with a transmission rate of at least 100 Mbit/s in not-spots.

Figure 19: 5G timeline in Germany



Source: IDATE DigiWorld, March 2021

3.1.12. Greece

Main points

- Trial licences in 3.4-3.8 GHz frequencies were issued before the auction
- 5G cross-border corridor (Bulgaria, Greece, Serbia) signed in July 2018
- Auction of 2×30 MHz in the 700 MHz band, 2×15 MHz in the 2100 MHz band (plus 2×45 MHz in the same band which is already allocated but licences expire in 2021), 280 MHz at 3.6 GHz, and up to 2,500 MHz in the 24 GHz – 28 GHz range completed on December 17, 2020
- 5G launches in December 2020 by Cosmote and Wind Hellas, in January 2021 by Vodafone.

In January 2019, the Hellenic Telecommunications and Post Commission (EETT) reviewed allocations in an attempt to allocate 5G spectrum. Apart from the three pioneer bands, 1500 MHz frequencies are also considered for 5G.

Multi-band auction incl. 700 MHz, 3.4-3.8 GHz and 26 GHz spectrum

Late in September 2020, EETT the Greek regulator kicked off the 5G auction process. It invited applications for spectrum until 23 October 2020. The auction had to be postponed twice, in October

2019 to 2020 and in 2020 due to covid-19. Licences in all pioneer bands will be valid for 15+5 years from December 20, 2020 till December 19, 2035 (except specific slots at 3.4-3.8 GHz which will be valid from May 1st, 2029).

The starting price for all the frequencies was 367.3 million EUR. The auction raised 372.3 million EUR. Vodafone paid 130.1 million EUR in total: 37.5 million EUR for 14 blocks in 3400-3800 MHz frequencies, 51.1 million EUR for 2 blocks in 700 MHz frequencies, 6.5 million EUR for 2 blocks in 26 GHz spectrum and 35.1 million EUR for 4 blocks in 2 GHz band. Cosmote spent 123 million EUR: 15 blocks at 3.4GHz to 3.8GHz for 30.7 million EUR, 50.6 million EUR for 2 blocks at 700 MHz, 4 blocks at 2 GHz for 35.27 million EUR and 2 blocks in 26 GHz frequencies for 6.5 million EUR. The third player, Wind Hellas, committed 119 million EUR for 10 blocks at 3.4-3.8 GHz for 30.3 million EUR, 2 blocks in 700 MHz spectrum for 5.1 million EUR and 1 in 26 GHz band for 3.245 million EUR.

Licences are sold with coverage obligations:

- The 3.4-3.8 GHz licence holder has to cover:
  - 20% of the population and deploy its network in at least two districts within 3 years,
  - Install at least 300 5G sites within 5 years
  - Provide at least 100 Mbps speeds with a maximum 10 ms latency
    - Within 3 years in most major continental motorways and on the major road north of Crete
    - Within 6 years in all Greek motorways
- Licensees at 700 MHz have to cover
  - Within 3 years: at least 99% of population at country level and 95% of population in each district, at least 95% of territory and maritime zones, 95% of motorways, 95% of railway networks (Athens-Patras and Athens-Thessaloniki (excluding tunnels)
  - At least provide 100 Mbps DL with a maximum latency of 10 ms and within 3 years to at least 60% of the population, 60% of motorways and rail networks (Athens-Patras and Athens-Thessaloniki (excluding tunnels) and 95% of major motorways (Athens-Thessaloniki-Evzoni, Peloponnese, Olympia-Odos, Ionian main road, Egnatia-Odos, Central Greece main road, Attiki-Odos, Northern Cretan main road
  - At least provide 100 Mbps DL with a maximum latency of 10 ms and within 6 years to at least 90% of the population, 90% of motorways and rail networks
  - At least provide 100 Mbps to 90% of the population in underserved areas within 5 years.

If the licensee is a new player, coverage obligations are less strict: it has to cover at least 80% of the population within 5 years.

3.1.13. Hungary

Main points

- “Digital Success Programme 2.0”. Strategic study
- European 5G hub for 5G
- 700z/2100/2600/3600 MHz auction ended end March 2020. 700 MHz spectrum not valid until 6 September 20205G launch by Vodafone in October 2019 with existing 3.5 GHz spectrum
- 5G launch by Magyar Telecom in April 2020, Vodafone in October 2019.

In July 2017, the domestic Government stated three major objectives for Hungary in its "Digital Success Programme 2.0". Strategic study.

- Hungary to become a European hub for 5G developments by 2018
- Hungary to play a leading regional role in testing applications based on 5G technology
- Hungary to be among the first to adopt 5G technology after 2020.

The 5G Coalition with up to 50 Hungarian government institutions, companies, business chambers, universities, research institutes and professional and civic organisations was formed mid-June 2017. The 5G Coalition set goals including drawing up a 5G development strategy and creating a testing environment to give Hungary a say in setting global 5G standards, aiming for the nation to become an early 5G adopter from 2020.

Multi-band auction (700/2100/2600/3600 MHz)

The auction was expected late in 2019 but, as the consultation showed limited market demand, it was postponed to 2020. Four MNOs have applied for the auction on 8 August 2019 and after the formal review the Authority entered three operators only (Magyar Telecom, Telenor and Vodafone). Digi Communications appealed the decision of the NMHH. The decision was upheld late in November 2019. The player which protested against its exclusion lost legal action in November 2020. The Supreme Court rejected a later appeal. No further appeal is permitted.

The multi-band auction was held at the end of March 2020 despite covid-19. 50 MHz was sold in the 700 MHz band (and freed up in September 2020), 30 MHz in the 2100 MHz band and 310 MHz in the 3600 MHz frequencies. No bids were submitted for the 2600 MHz spectrum. Magyar Telecom, Vodafone Hungary and Telenor Hungary won 15-year licences (until 2035, licences can be extended for 5 additional years once with the same pricing conditions) in the 700 MHz, 2100 MHz and 3600 MHz bands and acquired usage rights for 128.49 billion HUF (368 million EUR).

26 GHz band

- Intensive fixed service use currently in 24.5-26.5 GHz sub-band.
- Expiry date of most of the licences is 2027.
- Negotiation with present frequency users is ongoing.
- 26.5-27.5 GHz sub-band suitable for early introduction of 5G
- Strategy for implementing new technical criteria for the introduction of 5G is under elaboration and the rules for the transition period are to be developed.
- The Authority also considers 26 GHz spectrum for 5G. However, due to lack of demand on that specific band (Public consultation held on that topic during Summer 2019), plans are on hold.

3.1.14. Ireland

Main points

- National Roadmap on the use of 700 MHz frequencies published on March 2019, revised on May 2020
- 3.6 GHz licences auctioned by ComReg in May-June 2017

- On-going preparation of the multi-band auction for 700 MHz, 2100 MHz, 2300 MHz and 2600 MHz spectrum. Final decision expected in Q4 2020. Auction expected in 2021.
- Temporary licences issued to players from 9 April to 8 July 2020 in 700 and 2100 MHz spectrum. Licences were further extended up to April 1st, 2021. In March 2021, Comreg consulted on a further temporary framework beyond April 2021.
- 5G launch by Vodafone in August 2019, by Eir in October 2019 and by Three Ireland late in September 2020.

In May 2020, ComReg conducted tests at 20 5G antennas and concluded there were no health risks.

3.4-3.8 GHz band

360 MHz of TDD spectrum has already been auctioned in 2017. Licences for 5G services started in January 2019 and will expire on 31 July 2032 (fifteen years).

"The Auction resulted in the successful assignment of all 360 MHz of TDD spectrum. The Auction offered this spectrum in 594 lots spread over nine geographic regions (four rural and five urban) and is assigned on a contiguous basis." (Source: ComReg)

- Imagine Communications Ireland Ltd (Imagine), currently the largest Wireless Internet Service Provider (WISP) obtained spectrum rights of use for 60 MHz in each of the rural regions;
- Airspan Spectrum Holdings Ltd (Airspan), a new entrant and the UK arm of a US global provider of 4G broadband wireless systems and solutions. Airspan's products serve operators and markets such as smart utilities, transportation and public safety in both licenced and licence exempt frequency bands. Airspan obtained spectrum rights of use for 25 MHz in the rural regions and 60 MHz in the cities;
- Vodafone Ireland Ltd, a mobile network operator obtained 85 MHz in rural regions and 105 MHz in the cities;
- Three Ireland Hutchison Ltd, obtained 100 MHz nationally;
- Meteor Mobile Communications Ltd, obtained 80 MHz in the rural regions and 85 MHz in the cities.

700 MHz, 2.1/2.3/2.6 GHz bands

Due to covid-19, ComReg issued on-demand temporary licences to MNOs in April 2020. Meteor Mobile, Three Ireland and Vodafone Ireland received temporary licences valid from April to July 2020 in 700 and 2100 MHz spectrum.

Comreg will use a combinatorial clock auction. The format was previously used for 800/900/1800 MHz and for 3.6 GHz auctions. Licences will be valid 20 years in 700, 2.3 and 2.6 GHz frequencies. Validity of the 2.1 licences will be shorter as they expire in 2022 and 2027.

Licences in the 700 MHz frequencies go with coverage obligations to be met over the next three to seven years. They include providing a 3 Mbps service to 99% of the population and to 92% of the territory. 30 Mbps should be available on motorways, primary roads and 345 specific locations (business parks, hospitals, airports, seaports, bus and train stations, information points)

The 2.1/2.3/2.6 GHz bands go with obligations related to network deployment: a certain number of base stations in each band have to be installed. The 2.3 and 2.6 GHz bands will have additional technical obligations (co-existence with WLANs…).

26 GHz bands (24.745 – 25.277 GHz paired with 25.753 GHz – 26.285 GHz)

The 26 GHz auction took place from April to June 2018. 840 MHz or 15 of 19 Lots of 2 × 28 MHz in the range 24.745 – 25.277 GHz paired with 25.753 GHz – 26.285 GHz was auctioned to the three mobile players in place. Each mobile player was awarded 280 MHz. Vodafone paid 550,000 EUR, while Three and Meteor Mobile paid 350,000 EUR.

It consisted of a "sealed bid combinatorial auction" using a second price rule and applying processes and rules as set out in the Information Memorandum. Winning Bidders paid approximately 5 million EUR for spectrum rights of use, comprising 1.25 million EUR in upfront fees of 3.75 million EUR in spectrum usage fees which will be paid over the 10-year duration of the licences.

In January 2021, ComReg requested input on a study of the 26 GHz band. The study recommends against a future auction of the band. Stakeholders were asked to submit comments on this study by February 23, 2021.

3.1.15. Italy

Main points

- 5G for Italy, 2016, 5G strategy, pushed by TIM, around identified cities and application areas.
- Trial licences and trial cities, mid-2017
- 700 MHz/3.5 GHz auctions in October 2018, 26 GHz spectrum auctions, October 2018, first in Europe. Licences will be valid till year-end 2037
- TIM launched 5G services in June 2019, Vodafone in August 2019, Wind Tre in November 2020.

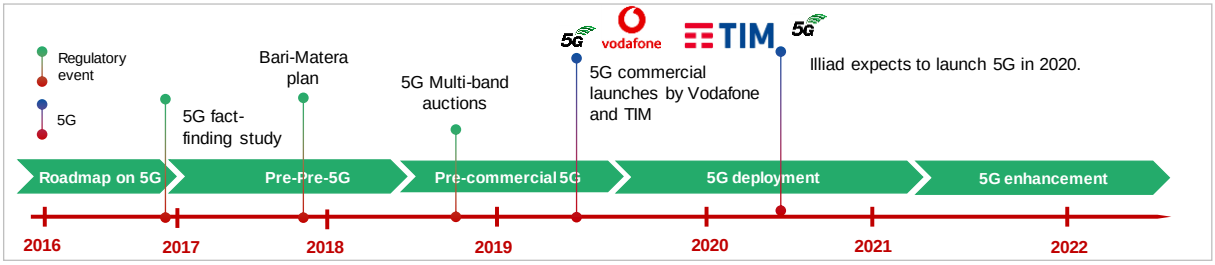
The Italian 5G strategy kick-started late in 2016 when the domestic NRA announced the start of a fact-finding survey for the development of mobile and wireless systems towards the 5G and the utilization of the spectrum above 6 GHz. In March 2017, the Government selected five 5G trial cities, including Milan (Vodafone), Prato (Wind Tre-Open Fiber), L'Aquila (Wind Tre-Open Fiber), Bari and Matera (Telecom Italia-Fastweb-Huawei Technologies), that will use 100 MHz of 3.6-3.8 GHz spectrum. Provisional licences are valid from September 2017 to 2020.

In August 2020, Agcom extended spectrum licences in the 900 and 1800 MHz bands, following a public consultation. The Iliad Italia's licence in the 900 MHz band is thus extended for 8 years from its current expiry date of end-2021, and TIM, Vodafone and Wind Tre's licences in the 2100 MHz frequency band are also extended until the end of 2029.

700 MHz, 3.6-3.8 GHz, 26 GHz

In May 2018, the NRA announced 5G multi-band spectrum auctions (in the 700 MHz, 3.6-3.8 GHz and 26 GHz bands). 700 MHz and 26 GHz spectrum auctions ended respectively in September and October 2018. The five 26 lots of 26 GHz spectrum raised 167.3 million EUR. 700 MHz frequencies raised globally 2.04 billion EUR. The 3.6-3.8 GHz spectrum auction hit over 4 billion EUR.

Figure 20: 5G timeline in Italy



Source: IDATE DigiWorld, March 2021

Coverage obligations related to spectrum auctions

To ensure widespread improvements in mobile coverage across the Italy, the Ministry of Economic Development, based on the national regulatory authority (AGCOM) rules, has established **coverage obligations for the 700 MHz FDD band and 3600-3800 MHz band**.

Concerning the **700 MHz FDD band**, the coverage obligations requires winning bidders to roll out improved mobile coverage of national population, tourist locations and main national road and rail transport routes.

700 MHz FDD
National population coverage
Within 36 months of the nominal availability of frequencies, Within **54 months** of the nominal availability of frequencies, each winning bidder has to reach at least the coverage of 80% the winning bidders have to collectively reach the coverage of of the national population; the new entrant has 12 months **99.4% of the national population**. more to achieve the same coverage goal.
National road and rail transport routes coverage
Within 42 months of the nominal availability of frequencies, the winning bidders have to collectively cover all the main national road and rail transport routes.
Tourist locations coverage
Within 66 months from the creation of the lists of Italian tourist locations, each winning bidder is required to cover at least 90% of the tourist locations included in the list associated with the rights of use awarded; the new entrant has 12 months more to achieve the same coverage goal.

Concerning the **3600-3800 MHz band**, the coverage obligations require **80 MHz** winning bidders to roll out improved mobile coverage in a **mandatory list of municipalities**. Within 90 days from the date of the award, the winning bidders have to submit a list of municipalities to be covered to the Ministry of Economic Development. Then, the winning bidders have **72 months** from the date of the award to prove they are ready to provide on demand the 5G service in all municipalities of their mandatory list. The mandatory list has to include at least 10% of all Italian municipalities under 5.000 inhabitants. All Italian municipalities under 5.000 inhabitants out the mandatory lists are signed in a free list. Any subject, which is not an TLC operator, from 120 days from the award can declare to the Ministry its willingness to offer the service in a municipalities of free list, using leasing contract with 3600-3800 MHz winning bidders.

Finally concerning the **3600-3800 MHz band**, the coverage obligations require **20 MHz** winning bidders to reach the coverage of **5% of the population of each Italian region**.

Auction results

In September-October 2018, the NRA auctioned 60 MHz of 700 MHz spectrum for 2 billion EUR, 200 MHz (divided in tow 80 MHz blocks and two 20 MHz blocks of 3.6-3.8 GHz spectrum for 4 billion EUR and 1,000 MHz (divided in five 200 MHz blocks) of 26.5-27.5 GHz for 167 million EUR. The whole auction ended after 14 days of intense bidding, far above expectations, reaching 6.55 billion EUR of which 4 billion EUR for the highly-coveted mid-frequencies.

- The 700 MHz auction process ended mid-September 2018. 700 MHz frequencies raised globally 2.04 billion EUR. Telecom Italia announced it had paid 680.2 million EUR for 2x10 MHz. Illiad paid 676.5 million EUR for 2x10 MHz. Vodafone spent 683.2 million EUR for 2x10 MHz. Licences are valid 15 years, starting in 2022.
- The mid-band auction ended on October 2nd, 2018, 14 days after start and 171 rounds. Telecom Italia and Vodafone won the largest blocks of spectrum (80 MHz each) for approx.1.7 billion EUR each. Respectively they paid 1.694 billion EUR and 1.685 billion EUR. Wind and Iliad paid 483.9 million EUR each for 20 MHz of spectrum each (483.92 million EUR for Wind and 483.9 million EUR for Illiad). Overall, the 3.7 GHz auction hit over 4 billion EUR reaching 4.3 billion EUR.
- The auction for 26 GHz frequencies have not shown a huge interest by players. The five lots were allocated, raising a total of 167.3 million EUR. Telecom Italia paid its lot 33 million EUR, Illiad received another lot for a little less at 32.9 million EUR, while Fastweb, Wind and Vodafone paid 32.6 million EUR each.
- TIM Italy and Vodafone have agreed on a passive network sharing deal for 5G including all 22,000 antenna sites controlled by the operators.

3.1.16. Latvia

Main points

- On-going preparation of 700 MHz spectrum assignment for 5G
- On-going preparation of 1500 MHz spectrum assignment for 5G
- 100 MHz of 3.5 GHz spectrum for 5G auctioned in November 2017. Remaining 50 MHz of 3.5 GHz spectrum for 5G auctioned in September 2018
- 5G launch by Tele2 in two sites in January 2020, LMT in July 2019.

700 MHz

The Latvian regulator issued a consultation on 700 MHz spectrum assignment for 5G in March 2020. Three lots of 2x10 MHz + 1x5 MHz of spectrum (703-713 MHz, 738-743 MHz and 758-768 MHz – 713-723 MHz, 743-748 MHz and 768-778 MHz – 723-733 MHz, 748-758 MHz and 778-788 MHz) are expected to be assigned. The reserve price is set at 1 MEUR for each lot. Licences would be valid for 20 years from the beginning of 2022. The consultation was opened till May 25, 2020.

1500 MHz

At the beginning of 2019, SRPK cancelled Lattelecom's rights of fixed use of 1427-1452 and 1492-1517 MHz frequencies as from 2021. SRPK intends to provide mobile 5G services in 1427-1517 MHz frequencies.

In August 2019, Latvia's regulator issued a consultation on its plans to auction the 1432–1492 MHz band before January 2021. The consultation was closed on September 4, 2019. The auction is expected to take place in 2021.

3.4-3.8 GHz

100 MHz of 3.4-3.8 GHz frequencies partially auctioned off in November 2017. LMT obtained the two 50 MHz blocks (3400-3450 MHz and 3650-3700 MHz) for the reserve price of 250,000 EUR a piece. The concessions are valid for 10 years, from January 2019 to December 2028.

Remaining 50 MHz of 3.5 GHz spectrum auctioned off in September 2018. SPRK auctioned off 50 MHz of spectrum for 5G services at 3550-3600 MHz to Tele2 Latvia in September 2018. The auction raised 6.5 million EUR for a 10-year licence valid from January 1st, 2019.

3.1.17. Lithuania

Main points

- General Plan for 5G approved on 3 June 2020 including coverage obligations: at least one of the 5 largest cities covered by 2022, all 5 by 2023 and main routes by 2025
- 3.4-3.8 GHz frequencies assignment was expected in the first quarter 2021 (temporary trials allowed in the band)
- 700 MHz frequencies assignment expected in 2021
- 26 GHz spectrum will be assigned when there will be enough demand.

700 MHz

The regulator plans to assign one 2 x 10 MHz lot of FDD spectrum, two 2 x 5 MHz lots of FDD spectrum and three 5 MHz lots of spectrum for supplementary downlink (SDL). A SMRA (Simultaneous Multiple Round Auction) is to be organized, but the bidder will be allowed to bid only for one block of FDD spectrum and one block of SDL spectrum.

The auction was expected in the first quarter 2021.

3.4-3.8 GHz / 3.8-4.2 GHz

3.4-3.8 GHz frequencies were expected to be awarded by year-end 2020 (depending on talks with Russia on interference issues in border areas) but the auction was delayed to 2021. 100 MHz is put aside for PPDR services and communications. In the meantime, 3.5 GHz band spectrum has been allocated on a temporary and non-commercial basis to Telia Lietuva.

Drafted guidelines indicate that at least one 5G network should cover at least one of the national largest cities (Vilnius, Kaunas, Klaipeda, Siauliai or Panevezys) by 2022 and that at least one 5G network should be available in all 5 cities by 2023. Guidelines also introduced coverage obligations of all urban areas and main transport routes and hubs (motorways, rail routes, airports) by 2025.

26 GHz

The regulator waits for enough market demand before assigning spectrum.

3.1.18. Luxembourg

Main points

- 5G strategy in September 2018
- 700 MHz and 3.4-3.8 GHz auction completed in July 2020
- 26 GHz spectrum assignment on hold as demand is lacking
- 5G launch by Post Luxembourg, Orange and Tango in October 2020.

700 MHz/3.4-3.8 GHz

Assignment of the 700 MHz (703-733/758-788 MHz) and 3.4-3.7 GHz (3420-3750 MHz) bands was initially scheduled for 2020 in a SMRA Clock Hybrid single round sealed bid auction. Spectrum from 3.7-3.8 GHz will be considered separately. It is intended to be used by local applications. The 700/3600 MHz auction was completed in July 2020.

Four out of the five bidders have acquired 5G frequencies in the 700 MHz FDD and 3600 MHz TDD spectrum auction, paying a total of 41.3 million EUR (Players' bids are not available). The 15+5 year-licences include strict geographical coverage obligations for 700 MHz spectrum (50% geographical coverage by year-end 2022 and 90% by year-end 2024). In 3420-3750 MHz frequencies, players have to light up a minimum of 10 sites by ear-end 2020, 20 by year-end 2021, 40 by year-end 2022 and 80 by year-end 2024.

Orange, Post and Proximus were each awarded one of the three available lots of 2×10 MHz in the 700 MHz band.

In the 3600 MHz band, Orange and Post each acquired 110 MHz of frequencies, Proximus bought 100 MHz and Luxembourg Online 10 MHz. Eltrona participated in the auction but failed to secure spectrum rights.

Assignment rules included:

- In 700 MHz frequencies, players could not get more than 2x10 MHz. In 3400-3800 MHz frequencies, players cannot bid for more than 130 MHz. Licences will be valid 15 +5 years.
- A reserve price had been set at 562 kEUR for 2x1 MHz in 700 MHz frequencies and at 30KEUR for 1 MHz of spectrum in 3400-3800 MHz frequencies.

Category	Band	Lot Size	# of lots	Lot rating	Reserve price
A1	700 MHz (703-713 MHz paired with 758-768 MHz)	2x10 MHz	1	4	€ 5,626,000
A2	700 MHz	2x10 MHz	2	4	€ 5,626,000

	(713-733 MHz paired with 768-788 MHz)				
B	3600 MHz	40 MHz	5	4	€ 1,200,000
C	3600 MHz	10 MHz	13	1	€ 300,000

26 GHz (24.5-27.5 GHz)

Following the late 2020 consultation, the regulator announced in March 2021 it will not assign 26 GHz frequencies for 5G for the time being. Feedback from players revealed a lack of demand in the band.

3.1.19. Malta

Main points

- Strategy for 2018-2020 issued in November 2017
- Radio Spectrum Policy Programme 2019-2023 published in July 2019
- Five-year Radio Spectrum Policy Programme 2020-2025
- Trial licences.

In June 2018, the MCA released the National Roadmap for the UHF band between 470-790 MHz. The 700 MHz band should be made available for commercial wireless mobile broadband services as from June 2021.

Apart from the pioneer bands, Malta considers assigning 800 (874-876 MHz), 900 (915-921 MHz) and 1500 MHz (1427-1517 MHz) frequencies for mobile services and 5G.

In September 2020, Melita was granted a trial 5G licence. The trial started in September 2020 at the Melita Data Center and at locations in Sliema, Saint Julians and Valletta.

In February 2021, MCA launched an open consultation on its proposals to auction spectrum in the 700 MHz, 3.4-3.6 GHz and 26 GHz bands. Proposals include spectrum caps and indoor coverage obligations. The consultation closed on February 27, 2021.

3.1.20. Netherlands

Main points

- Connectivity Action Plan, July 2018
- In December 2018, the Netherlands Authority for Consumers and Markets (ACM) published a 5G paper “5G and the Netherlands Authority for Consumers and Markets”
- Multi-band 700/1500/2100 MHz completed in July 2020 raised 1.23 billion EUR
- 3400-3450 and 3750-3800 MHz intended for local use scheduled respectively for 2022 and 2026
- 5G launch by VodafoneZiggo in April 2020, by T-Mobile and KPN in July 2020.

In June 2019, the ACM released an updated spectrum plan for 5G. The telecom regulator intends to auction the 700, 1500, 2100 and 3500 MHz bands.

700/1500/2100 MHz

In December 2019, a public consultation was opened potential spectrum caps for 700/1500/2100 MHz spectrum and a reserve price that would raise at least 0.9 billion EUR. Licences will include coverage obligations of 98% geographic coverage of all domestic municipalities. The auction itself is scheduled for June 2020. Applications are due before 6 April 2020.

The multi-band auction started on 29 June 2020 and it raised 1.23 billion EUR. Each operator won 2×10 MHz in the 700 MHz band and 2×20 MHz in the 2100 MHz band. In the 1400 MHz band, KPN and VodafoneZiggo bought 1×15 MHz each and T-Mobile acquired 1×10 MHz. Spectrum in the 700 MHz and 1400 MHz will become available immediately, the 2100 MHz licences will be available from early 2021. Licences include coverage obligations of 98% geographic coverage of all domestic municipalities. Licences which will be issued in summer 2020 will run until 2040. The auction was cleared by the Court of The Hague one day before the announcement by the regulator. A lawsuit had been launched by Stop5GNL to block 5G auctions and rollout blaming negative health effects.

3400-3800 MHz

The 3500 MHz (3400-3450 MHz) is scheduled as from September 2022 and 3750-3800 MHz frequencies from 2026. The 3500 MHz auction is planned for 2022 as the band is currently used for satellite communications.

3400-3450 MHz

The 3.6 GHz auction is planned for 2022 as the band is currently used for satellite communications. Spectrum at 3400-3450 MHz is intended to be made available for local use.

In February 2021, MNOs warned the Parliament that assigning 3.4-3.8 GHz spectrum into two separate auctions “would yield unpredictable and perhaps undesired results” meaning prices could be too high. The auction process is expected to be published before the end of June 2021. The application procedure is scheduled for December 2021 at the latest with the auction to start in Q1 2022. Licences could be valid as from September 1st, 2022.

3750-3800 MHz

The 3750-3800 GHz auction is planned for 2026 as the band is currently used for satellite communications. Spectrum is intended to be made available for local use.

26 GHz

The use of the 26 GHz band is under consultation use of spectrum either for shared use or local authorizations from 2020. The consultation closed at the end of February 2020.

3.1.21. Poland

Main points

- Updated version of the National Broadband Plan (2020-2025) adopted in November 2020
- 5G Strategy for Poland, January 2018
- National Broadband Plan 2020-2025
- 5G spectrum consultation, July 2018
- A few trials to date
- 3.4-3.8 GHz auction stopped in March 2020 due to covid-19, expected by 27 August 2021
- 700 MHz auction expected by 30 July 2022
- 26 GHz frequencies to be assigned by 31 December 2022
- 5G services launched by Polkomtel with 2.6 GHz spectrum in May 2020, by T-Mobile Poland and Play early June 2020 in 2100 MHz spectrum, by Orange in July 2020 on 2100 MHz frequencies.

The updated version of the National Broadband Plan covering the 2020-2025 period adopted in November 2020 include plans for 5G in the country:

- 700 MHz frequencies should be assigned by 30 July 2022
- 3480-3800 MHz frequencies should be assigned by 31 August 2021 (initial goal of 30 July 2020 not met)
- 26 GHz frequencies should be assigned by 31 December 2022.

700 MHz

In December 2018, UKE asked if 700 MHz spectrum could be opened up in 2020 to 2022. In November 2020, UKE announced the auction should be completed by 30 July 2022.

3480-3800 MHz

In December 2019, UKE opened a consultation into its planned auction of four licences in the 3.4-3.8 GHz band. The NRA indicated it wants to award the four licences by mid-2020. The licences will be valid until the end of June 2035. The proposed starting price for each block is PLN 450 million (103.4 million EUR). The process kicked off in March 2020. Four lots of 80 MHz were auctioned: concessions A (3480-3560 MHz) and B (3560-3640 MHz) offer full nationwide coverage, licences C (3640-3720 MHz) and D (3720-3800 MHz) have geographic restrictions:

- at least 10 base stations in the area of 1 voivodship city selected from the cities indicated within 4 months of receiving the licence;
- until 31 December 2023, at least 300 base stations throughout the country, including at least 10 base stations in the area of each of at least 20 municipalities selected from the indicated municipalities, with the proviso that at least 9 voivodship cities will be selected;
- until 31 December 2025, at least 700 base stations throughout the country, including at least 10 base stations in the area of each of at least 30 municipalities selected from the indicated municipalities, provided that at least 16 voivodship cities are selected.

The commitments were designed in a way to ensure network roll-out in the largest population centers, i.e. municipalities with more than 80,000 residents.

The auction was postponed from March to year-end 2020 due to covid-19. It is expected to take place by 27 August 2021.

26 GHz

The auction is expected by year-end 2022.

3.1.22. Portugal

Main points

- Multi-band auction (700/900/1800/2100/2600/3600 MHz) postponed in March 2020 due to covid-19 and rescheduled for October 2020, and further rescheduled to early 2021. Resumed in March 2021, still ongoing
- 26 GHz auction expected in 2023.

Multi-band auction (700/900/1800/2100/2600/3600 MHz)

Early 2020, ANACOM launched a consultation on the upcoming multi-band auction including coverage and speed obligations. ANACOM also approved the draft rules for the auction with reserve prices as follows:

- 700 MHz; six lots of 2×5 MHz (19.20 million EUR per lot)
- 900 MHz; one lot of 2×5 MHz (30.00 million EUR per lot)
- 900 MHz; four lots of 2×1 MHz (6.00 million EUR per lot)
- 1800 MHz; three lots of 2×5 MHz (4.00 million EUR per lot)
- 2100 MHz; one lot of 2×5 MHz (2.00 million EUR per lot)
- 2600 MHz; two lots of 2×5 MHz (3.00 million EUR per lot)
- 2600 MHz; one lot of 25 MHz (3.00 million EUR per lot)
- 3.6 GHz (with restrictions until 2025); twenty lots of 20 MHz.

700 MHz and 3.6 GHz licences are accompanied with coverage or network development obligations.

- 700 MHz spectrum licensees have to provide speeds of 100 Mbps for 75% of the population in 2023 and 95% in 2025. In addition, obligations include coverage of highways (95% in 2025), main roads (85% in 2025) and trunks roads (85% in 2025) and rail routes (95% in 2025 for the Atlantic Corridor, Braga-Lisbon, Lisbon-Faro, Lisbon-Porto, 85% for remaining rail routes by 2025). Coverage obligations also include metro networks in Lisbon, Porto and Sul do Tejo. 90% of the population in low-dense areas have to be covered by 2025. New entrants have lighter coverage obligations (25% instead of 75/85 or 95%).

- Holders of 50 MHz of 3.56 GHz spectrum have to install 917 macro base stations of their own or 9,170 outdoor small cells of their own across the country. Holders of between 60 and 100 MHz of 3.6 GHz spectrum have to install a further 183 macro base stations of their own or a further 1,830 outdoor small cells of their own across the country, for every 10 MHz above 50 MHz they have acquired. In addition, 3.6 GHz spectrum licensees are obliged to install at least one macro cell or 10 outdoor small cells or a combination of the two types of station that ensures the maintenance of a ratio of 1 to 10 between them.
    - In each low-density municipality and in each municipality in the Autonomous Regions of Madeira and the Azores.
    - In each municipality with more than 50 thousand inhabitants

  Furthermore, 3.6GHz licensees have to install macro bae stations or outdoor small cells up to 2 years after the issuance of rights of use in hospitals and health centres, universities, ports and airports, military institutions, business parks.

The multi-band auction initially scheduled for sometimes between April and June 2020 was postponed due to the Covid. Auction rules were published in November 2020. New entrants are encouraged to participate: a bloc of 900/1800 MHz spectrum has been set aside for them. In addition, providing them nationwide roaming is mandatory. Nos, Vodafone, MEO, Novo (Grupo Masmovil) and DenseAir.

The auction started on December 22, 2020, paused on December 23 and resumed on January 6, 2021. It was still ongoing on March 19, 2021, after 46 days of bidding.

3.1.23. Romania

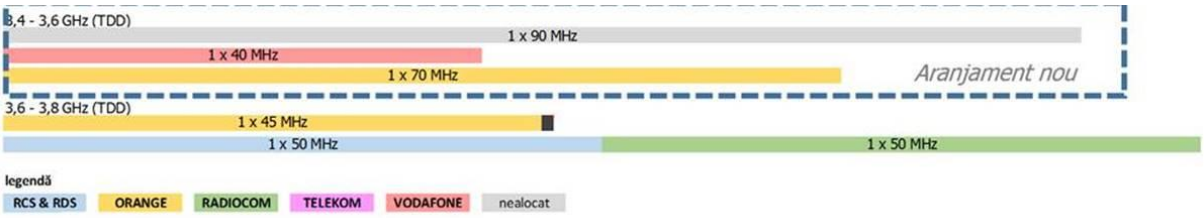
Main points

- 2021 5G Action Plan published late in 2020 with three priorities including the transposition of the European Electronic Communications Code (EECC), the organisation of the 5G multi-band spectrum auction in 2021 and the review of the wholesale market for high-quality access services
- National Strategy for the Implementation of 5G in Romania
- Multi-band 5G auction rescheduled for the second quarter 20215G launch by RC&RDS (3700 MHz licence granted in October 2015 valid for a period of 9 years starting from January 1st, 2016) and Vodafone in June 2019, by Orange in November 2019
- The National Authority for Management and Regulation in Communications (ANCOM) launched a public consultation on 5G spectrum between May and June 2018.

In December 2020, ANCOM published its Action Plan for 2021 for comments before January 4, 2021. The Plan mentions the multi-band auction process will be rescheduled for the second quarter 2021.

700 MHz/1500 MHz/2600 MHz/3400-3800 MHz

In June 2019, ANCOM published plans to auction spectrum in 700 (703-733/758-788 MHz and 738-753 MHz SDL), 800 (2x5 MHz FDD), 1500 (40 MHz SDL), 2600 (2x40 MHz FDD), and 3400-3800 MHz (90 MHz TDD valid in the 2020-2025 period, and 400 MHz TDD valid form 2026) frequencies by the end of October 2019. In July 2019, a consultation was issued to discuss technical details of the auction process. The auction should take place by the end of June 2021.



Source: Ancom

Romanian regulator released the draft terms of its 5G contest in August 2019. The procedure will include a first stage, in which operators can obtain frequency blocks for optional commitments, before a second stage (auction), which will allow candidates to obtain additional frequencies.

In November 2019, the auction was rescheduled to March 2020, the process was again postponed to Q4 2020 in March 2020. In September 2020, ANCOM's head told the auction could again be delayed from the initial target of December 2019 and be rescheduled for the second quarter 2021.

26.5-27.5 GHz

At least 1 GHz will be made available in the upper parts of the 26 GHz frequencies. The auction is expected before 2022, subject to market demand.

3.1.24. Slovakia

Main points

- 700/900/1800 MHz auction initially scheduled for June 2020 ended in November 2020 raising a total of 100.2 million EUR
- 3400-3600 MHz frequencies could be auctioned in 2021
- 5G launch by Slovak Telekom in December 2020.

700 MHz (primarily for 5G)/900 MHz/1800 MHz

In April 2020, Regulacny Urad (RU) invited applications for the multi-band 700/900/1800 MHz auction. In the 700 MHz band, spectrum 2x30 MHz is available broken down into 15 2x5 MHz blocks at a reserve price of 16 MEUR each. RU set a spectrum cap of 2x15 MHz by player in 700 MHz frequencies. No spectrum is finally not reserved for the fourth player in the market, SWAN Mobile. 700 MHz licences will be valid for 20 years (till year-end 2040). 700 MHz licences will be granted with coverage obligations of 95% of the population of every county town by year-end 2025 and 90% of the population outside county towns by 2027, with 70% of the country inhabitants covered by 5G by year-end 2027. 900 MHz spectrum will be sold with a reserve price of 840 kEUR for each 2x4.2 MHz block. Licences will be valid six months after the auction till year-end 2025. 1800 MHz spectrum will be sold in three 3 MHz blocks to be used within a year after the auction. Licences will be valid till year-end 2025.

The auction ended on November 24, 2020 raising a total of 100.229 million EUR. All the blocks were allocated. Orange paid 33.63 million EUR, O2 paid 33.39 million EUR and Slovak Telecom 32.66 million EUR.

- Orange, O2 and Slovak Telekom got a 2x10 MHz lot in 700 MHz frequencies (Orange: 723-733/778-798 MHz, 33.633 million EUR – O2: 703-713/758-768 MHz, 32 million EUR – Slovak Telecom: 713-723/768-778 MHz, 32.106 million EUR)
- At 900 MHz, O2 got 2x4.2 MHz spectrum for 840 KEUR
- O2, Slovak Telecom and 4ka (SWAN) obtained a 2x3 MHz lot of 1800 MHz each (O2: 1776.1-1779.1/1871-1874.1 MHz, 550 KEUR – Slovak Telecom: 1710-1710.1/1805-1805.1 MHz – 4ka: 1779.1-1782.1/1874.1-1877.1 MHz, 550 KEUR).

3.6 GHz band

(Source: ec.europa.eu/newsroom/document.cfm?doc_id=44456)

This frequency band has been assigned for fixed wireless broadband access so it is likely to be used for 4G and not for 5G.

RÚ completed the assignment of the 3.5 GHz frequency band (3.4-3.6 GHz) in 2016. Frequency licences were assigned through electronic auction to three operators for the whole country (O2 Slovakia, SWAN and Slovanet). These run until August 2025.

However, the assignment procedure for the 3.7 GHz frequency band (3.6-3.8 GHz) is still ongoing. RÚ has started the assignment process for the remaining frequencies in this band concerning two segments: the 3600-3640 MHz and the 3760-3800 MHz bands. Licences for these frequencies are granted locally at district level.

In early 2020, the conditions of the existing licences (valid until December 2024 for 3600-3800 MHz frequencies and August 2025 for 3400-3600 frequencies) were modified into 5G-compatible ones. In 2021, RU launched a consultation on these frequencies. 3440-3800 MHZ spectrum could be auctioned in 2021 with a spectrum cap of 100 MHz. Licences will be national. 3400-3440 MHz frequencies will be assigned separately.

3.1.25. Slovenia

Main points

- Consortium on 5G PPDR issues created in 2017
- Multi-band auction for 700/1500/2100/2300/3600 and 26 GHz spectrum to take place in 2021
- Temporary licences till the auction
- 2.6 GHz 5G launch by Telekom Slovenije in July 2020.

AKOS awarded trial licences in 5G pioneer bands until the public tender for auction:

- in the band 3400-3800 MHz until 31 December 2020,
- in the 700 MHz band until 30 June 2020,
- in the 26 GHz band until the award is due, until 31 December 2019.

In December 2019, AKOS delayed the launch of the planned multi-band auction to the second half 2020. The delay is due to a delay in adopting an updated Radio Spectrum Management Strategy. The auction is scheduled for year-end 2020. In May 2020, AKOS begun preparations for the auction.

In December 2020, AKOS issued a consultation on its spectrum management strategy for 2021-2023. Due to the delay in publishing its management strategy, the multi-band auction is expected to be further delayed and take place in 2021.

Multi-band 700/1500/2100/2300/3600 MHz and 26 GHz auction (700/3600 MHz and 26 GHz for 5G)

The regulator plans to sell spectrum in all three 5G pioneer bands (700 MHz, 3.6 GHz and 26 GHz) at the same time by April 2021, alongside with 1500/2100/2300 MHz complementary spectrum.

Licence holders are expected to launch 5G in at least one city within one year after being awarded the licence and to use all frequencies within five years to cover all major cities. 700 MHz 5G service should also cover 99% of motorways and 60% of all train lines and main roads by December 2025.

AKOS introduced spectrum caps by frequency bands: 2x35 MHz in 700/800/900 MHz frequencies, 190 MHz in the 2.3/3.6 GHz spectrum, 800 MHz in the 26 GHz band and a global spectrum cap whatever the band: each bidder should not hold more than 425 MHz in 700/2100/2300/3600 MHz bands (including spectrum already owned in 800/900/1800/2600 MHz). AKOS also introduced special conditions for players holding less than 2x30 MHz in sub-1 GHz frequencies: they can provide speeds of at least 10 Mbps DL and 2 Mbps UL compared to at least 30 Mbps DL and 3 Mbps UL for players holding more than 2x30 MHz in sub-1 GHz frequencies.

Early 2021, AKOS published a call for a public auction of 5G frequencies announcing the auction should take place in March or April 2021.

In mid-February 2021, AKOS confirmed it received four bids for 5G licences.

Two blocks (56 MHz and 112 MHz) in the 26 GHz frequencies were awarded in January 2018. However, they cannot be used for 5G services.

3.1.26. Spain

Main points

- 3.4-3.6 GHz spectrum likely to be used for 4G.
- The 3.6-3.8 GHz auction ended in July 2018 and the band will be used by 5G networks:

- Vodafone has eighteen 5 MHz blocks (198.1 million EUR)
- Orange has twelve 5 MHz blocks (132.1 million EUR)
- Telefonica has ten 5 MHz blocks (107.4 million EUR)

- Remaining 2 slots of 10 MHz of 3.5 GHz spectrum auctioned late in February 2021 assigned to Telefonica and Orange
- The 700 MHz auction initially scheduled for March and then for May 2020 postponed due to covid likely to the first quarter 2021

- 5G National Plan 2018-2020 – 5G Observatory in Barcelona, July 2017 consultation, release in 2018
- The 5G process in Spain started in July 2017 when the Government opened a public consultation about the 5G National Plan consisting of 25 questions
- The 5G National plan 2018-2020 aims at "promoting the development and deployment of 5G technology" via the auction of spectrum in the 1.5 GHz and the 3.6 GHz bands in early 2018, and at "developing their infrastructures and telecommunications networks with a 5G platform"
- 5G launch by Vodafone on June 15, 2019, by Movistar, Masmovil (Yoigo) and Orange in September 2020.

3.6-3.8 GHz

The 3.6-3.8 GHz spectrum auction raised 438 million EUR in the end of July 2018. The two remaining 3.5 GHz licences went on sale on February 22, 2021. Orange Spain and Telefonica each got a 10 MHz slot of 3.5 GHz spectrum at the starting price of 21 million EUR. The starting price applied because of the lack of demand: only Telefonica and Orange bid. Licences are valid until 2038. Orange confirmed it holds a total of 110 MHz of 3.5 GHz spectrum after this auction.

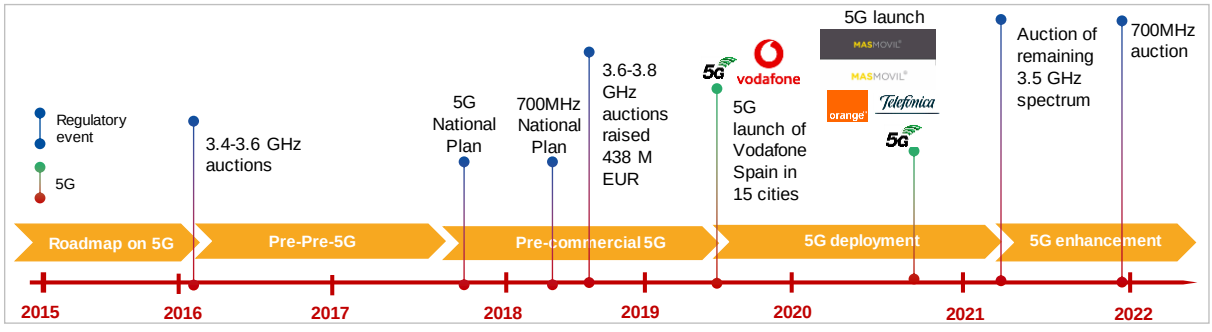
700 MHz

The 700 MHz auction initially scheduled for spring 2019 was postponed late November 2018 to the first months of 2020 and again postponed to the first months 2021 (700 MHz spectrum freed on 31 October 2020). 2x15 MHz spectrum caps were decided in July 2020. 2x30 MHz of frequencies will be for sale in 2x5 MHz blocks.

Eight blocks of frequencies will be auctioned at a reserve price of 1.17 billion EUR for 20 years: the first block will be a 2x10 MHz priced at a minimum of 340 million EUR. Four 2x5 MHz blocks will be sold at a starting price of 200 million each. Three 5 MHz blocks will be for sale at 10 million EUR each.

Licensees will have to cover 100% of municipalities with over 20,000 inhabitants in three years' time. In cities over 50,000 inhabitants, licensees will have to cover 50% of the population in the first year of service, 75% in the second year and 100% in the third year. Transport roads (Highways, freeways, multilane roads and high-speed lines stations) will also have to be covered.

Figure 21: 5G timeline in Spain



Source: IDATE DigiWorld

3.1.27. Sweden

Main points

- Broadband strategy paper
- Nordic co-operation on 5G
- The 5G strategy in Sweden is based on the paper released in March 2017 entitled "A Completely Connected Sweden by 2025 – a Broadband Strategy".
- Trial licences have been granted on a first-come first served basis, valid from 2017 until 31st December 2019; 200 MHz of spectrum was made available in the 3.4-3.6 GHz band and 1000 MHz in the 24.25-27.5 GHz band.
- The 700 MHz auction took place in December 2018
- The 2.3 and 3.5 GHz auction which was delayed twice raised 2.317 billion SEK (226 million EUR) on 19 January 2021. Hi3G Access, Net4 Mobility and Telia won 100 MHz and 120 MHz of 3.4-3.8 GHz spectrum. Teracom won 80 MHz of 2.3 MHz spectrum.
- PTS has opened up additional trial licences for 5G in 3.6GHz-3.8GHz, 3.8GHz-4.2GHz, 40.5GHz-43.5GHz, 45.5GHz-47.0GHz, 47.2GHz-48.0GHz and 66GHz-71GHz. Testing is already being carried out using 3.4GHz-3.6GHz and 26.5GHz-27.5GHz spectrum.
- 5G launch by Tele2 and Telia in May 2020, by Tre in June 2020 and by Telenor in October 2020.

2.3 and 3.5 GHz

The auction was initially scheduled for the first quarter 2020. In November 2019, it was postponed to a later date in 2020 by PTS due to work being carried out to update the country's Electronic Communications Act to come into force in January 2020. It was further postponed twice to November 2020 due to an appeal against the clause barring licensees to use Huawei equipment and further to January 2021. It resumed on January 19, 2021 and ended on first day. The sale reached 2.317 billion SEK (226 million EUR).

All the 320 MHz for sale in the 3.5 GHz band (3400-3720 MHz; the 3720-3800 MHz portion will be made available on a local basis) in up to 15 licences was assigned. Full allocations are as follows:

- Telia secured 120 MHz (3500-3620 MHz) for 760.25 million SEK (75 million EUR)
- Net4Mobility (a joint initiative by Tele2 and Telenor's local units) won 100 MHz (3620-3720 MHz) for 665.5 million SEK (65 million EUR)
- Hi3G got 100 MHz (3400-3500 MHz) at 491.25 million SEK (48 million EUR)
- Teracom Group which took over Net1 in 2019, took all 80 MHz on offer in the 2.3 GHz band for a total of 400 million SEK (40 million EUR).

The regulator wanted to offer up to 15 blocks of at least 20 MHz in the 3400-3720MHz frequencies (a licence will have 40 MHz), plus up to 8 nationwide 2.3 GHz licences, with at least 10MHz of spectrum each. Each bidder could get at least 80 MHz of spectrum in the 3.5GHz band. The minimum bid was set at 100 million SEK (9.7 million EUR) per 3.5 GHz lot (146 million EUR in total). The reserve price per 2.3 GHz licence was set at 20 million SEK (1.9 million EUR), for 160 million SEK (15.6 million EUR) in total.

3.1.28. UK

Main points

- 5G strategy for the UK, 2016
- Strategy paper "Next Generation Mobile Technologies: A 5G Strategy for the UK", March 2017
- Group of 5G research centres
- 3.4-3.6 GHz spectrum auctioned in April 2018.
- "5G Testbeds and Trials", April 2018-March 2019; updated in July 2019
- Statement on the review of spectrum used by fixed wireless services published in July 2018
- Launch of 5G services by EE 5G on May 30, 2019, by Vodafone on July 3, 2019, by O2 in October 2019 and by Three on Feb. 14, 2020 (5G mobile) and August 19, 2019 (FWA)
- 700 MHz spectrum auctioned in March 2021 (first phase, assignment stage to follow)
- 3.6-3.8 GHz auction expected in 2021
- Consultation on human exposure to ElectroMagnetic Field (EMF) Emissions; tests failed to find health risks
- Consultation on 100-200 GHz frequencies.

5G was initiated in 2016 when the Government announced its National Productivity Investment Fund (NPIF) worth in total of 23 BGBP, of which 740 MGBP funded by the government aiming at 5G trials and full fiber deployment across the UK by 2020-2021.

In November 2018, the UK Government published the "National Infrastructure and Construction Pipeline" report for 2018. It gives an overview of investment (both public and private) that is underway or expected to be put toward 5G and full fibre (FTTP) between 2018/19 and 2020/21 (financial years). 6.85 billion GBP should be devoted to full fibre and 5G upgrades by 2021.

700 MHz

The auction's first stage ended on March 17, 2021. The four UK MNOs secured the 200 MHz for sale in the two bands (80 MHz in 700 MHz frequencies and 120 MHz in 3.6-3.8 GHz spectrum), with the state raising a total of 1.356 billion GBP (1.58 billion EUR), beating the reserve prices. EE and O2/Telefonica were the largest spenders with bids above 448 million GBP (523.6 million EUR)

- EE bid for a total of 452 million GBP (528 million EUR) broken down into two lots in the 700 MHz spectrum and one 3.6-3.8 GHz portion:
  - 280 million GBP (327.3 million EUR) for 2×10 MHz of paired frequency spectrum in the 700 MHz band,
  - 4 million GBP (4.7 million EUR), for 20 MHz of supplementary downlink (SDL) spectrum in the same band sold in 4 lots,
  - and 168 million GBP (196.4 million EUR) for 40 MHz in the 3.6-3.8 GHz band.
- O2 UK secured frequencies paying 280 million GBP (327.3 million EUR) for 2×10 MHz paired in the 700 MHz band and 168 million GBP (196.4 million EUR) for 40 MHz in the higher band.
- Vodafone UK did not bid for 700 MHz spectrum. It offered 176.4 million GBP (206.1 million EUR) for a 40 MHz block of spectrum in the 3.6-3.8 GHz band
- Three UK did not bid for additional mid-band spectrum as it already owns 140 MHz of spectrum in 3.5 GHz and only got 2 x 10 MHz of 700 MHz spectrum for a total amount of 280 million GBP (327.3 million EUR).

The 80 MHz in 700 MHz frequencies were sold in six 2x5 MHz lots with a reserve price of 100 million GBP (110 million EUR) per lot and four 5 lots of 5 MHz SDL with a reserve price of 1 million GBP (1.10 million EUR) per lot. Licences will not include coverage obligations. The assignment stage in which the players can bid for the frequency positions they prefer will follow.

3.4-3.8 GHz band

3400-3600 MHz spectrum was auctioned in April 2018.

3.6-3.8 GHz

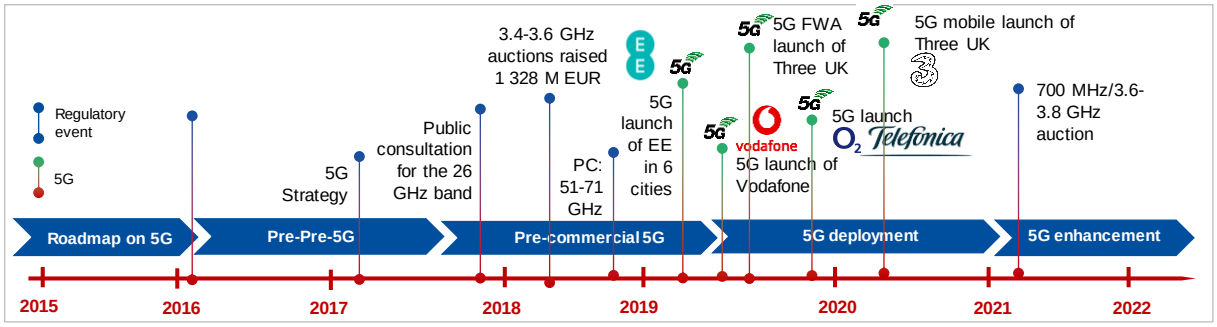
24 lots of 5 MHz of 3.6-3.8 GHz spectrum were auctioned using a simultaneous multiple round ascending format. The reserve price is set at 21 million GBP (22 million EUR) or 22 million GBP per lot. O2 launched a legal claim against Ofcom for getting a larger chunk of spectrum. OfCom decided to delay the auction. Nevertheless, the regulations for the auction came into force on 18 November 2020.

The auction ended on March 17, 2021. 120 MHz in 3.6-3.8 GHz spectrum was sold. EE and Telefonica won 8 lots (40 MHz) for 168 million GBP each (lot at 21 million GBP per lot). Vodafone got the same amount of spectrum for 176.4 million GBP (lots at 22 million GBP per lot).

26 GHz band

In July 2019, Ofcom published a document «Draft UK Interface Requirement (IR) 2105" defining the technical conditions for "Shared Access Indoor 26 GHz". 26 GHz frequencies are available on demand.

Figure 22: 5G timeline in the UK



Source: IDATE DigiWorld, March 2021

3.2. 5G strategy and pioneer bands follow-up

Table 16: 5G strategy and pioneer bands follow-up for EU-27 Member States (March 2021)

Member State	Frequency band	5G strategy published	Spectrum assigned	Availability for 5G use	Channel width	Coverage obligations	Licence duration
Austria	700 MHz	✓	✓	✓	5 MHz	✓	20 years
	3.4-3.8 GHz	✓	✓	✓	5 MHz	✓	20 years 31 December 2039
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Belgium	700 MHz	✓	✗	✗	N/A	✓	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	✓ likely	N/A
	26 GHz	✓	✗	✗	200 MHz	N/A	N/A
Bulgaria	700 MHz	✓	✗	✗	N/A	N/A	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	✓	20
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Croatia	700 MHz	✓	✗	✗	N/A	N/A	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	N/A	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Cyprus	700 MHz	✓	✓	✓[9]	5 MHz	✓	20 years
	3.4-3.8 GHz	✓	✓	✓[10]	50 MHz	✓	20 years
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Czech Republic	700 MHz	✓	✓	✓	5 and 10 MHz	✓	15 years (2035)
	3.4-3.8 GHz	✓	✓	✓	20 MHz for 3.4 GHz 40 MHz for 3.7 GHz	✓	12 years for 3.4 GHz (2032) 15 years for 3.7 GHz
	26 GHz	✗	✗	✗	200 MHz	N/A	N/A
Denmark	700 MHz	✓	✓	✓[11]	5 MHz	✓	20 years
	3.4-3.8 GHz	✓	✗	✗	N/A	✓[12]	20 years (1 June 2021-31 January 2042)
	26 GHz	✓	✗	✗	N/A	✗[13]	20 years
Estonia	700 MHz	✓	✗	✗	N/A	N/A	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	N/A	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Finland	700 MHz	✓	✓	✓	60 MHz in 2x5 MHz+4x5 MHz SDL	✓	17 years
	3.4-3.8 GHz	✓	✓	January 2019	10 MHz?	✗	15 years
	26 GHz	✓	✓	July 2020	N/A	N/A	31/12/2033
France	700 MHz	✓	✓	✓	5 and 10 MHz duplex	✓	15 years
	3.4-3.8 GHz	✓	✓	✓	10 & 50 MHz	✓	15 years
	26 GHz	✓	✗	✗	N/A	✗	15 years?

[9] January 2021

[10] January 2021

[11] 700 MHz spectrum available in April 2020

[12] Coverage obligations for some licences. Licences no subject to coverage obligation or leasing obligation will be subject to usage requirements.

[13] Usage requirements

Member State	Frequency band	5G strategy published	Spectrum assigned	Availability for 5G use	Channel width	Coverage obligations	Licence duration
Germany	700 MHz	✓	✓	✓	5 MHz	✓	15 years
	3.4-3.7 GHz	✓	✓	✓	10 MHz	✓	31/12/2040
	26 GHz	✓	✗	?	N/A	N/A	N/A
Greece	700 MHz	✓	✓	✓Dec. 2020	10 MHz	✓	15+5 years (2035)
	3.4-3.8 GHz	✓	✓	✓ Dec. 2020	5 MHz	✓	15+5 years (2035)
	26 GHz	✓	✓	✓ Dec. 2020	200 MHz	✗	15+5 years (2035)
Hungary	700 MHz	✓	✓	✓ Sept. 2020	5 MHz	N/A	15+5 years (2035/2040)
	3.4-3.8 GHz	✓	✓	✓ Sept. 2020	5 MHz	N/A	15+5 years (2035/2040)
	26 GHz	✗	✗	✗	N/A	N/A	N/A
Ireland	700 MHz	✓	✗	✗	N/A	✓	20 years
	3.4-3.8 GHz	✓	✓	✓	5 MHz	✗	15 years (July 2032)
	26 GHz	✗	✗	✗	N/A	N/A	N/A
Italy	700 MHz	✓	✓	✗ July 2022	5 MHz duplex	✓ FDD only	15.5 years (YE 2037)
	3.4-3.8 GHz	✓	✓ 200 MHz (3.6-3.8 GHz)	✓	20 MHz & 80 MHz	✓ 3.6-3.8 GHze[14]	18 years (YE 2037)
	26 GHz	✓	✓ 1 GHz (26.5-27.5 GHz)	✓	200 MHz	✗	18 years (YE 2037)
Latvia	700 MHz	✗	✗	✗	10 MHz/15 MHz	N/A	20 years (2022-2042)
	3.4-3.8 GHz	✗	✓	✓	50 MHz	N/A	10 years (January 2019-Dec. 2028)
	26 GHz	✗	✗	✗	N/A	N/A	N/A
Lithuania	700 MHz	✓	✗	✗	5 and 10 MHz	Likely	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	Likely	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Luxembourg	700 MHz	✓	✓	✓[15]	10 MHz	✓	15 years
	3.4-3.8 GHz	✓	✓	✓[16]	10 MHz	✓	15 years
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Malta	700 MHz	✓	✗	✗	N/A	✓likely	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	✓ likely (indoor)	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Netherlands	700 MHz	✓	✓	✓	N/A	✓	20 years (2040)
	3.4-3.8 GHz	✓	✗	✗ **2022/2026**	N/A	N/A	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Poland	700 MHz	✓	✗	✗	N/A	N/A	N/A

[14] Only for players holding at least 80 MHz in the 3.4-3.8 GHz frequencies

[15] When the licences will be awarded

[16] When the licences will be awarded

Member State	Frequency band	5G strategy published	Spectrum assigned	Availability for 5G use	Channel width	Coverage obligations	Licence duration
	3.4-3.8 GHz	✓	✗	✗	80 MHz	✓	June 30, 2035
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Portugal	700 MHz	✓	✗	✗	2x5 MHz	✓	20 years
	3.4-3.8 GHz	✓	✗	✗	10 MHz	✓[17]	20 years
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Romania	700 MHz	✓	✗	✗	5 MHz	N/A	N/A
	3.4-3.8 GHz	✓	✓	✓	N/A	3.7 GHz : ✗	3.7 GHz : 9 years (January 1, 2016-December 31, 2025)
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Slovakia	700 MHz	✓	✓	✓	5 MHz	✓	20 years (2040)
	3.4-3.8 GHz	✓	✓	✓	10 & 20 MHz	N/A	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Slovenia	700 MHz	✓	✗	✗	N/A	✓	N/A
	3.4-3.8 GHz	✓	✗	✗	N/A	N/A	N/A
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Spain	700 MHz	✓	✗	✓	5 MHz	✓	N/A
	3.4-3.8 GHz	✓	✓	✓	5 MHz	✗	20 years/18 years (2038)
	26 GHz	✓	✗	✗	N/A	N/A	N/A
Sweden	700 MHz	✓	✓	✓	5 and 10 MHz duplex	✓	21 years
	3.4-3.8 GHz	✓	✓	✓[18]	20 MHz & 40 MHz[19]	N/A	25 years (January 20, 2021-December 31, 2045)
	26 GHz	✓	✗	✗	N/A	N/A	N/A

Legend: ✓: Yes ✗:No ✓✗:licences granted on an on-demand basis

Source: IDATE DigiWorld

Table 17: 5G strategy and pioneer bands follow-up for the UK (June 2021)

Country	Frequency band	5G strategy published	Spectrum assigned	Availability for 5G use	Channel width	Coverage obligations	Licence duration
United Kingdom	700 MHz	✓	✓	✓	5 MHz	✗	Indefinite term
	3.4-3.6 GHz	✓	✓	✓	20, 40 and 50 MHz 5 MHz[20]	✗	Indefinite term
	26 GHz	✓	✓✗	✓✗	N/A	N/A	N/A

Legend: ✓: Yes ✗:No ✓✗:licences granted on an on-demand basis

Source: IDATE DigiWorld

[17] Network development obligations

[18] 20 January 2021

[19] 40 MHz for only one licence

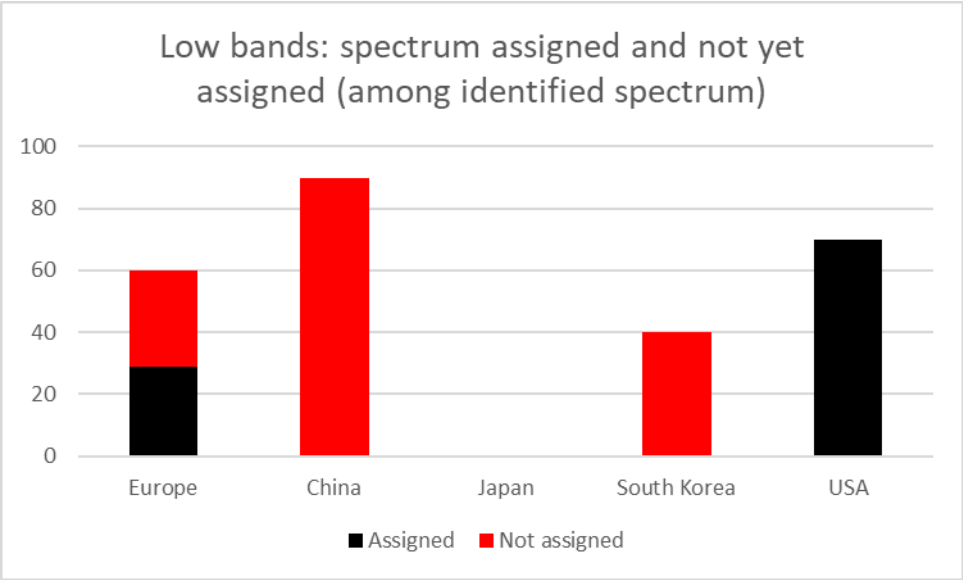
[20] 5 MHz for 3.6-3.8 GHz spectrum

3.3. 5G Spectrum comparison between EU and other leading countries

We compare spectrum in low, mid and high bands in the USA, China, Japan and South Korea with the EU-27 plus the United Kingdom. Bearing in mind non-European countries do not have specific pioneer bands for 5G, we assessed spectrum identified and spectrum assigned and took into account national discrepancies.

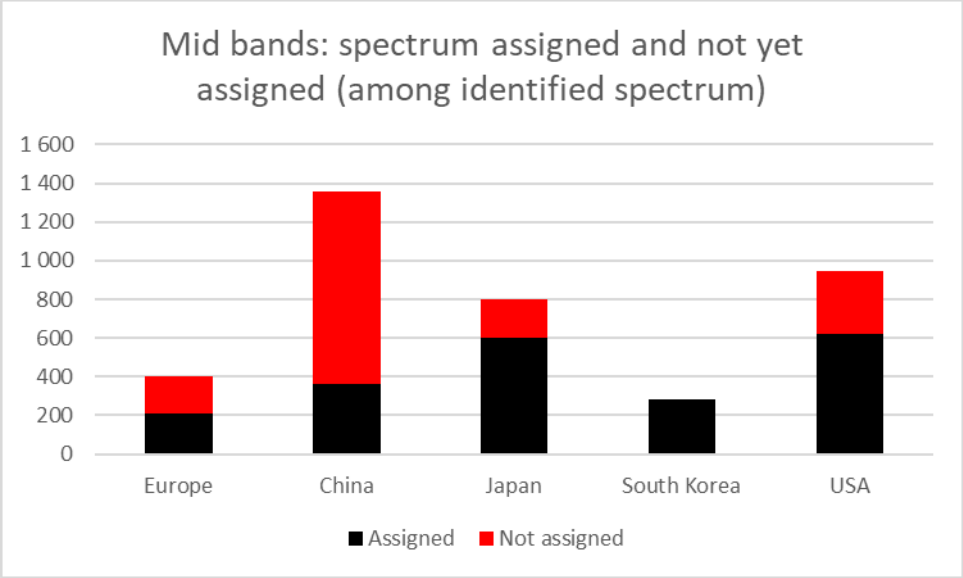
The graphs below show amounts of spectrum identified and assigned in low bands, mid-bands or high bands for each country or region.

Figure 23: Identified and assigned 5G spectrum (MHz) – Low bands (June 2021)



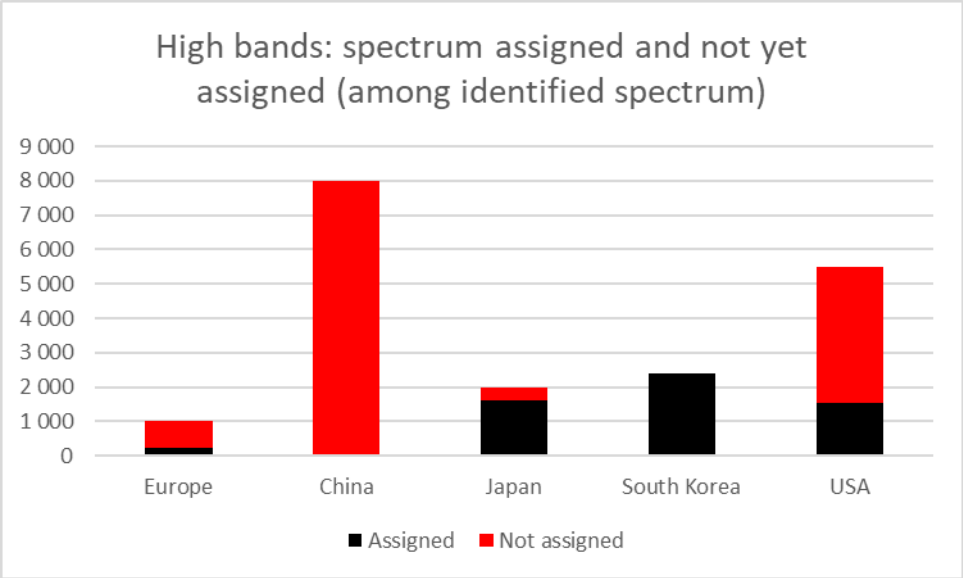
Source: IDATE DigiWorld

Figure 24: Identified and assigned 5G spectrum (MHz) – Mid bands (June 2021)



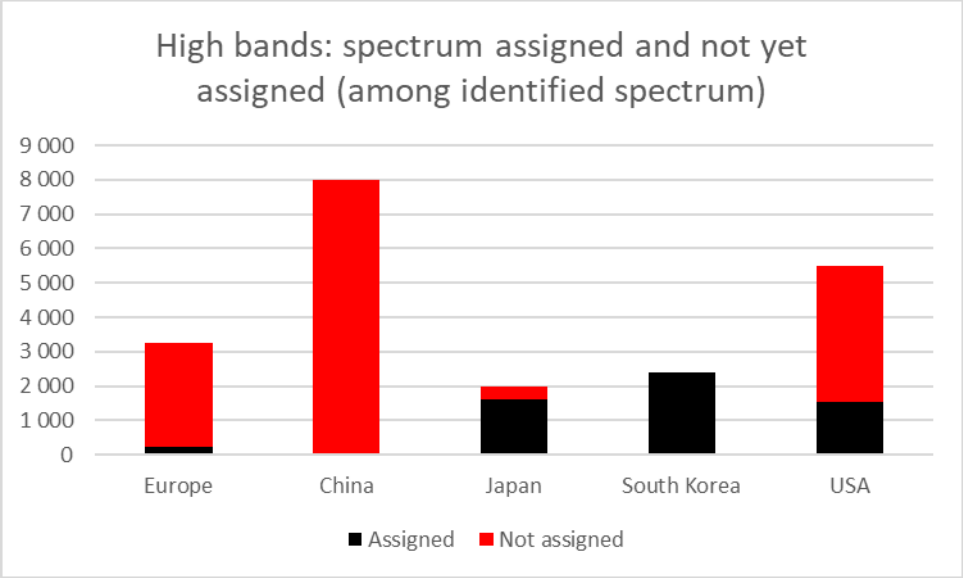
Source: IDATE DigiWorld

Figure 25 : Identified and assigned 5G spectrum (MHz) – High bands (June 2021) – 1 GHz considered for EU-27



Source: IDATE DigiWorld

Figure 26 : Identified and assigned 5G spectrum (MHz) – High bands (June 2021) – 3.25 GHz considered for EU-27



Source: IDATE DigiWorld

In order to compare identified/assigned 5G spectrum in South Korea, Japan, China and the United States, we listed hereafter frequency bands considered in the low-bands (< 1GHz), mid-bands (>1 GHz and <6 GHz) and high-bands (> 6 GHz):

In the USA:

- Low bands: 600 MHz
- Mid-bands: 2500 MHz, 3550-3700 (CBRS), 3700-4200 and 3450-3550 MHz.

- High-bands considered are: 24250-24450, 24750-25250, 25250-27250, 26500-29500, 37600-38600, 38600-40000, 47200-48200, 42000-42500 and 31800-33000 MHz.

  The FCC auctioned 24 (24.25-24.45/24.75-25.25 GHz, 2x100 MHz and 5x100 MHz) and 28 GHz spectrum (27.5-27.925/27.925-28.35 GHz, 2x425 MHz) in 2018-2019, raising respectively 2.023 billion USD (1.794 billion EUR) and 703 million USD (623 million EUR). The upper 37 GHz, the 39 GHz and the 47 GHz auction began on time on December 10th, 2019. The bidding phase or clock phase ended on 5 March 2020 with gross bids totalling 7.6 billion USD. The following phase will see the winners trying to get specific frequencies.

In South Korea:

- Low bands: 700 MHz
- Mid-bands: 3420-3700 MHz
- High bands: 26500-28900 MHz

In China:

- Low bands: 700 MHz
- Mid-bands: 2600, 3300-3400, 3400-3600, 3600-4200; 4400-4500, 4800-5000 MHz
- High bands: 24750-27500, 37000-42500 MHz

In Japan:

- Low bands: no band identified below 1 GHz
- Mid-bands: 3600-4200, 4400-4900 MHz
- High bands: 27500-29500 MHz

The figure indicated for Europe corresponds to the % of spectrum assigned by Member States for each one of the pioneer bands.

3.5. International developments/trials

USA, Japan, South Korea and China are the leading countries in terms of 5G readiness. Several Gulf countries claim to the firsts to have launched 5G networks:

- **China:** Commercial launches for the three mobile players started in November 2019.
- **USA:** AT&T and Verizon launched mobile commercial services in early 2019. Sprint launched in May 2019 and T-Mobile USA in December 2019.
- **Japan:** KDDI, Softbank and NTT DoCoMo launched commercial 5G services in March 2020. Rakuten launched in September 2020.
- **South Korea:** 5G services for business users were launched in December 2018. Full commercial launch took place in April 2019.
- **Gulf Countries:** Qatar and UAE both claimed to be the world firsts to have launched 5G networks (only).

3.5.1. USA

The four main players have launched 5G commercial services.

Spectrum for 5G was identified in July 2016 by the FCC (10.85 GHz in the 28 GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz) and 39 GHz (38.6-40 GHz) bands, and in an unlicensed band at 64-71 GHz). 24 and 28 GHz spectrum was auctioned in the first half 2019. The FCC auctioned the upper bands in early 2020.

A specific fund for 5G was opened in 2016.

5G spectrum

The FCC voted in 2016 for the release and development of nearly 11 GHz of high-frequency spectrum intended to be used for fixed and mobile broadband bandwidth uses: 3.85 GHz to be assigned under licences in the bands 27.5-28.35 GHz and 37-40 GHz and 7 GHz, under general authorization, in the band 64-71 GHz.

- July 2016: the FCC made available a total of 10.85 GHz in the 28 GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz) and 39 GHz (38.6-40 GHz) bands, and in an unlicensed band at 64-71 GHz.
- November 2017: the FCC made available an additional 1700 MHz of high band spectrum for flexible terrestrial wireless use in the 24 GHz (24.25-24.45/24.74-25.25 GHz) and 47 GHz (47.2-48.2 GHz) bands.
- March 2018: the FCC announced that it would like to held auctions of the 28 GHz and 24 GHz bands by the end of the year (November 2018 for the 28 GHz auction).
- June 2018: the FCC voted to proceed with making the upper 26 GHz (25.25–27.5 GHz) and 42 GHz (42–42.5 GHz) bands available for 5G services, while examining further aspects of the bands already in the 5G pipeline. The auction for the 28 GHz spectrum (27.5-28.35 GHz) and 24 GHz spectrum (24.25-24.45-24.75-25.25 GHz) is scheduled to begin on November 14, 2018.
- July 2018: the FCC is considering options for up to 500 MHz of spectrum in the 3.7-4.2 GHz range. Satellite companies currently use these frequencies.

- 28 GHz auction results:
  - The FCC's auction of residual 28 GHz[21] (27.5-28.35 GHz) frequencies began on November 14th, 2018. The auction closed on January 24th, 2019 when a round ended without bids placed.
  - According to the FCC Auction Bidding System Public Reporting System (PRS), winning bids reached 702.6 MUSD on Jan. 24th, 2019, after 38 days of bidding and 176 rounds completed. The residual licences were sold on a county basis. Two blocks of 425 MHz were available.
- 24 GHz spectrum (24.25–24.45 GHz + 24.75–25.25 GHz) auctions started in March 2019 and ended on May 28, 2019. 24 GHz frequencies were auctioned in 100 MHz blocks and sold by partial economic areas (PEAs, PEAs are larger than counties). In total, the auction raised 2.02 billion USD.
- The Federal Communications Commission announced the conclusion of Auction 103 in March 2020. This is its third auction of 5G suitable millimetre wave spectrum to date. The process started in December 2019 and involved frequencies in the upper 37GHz, 39GHz, and 47GHz bands, offering a total of 3,400 MHz of spectrum. The auction bid reached 7.6 billion USD (6.9 billion EUR). The price per MHz per capita for 10 years is 0.06 cEUR. The amount is much inferior to the price of past auctions in the 24 and 28 GHz bands.

  Verizon spent 1.6 billion USD (1.45 billion EUR) on 4,490 licences in 411 areas. AT&T dropped nearly 1.2 billion USD (1.09 billion EUR) on 3,267 licences in 411 areas. T-Mobile spent a total of 873 million USD (793 million EUR) in the auction and won 2,384 spectrum licences covering 399 areas. Sprint bid almost 114 million USD (103 million EUR) on 127 licences in 38 areas.
- The Federal Communications Commission (FCC) awarded Priority Access Licenses in the 3550-3650 MHz band, also called CBRS (Citizens Broadband Radio Service) during the first mid-band auction in the USA. According to the FCC, this 70 megahertz of licensed spectrum will "further the deployment of 5G, the next generation of wireless connectivity, as well as the Internet of Things and other advanced spectrum-based services". 20,625 of 22,631, or more than 91.1%, of available licences were won during the auction process that reached a total of $4,585,663,345.
- The FCC auction in the 3.7 GHz to 4.2 GHz band started on December 8, 2020. The 8 December 2020-15 January 2021 clock phase was followed by the assignment phase, which kicked off on 8 February 2021 and ended on 17 February 2021. Auction 107 net winning bids totalled 81.1 billion USD (66.3 billion EUR) for 280 MHz of spectrum (3.7-3.98 GHz). Verizon spent approximately twice as much as AT&T. It paid 45.4 billion USD in bids for 3,511 licences while AT&T's bids totalled 23.4 billion USD for 1,621 licences won. T-Mobile ranked third far behind the two leaders with "only" 9.4 billion USD and 142 licences: T-Mobile did not rush in because it already owns a lot of mid-band spectrum thanks to its Sprint acquisition in 2020. Conversely, Verizon and AT&T 5G services cannot enjoy this competitive advantage with less prime spectrum for 5G. They majorly rely on millimetre wave spectrum and on low-band spectrum.

3.5.2. China

5G deployment in China is strongly backed by the government. 5G ranks among the strategic priorities for the whole country (13th 5-year plan 2015-2020 and "Made In China" 2025 Initiative launched in 2013). In January 2017, the Ministry of Industry and Information Technology (MIIT) of the Chinese

[21] The 28 GHz band had already been assigned. This auction assigned residual spectrum.

government published a report on "Development Planning for Information and Communication Industry (2016-2020) in which it sets the objective of becoming one of the global leaders of 5G.
The "Made in China 2025" initiative aims for a commercial 5G launch by 2020. As part of the country plan and initiative, the authorities awarded grants to local 5G oriented companies including ZTE and Huawei. ZTE and Huawei received 72 million USD for 5G.
In October 2017, the Chinese government kicked off the 3rd phase of 5G technology research and development tests. This phase aimed to get pre-commercial products ready for when the first version of 5G standard came out in June 2019.

According to the China Academy of Information and Communications Technology (CAICT), China is expected to invest CNY900 billion - 1.5 trillion (USD134 – 223 billion) in 5G networks during the 2020-2025 period.

China awarded four 5G licences to China Mobile, China Unicom, China Telecom and China Broadcasting Network early June 2019, faster than anticipated.

China Mobile, China Telecom and China Unicom have launched 5G services on November 1st, 2019. The operators unveiled their monthly 5G packages. Price plans are quite similar among the three MNOs. Entry-level plans cost 129 CNY (16 EUR) per month and offer 30GB data with 300 Mbps of download speeds and 500 minutes of voice. Most expensive plans cost 599 CNY (76 EUR) and offer 300GB of data with download speeds of up to 1Gbps. Only high-end price plans offer 5G-like speeds.

5G spectrum

MIIT (Ministry of Industry and Information Technology) has approved/reserved a number of bands for 5G:

- The 3.3-3.6 GHz is officially reserved. Trials were approved in the band in January 2016. The 3.3-3.4 GHz part is limited to indoor use.
- The 4.8-5 GHz is also reserved for 5G service, China has also solicited opinions on the 24.75-27.5 GHz) and 37-42.5 GHz bands. Trials were approved in the mm-wave frequencies in July 2017.

MIIT identified other bands for 5G:

- MIIT will likely free up the 3.6-4.2 GHz
- Lower frequencies (below 3 GHz were also mentioned for 5G, notably the 700 MHz band which has the largest spectrum band available. However, the 700 MHz spectrum is not available to China Unicom. MIIT might make available spectrum at 1 GHz or 2.5 GHz to Unicom. China Mobile will receive spectrum in the 4.8 GHz-5.0 GHz frequencies.
- Mobile operators have to give back 2.6 GHz spectrum currently used for 4G.

In December 2018, the Chinese government allocated spectrum to players for 5G national trials until June 2020. China Telecom and China Unicom received 100 MHz of spectrum in 3.5 GHz frequencies (3.4-3.5 GHz for China Telecom, 3.5-3.6 GHz for China Unicom). China Mobile obtained 260 MHz in 2.6 GHz (2515-2675 MHz) and 4.8 GHz (4800-4900 MHz) frequencies. Under the arrangement, China Telecom and China Unicom will stop using 2.6 GHz frequencies by end March 2019.

MIIT (Ministry of Industry and Information Technology) issued four 5G licences to China Mobile, China Unicom, China Telecom and China Broadcasting Network at the beginning of June 2019.

In February 2020, the MIIT asked China Telecom, China Unicom and China Broadcasting Network to share the 3.3-3.4 GHz band for indoor 5G use. Licensees will share 5G indoor access networks to further support quick 5G deployments. China Mobile is not allowed to use the 3.3-3.4 GHz spectrum in a move to increase competition.

3.5.3. South Korea

In South Korea, the Korean Government (Ministry of Science, ICT and Future Planning) and the public-private partnership, 5G Forum, itself established in Seoul on 30 May 2013, defined the 5G mobile strategy as early as January 2014. For that purpose, the Government allocated 1.5 billion USD.

The program of the 5G Forum (www.5gforum.org) runs over the seven-year period of 2014-2020 with a joint investment of 1.6 trillion KRW by both the Government and the private sector. Some 26 companies/institutions are part of the project comprised of private companies (operators, equipment vendors), research institutes and universities.

The South Korean carriers agreed mid-2018 to build single 5G network to save money and time. 5G services were jointly launched by the three MNOs on April 3rd, 2019.

5G spectrum

The government assigned 280 MHz of the 3.4-3.7 GHz spectrum in June 2018 at 3.3 trillion KRW (2.4 billion EUR). Prices raised very high levels (more than 16 EUR per MHz per pop for 10 years). At the same time, the South Korean government assigned 2400 MHz (800 MHz for each player) of 28 GHz spectrum. Each player paid 160 million EUR for the 28 GHz spectrum.

3.5.4. Japan

The Radio Policy Vision Council of the MIC (Ministry of Internal Affairs and Communications) held in 2014 presented the roadmap for 5G. Following this report, the 5GMF (5G Mobile Forum) was established late in September 2014. Around 300 million USD have been dedicated by the Japanese authorities to promote the Industrial IoT and related technologies such as big data, artificial intelligence, and robotics. Japanese operators target to roll out 5G in time for hosting the Summer Olympic and Paralympic Games initially planned in August 2020, then moved to July-August 2021.

5G spectrum

In April 2019, The Ministry of Internal Affairs and Communications (MIC) has assigned spectrum in the 3.7 GHz, 4.5 GHz and 28 GHz bands through a beauty contest to the four mobile operators in Japan. Spectrum has been assigned as follows:

- NTT Docomo: 3.6-3.7 GHz, 4.5-4.6 GHz and 27.4-27.8 GHz
- KDDI: 3.7-3.8 GHz, 4.0-4.1 GHz and 27.8-28.2 GHz
- Softbank: 3.9-4.0 GHz and 29.1-29.5 GHz
- Rakuten: 3.8-3.9 GHz and 27.0-27.4 GHz

3.5.5. India

The Indian government is strongly backing 5G deployment. Indian authorities established a 5G forum with a budget of approximately 76 million USD dedicated to 5G research and development.

The government launched two strategic initiatives to address these challenges: India's Smart Cities Mission and Digital India. 5G will be central in achieving these government-backed initiatives that focus on easing the stress of urban population growth and closing the digital divide among the citizens from different social backgrounds.

India has significant infrastructure challenges that will limit 5G deployment, such as the lack of a robust network to connect cellular sub-networks to a core network. The majority of mobile subscriptions are still 2G, and MNOs have already begun considering leapfrogging from 2G/3G directly to 5G.

A likely target for 5G launch is 2022.

The Department of Telecom (DoT) is harmonizing spectrum in the 3.3-3.6 and 26 GHz bands, along with the 71-76 GHz, the 81-86 GHz and the 57-64 GHz frequencies as 5G candidate bands.

The DoT ordered operators to vacate spectrum in the 3.3-3.4 GHz range by the end of September 2018. In August 2018, the government and the regulator TRAI suggested a reserve price of 30% of 1800 MHz FDD band for the 3.3-3.6 GHz spectrum i.e. 985 INR per MHz (12.4 EUR) considering the 1800 MHz reserve price of 3285 INR. Mid-frequencies should be put for sale in 20 MHz blocks with a spectrum cap of 100 MHz per bidder.

India's 5G auction, which was postponed in 2019 and re-scheduled for April 2020, was again postponed by the authorities due to the operator's financial difficulties to pay licensing fees and other penalties.

India's Department of Telecommunications put up for sale a total of 2,308 MHz of airwaves across seven bands. The auction ended in early March, with the government getting 778.15 billion INR (9 billion EUR), well below the reserve price of 3.92 trillion INR (45 billion EUR) for the total available spectrum. Around two-thirds of the available spectrum was left unsold. Reliance Jio Infocomm, Bharti Airtel and Vodafone Idea didn't bid for the 700 MHz band, considering the spectrum overpriced like in the 2016 auction. The operators also avoided the 2500 MHz band, while just 15 MHz of the 175 MHz available in the 2100 MHz band was sold.

According to Indian press, Jio purchased the most spectrum, paying 571.23 billion INR (6.6 billion EUR) for 488.35 MHz, focusing primarily on renewing its 800 MHz licences alongside frequencies in the 1800 MHz and 2300 MHz bands. Airtel paid the next largest amount, with 186.99 billion INR (2.16 billion EUR) for a total of 355.45 MHz across the 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2300 MHz bands. Vodafone Idea purchased just 11.8 MHz of spectrum in the 900 MHz and 1800 MHz bands for a total of 19.93 billion INR (230 million EUR).

With the high reserve prices set by the regulators and the substantial debt burden on the industry, bidding matched expectations, with the trio focused on renewals and consolidating their positions in the bands they already utilised. The operators also prepared the ground for 5G by adding spectrum in the 2300 MHz band.

3.6. 5G commercial launch dates

Table 18: 5G commercial launch dates in EU-27

Country	Operator	5G commercial launch	Expected 5G commercial launch
Austria	T-Mobile Austria	March 2019	
	A1 Telekom Austria	January 2020	
	Hutchison 3G Austria	September 2019	
Belgium	Proximus	April 2019	
	Orange Belgium		H2 2021
	Telenet Belgium		H2 2021
Bulgaria	A1	November 2020	
	Telenor		Summer 2021
	Vivacom	September 2020	
Croatia	A1 Croatia		H2 2021
	Hrvatski Telekom	October 2020	
	Tele2 Croatia		H2 2021
Cyprus	MTN		Q4 2021
	Cytamobile-Vodafone	February 2021	
	PrimeTel		Q4 2021
Czech Republic	Telefonica	July 2020	
	T-Mobile	November 2020	
	Vodafone	October 2020	
Denmark	TDC	September 2020	
	Telenor Denmark	November 2020	
	Telia Denmark	November 2020	
	3 (Hi3G)	December 2020	
Estonia	Telia Estonia	November 2020	
	Tele2 Estonia		H2 2021
	Elisa Estonia		H2 2021
Finland	Elisa Finland	June 2019	
	DNA	December 2019	
	Telia Finland	October 2019	
France	Orange France	December 2020	
	SFR	November 2020	
	Bouygues Telecom	December 2020	
	Free Mobile	December 2020	
Germany	Deutsche Telekom	July 2019	
	Telefonica Germany	October 2020	
	Vodafone Germany	July 2019	
Greece	Vodafone Greece	January 2021	
	Cosmote	December 2020	
	WIND Hellas	December 2020	
Hungary	Magyar (Deutsche Telekom)	April 2020	
	Telenor Hungary		H2 2021
	Vodafone Hungary	October 2019	
Ireland	Vodafone Ireland	July 2019	
	EIR Mobile	December 2019	
	Hutchison 3G Ireland	September 2020	
Italy	TIM	June 2019	
	Wind Tre	October 2020	

Country	Operator	5G commercial launch	Expected 5G commercial launch
	Vodafone Italy	June 2019	
	Iliad	December 2020	
Latvia	Tele2 Latvia	January 2020	
	Bite Latvia		2023
	LMT	July 2019 (network only)	
Lithuania	Bite Lithuania		2022
	Tele2 Lithuania		H2 2021
	Telia Lithuania	H2 2019 (network only)	
Luxembourg	POST	October 2020	
	Tango	November 2020	
	Orange	November 2020	
Malta	Melita	May 2021	
	Vodafone Malta		H2 2021
	GO		H2 2021
Netherlands	T-Mobile	July 2020	
	VodafoneZiggo	April 2020	
	KPN	July 2020	
Poland	T-Mobile Polska		H2 2021
	Orange Poland	July 2020	
	Plus	May 2020	
	Play	June 2020	
Portugal	Altice (MEO) Portugal		H2 2021
	NOS		H2 2021
	Vodafone Portugal		H2 2021
Romania	Orange Romania	November 2019	
	Telekom Romania		H2 2021
	Vodafone Romania	June 2019	
	RCS&RDS (DIGI)	June 2019	
Slovakia	Orange Slovakia	May 2021	
	T-Mobile Slovakia	December 2020	
	O2 Slovakia		H2 2021
Slovenia	Telekom Slovenije	July 2020	
	A1		H2 2021
	Telemach		H2 2021
	T-2		H2 2021
Spain	Orange Spain	September 2020	
	Telefonica (Movistar)	September 2020	
	Vodafone Spain	June 2019	
	MasMovil (Yoigo)	September 2020	
Sweden	Telia	May 2020	
	Tele2	May 2020	
	Telenor	October 2020	
	Tre Sweden	June 2020	

Source: IDATE DigiWorld – June 2021

3.7. Number of cell sites for 5G trials and commercial deployments

A number of mobile operators have already announced the number of 5G cell sites they are using or planning to use for their 5G trials and commercial deployments.

Large scale deployments are observed in China and South Korea with massive numbers - over 100,000 5G cell sites. Medium scale deployments are taking place in the USA, Japan and in Germany (10,000s). Small scale deployments took place with tactical rollouts of pockets (100s) of 5G cell sites (Australia, UK, Saudi Arabia, Switzerland, UAE).

Table 19: Number of cell sites/base stations for 5G trials and networks – EU 27

Country	Operator	Number of 5G cell sites	Announcement date
Austria	T-Mobile	600 cell sites across the country. 1,200 cell sites in all federal provinces by the end of the year	July 2020
Austria	Drei	100 5G cell sites by the end of 2019. The 6000 cell sites the MNO operates should be 5G equipped within 2 years	December 2019
Denmark	TDC	3800 cell sites upgraded for 5G (national coverage)	March 2021
Europe	Vodafone	Setting up trial areas in seven cities and plans to expand to 1,000 sites by 2020	September 2018
France	Free Mobile	7054 sites in 700 MHz and 574 in 3.6 GHz	March 2021
France	Orange	260 sites in 2100 MHz and 808 in 3.6 GHz	March 2021
France	Bouygues Telecom	2405 sites in 2100 MHz and 435 in 3.6 GHz	March 2021
France	SFR	731 sites in 2100 MHz and 260 in 3.6 GHz	March 2021
Germany	Deutsche Telekom	Deutsche Telekom currently maintains about 28,000 cell sites across Germany, but the operator has formerly suggested that figure could even double with the rollout of 5G technology in the 2020s	February 2018
Germany	Deutsche Telekom	12,000 5G cell sites in operation. Plans 40,000 by the end of 2020	June 2020
Germany	Deutsche Telekom	15,000 new cell sites supporting 5G on the 2.1 GHz band	July 2020
Germany	Telefonica	1000 5G cell sites	March 2021
Germany	Vodafone	25 5G cell sites in 20 cities Already operates 60 5G sites and 140 cell sites in 40 German cities. Will add 150 5G cell sites before year end.	July 2019 November 2019
Italy	Vodafone	The 5G network in Milan covers 80% of the city's population via 120 active sites	December 2018
Poland	T-Mobile	1,600 cell sites across the country	June 2020

Source: IDATE DigiWorld – March 2021

Outside of EU-27, the number of 5G cell sites/base stations are the following:

Table 20: Number of cell sites/base stations for 5G trials and networks – Outside EU 27

Country	Operator	Number of 5G cell sites	Announcement date
Australia	Telstra	2,000 5G cell sites, availability in more than 60 cities and towns covering in excess of 41 per cent of the population	October 2020
China	China Mobile	300,000 cell sites by the end of 2020.	July 2020
China	China Telecom	380,000 sites at the end of 2020 700,000 sites planned for the end of 2021	March 2021
China	China Unicom	China Unicom deployed a total of approximately 210,000 5G cell sites. China Unicom, together with China Telecom, deployed approximately 150,000 5G cell sites across China in S1 2020	August 2020

Country	Operator	Number of 5G cell sites	Announcement date
China	3 operators	Chinese operators built 257,000 new 5G cell sites in the first half of 2020.	December 2020
		700,000 5G cell sites at the end of 2020	
China	3 operators	China's capital Beijing has deployed a total of 21,086 5G cell sites	June 2020
Japan	Rakuten Mobile	11,000 cell sites. Plans to have 27,000 cell sites in summer 2021	January 2021
Kuwait	Viva	Viva is rolling out a nationwide 5G network with over 1,000 5G NR-based radio sites in 2019	March 2019
New Zealand	Vodafone	Plans to have at least 100 5G cell sites by YE-2019. Tested 5 5G sites as from September 2019	August 2019
South Korea	KT	Around 1500 5G cell sites deployed in January 2019.	January 2019
		30,000 cell sites by April 5, 2019 (including 15,000 in Seoul)	March 2019
South Korea	LG Uplus	5,500 5G cell sites deployed in January 2019	January 2019
		18,000 cell sites deployed in March 2019. The operator plans to install 50,000 base stations within the first half of the year.	March 2019
		80,000 5G cell sites planned for end 2019	
South Korea	SK Telecom	Around 1500 5G cell sites deployed in January 2019	January 2019
		34,000 5G cell sites	April 2019
		54,202 5G cell sites	May 2019
South Korea	3 operators	The three operators have already installed a total of 121,000 5G cell sites in July 2020. Approximately 150,000 5G cell sites at the end of 2020	December 2020
UAE	Du	Plans 700 5G cell sites by year-end 2019	February 2019
UK	Vodafone	In 2018, tested 5G at more than 40 sites in Birmingham, Bristol, Cardiff, Glasgow, Liverpool, London and Manchester	June 2018
		Extension to 1,000 sites by 2020	December 2018
		Operates 200 5G sites and plans 500 additional sites by YE2019	July 2019
UK	EE/BT	2,000 5G cell sites in May 2020	June 2020
UK	Three	Operates 1,250 5G sites in 193 towns and cities	February 2021

Source: IDATE DigiWorld – March 2021

3.8. 5G Private networks

In this section, we present a non-exhaustive list of 5G private networks in Europe and in the 5G most advanced countries.

Private networks, or campus networks, are defined as networks owned by private entities and only accessible to their employees, stakeholders and/or customers. Public networks ('public electronic communications network') means an electronic communications network used wholly or mainly for the provision of publicly available electronic communications services which support the transfer of information between network termination points.

Table 21: Non-exhaustive list of 5G private networks in EU-27

Country	Company/Entity	Operator	Equipment Vendor	Comments
Austria	Automative manufacturer Magna Steyr	A1 Austria	Nokia	n/a
Austria	Siemens' microgrid	A1 Austria	Nokia	Nokia and A1 have joined forces to provide a private wireless network for Siemens' microgrid, which is deployed at its Austrian headquarters in Vienna. The A1 campus solution demonstrates the advantages of using a private wireless solution to operate critical applications such as enterprise or utility microgrids, and how they can be efficiently implemented with secure, reliable and fast connectivity.
Austria	Vienna Airport	A1 Austria	Nokia	n/a
Belgium	Brussels Airport Company		Nokia and Citymesh	Brussels Airport Company is developing a private 5G-ready network in partnership with Nokia and Belgian operator Citymesh which it says will be operational in Brussels Airport by the end of March 2020. IoT, automated vehicles, mobile safety systems and track & trace solutions. In a first phase, the 5G network will provide outdoor connectivity. A second phase will deliver 5G services indoors.
Belgium	Port of Antwerp	Proximus		February 2020: Belgian full-service telecoms operator Proximus and the Port of Antwerp have signed a Memorandum of Understanding (MoU) to develop and test a private 5G network to evaluate potential industrial applications.
Belgium	Port of Zeebrugge		Nokia in collaboration with local service provider Citymesh	5G-ready private wireless connectivity. Connectivity to more than 100 endpoints across the entire port operations.
Denmark	Grundfos (pump manufacturer).	TDC NET	Ericsson	The project is a trial-run, with a view to a broader 5G-enabled Industry 4.0 deployment across its factories.
Finland	Fortum Power and Heat (State owned energy company)			Traficom has granted the firm a 20MHz chunk of local airwaves at 2300–2320 MHz at the site

Country	Company/Entity	Operator	Equipment Vendor	Comments
Finland	KymiRing motor racing circuit		Nokia, EDZCOM (Cellnex)	Nokia is to implement an industrial-grade private 5G network at the KymiRing motor racing circuit in Finland. It will be completed in 2021 by EDZCOM, a European provider of edge connectivity solutions with particular expertise in broadcasting. It is part of Cellnex, which is probably better known for its towerco business.
Finland	Qualcomm, UROS	Elisa		Finnish network operator Elisa has deployed a private 5G network for a new-generation IoT hub developed by UROS and Qualcomm set to open this year in Oulu, Finland. The Innovation Centre is the first facility in Finland to utilise private 5G networking in IoT product development and validation. The network itself is already up and running and will serve all IoT ecosystem partners at the hub facility.
Finland	Sandvik mining		Nokia	The network will enable fast, reliable and secure voice and video communications in a mining setting, which presents highly challenging deployment conditions. Its 5G capability will also be used for automated mining processes, enabling remote machine operations over 4K video links between deep underground and the surface control center.
Finland	KymiRing motorsports venue		Edzcom, Nokia	The KymiRing motorsports venue in Finland is to get its own private 5G network to augment media streaming and television broadcast services, as well as to help with testing autonomous and connected vehicles. Local private networking specialist Edzcom has been appointed to manage the installation. Edzcom is using Nokia for the edge network and computing infrastructure.
France	ADP Group and its subsidiary Hub One, Air France		Ericsson	Acquired a 10-year 4G and 5G license by ARCEP in February 2020 to be used in Paris' airports. Air France will also benefit from HubOne's 40 MHz. The 4/5G network will serve a professional ecosystem of more than 120,000 people who work at the three Paris airports every day, across about 1,000 companies of differing sizes and sectors.
France	EDF (French electricity company)			Acquired a 10-year license in the 2.6 GHz TDD band (20 MHz)
France	Lacroix	Orange	Ericsson	November 2020: French electronics manufacturer Lacroix Group has appointed Orange to deploy an indoor 5G network from Ericsson at a factory in France (Montrevault-sur-Evre) to run the rule over its value as a springboard for Industry 4.0, and as a foundation stone for its 'flagship' new 'factory-of-the-future'. Orange will manage a virtualized network core, distributed between the premises of Orange and the Lacroix plant. The spectrum band utilised for the new 5G network is unconfirmed.
France	Schneider Electric	Orange		September 2020: Schneider Electric, a leader in the digital transformation of energy management and automated processes, and Orange are working together to evaluate the feasibility of opportunities brought by 5G in industrial production processes.
France	TansDev (mobility company)			Allowed to use the 2575-2595 MHz spectrum in Rouen, North West of France from 12 March 2020 to 11 March 2024

Country	Company/Entity	Operator	Equipment Vendor	Comments
Germany	BMW Group Leipzig plant.	T-Mobile	Ericsson	The campus network at the BMW Group plant in Leipzig is initially based on the LTE standard. In addition to the private campus network, the public network will transmit the same signal strength. This ensures a perfect connection even for terminal devices that are not allowed to transmit in the private network. Ericsson and Telekom are currently working together to further develop the functionalities of campus solutions based on 5G standalone. The development includes a 5G dual-slice solution that can also integrate the industry spectrum. The company bought spectrum in the 3700MHz-3800MHz band.
Germany	Bosch		Ericsson	Bosch acquired a 3.7—3.8 GHz local licence. The company is preparing to set up campus local area networks. Bosch started to build a private industrial 5G network at its semiconductor factory in Reutlingen, in Baden-Württemberg in Germany, to test for Industry 4.0 compatibility and network optimisation, along with industrial partners including ABB, Ericsson, Orange, and T-Systems.
Germany	Center Connected Industry (CCI)	Deutsche Telekom	Ericsson	Switched on a 5G standalone private network in April 2020, at the Center Connected Industry (CCI) at RWTH Aachen Campus. The end to end private network system is based on Ericsson's 5G standalone technology running in Deutsche Telekom's 5G spectrum. The network is currently built as an indoor solution integrated with an autonomous logistics device to demonstrate possible industry use cases.
Germany	Deutsche Messe	Deutsche Telekom	Siemens	February 2021: Trade fair operator Deutsche Messe secured a private 5G licence from German network agency BNetzA for the Hanover fairground, home to Germany's flagship Industrie 4.0 event. Deutsche Telekom will set up "one of the largest 5G zones in Europe" and "Europe's largest 5G exhibition centre". The network will cover 1.4 million square metres, including all 30 halls and buildings at the site, as well as outdoor spaces.
Germany	German electric microcar company e.GO Mobile AG at its Aachen complex	Vodafone	Ericsson	June 2019: In e.GO's Factory 1, where the e.GO Life model is manufactured, an Ericsson Private Networks solution – spanning 5G Core and 5G New Radio solutions from Ericsson's 5G Platform – will deliver secure and almost real-time data networking across the production chain, from digital material management to autonomous vehicle control.
Germany	Lufthansa, airline's aircraft hangar in Hamburg airport	Vodafone	Nokia	March 2020: The private network covers an area of 8,500 square metres. Lufthansa acquired a 3.7—3.8 GHz local licence. The idea is the new private 5G network, offering "industrial grade" reliability, alongside ring-fenced latency and bandwidth performance, precludes customers from physically attending inspections; instead they are able to provide live high-definition video feeds of their engine overhauls in their own facilities to the Lufthansa Technik team in Hamburg.

Country	Company/Entity	Operator	Equipment Vendor	Comments
Germany	Mercedes-Benz, Sindelfingen plant	Telefonica	Ericsson	Ericsson and Telefónica Germany built the network in the 220,000sq m complex and will hand over to Mercedes-Benz upon completion for operation. Initial applications will be factory automation and use to guide autonomous vehicles. The 730 million EUR Factory 56 facility is part of a €2.1 billion "future-oriented" car plant and the administrative area in Sindelfingen, in Germany. The company claimed that the factory will have zero-carbon production, and a 25 percent jump in efficiency compared with the old assembly line at the site.
Germany	Port of Hamburg	Deutsche Telekom	Nokia	February 2018:Deutsche Telekom and Nokia partnered in 5G network slicing trials on private deployment on site at the port of Hamburg.
Germany	Rohde & Schwarz		Nokia	November 2020: The network is running in the 3.7-3.8 GHz band. Rohde & Schwarz has installed a private 5G network from Nokia at its plant in Teisnach, Germany. The network test company wants to run the rule over cellular-enabled Industry 4.0 applications in a dedicated 5G setup.
Germany	Siemens		Qualcomm: 5G test network and 5G industrial test devices	Late 2019: Proof-of-concept project at the Siemens Automotive Test Center in Nuremberg, Germany, demonstrating the first private 5G standalone (SA) network in a real industrial environment using the 3.7-3.8GHz band. The goal is to research the capabilities of 5G stand-alone networks for industrial applications. Siemens provided the industrial set-up (including the control systems and the IO devices) while Qualcomm provided the test network and equipment. Siemens has been reported in the press as having applied for local licences at six of its factory sites in Germany.
Germany	Volkswagen			Volkswagen will start construction of its own 5G mobile networks in 122 factories in Germany in 2020. The company bought spectrum in the 3700MHz-3800MHz band.
Ireland	Irish Manufacturing Research	Vodafone	Ericsson	Vodafone has deployed what is being considered Ireland's first private standalone (SA) 5G network at Irish Manufacturing Research's (IMR) facility in Mullingar. IMR, an independent not-for-profit manufacturing and industrial energy efficiency research organization, will use the dedicated 5G network to develop and demonstrate smart manufacturing use cases in automated production lines and mobile robots, as well as augmented reality (AR) and virtual reality (VR) displays.
Netherlands	Shell, ABB and ExRobotics	KPN	Huawei	First industrial 5G-applications in Rotterdam harbour in the Netherlands. Thanks to 5G mobile networks manufacturing can be optimised, industrial maintenance can be better predicted and safety further improved. By using Ultra High Definition (UHD)-cameras connected to 5G combined with machine learning algorithms, future maintenance can be better predicted.
Poland	Orange Polska Campus	Orange Polska	Ericsson	The operator says the network will be deployed in Ksawerów near Łódź, on a 6,000 square metre site of Miele's domestic appliances plant. The contract will last two years and the network will digitialise and automate the quality control process for manufactured

Country	Company/Entity	Operator	Equipment Vendor	Comments
				products, as well as facilitate large-scale employee training programmes using virtual reality (VR).
Poland	PGE Systemy		Nokia	Nokia announced that Polish energy company PGE Systemy has chosen its 5G-ready, industrial-grade private wireless solution, following the successful trial of a 450MHz proof of concept (PoC) network in operation since April 2019.
Spain	BASF	Masmovil	Cellnex, Nokia, Lenovo	November 2020: German chemicals company BASF and Spanish telecommunications infrastructure and services operator Cellnex Telecom signed an agreement to install what Cellnex said will be the first private network based on 5G technology in the Spanish chemical industry.
Spain	FC Barcelona Stadium	Telefonica	Huawei	February 2019: Huawei collaborated with Telefónica to build standard dedicated 5G at the Nou Camp football stadium in Barcelona.
Sweden	Arlas Copco	Telenor	Ericsson, Fujitsu	October 2020: private 5G network in localised 3.7 GHz spectrum at Swedish tool manufacturer Arlas Copco's factory in Stockholm. The radio gear and core network are from fellow Swede Ericsson; Japan-based IT firm Fujitsu is also engaged.
Sweden	Saab		Nokia, Vinnergi	December 2020: Aerospace and defence company Saab has deployed a factory-wide private 5G network at a manufacturing plant in Sweden. The facility in Linköping, in the south of the country, produces 'aerostructures', notably for Airbus and Boeing. The project is starting with LTE in the upper part of the 1.8 GHz band, which works for indoor coverage; it will migrate to 5G in the second quarter of 2021

Source: IDATE DigiWorld – June 2021

Table 22: Non-exhaustive list of 5G private networks outside EU-27

Country	Company/Entity	Operator	Equipment Vendor	Comments
China	Bluetron	China Telecom	ZTE	The network is being used to test out a new machine vision application. This combines the 5G network, with its network slicing capabilities, and mobile edge computers to provide enhanced machine vision analytics. The 5G network enables fast backhaul of the video streams to the MEC facilities in network slices that guarantee the latency, jitter and packet loss parameters.
China	West China Second University Hospital in Sichuan Provinc	China Mobile	Huawei	The 5G network, augmented with mobile edge computing facilities has been used to showcase a variety of new applications including a hospital management system that incorporates data about patients, waiting times, asset location, and live video camera feeds to provide a visual smart hospital management system. This will encompass a 5G and AR system enabling parents to see their prematurely born babies in intensive care, neonatal monitoring in ambulances in transit and 5G-enabled guidance robots for hospital visitors.
China	Haier	China Mobile	Huawei	China Mobile, Huawei and Haier have completed a deployment of edge computing, 5G and machine vision into Haier's manufacturing environment. With this solution top of the range stainless steel refrigerators are visually inspected, in near real-time, to screen out production defects

Country	Company/Entity	Operator	Equipment Vendor	Comments
China	Yangquan Coal Group	China Mobile		China Mobile, and Yangquan Coal Group successfully built the first 5G underground coal mine network in China. With the help of this "super Gigabit uplink" underground network, supporting a peak uplink rate of 1100mbps, the network enables high-definition audio and video communication, rapid data transmission and remote intelligent control of equipment.
Japan	Fujitsu		Fujitsu Telecom Networks	Japan's first commercial private 5G radio station license from the Kanto Bureau of Telecommunications. - Spectrum: 28.2 GHz to 28.3 GHz spectrum for 5G and 2.575 GHz to 2.595 GHz spectrum for LTE. - System configuration: 5G-NSA for data transmission, LTE for connection control between base stations and land mobile stations. - About 28,000 square meters on the grounds of Fujitsu Shin-Kawasaki Technology Square
Japan	Mitsubishi Electric C.			Allowed to test a local 5G system in a limited area using the 28.2 GHz-28.3 GHz spectrum band. Mitsubishi Electric said that it expects to launch demonstration tests at other business sites as well as establish new 5G infrastructure at its business sites and laboratories.
Japan	Toyota Production Engineering Corporation's manufacturing sites		Nokia	5G ready private network to support IoT devices, equipment digitization and visualization. Nokia: connectivity piece–base stations, radios and core network equipment and Digital Automation Cloud for scalable operations and management. Japanese NS Solutions Corporation (ICT solution provider): wireless area design, license application support, system construction, and on-going maintenance and operation.
Japan	OMRON Corporation	NTT DOCOMO	Nokia	Espoo, Finland – Nokia, NTT DOCOMO, INC. and OMRON Corporation have agreed to conduct joint field trials using 5G at their plants and other production sites. Aims to establish the feasibility of a layout-free production line using Autonomous Mobile Robots (AMRs). By taking advantage of 5G's tech, the solution will see AMRs automatically conveying components to the exact spot where they are required based on communication with production line equipment.
Russia	EVRAZ	Mobile TeleSystems PJSC (MTS)	Ericsson	Ericsson and Mobile TeleSystems PJSC (MTS) announced plans to jointly deploy a commercial LTE/5G-ready private network at steel and mining company EVRAZ's digital Sheregeshskaya mine in south-central Russia. The private network will be built on the Ericsson Dedicated Networks solution.
Taiwan	Inventec		Affirmed Networks (Microsoft), ASOCS	October 2020: Electronics manufacturer Inventec deployed a 5G standalone (5G SA) network at its plant in Taiwan, to bring automation and intelligence to its production line.
United Kingdom	AE Aerospace	EE (BT)		AE Aerospace, a manufacturer in England's West Midlands, is the first UK SME to deploy a 5G private network, working with government-backed inititatives West Midlands 5G (WM5G), and Worcestershire 5G (W5G) and its technology partner BT. The 5G network is provided by BT's mobile arm, EE. AE Aerospace operates a high precision engineering facility that produces parts for customers including Rolls Royce, Raytheon UK and Moog.

Country	Company/Entity	Operator	Equipment Vendor	Comments
United Kingdom	Aerospace manufacturer Leonardo	Telefonica		Telefónica and Italy-based aerospace manufacturer Leonardo have announced a deal to collaborate on private 5G for Industry 4.0, including for the “high-pace” manufacturing of the “next-generation” Tempest combat aircraft system, a joint defence project between the UK, Italy, and Sweden.
United Kingdom	Centrica Storage Limited, the gas storage and processing unit of UK gas and electricity supplier Centrica.	Vodafone	Ericsson	The new private "5G ready" network, at Centrica’s Easington facility in County Durham, will use Ericsson radio and core networking gear. Annouced by Vodafone in August 2020, The setup will help CSL digitalise much of its critical maintenance and engineering operations
United Kingdom	Ford, electric vehicle production site in Essex	Vodafone		The project has received state funding as part of a GBP65 million (USD81 million) investment in 5G by the UK government. The facility is scheduled for completion in the autumn 2020. The aim is to reduce delays in manufacturing, increase bandwidth across the campus, improve security and reliability, and increase productivity.
United Kingdom	Port of Felixstowe	Three UK	Ericsson, Siemens	The port’s installation is part of the government’s 5G Trials and Testbeds Programme which is intended to drive investment and innovation in 5G and to support the development of new use cases and commercial deployment. the port will test the potential of 5G to enable remote-controlled cranes via CCTV, and deploy IoT sensors and AI to optimise the predictive maintenance cycle of Felixstowe’s 31 quay-side and 82 yard cranes.
United States	Phillips 66 (US oil company)	AT&T	Accenture	Industrial LTE and 5G setup for low-latency refinery automation and analytics.
United States	Tideworks Technology		Nokia	Nokia announced an agreement with Tideworks Technology, a wholly owned subsidiary of Carrix, to deploy Nokia Digital Automation Cloud (DAC) at the Port of Seattle, Terminal 5. The objective is to deliver increases in efficiency, worker safety and terminal handling performance by reducing the complexity of port flow.
United States	Whirlpool	AT&T	Seegrid	December 2019: Whirlpool is deploying a private 5G network in one its Ohio factories to solve a major problem: Driverless vehicles inside the plant rely on Wi-Fi to navigate.
United States	Samsung	AT&T		AT&T and Samsung have deployed a 5G testbed at Samsung's Austin manufacturing facility as part of a "5G Innovation Zone". This provides a private 5G network that uses millimeter-wave (mmWave) spectrum, and also leverages LTE and Wi-Fi.
United States	Corning	Verizon		Verizon 5G Ultra-Wideband is being used at the Corning factory in Hickory North Carolina where the companies are working together to build the 5G factory of the future. The network is being used prove how 5G can enhance functions such as factory automation and quality assurance in one of the largest fibre optic cable manufacturing facilities in the world. Engineers from Verizon and Corning can use 5G to dramatically speed data collection, allow machines to communicate with each other in near real time, and wirelessly track and inspect inventory using 5G-connected cameras.

Source: IDATE DigiWorld – June 2021

3.9. 5G network equipment –main manufacturers

3.9.1. Ericsson

Ericsson as well claim to offer the "Market first global 5G access and transport portfolio", having created its Radio System as the basis for its future 5G offering including a transport and access solution. Ericsson put the stress on the smooth transition from 4G to 5G with its Ericsson Spectrum Sharing solution (also known as DSS in 3GPP standard), a solution where Ericsson seem to lead. This capability enable spectrum sharing between 4G and 5G departing from the need for operator to dedicate a fixed portion of spectrum to each of its Radio Access Technology, as is usually the case with refarming.

While providing a wide range of deployment possibilities with equipment geared for all the situations (Macro, small cell, indoor…) Ericsson put the stress on the necessity to build the network with precision using the right equipment with the right capability at the right place, in order to maximize the required capability while enabling energy consumption saving. Thanks to Machine Learning, Ericsson is also providing a suite of software services aimed at managing performance and activating energy saving features when needed.

Figure 27: Presentation of Ericsson 5G solution

Source: Ericsson

3.9.2. Huawei

With more than 90 5G contract secured as of February 2020, Huawei claim the 5G leadership with an end to end solution from Core network to 5G RAN, by way of transport, backhauling and dedicated radio solutions to different situation of deployment. In its February 2020 product update announced in London, Huawei particularly put the stress on its third generation of Massive MIMO solution boasting the support for up to 400 MHz of bandwidth, notably geared for network sharing situation, integrated active and passive antenna solution for simplified deployment and a weight < to 25 kg for the 32T32R solution and < to 30 kg for its high-end 64T64R massive MIMO solution.

As densification of the network is key for operators, Huawei want to simplify as much as possible the deployment on-site and claims that its massive MIMO solution reduce on-site maintenance by 20% while also reducing the deployment time by 35% thanks to an integrated and simplified Active Antenna

Unit. Also thanks to its complete outdoor simplified site solution, enabling to deploy Power, the blade RRU and blade AAU, the need for air conditioning is removed resulting in a 40% power saving claim.

Despite facing a ban on its products in the US and increasing pressure for US allies to implement a similar ban, Huawei is claiming the 1st position in terms of essential patent with 19% of the 5G essential patents.

Figure 28: Huawei 5G RAN portfolio

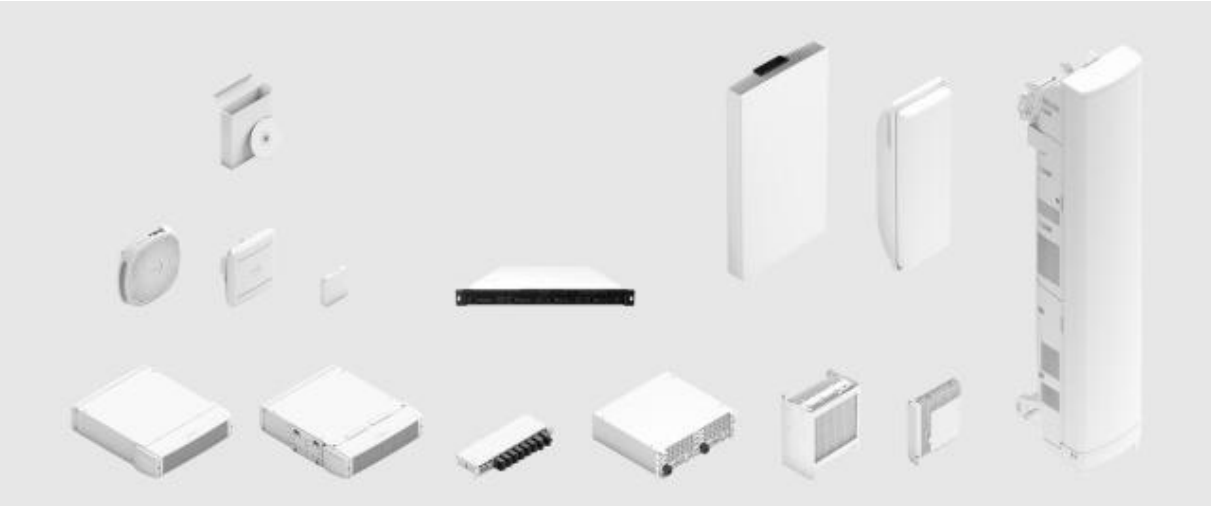
Source: Huawei

3.9.3. Nokia

Nokia also proposes a complete 5G portfolio from core network to the RAN with its Airscale RAN solution. Having developed its own chipset solution called ReefShark, Nokia claimed the capability to decrease the size of massive MIMO antennas by 50%, and allow a 64% reduction in the power consumption of baseband units. After a first generation of chipset, Nokia has developed a lower cost chipset and inked partnership with Marvel, Intel and Broadcom to further develop its range of baseband chipset for its equipment

In April 2020, Nokia announced its next generation of 5G Airscale portfolio, putting the stress on its integrated antenna system supporting both passive and active antennas compact with dual and triple-band remote radio heads supporting cell site deployment requirements. While late in releasing its DSS solution, Nokia is also supporting the sharing of spectrum with 2G and 3G to facilitate user transition to the latest and most efficient radio technologies while maximizing spectrum usage.

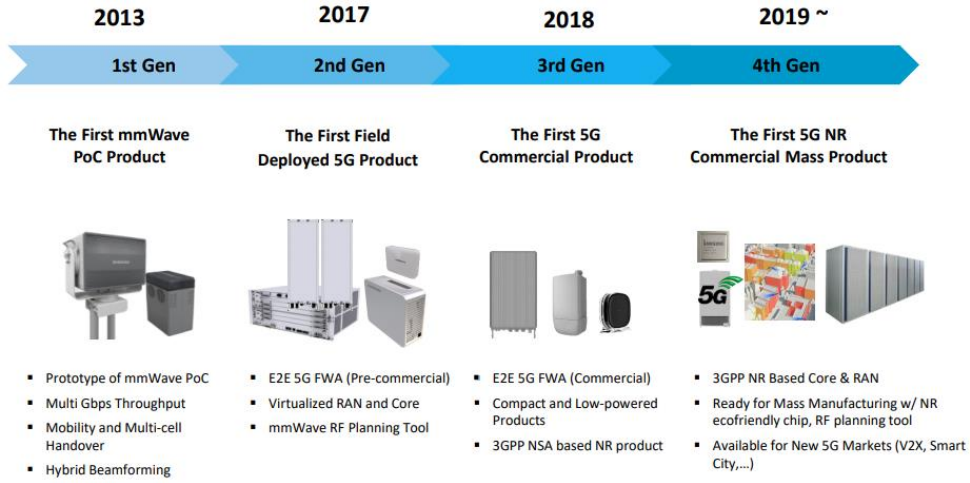
Figure 29: Nokia AirScale Radio Access for 5G



Source: Nokia

3.9.4. Samsung

Figure 30: Samsung 5G products evolution



Source: Samsung

With 5G, Samsung has been much more vocal about its technological prowess than with 4G, touting a host of first with notably the first mm-wave Proof of Concept as early as in 2013 and the first field deployed 5G product in 2017. Not yet present in 3G, it quietly developed its 4G portfolio and now 5G for which it heavily invested in mmWave. After its domestic market, where it is working with the 3 domestic operators it became a supplier of Jio network and it is now expanding in the US with 5G providing 5G equipment to Verizon and AT&T.

While appreciated for its solution in Europe, the lack of support is seen as a current obstacle to further deployment in the EU.

As other main equipment vendors, Samsung is designing its own base station chipset. In 2019 it launched its second generation chipset.

Figure 31: Samsung 5G commercial products

Source: Samsung

3.9.5. ZTE

While being a smaller equipment vendor than the four main ones, ZTE has developed a complete 5G portfolio and benefited from the breadth of its domestic market. ZTE is known notably for its expertise in Massive MIMO, which it developed quite early for 4G commercial network and it has pursued the development of this solution for 5G network.

In March 2020, it launched its latest massive MIMO solution, claiming the lightest Active Antenna Unit solution available with less than 22 kg for the 32T32R configuration and support for 400 MHz bandwidth, like Huawei.

Like most of the main equipment vendors, ZTE is working on easing the integration and installation of 5G equipment by developing a range of radio unit adapted to different scenario, such as indoor coverage with QCell 5G solution but also with the Unisite+ solution that supports 7 different frequency bands in active, passive antenna system. This solution is aimed at replacing older equipment to provide increased capacity while enabling 30% power saving according to ZTE.

As part of the notable other solutions provided by ZTE, SuperDSS, a DSS solution supporting the deployment of 3 different RAT in the same spectrum (as opposed to two normally) or an integrated MEC solution ready for deployment.

Figure 32: ZTE Unisite+ solution

Source: ZTE

3.9.6. NEC

Veteran supplier of telecoms infrastructures in the optical and backhaul segments, NEC is now positioned in 5G wireless through the development of vRAN solutions for the domestic market initially. Recently it made the headline through its development of Open RAN 5G Radio Equipment for Rakuten fully virtualized 5G network in Japan, a radio unit that will also be provided to NTT Docomo. This radio unit supports massive MIMO for 5G in the 3.7 GHz frequency band and complies with the open architecture standard. It is produced in NEC's Fukushima plant.

As part of its nascent 5G Radio portfolio, NEC has also developed mmWave Distributed Unit to support 5G indoor coverage. In addition to Rakuten Mobile, NEC is providing equipment for NTT Docomo (3.7 GHz, 4.5 GHz and 28 GHz) E as well as for Etisalat.

Through its sister company Netcracker, NEC also provides OSS/BSS solution to operators.

Figure 33: NEC network portfolio

Converged Packet Optical Transport System

Fiber Optic Devices

IoT Platform Software "CONNEXIVE"

Mobile Backhaul "PASOLINK"

Optical Fiber Sensing

Submarine Systems

Traffic Management Solution

User Data Utilization Platform "NC7000-3A"

Source: NEC

3.10. Electromagnetic Fields (EMF) in the EU-27 Member States plus the UK

As regards wireless services in general, and mobile services in particular, there have been long-standing public concerns over possible health effects due to exposure to electromagnetic fields (EMF).

In Europe, EMF guidelines for non-ionising[22] EMF are primarily based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The current ICNIRP guidelines are reflected in a 1999 Council Recommendation[23] on the permissible level of emissions for equipment to be deployed. Article 58 of the newly enacted European Electronic Communications Code (EECC) effectively requires Member States to notify the Commission of draft measures where the Member State intends to deviate from the Council Recommendation, and empowers the Commission or other Member States to propose amendments to the draft measure in order to remove or reduce barriers this might create to the free movement of goods.

Table 23 : Adoption of ICNIRP limits in the EU-27 Member States plus the UK

Countries	ICNIRP (Y/N)	Details on EMF
Austria	Yes	
Belgium	No	More restrictive than ICNIRP. Each region has its own limits. Current limits do not allow 5G deployment in the city of Brussels.
Bulgaria	No	Public exposure limit of 0.1 W/m² (300 MHz to 30 GHz)
Croatia	No	Exposure limits for power density 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	
Lithuania	No	Public limits for power density set at 10% of ICNIRP limits
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	

[22] Non-ionizing radiation is the term given to radiation in the part of the electromagnetic spectrum where there is insufficient energy to cause ionization. It includes electric and magnetic fields, radio waves, microwaves, infrared, ultraviolet, and visible radiation (see https://www.who.int/topics/radiation_non_ionizing/en/).

[23] European Council (1999), Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), (1999/519/EC).

Countries	ICNIRP (Y/N)	Details on EMF
Poland	Yes	As of 1 January 2020, Poland applies the ICNIRP/EC Guidelines (Before 2020: 0.1 W/m² between 300 MHz and 3 GHz. 1% of ICNIRP limits above 2 GHz.)
Portugal	Yes	ICNIRP limits adopted in 2004
Romania	Yes	
Slovakia	Yes	ICNIRP limits adopted in 2007
Slovenia	Yes	
Spain	Yes	ICNIRP limits adopted in 2001
Sweden	Yes	
UK	Yes	ICNIRP limits adopted in 2000. EMF consultation in February 2020

Source: GSMA and IDATE DigiWorld

3.11. TDD synchronisation in the EU-27 Member States plus the UK

3.11.1. Context

TDD synchronisation status in the EU-27 plus UK

Up to now, all 2G and 3G networks and the vast majority of 4G networks were deployed in FDD mode in Europe. 5G networks are going to use the TDD mode in the 3.4-3.8 GHz band. ECC report 296, "National synchronization regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz" addresses the question of Time Division Duplex (TDD) synchronisation between mobile (4G and 5G) networks. Annex 1 "synchronisation frameworks in recent C-Band award procedures" provides some information on national conditions in Austria, Ireland, Italy and the United Kingdom.

In Europe, the majority of legacy TDD networks deployment can be grouped in two categories (source ECC report 296):

- Based on synchronised operation when operators run their networks without relying on sufficient isolation (e.g. this is the case of LTE-TDD networks, comprising thousands of BS, in Italy operating in the 3400- 3600 MHz band);
- Based on unsynchronised operation when there is sufficient isolation between operators running their networks on adjacent frequency blocks (e.g. one operator per region is often assumed).

Going forward, recent advances for newer TDD systems in a multi-operator context encourage synchronisation more strongly, therefore this situation is expected to evolve in the coming years.

TDD synchronisation frameworks in the EU Member States

ECC Report 296 section 3.3 describes some potential situations where inter-operator agreement relying solely on the market may be challenging in a multi-operator context (either at the time of auction, or later in time). Therefore regulators may get involved at some point in the process in order to ensure an efficient spectrum usage. This has already been done in the past, and ECC Report 216 Annex 3 already describes a few of them: Austria, Ireland, Italy and the United Kingdom. France and Sweden have also recently addressed this question.

Standardisation work on TDD synchronisation

In the upcoming 3GPP Release 16 specifications, a new feature called Dynamic TDD may provide a possibility of unsynchronised TDD network arrangement in certain usage scenarios. This may allow unsynchronised TDD deployment in indoor environment or small cells deployment, while outdoor deployment may still require proper coordination between 5G operators operating in the same frequency band.

3.11.2. Austria

(source ECC report 296)

The Austrian Administration is planning to start the assignment procedure for the 3410-3800 MHz range in Q1 '19. The following provisions are described in the tender document from the Telekom-ControlKommission.

The “LTE compatible” NR frame structure (DSUDDDSUDD) is defined as the “default frame structure” for which the ECC baseline out of block power limit applies. "Licence holders are responsible for ensuring that frames are based on a uniform reference time (+/- 1.5 µs), so that all of any licence holder’s frames are aligned equally and transmissions are consequently synchronised". "…Small cells inside buildings are exempt from synchronisation. The default BEM can be used for such small cells in buildings, provided that no damaging interference occurs to other licence holders".

According to the tender document: "… the synchronisation frame specified here can be altered by the TKK to reflect technical and economic conditions when 5G reaches market maturity, in accordance with Art. 57 TKG 2003. If such modifications are indeed made, consideration will nonetheless have to be given in each case to the proportionality of the measure and the economic impact on the parties affected. Even if any such change is made, the spectrum holders will have the option of stipulating under private law a synchronisation frame".

The tender document also provides conditions associated with the use of the restrictive BEM when "other frame structures" are adopted.

3.11.3. France

On August 1st, 2019, ARCEP published Decision n° 2019-0862 on synchronisation of terrestrial networks in the 3.4-3.8 GHz band in France. This decision requires that terrestrial networks operating in the 3.4-3.8 GHz band will have to use the same synchronisation frame from July 1st 2020.

However, terrestrial networks in the 3.4-3.8 GHz band will be allowed to use another synchronisation frame as long as they do not generate harmful interferences to other networks.

3.11.4. Germany

Decision of the President's Chamber of the Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen of 14 May 2018 on the order for and choice of proceedings for the award of spectrum in the 2 GHz and 3.6 GHz bands for mobile/fixed communications networks (MFCN); decision taken under sections 55(4), (5) and (10), section 61(1) and (2) and section 132(1) and (3) of the Telecommunications Act (TKG) – Reference: BK1-17/001 –[24]

“Moreover, the nationwide operation of TDD networks in Germany is new. In the case of unsynchronised operation, guard bands of 20 MHz will be needed between adjacent TDD usages by different network operators, or the networks will have to be synchronised. The 20 MHz guard bands required mean that the total spectrum of 300 MHz would lead to a net usable spectrum of only 240 MHz. However, channel bandwidths of 100 MHz are required to achieve full performance of 5G. The synchronisation is technically difficult and this issue is made even more difficult by the regional reservation.”

[24] Source: https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/FrequencyAward2018/20180613_Decision_I_II.pdf?__blob=publicationFile&v=2

Germany & Sweden[25]

An Agreement signed in September 2018 between the German Federal Network Agency and the Swedish Post and Telecom Authority concerning the use of the 3.6 GHz (3400-3800 MHz) frequency band states the following:

Use of frequencies without coordination by administrations:

- Germany may use the 3.6 GHz band without coordination with Sweden, if the predicted mean field strength produced by a base station does not exceed 32 dB(µV/m)/5 MHz, calculated for 10 % of the time, at a height of 3 m above the ground at the Swedish borderline or beyond.
- Sweden may use the 3.6 GHz band without coordination with Germany, if the predicted mean field strength produced by a base station does not exceed 32 dB(µV/m)/5 MHz, calculated for 10 % of the time, at a height of 3 m above the ground at the German borderline or beyond.
- For base stations that are synchronized1 between Germany and Sweden or deployed as downlink only on both sides of the border, the following applies:
  - Germany may use the 3.6 GHz band without coordination with Sweden, if the predicted mean field strength produced by a base station does not exceed 67 dB(µV/m)/5 MHz at the Swedish borderline or beyond and 49 dB(µV/m)/5 MHz at a distance of 6 km from the Swedish borderline or beyond, calculated for 10 % of the time, at a height of 3 m above the ground.
  - Sweden may use the 3.6 GHz band without coordination with Germany, if the predicted mean field strength produced by a base station does not exceed 67 dB(µV/m)/5 MHz at the German borderline or beyond and 49 dB(µV/m)/5 MHz at a distance of 6 km from the German borderline or beyond, calculated for 10 % of the time, at a height of 3 m above the ground.

This Agreement entered into force from January 2019.

3.11.5. Ireland

(source ECC report 296)

In its June 2017 Spectrum 3600 MHz band spectrum award [1] Ireland mandated the LTE-TDD frame configuration #2 with special sub-frame configuration #6 (or equivalent frame structures whose transmit and receive periods are aligned with this configuration) as the default frame structure which an operator must comply with in order to be allowed to comply with the "permissive Block Edge Mask". The operator must also ensure compliance with a common reference time of +/- 1.5µs.

3.11.6. Italy

(source ECC report 296)

In September 2018, a multiband 5G spectrum auction in Italy followed a light touch approach with respect to the definition of the synchronisation framework for the 3600-3800 MHz band. The auction rules [12] did not include specific provisions in relation to the synchronisation framework, leaving to operators the task to agree on the most suitable framework. Soon after the frequency assignment, the Italian Ministry has announced that it will facilitate the process by setting up a specific working group among operators that acquired licences in the band.

[25] Source: https://www.pts.se/contentassets/1bb1d2473d724553a62c82007931e5e9/agreement_sweden_germany_3400-3800mhz_180827_final.pdf

3.11.7. Sweden

Source: PTS

PTS issued a consultation covering synchronisation of TDD networks in the 2.3 GHz and 3.5 GHz in 2018. PTS is proposing licensing conditions enabling co-existence without geographical separation, implemented by a “relaxed” BEM and a common frame structure, in case the licencees cannot reach an agreement themselves, and it should be re-considered every 5 years in order to follow technology development.

3.11.8. United Kingdom

(source ECC report 296)

In its May 2015 statement on the award of the 3.4 GHz spectrum band [14], the UK decided on the LTE-TDD frame configuration #2 with special sub-frame configuration #6 (or equivalent frame structures whose transmit and receive periods are aligned with this configuration) as the "preferred frame structure" which an operator must comply with in order to be allowed to comply with the "permissive transmission mask. An operator unwilling to adopt the "preferred frame structure" must comply with the "restrictive transmission mask" and the "compatible frame structure", i.e. must comply with semi-synchronised operation.

Licencees are required to synchronise their networks in order to avoid interference to one another, so traffic alignment and the “preferred frame structure” for transmission with the limits of the "permissive transmission mask" are mandated to implement the synchronisation. Timeslots must have a duration of 1ms. LTE-TDD frame configuration #2 (3:1) is compatible with this frame structure.

Indoor base stations with a transmit power level below 24 dBm are exempt from synchronisation requirements unless they cause interference to the macro-cellular network, in which case they are required to synchronise.

In April 2018, Ofcom conducted the auction, and the 3.4 GHz band plan based on final auction results as below, as announced by Ofcom. Ofcom will auction 3600-3800 MHz in second half of 2019.

European Commission

5G Observatory – Quarterly report 12
Luxembourg, Publications Office of the European Union

2021