The 5G C-band auctions across Europe: An assessment

Journal:	*Digital Policy, Regulation and Governance*
Manuscript ID	DPRG-08-2022-0090.R1
Manuscript Type:	Original Article
Keywords:	C-band, Auction, Licensees, Launches, Spectrum caps

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1. Introduction

5G is the most recent mobile technology. Due to its ability to deliver fast speeds and lower latency than previous generations of mobile technology, 5G has been welcomed by many as a transformational technology. Not only has a broad range of use cases been suggested (Deloitte, 2018; ITU, 2018) but the economic impact of 5G has also been highlighted by many commentators – for example, 5G will, by 2035, contribute $3.6 trillion to the global economy (IHS Markit, 2019). Another report, looking solely at the European Union, suggested that 5G will add €2.2 trillion to the bloc's economy between 2020 and 2030 (European Commission, 2020).

But for these benefits to occur, 5G needs to be widely available. 5G iscurrently being rolled out – and increasingly being launched – across developed countries and it will eventually become established worldwide (European 5G Observatory; 2022; GSMA, 2022a). However, progress is dictated by a number of features that are not fully appreciated by the millions of smartphone owners who constantly clamour for ever-faster data transfers across an ever-wider area. One of these features concerns the use of specific spectrum or bandwidth to convey the signal from origin to destination. For a variety of reasons, the optimum spectrum that can be used for 5G in circumstances where human involvement is involved[1] is quite limited, and much of it is already occupied. It has accordingly been concluded that, with a view to utilising spectrum that is still to a great extent unused worldwide and which is spectrally efficient for the purposes of mobile communications, the spectrum band comprising 3.4-3.8 GHz (3400-3800 MHz) – otherwise known as the C-band – is the optimum choice.

A new generation of mobile telephony occurs roughly every ten years (IDATE Digiworld, 2019b). The first licences for long term evolution (LTE – more widely known as 4G) were issued over ten years ago and in advanced countries, at least, the technology has been rolled out and is widely available (Curwen and Whalley, 2013a; GSMA, 2022a). As is customary, initial meetings were held to determine what would be known as 5G while 4G was being rolled out with the intention of having the technology specifications agreed world-wide by 2020 (Curwen and Whalley, 2021).

At the time of writing (December 2022), 5G networks have been extensively licensed throughout the world and a significant number are now operational (GSMA, 2022a), albeit rarely at a nationwide level. But these networks are not fully compatible since they use a variety of spectrum bands and some are more advanced technically than others. Although it can be argued that 5G has developed most rapidly in the USA and relatively advanced Asian countries such as Japan and South Korea (GSMA, 2022c), it is in Europe that progress has most obviously been made across a substantial group of related countries (EU 5G Observatory, 2022; GSMA, 2022b). Hence, when examining the progress of 5G, it is sensible, at least initially, to concentrate on Europe.

It is increasingly common to use 'Europe' and the 'European Union' (EU) interchangeably. EU Member states, with the exception of the recently departed UK, encompass Europe's most developed countries and are governed by a common set of regulations laid down by a single over-arching body, the European Commission (EC).There are, however, advantages to adopting a broad geographical approach to determining which countries are within the sample, not least of which is that the use of the term 'Europe' maximises the number of countries that can be included within the analysis. That said, defining the precise geographical boundaries of Europe presents difficulties, but as it happens a potentially awkward country such as Russia, which is largely in Asia but has its main cities in Europe, has yet to licence the C-band nationwide. Another advantage of adopting a broad geographical focus is that this paper complements existing research that looks at a smaller number of countries (such as, for example, Kuś and Massaro, 2022).The analysis of Kuś and Massaro (2022) is arguably unusual within the literature on 5G, not only in terms of its detailed assessment of auctions within Europe, but also because it examines how spectrum is awarded and not how it may be monetised. The monetisation of 5G has attracted considerable attention, with researchers examining value creation within the context of verticals (see, for example, Curwen and Whalley, 2021) as well as local licences (see, for example, Ahokangas et al., 2019).

The remainder of this paper is divided into five sections. In the following section, a brief overview of contextual information relating to 5G is provided before Section 3 describes the spectrum allocation methods that are available. The sample is described in Section 4, before an analysis of auctions in the C-band occurs in Section 5. Conclusions are drawn in the final section of the paper.

2. Background

5G is not restricted to one particular spectrum band. However, what follows is concerned very largely with a single contiguous band of spectrum – 3.4-3.8 GHz – that is currently most closely associated with the roll-out and launch of 5G mobile networks. The first generation to use digital technology and hence allow the transfer of data was 2G. Both 2G, and the subsequent 3G generation did not operate in the same spectrum bands worldwide. However, the growth of the EU meant that the mobile industry needed to operate internally on a compatible basis. In the case of 2G the 900 MHz and 1800 MHz bands had been selected although they provided relatively little bandwidth, and it happened that the 2.1 GHz was vacant across the EU so that was enlisted for 3G.

Nevertheless, spectrum remained scarce because the growth of data transfers was exceptionally rapid. To some extent, this could be accommodated by improving the efficiency of 3G technology, but the advent of 4G meant that the existing spectrum rapidly became inadequate and hence the 2.6 GHz band needed to be added to what was available across the EU. Despite this, the move to 5G meant that yet further spectrum would be needed, although it is worth noting that it is possible to shut down 2G and 3G and to re-use the vacated spectrum more efficiently for 4G and 5G.[2]

Although this paper is concerned with Europe as a whole[3], it is important to stress that the driving force with respect to spectrum use is inevitably the EU. This is due mainly to the need to roam – that is, for a signal originating in one country to be accessible via a mobile device in other countries. Once the EU has determined that a particular band should be used, this provides a significant inducement for other countries, not only in Europe, to follow suit if only because equipment vendors such as Ericsson and Nokia will concentrate their production on devices that can use these frequencies.

A handheld smartphone can contain only so many antennas, hence equipment vendors necessarily have a preference for spectrum bands in use across Europe and in the USA.[4] If both of these adopt the same bands then life becomes much simpler for vendors. Although the USA had gone its own way with earlier generations, when 5G came along all countries faced the same difficulty: The spectrum bands below 3 GHz were nearing capacity. But there is a further issue which is that the spectral characteristics of spectrum alter as the band is forced upwards. Signals in relatively low bands are very robust – they can travel considerable distances and penetrate solid objects, meaning, for example, that a user can happily download data at high speed even if indoors.

Beyond a certain point, however, the signal weakens considerably, meaning that the distance between towers must be reduced and eventually that the signal will be unable to pass around obstructions or penetrate walls. It is important to understand, however, that signals in bands well above 3 GHz are crucial to the development of 5G because 5G comes in two varieties. These are known respectively as Non-Standalone (NSA) and Standalone (SA). NSA means that additional hardware is added on top of that already existing for 4G with an associated upgrade in software. In principle, there is an array of software that can be used to upgrade 4G to 5G where the emphasis is currently upon Dynamic Spectrum Sharing (DSS)[5] (Curwen and Whalley, 2021: chapter 2). SA means that the network operates independently of 4G and hence requires massive new investment in licences and network rollouts.

In respect of spectrum bands that are to be used for 5G, those European countries that are EU Member States are expected to fall in line with the over-arching framework prepared by the European Commission. One aspect of this is the 5G for Europe Action Plan (European Commission, 2019a) launched in September 2016 – see Communication from the Commission to the European Parliament, the Council, the European and Social Committee and the Committee of the Regions: "5G for Europe: An Action Plan" – COM(2016)588 and Staff Working Document – SWD(2016)306 (European Commission, 2016).

The European Electronic Communications Code came into force on 21 December 2018. This required Member States to make pioneer bands available by the end of 2020 with investment certainty and predictability for at least 20 years in terms of spectrum individual licensing (IDATE DigiWorld, 2019a: 10). The initial pioneer bands were the 700 MHz band and the 3.4-3.8 GHz band commonly identified as the C-band. The final pioneer band – the 24.25-27.5 GHz (26 GHz) band was adopted in May 2019 (European Commission, 2019b).

Although most attention in Europe has been paid to the pioneer bands, other bands are either being made available for 5G via technology-neutral licences, re-farmed from 2G/3G to 5G or able to switch between LTE and 5G as required using DSS. In part, the use of these bands reflects difficulties in clearing and subsequently auctioning the pioneer bands. However, these may initially provide modest additional bandwidth for 5G provision. Examples are as follows (Curwen and Whalley, 2021 - updated):

- 900 MHz: Hungry, Montenegro.
- 1400 MHz: Belgium, Netherlands.
- 1500 MHz: Austria, Denmark, Latvia, Romania.
- 1800 MHz: Hungary, Italy, Malta, Montenegro.
- 2.1 GHz: Austria, Croatia, Denmark, Germany, Greece, Hungary, Lithuania, Netherlands, Poland, Portugal.
- 2.3 GHz: Denmark, Sweden, UK.
- 2.6 GHz: Hungary, Italy, Montenegro, Norway, Poland, Portugal, Romania.

For an extensive analysis of the use of non-pioneer bands see European 5G Observatory (2022).

3. Spectrum allocation methods

Spectrum is mostly allocated and assigned via an auction – there is often a two-stage process whereby a specified quantity of spectrum is awarded to each successful bidder (clock phase) followed by a second stage when winners are awarded specific blocks of spectrum (assignment phase) which they may have to pay an additional fee to acquire.

In the case of 3G a number of countries preferred to use administrative methods known popularly as 'beauty contests' which did not involve up-front payments for spectrum. The advantage of beauty contests is that licensees have more money left to invest in their networks, against which must be set arguments relating to the superior efficiency of auctions in allocating spectrum. By the time 4G licences came up for grabs – effectively post-2000 – the revenue-raising and efficiency virtues of auctions meant that virtually all bandwidth suitable for 4G was sold off to the highest bidder**.**This has also been the case for 5G.

In essence, auctions can take three main forms as follows (Australian Communications and Media Authority, 2022):

- Simultaneous multi-round ascending (SMRA).
- Combinatorial clock (CCA).
- Sealed bid.

A SMRA, as the name indicates, involves operators bidding simultaneously for more than one spectrum block, thereby catering for blocks that are substitutes or complements. It may require operators to place bids during each round or be locked out. A standing high bidder for each block emerges after each round and the winning bidders are named**.** Bidding continues until there is no additional bid registered for any lot. One drawback is that once the strategies of bidders become reasonably clear, there is an incentive for them to collude in various ways in order, say, to keep out new entrants.

A further drawback is that the minimum increase for a bid must be specified in each round, and if set at too low a level an auction can drag on for months. This was the case, for example, in Portugal where the auction lasted for 1,727 rounds over 10 months (Aetha, 2021).

A simple clock auction differs from a SMRA in that bidders specify the number of generic blocks they wish to buy at the prevailing price, which is the same for all identical blocks. If too many blocks come under offer, the price rises until demand equals supply. Because bidders can make mutually exclusive package bids, it is clearly suitable for occasions where spectrum in several bands is being sold simultaneously (Specure, 2020). It is customary to announce the total bids made after each round of a clock auction but not to name the bidders. Where a clock auction is followed by a sealed package bid it is known as a CCA (Levin and Skrzypacz, 2016).

As can be seen from the data on the 2.6 GHz auctions in Europe in Aetha (2021: 31), there was much disagreement as to which kind of method should be used, and it would serve little useful purpose to examine in detail the reasons why a particular method was adopted in any individual case for an auction of 5G spectrum. That is because, ultimately, there is no clear relationship between the method used and the amount raised when expressed in dollars per MHz per head of population ($/MHz/pop) which is the standard valuation procedure for comparing results – with the potential added refinement of adjustments to take account of inflation over time and/or the length of the licence awarded.

4. The sample

In order to undertake a review of 5G in Europe, a number of original databases have been developed. Multiple sources, such as press releases from regulatory authorities and mobile network operators (MNO) as well as reports from the trade and financial press, have been combined together to create the databases. Such an approach enables claims, concerning such matters as how much spectrum has been awarded or when the MNO launched its 5G services, to be cross-checked (Yin, 2018). The advantage of such an approach, which is consistent with Curwen and Whalley (2013a, 2021), is that it avoids relying on a single source that may, for example, be inconsistent with other sources or be proprietary in nature. Moreover, this approach enables a more detailed dataset to be developed than is typically available in many sources. This, in turn, enables, a more nuanced understanding of 5G to emerge from the subsequent analysis. Finally, the database can be updated on a real time basis to reflect developments in the licensing of 5G. The databases that have been compiled and then used in the ensuing analysis are fully updated as of the point of final submission in December 2022.

The sample set in Table 1 consists of 33 countries although only 32 are strictly relevant as Kosovo is not universally recognised as an independent country. Of the remaining 32, 27 are EU member states now that the UK has left the EU whereas five countries outside the EU are included – Montenegro, North Macedonia, Norway, Switzerland and the UK. It should be noted that the C-band auction in Montenegro has yet to be completed, while those in the Netherlands and Poland have been indefinitely postponed. Hence, there have so far been C-band auctions in 25 member states which accordingly form a clear majority of the 28 European countries where C-band auctions have taken place so far.

[Table 1 roughly here]

5. Analysis

Size of spectrum bands

As shown in Table 2, the amount of spectrum on offer has been quite variable, although in the case of Latvia in 2017 the two separated blocks should sensibly be treated as one for this purpose. Normally, there are guard bands at either end of a large block of spectrum, but in several cases the full 400 MHz was sold while in others it was 390 MHz plus a guard band. In total, auctions of 300 MHz or more appear 26 times out of a sample of 36 (including planned auctions), which indicates in part why the 3.4-3.8 GHz band was chosen as it presented the opportunity for harmonisation across the whole of Europe.

[Table 2 roughly here]

Nevertheless, in many countries all or part of the spectrum was occupied when the EU pioneer bands were announced, sometimes by satellite operators, and in some cases this led to delays of many years before enough of the spectrum could be cleared. In some cases that resulted in less than 200 MHz becoming available before mid-2022 although occasionally it was existing incumbents that were already licensed in the parts of the band awaiting clearance which affected what they were able to add to their holdings during the auction.

It is notable that in France only 110 MHz was actually auctioned as 200 MHz had previously been awarded to the four incumbents, so the total allocated was 310 MHz. In Germany, by way of comparison, the 3.7-3.8 was set aside to be used by private and public sector groups for the construction of so-called 'private' networks.

It may be noted that it is generally advantageous to offer small blocks because it enables incumbents to aim for the optimal amount of bandwidth to suit their needs while allowing potential new entrants to acquire the more modest amounts that better suit their circumstances. It is very unlikely that a block of, say, 100 MHz would be acquired by a non-incumbent even if it is reserved for a new entrant.

In some cases, as shown in Table 2, the regulator decided either that it preferred incumbents to acquire all of the available spectrum to maintain competition between them or that it might as well offer large blocks as there was little prospect of new entry. Nevertheless, blocks of 5 MHz or 10 MHz predominate as is to be expected.

Auction results

Table 3 provides a representative sample of the results of C-band auctions within Europe, covering 23 countries and 26 auctions in total. Much the earliest, in Romania, is worth noting insofar that at that time there was very little interest in the C-band partly due to the lack of vendor support, and hence not all of the available blocks were sold and the price achieved was extremely low. It may be noted that a further auction was scheduled for November 2021where 18 blocks of 5 MHz were on offer in the 3400-3490 MHz band, but only one was acquired at the minimum price of €700,000. A further auction took place in November 2022, but only 310 MHz of the available 400 MHz was acquired as the fourth incumbent declined to participate in the auction.

[Table 3 roughly here]

The fact that Romania was a relatively minor European country economically may also have been relevant since the only other values below $0.01/MHz/pop were recorded in Bulgaria – despite its more recent auction and the sale of every lot – and in Latvia in 2017 where there were two non-contiguous blocks on offer at a very low reserve but only one bidder. However, there is clearly no strong correlation between the economic importance of a country and the auction results since of the six occasions where in excess of $0.1/MHz/pop was achieved, one related to Luxembourg and one to Norway. On the other hand, it can be argued that per capita incomes are high in those countries and that four of the 'big five' economies – France, Germany, Italy, Spain and the UK – did fall into that category.

It is remarkable that the result in Italy was more than twice that achieved anywhere else. Undoubtedly, the small amount of spectrum available and the odd distribution of two 80 MHz carriers and two 20 MHz carriers were significant contributory factors as were to a lesser extent a desire on the part of incumbents to try to restrict the total spectrum acquired by new entrant Iliad as well as payment by instalments (Aetha, 2018).

The French 'auction' was rather unusual in that before the auction proper the four incumbents were each awarded a 50 MHz block at a fixed price of €350 million (Curwen and Whalley, 2021: 79-80). A total of €2.79 billion ($3.27 billion) was raised, including the auction of a further 110 MHz, which was equivalent to $0.16/MHz/pop. However, given that the initial allocations totalling 200 MHz sold for €1.4 billion whereas the 110 MHz that was actually auctioned sold for €1.39 billion, the two elements clearly raised significantly different amounts on a $/MHz/pop basis.

In Germany, only 300 MHz was made available to operators and this created pressure when 1&1 Drillisch, a MVNO with nine million customers, decided to compete with the three incumbents in the hope of itself becoming one, attracted also by relatively modest roll-out obligations for new entrants compared to the incumbents. Because of the auction rules, progress with bidding was unusually long-winded (Curwen and Whalley, 2021: 80-82) which also helped push up the final price.

In the UK, in 2018, the auction took place in a complicated context whereby Hutchison (3UK) already controlled 840 MHz in the 3.4-3.6 GHz band while EE was excluded from the simultaneous auction for 2.3 GHz spectrum and was accordingly keen to win blocks in the higher band where it was also subject to a spectrum cap. There was also competition from an ultimately unsuccessful new entrant, Airspan (Curwen and Whalley, 2021: 104-05). The result in terms of $/MHz/pop was somewhat biased upwards by the unusually high number of dollars to the pound at the time. In 2021, a relatively modest amount of spectrum was available and the pound was again unusually strong against the dollar. However, Hutchison had no real need for further C-band spectrum and left the other three incumbents to share out what was available.

The clear majority of values in the table – 16 out of 26 – fall within the $0.01-0.10/MHz/pop range so that can reasonably be regarded as the norm for C-band auctions inside Europe. The amount of spectrum on offer does not appear to have had a significant effect. The earliest auctions achieved relatively low values as might be expected given that the role of the C-band in the provision of 5G had yet to be established, but recent auctions have kept within the norm so there has been no tendency for values to escalate despite the launch of 5G networks.

Interestingly, the European norm contrasts significantly with the experience of C-Band auctions outside Europe, although the number of countries involved is much lower as shown in Table 4 and the C-band has played a relatively significant role in the roll-out of 5G in the USA. It may be noted that the amounts of spectrum on offer were generally less than was the case in European auctions and also that there were no national licences on offer in Australia and the USA.

[Table 4 roughly here]

Launches

It is generally not difficult to pin down the dates on which operators initially launched their 5G networks if they did so using the C-band. However, that is not always the case as some operators initially launched 5G using another band – quite possibly using re-farmed spectrum – and it is more difficult to establish the date on which they added their C-band spectrum to their existing networks. Table 5 is an attempt to provide an accurate picture of the C-band launches to date with respect to the incumbent operators.

[Table 5 roughly here]

Spectrum caps and reserved spectrum

The issue of attracting new entry when new bands are opened up is important in circumstances where there is felt to be insufficient competition in a country's mobile market. However, the definition of 'insufficient' cannot be dealt with in a general way – ultimately, it is up to individual regulators to decide, often by comparing such matters as the prices being charged to customers with those in comparable countries.

Auctions are expected to favour incumbents because they are better placed than outsiders to evaluate what a licence is worth. Over time, the number of incumbents in most countries has tended to decline as a result of merger and acquisition (M&A) activity and occasionally bankruptcy, which is a trend that is unpopular with most regulators. As a result, they have sometimes considered it desirable to take steps to encourage new entry. The two methods in common usage – as shown in the 5G case studies – are to reserve certain bandwidth exclusively for new entrants – see Table 1 – and/or to cap the spectrum available to incumbents as shown in Table 5. These methods have drawbacks – for example, incumbents may be prevented from acquiring spectrum that they value more highly than a potential new entrant or the reserved spectrum may prove not to be optimal for a potential new entrant (Cramton et al., 2011).

[Table 6 roughly here]

One evident consequence is that incumbents have mopped up the great majority of the available 4G and 5G licences. In fairness, this was to some extent a reaction to the fact that there was not much significant new entry as a result of 3G allocations despite the widespread use of beauty contests (Curwen, 2002; Curwen and Whalley, 2006).

Spectrum caps are clearly intended to restrict the ability of incumbents to prevent new entrants from gaining a significant toehold in the market by themselves acquiring the entire spectrum on offer. A factor here is that incumbents may feel that it is better to acquire spectrum for which they have no immediate economic use rather than let it get into the hands of a potential rival. However, if the caps are set at a level that incumbents themselves feel are uneconomic, this may induce them either to take court action that will hold up the process of auctioning the spectrum – although this is rarely successful – or to refuse to participate in the auction (Curwen and Whalley, 2021).

An alternative is to reserve spectrum for non-incumbents. In principle this appears to guarantee new entry, but the reality is that relatively small blocks of spectrum hold little appeal as the new entrant is still obliged to negotiate roaming agreement to cover 2G/3G/4G with incumbents and they are unlikely to cooperate voluntarily in arrangements that enable a potential competitor to eat into their market share.

It must also be borne in mind that the number of incumbents is not necessarily all that much of a guide in this respect because if, say, a regulator believes that four incumbents are necessary to achieve a competitive market, it is very unlikely that they will be of roughly equal size – indeed, where four operators serve a market the smallest is likely to have an uneconomic market share.

Not surprisingly, potential new entrants are well aware of this and experience dictates that they will not seek to break into a market with three or more established networks unless they are backed by a company with deep pockets that is willing to make significant short-term losses (Curwen, Whalley and Vialle, 2019: chapter 2). Given that most companies with aspirations to become a mobile incumbent chanced their arm when 3G and 4G licences were issued, it was always unlikely that 5G licences would attract much new entry and regulators accordingly made only modest efforts to attract it.

One possible exception is where an established MVNO, having acquired a critical mass of 3G and/or 4G customers, decides to upgrade to incumbent status by rolling out its own 5G network while continuing to roam over the network with which it has its MVNO contract. Alternatively, where licences are issued on a regional rather than national basis, relatively small regional operators may choose to try to upgrade their existing networks with 5G. In practice, neither of these possibilities has played much of a role in the development of 5G, largely because regional licences have not been issued on any scale.

New entrants

In the light of the above, it is of interest to assess the role played so far by potential new entrants in the development of the C-band given that the great majority of licences have now been awarded. As previously noted, there are two basic ways of favouring these, namely reserving spectrum for their exclusive use and placing spectrum caps upon incumbents. Setting low reserve prices may also prove to be helpful although incumbents are unlikely to let licences be awarded cheaply to new entrants when the incumbents are themselves in need of additional spectrum for the roll-out of 5G networks.

In Austria in 2019, the licences were awarded on a regional basis where the regulator set spectrum caps on the incumbents Telekom Austria, T-Mobile and Hutchison. Although each acquired between 100 MHz and 140 MHz on a nationwide basis, four other bidders were also successful – LIWEST (80 MHz in two regions), Salzburg AG (80 MHz in Salzburg City, 80 MHz in Salzburg state and 40 MHz in Styria), Holding Graz (50 MHz in Graz and 40 MHz in Styria) and Mass Response (30 MHz in two regions).

In Belgium, in 2022, a 20 MHz block was reserved for a new entrant and won by Network Research Belgium which it intends to devote to corporate provision. More significantly, Citymesh won 50 MHz in the auction proper as well as spectrum in the 2G and 3G bands, and hence is in a position to roll out its own 4G/5G network, particularly as it intends to do so in conjunction with DiGi which operates elsewhere in Europe, for example as RCS&RDS.

In the Czech Republic in 2017, the incumbents were restricted to one block and new entrants to two blocks of the five available blocks of 40 MHz. Nordic Telecom 5G won two blocks while PODA won one block. Suntel Net and Radio Spectrum CZ were unsuccessful bidders.

In the Czech Republic in 2020, the incumbents were capped at 60 MHz in the 3.4-3.6 GHz band while new entrants were capped at 100 MHz. CentroNet won 80 MHz while Nordic Telecom 5G won 20 MHz. However, PODA and Sev.en Innovations were unsuccessful bidders. The incumbents all won licences and no potential fourth MNO emerged from the auction.

In Germany in 2019, coverage requirements were less onerous for new entrants but they were expected to strike commercial roaming arrangements without regulatory interference. They were also aided by the absence of reserve prices. 1&1 Drillisch was successful, albeit winning less spectrum than the three incumbents, but it was already an established MVNO with millions of customers and an aspiration to become a fourth incumbent.

In Ireland in 2017, the available licences comprised 594 blocks in nine regions of which five were urban and four were rural. A spectrum cap was set at 150 MHz. Imagine Communications won 60 MHz in rural areas and Airspan Spectrum Holdings won 60 MHz in urban areas plus 25 MHz in rural areas.

In Italy in 2018, Fastweb and Linkem pre-qualified to bid but only Fastweb, which had previously acquired spectrum in the 3.5 GHz band from Tiscali, took part. However, it was unsuccessful.

The Latvian auction in 2018 attracted a potential new entrant in the form of Lattelecom but only a small amount of spectrum was available and it was unsuccessful.

The Luxembourg auction in 2020 attracted potential new entrants in the form of Eltrona and Luxembourg Online, but whereas the latter was successful it obtained only one-tenth as much spectrum as the incumbents.

In North Macedonia in 2022, 100 MHz was reserved for a new entrant who would be offered a lower one-off fee and reduced coverage obligations (O'Grady, 2021). Bitstream Mobile registered an interest in one of the three available 100 MHz licences but was unsuccessful.

The Portugal auction in 2021 attracted an unusual amount of interest from non-incumbents, namely cable operator/MVNO Nowo owned by Spain's MásMóvil, Dixarobil – apparently an affiliate of Romania's RCS&RDS – and Dense Air which intended to operate as a wholesaler. Also unusually, all won 40 MHz, albeit considerably less than the incumbents.

The UK auction in 2018 attracted potential new entrants in the form of Airspan Spectrum Holdings and Connexin (which subsequently withdrew). However, only a small amount of spectrum was available and Airspan was unsuccessful.

The dominant role played by incumbents can be seen clearly by reference to Table 7. Overall, it is fair to say that regulators do not appear to have made much effort to attract new entry in the C-band. By and large this has also been the case in the 700 MHz band where it has been licensed for 5G. In terms of new entrants with a realistic chance of competing with incumbents on a nationwide basis in the provision of 5G, only 1&1 Drillisch currently looks to be a good prospect due to its established position as a large MVNO, but it is notable that, due to the tight spectrum caps imposed, it was in the Czech Republic in 2017 that a new entrant, Nordic Telecom, obtained the largest allocation at 80 MHz, a feat replicated in 2020 by CentroNet (with Nordic Telecom obtaining an additional 20 MHz.

[Table 7 roughly here]

Licence duration

Although it is not possible to assert theoretically what should be the optimum length of a mobile licence, it is evident that as a matter of practicality it must be possible for an operator to show a profit from the provision of 5G services having covered the licensing and roll-out costs involved. This suggests strongly that a minimum period for a licence to run from the date of its hand-over to the licensee should be 10 years.

[Table 8 roughly here]

According to the EU, the optimum length of time over which a licence should be awarded is 15 years renewable for a further five years (European Parliament and Council (2018). This issue is addressed in Table 8 where, as can be seen, the EU's advice has been followed precisely in eight of the 34 possible cases. However, the four cases of 15 years may yet prove to be renewable and there are a further 13 cases where a licence term of either 18 years or 20 years has been awarded and three where more than 20 years has been awarded.

Licence conditions

The most significant conditions imposed in most of the sample set can be found in Curwen and Whalley (2021: chapter 4). An exhaustive list of the licence conditions imposed in the EU auctions up to end-2020 is to be found in Kuś and Massaro (2022). Kuś and Massaro (2022) divide these into coverage or rollout obligations (13 of 16 cases), usage obligations (5 of 16 cases), access obligations (5 of 16 cases) and Quality of Service (QoS) obligations (4 of 16 cases).

As can be seen, it is only really the coverage and rollout conditions that are critical and that is because one of the obvious problems with unconditional licences is that the licensees will be keen to roll out their networks in urban areas with large clusters of relatively wealthy inhabitants and much less keen to continue the roll-out to more rural or less densely-inhabited areas. There also tend to be issues over coverage along roads where signals could become weak or non-existent without the provision of additional towers.

In recent years, governments have increasingly been pressurised to treat broadband connectivity as a human right so it is unsurprising that regulators almost always set time limits for rollouts, mostly linked to the percentage of the population or land mass that needs to be covered, although recent problems with the equipment supply chain may require some latitude to be introduced in practice.

Another issue that has needed to be addressed is the perhaps understandable tendency for incumbents to make roaming onto their networks by new entrants as difficult and expensive as possible, and it must be borne in mind that it is also likely to involve earlier generations of mobile. Hence, licences generally contain an obligation for the winners – among which are always numbered most or all of the incumbents – to provide wholesale access on terms that can potentially yield a profit for new entrants. The downside is obviously that, in general, the more onerous the conditions, the lower the amounts likely to be bid which is why, occasionally, licensees signing up for particularly onerous obligations are offered a discount.

6. Conclusion

This paper has attempted to give a snapshot of progress with the licensing of the C-band in Europe – spectrum that is considered to be essential for the successful roll-out of 5G in Europe. The licensing of the band is now more or less complete, although the associated network launches are still a work in progress.

Licensing of spectrum bands is a complex process, if only because there may initially be entities occupying the desired spectrum that have to be moved to other bands. Then there is a need to draw up the rules for an auction – a means of allocation that is almost always used if only because it yields potentially significant revenues for governments. However, regulators are free to do their own thing in this respect, so other than keeping within the bounds of the band – 3.4-3.8 GHz – there can, and has been, considerable variation in respect of such matters as spectrum caps and obligations placed on licensees. On the whole, therefore, it would be unwise to draw too many conclusions that apply across the full sample set.

This paper has drawn on a variety of databases, compiled by the authors from multiple sources, to highlight key aspects of the C-band auctions in Europe. Given that other bands, especially the 700 MHz band and, eventually, the 26 GHz band will play an increasing role in the provision of 5G, these databases can be supplemented in due course to provide a detailed picture of the development of 5G in Europe. Thus, one area for further research is analysing how this additional spectrum is awarded and ascertaining whether differences exist between the bands. Related to this is another area, namely exploring the extent to which mobile operators are able to assemble across multiple allocative rounds a portfolio of spectrum that best suits their business model. As it has, of necessity, been focussed on national incumbents, this paper has not explored one other significant development associated with 5G, namely local licensing. Such licences, as their name suggests, are not national in scale and are often associated with verticals – industries where 5G may be implemented to utilise one of its key attributes such as low latency or fast data rates (Curwen and Whalley, 2021). Further research could map how these licences are awarded across a broadly defined Europe, which would be a first step towards understanding their impact on incumbents (Whalley, 2022).

Notes

1. Where communication is required between machines, normally in close proximity, the high-band spectrum above 20 MHz (mmWave) is used.

2. However, this takes a long time to effect because the vast majority of users must be persuaded that it is in their interests voluntarily to upgrade their handsets to cope with the upgraded technology.

3. The concept of 'Europe' is somewhat flexible as noted in Curwen and Whalley (2013b). The Eurovision Song Contest may suggest that a country such as Israel – or even Australia – belongs in Europe but common sense suggests to the contrary.

4. In order to avoid unnecessary digression, despite the fact that China is the largest mobile market in the world, it suffices to note that it has become increasingly detached from events in Europe and the USA due to the travails of Huawei and ZTE – see Curwen (2020) and Curwen and Whalley (2021: chapter 6).

5. DSS involves the use of software to enable a signal to switch between 4G and 5G on a dynamic basis. This differs from standard spectrum re-farming in that 10 MHz paired currently used for 4G does not need to be split up into 5 MHz paired for 4G and 5 MHz paired for 5G, but rather used for both as appropriate.

References

Aetha. (2018). *The 5G auction conditions and procedure are now in place*. Retrieved from https://aethaconsulting.com.

Aetha. (2021). *Portugal's 5G auction.* Retrieved from https://aethaconsulting.com.

Ahokangas, P., Matinmikko-Blue, M., Yrjölä, S., Seppänen, V., Hämmäinen, H., Jurva, R. &Latva-aho, M. (2019). Business models for local 5G micro operators. *IEEE Transactions on Cognitive Communications and Networking, 5*(3), 730-740.

Australian Communications and Media Authority. (2022). *About spectrum auctions.* Retrieved from https://www.acma.gov.au.

Cramton, P., Kwerel, E., Rosston, G. &Skrzypacz, A. (2011). Using spectrum auctions to enhance competition in wireless services. *Journal of Law and Economics*, *54*(4), 167-188.

Curwen, P. (2002). *The Future of Mobile Communications: Awaiting the Third Generation*, Basingstoke, UK: Palgrave.

Curwen, P. (2020). Huawei and goodbye.*Digital Policy, Regulation and Governance, 22*(1), 50-51.

Curwen, P. & Whalley, J. (2006). The prospects for third generation new entrants in the European mobile telecommunications industry. *Telecommunications Policy, 30*(10/11), 622-632.

Curwen, P. & Whalley, J. (2013a). *Fourth Generation Mobile Communication: The Path to Superfast Connectivity*, London:Springer.

Curwen, P. & Whalley, J. (2013b). Mapping worldwide mobile networks: Some problems and indicative solutions. *Telecommunications Policy, 37*(11), 1150-65.

Curwen, P., Whalley, J. and Vialle, P. (2019). *Disruptive Activity in a Regulated Industry: The Case of Telecommunications,* Bingley, UK:Emerald Publishing.

Curwen, P. & Whalley, J. (2021). *Understanding 5G Networks: A Multidisciplinary Primer*, Bingley, UK:Emerald Publishing.

Deloitte. (2018, June). *The Impacts of Mobile Broadband and 5G – A Literature Review for DCMS*. Retrieved from https://www.gov.uk.

European Commission. (2016). *Communication – 5G for Europe: An Action Plan and accompanying Staff Working Document.* Retrieved from https://ec.europa.eu.

European Commission. (2019a). *5G for Europe Action Plan*. Retrieved from https://ec.europa.eu.

European Commission. (2019b). *5G. European Commission to harmonise the last pioneer frequency band needed for 5G deployment*. Retrieved from https://ec.europa.eu.

European Commission. (2020, September). Shaping the Digital Transformation in Europe. Directorate-general for Communication Networks, Content and Technology. Retrieved from https://www.eur.lex.europe.eu.

European Parliament and Council of the EU. (2018). *Directive (EU) 2018/1972 of 11 December 2018 establishing the European Electronic Communications Code*. Retrieved from https://www.eur.lex.europe.eu.

European 5G Observatory. (2022). *5G Observatory Quarterly Report 15: Status in March 2022.* Retrieved from https://www.5gobservatory.eu.

GSMA. (2022a). *The Mobile Economy 2022*. Retrieved from https://www.gsma.com.

GSMA. (2022b). *The Mobile Economy – Europe 2022*. Retrieved from https://www.gsma.com.

GSMA. (2022c). *The Mobile Economy – Asia-Pacific 2022*. Retrieved from https://www.gsma.com.

IDATE Digiworld. (2019a). *5G Observatory Quarterly Report 5*. Retrieved from https://www.idate.org.

IDATE Digiworld. (2019b). *Digiworld Yearbook – Challenges of the digital world*. Retrieved from https://www.idate.org.

IHS Markit. (2019, November). *The 5G Economy – How will 5G contribute to the Global Economy?* Retrieved from https://ihsmarkit.com

ITU. (2018). *Setting the scene for 5G: Opportunities and challenges*. Retrieved from https://www.itu.int.

Javid, S. (2021). *FCC Auction 110*. Retrieved from https://www.sashajavid.com.

Kuś, A. and Massaro, M. (2022). Analysing the C-Band spectrum for 5G in Europe: Achieving efficiency and fair decisions in radio spectrum management. *Telecommunications Policy*, *46*(4).

Levin, J. and Skrzypacz, A. (2016). Properties of the Combinatorial Clock auction. *American Economic Review*, *106*(9), 2528-51.

O'Grady, V. (2021). *North Macedonia to award 5G spectrum this year.* Retrieved from www.developingtelecoms.com.

Radio Spectrum Policy Group. (2021, June). State of play regarding award of pioneer bands. RSPG21-019 FINAL.

Specure. (2020). *Spectrum auction formats.* Retrieved from https://specure.com.

Whalley, J. (2022). The challenge for mobile operators to create value with 5G, in, Bohlin, E. and Cappelletti, F., editors, *Europe's Future Connected: Policies and Challenges for 5G and 6G Networks,* Brussels, Belgium: European Liberal Foundation.

Yin, R. (2018). *Case study research and applications: Design and methods*, Sixth Edition, Thousand Oaks, California: SAGE Publications.

Table 1. Spectrum auctions within the C-band across Europe, 30 November 2022

Country	Spectrum Band	Reserved New Entry	Date	Licence winners
Austria	3.4-3.8 GHz[1]	-[4]	Mar 2019	Hutchison, Telekom Austria, T-Mobile + 4 regional
Belgium	3.4-3.8 GHz	-	Jun 2022	Belgacom, Citymesh, NRB, Orange, Telenet
Bulgaria	3.5-3.8 GHz	-	Apr 2021	Telekom Austria, Telenor, Vivacom
Croatia	3.4-3.8 GHz	-	Aug 2021	Hrvatski Telekom, Telekom Austria, Telemach
Cyprus (South)	3.4-3.8 GHz	-	Dec 2020	Cablenet, CyTA, Epic, PrimeTel
Czech Repub.	3.6-3.8 GHz	-[5]	Jul 2017	Nordic Telecom 5G, PODA, PPF Group, Vodafone
Czech Repub.	3.4-3.6 GHz	-	Nov 2020	CentroNet, Nordic Telecom 5G, PPF Group, T-Mobile, Vodafone
Denmark	3.4-3.8 GHz	-	Apr 2021	Hutchison, TDC, TT-Netværket
Estonia	3.4-3.8 GHz	-	May 2022	Elisa, Telia Company
Finland	3.4-3.6 GHz	-	Oct 2018	Elisa, Telia Company
Finland	3.6-3.8 GHz	-	Oct 2018	DNA
France	3.4-3.8 GHz	-	Oct 2020	Altice, Bouygues, Iliad[9], Orange
Germany	3.4-3.7 GHz[2]	-[6]	Jun 2019	Deutsche Telekom, Telefónica, Vodafone, 1&1 Drillisch
Greece	3.4-3.8 GHz	-	Dec 2020	OTE, Vodafone, Wind
Hungary	3.4-3.8 GHz	-	May 2016	DiGi Communications[10], Vodafone
Hungary	3.4-3.8 GHz	-	Mar 2020	PPF Group, T-Mobile, Vodafone
Ireland	3.4-3.8 GHz[3]	-	May2017	Airspan, eir, Hutchison, Imagine, Vodafone
Italy	3.6-3.8 GHz	-	Oct 2018	Iliad, Telecom Italia, Vodafone, Wind
Kosovo	3.4-3.7 GHz	-	-	Forthcoming
Latvia	3.4-3.7 GHz	-	Sep 2017	Telia
Latvia	3.5-3.6 GHz	-	Sep 2018	Tele2
Lithuania	3.4-3.7 GHz	-	Aug 2022	Bité, Tele2, Telia
Luxembourg	3.4-3.8 GHz	-	Jul 2020	Belgacom, Luxembourg Online, Orange, Post Luxembourg
Malta	3.4-3.8 GHz	-	May 2021	Epic, GO, Melita[11]
Montenegro	3.4-3.8 GHz	-	2022	Forthcoming
Netherlands	Not specified	-	-	Postponed
North Macedonia	3.5-3.8 GHz	-[7]	Jun 2022	Makedonski Telekom, Telekom Austria
Norway	3.4-3.8 GHz	-	Sep 2021	Altibox, ice Group[12], Telenor, Telia Company
Poland	3.4-3.8 GHz	-	-	Postponed
Portugal	3.5-3.8 GHz	-	Oct 2021	Altice, Dense Air, Dixarobil, Nos, Nowo, Vodafone[13]
Romania	3.4-3.6 GHz	-	Oct 2015	Orange, RCS&RDS, SNR
Romania	3.6-3.8 GHz	-	Oct 2015	Orange, Vodafone, 2k
Romania	3.4-3.5 GHz	-	Nov 2021	Invite Systems
Romania	3.4-3.8 GHz	-	Nov 2022	Orange, RCS&RDS, Vodafone
Slovakia	3.4-3.6 GHz	-	Oct 2015	SWAN, Telefónica
Slovakia	3.6-3.8 GHz	-	Oct 2017	Regional awards
Slovakia	3.4-3.8 GHz	-	May 2022	Orange, PPF Group, Slovak Telekom, 4ka[
Slovenia	3.4-3.8 GHz	-	Apr 2021	Telekom Austria, Telekom Slovenije, Telemach
Spain	3.4-3.6 GHz	-	Mar 2016	Orange, Telefónica
Spain	3.6-3.8 GHz	-	Jul 2018	Orange, Telefónica, Vodafone
Sweden	3.4-3.8 GHz	-	Jan 2021	Hutchison, Net4Mobility, Telia
Switzerland	3.5-3.8 GHz	-	Feb 2019	Salt, Sunrise, Swisscom
UK	3.4-3.6 GHz	-[8]	Apr 2018	BT/EE, Hutchison, Telefónica, Vodafone
UK	3.7-3.8 GHz	-	Mar 2021	BT/EE, Telefónica, Vodafone

Notes: [1]390 MHz in 10 MHz blocks were auctioned in 12 regions. The 3.6-3.8 GHz band would be for immediate use while the 3.41-3.60 GHz band would become available on 1 January 2020; [2]Telekom Austria and T-Mobile were capped at 150 MHz while other bidders were capped at 170 MHz. However, if not all the spectrum was sold then the caps would be raised to 160 MHz and 190 MHz respectively; [3]A 350 MHz block was offered within the 3435-3800 MHz band divided into nine regional licences which in turn were divided into five urban and four rural regions. All bar Imagine Communication s obtained nationwide coverage; [4]A 20 MHz block in the 3.40-3.42 GHz band plus 270 MHz in the 3.42-3.70 GHz band; [5]Incumbents were restricted to one of the 5 available blocks of 40 MHz apiece and new entrants to two blocks apiece; [6]Coverage requirements were less onerous for new entrants but they were expected to strike commercial roaming arrangements without regulatory interference; [7]100 MHz was reserved for a new entrant but was not awarded; [8]A cap was applied that limited incumbents to 37% of the useable spectrum in 2020; [9]Having taken over Numericable-SFR. Iliad is branded as 'Free'; [10]In December 2021, Digi was provisionally acquired by 4iG; [11]Melita (3.5-3.6 GHz) in May, Epic (3.6-3.7 GHz) in August and GO (3.7-3.8 GHz) in October; [12]In March 2022, Lyse – the owner of Altibox – acquired the licences held by ice Group; [13]In October 2020, Vodafone and Zon Optimus (Nos) signed an agreement to share active and passive infrastructure.

Source: Compiled by the authors from a variety of publications including Radio Spectrum Policy Group (2021).

Table 2. C-band auctions in Europe. May 2016 to December 2022 + plans

Country	Date	Spectrum (MHz)	MHz on offer	Block Size (MHz)	No. of Blocks
Austria	Mar 2019	3410-3800	390	10	39[4]
Belgium	June 2022	3430-3600	370[2]	10/20	35/1
Bulgaria	Apr 2021	3500-3800	300	100	3
Croatia	Aug 2021	3480-3800	320	10	32[5]
Cyprus (S)	Dec 2020	3400-3800	400	50	8
Czech Republic	Jul 2017	3600-3800	200	40	5
Czech Republic	Nov 2020	3400-3600	200	20	10
Denmark	Apr 2021	3410-3800	390	10	39
Estonia	May 2022	3410-3800	390	130	3
Finland	Oct 2018	3410-3800	390	130	3
France[1]	Oct 2020	3490-3800	110	10	11
Germany	Jun 2019	3400-3700	300	10/20	28/1[6]
Greece	Dec 2020	3410-3800	390	10	39
Hungary	May 2016	3410-3800	300	5 /5 paired	40/10[7]
Hungary	Mar 2020	3490-3800	310	10	31[7]
Ireland	May 2017	3410-3800	350	5	[8]
Italy	Oct 2018	3600-3800	200	20/80	2/2
Kosovo	Planned	3400-3700	300	5	60[9]
Latvia	Nov 2017	3400-3450	50	50	1
Latvia	Nov 2017	3650-3700	50	50	1
Latvia	Sep 2018	3550-3600	50	50	1[10]
Lithuania	Aug 2022	3400-3700	300	100	3
Luxembourg	Jul 2020	3420-3750	330	10	33
Malta	May 2021	3400-3800	400	5/80	16/4
Montenegro	Planned	3400-3800	400	10	40
Nth Macedonia	Dec 2021	3500-3800	300	100	3[11]
Norway	Sep 2021	3400-3800	400	10/40	24/4
Poland	Dec 2023	n/a	320	80	4[12]
Portugal	Oct 2021	3400-3800	400	10	40
Romania	Nov 2021	3400-3490	90	5	18
Romania	Nov 2022	3400-3800	400	40	10
Slovakia	May 2022	3410-3800	390[3]	10	39
Slovenia	Apr 2021	3420-3800	380	10	38
Spain	Jul 2018	3600-3800	200	5	40[13]
Sweden	Jan 2021	3400-3720	320	20/40	14/1[14]
Switzerland	Feb 2019	3500-3800	300	20	15
UK	Apr 2018	3410-3580	150	5	30
UK	Mar 2021	3680-3800	120	5	24

Notes:

1. The four incumbents were each awarded a 50 MHz block prior to the commencement of the auction. The 3800-4000 MHz band was set aside for private networks.
2. The auction was delayed. As a result, 5 temporary licences were awarded in July 2020. However, in October one of the two non-incumbents was disqualified and 10 MHz of its spectrum redistributed to each of the three incumbents. In addition to the 35 blocks of 10 MHz auctioned, a 20 MHz block (3430-3450 MHz) was offered. 3410-3430 MHz was available only to Citymesh and Gridmax**,** but when they failed to bid the spectrum was offered to all operators other than those that had already reached the cap of 100 MHz**.**

3. In August 2015 an auction of spectrum in the 3.4-3.6 GHz band was largely unsuccessful. In October 2017, some regional licences were sold in the 3.6-3.8 GHz band. All existing licences are due to terminate before end-August 2025 and termination dates will therefore be the commencement dates for licences acquired during the auction that took place in May 2022.
4. Per region.
5. In addition, 80 MHz (3400-3480 MHz) was sold via regional licences.
6. One licence covered 3400-3420 MHz, the rest were each of 10 MHz. The 3700-3800 MHz band was set aside for the construction of private networks.
7. Although 10 licences of 5 MHz paired plus 40 more of 5 MHz were on offer, only 6 paired licences and 5 unpaired licences were acquired, a total of 80 MHz. Hence it was possible to re-offer 3490-3800 MHz in March 2020.
8. 594 licences were on offer in 9 regions (5 urban and 4 regional).
9. Allocated on a nationwide basis. In addition,, the 3.7-3.8 GHz band, divided into 20 blocks of 5 MHz, would be awarded on a local basis to private networks.
10. It was also claimed that Tele2's existing licence in the 3500-3550 MHz band was extended to end-December 2028.
11. One of which was reserved for a new entrant. The 3.6-3.7 GHz and 3.7-3.8 GHz bands were won by the incumbents.
12. Of these, two would be nationwide and the other two designated as 'supra-regional' with a view to excluding parts of the country where the requisite spectrum was already in use.
13. Some incumbents had previously acquired holdings in the band: MásMóvil (80 MHz) which accordingly declined to bid and Telefónica (40 MHz) which acquired a further 50 MHz.
14. The 3400-3420 MHz band – subject to special obligations – was to be awarded to the winner of the 3420-3440 MHz band.

Source: Compiled by the authors from a variety of official and internet publications. The table is formatted much the same as Table 2 in Kuś and Massaro (2022) for ease of comparison but defines Europe more broadly, is much more up-to-date and disagrees with some of the former's entries.

Table 3. Illustrative[1] results of auctions of C-band spectrum inside Europe

Country	Date	Band	MHz Sold	Revenue Million	Revenue $ million	$ per MHz per pop[8]
Austria	Mar 2019	3.4-3.8 GHz	390[2]	€186	210	0.06
Belgium	Jun 2022	3.4-3.8 GHz	370	€208	219	0.05
Bulgaria	Apr 2021	3.5-3.8 GHz	300	LEV13.4	8.1	0.004
Cyprus South	Dec 2020	3.4-3.8 GHz	400	€20.2	27.6	0.06
Czech Repub.	Jul 2017	3.6-3.8 GHz	200	CZK1,015	44	0.02
Czech Repub.	Nov 2020	3.4-3.6 GHz	200	CZK1,470	72.3	0.03
Finland	Oct 2018	3.4-3.8 GHz	390	€78	89	0.04
France	Oct 2020	3.4-3.8 GHz	310	€2,760	3,270	0.16
Germany	Jun 2019	3.4-3.7 GHz	300	€4,200	4,704	0.19
Greece	Dec 2020	3.4-3.8 GHz	390	€99	121	0.03
Hungary	Mar 2020	3.4-3.8 GHz	310	€144	160	0.05
Ireland	May 2017	3.4-3.8 GHz	350[3]	€78[5]	94	0.05
Italy	Oct 2018	3.6-3.8 GHz	200	€4,350	5,045	0.42
Latvia	Nov 2017	3.4-3.7 GHz	100	€0.5	0.59	0.003
Latvia	Sep 2018	3.5-3.6 GHz	50	€6.5	7.5	0.08
Lithuania	Aug 2022	3.4-3.7 GHz	300	€13	13	0.016
Luxembourg	Jul 2020	3.4-3.8 GHz	330	€24.5	27.2	0.13
Norway	Sep 2021	3.4-3.8 GHz	400	NOK3,122	364	0.17
Portugal	Oct 2021	3.4-3.8 GHz	400	€328.0	379	0.09
Romania	Oct 2015	3.4-3.8 GHz	255[4]	€10	11	0.002
Slovakia	May 2022	3.4-3.8 GHz	390	€63.6	67.2	0.03
Slovenia	Apr 2021	3.4-3.8 GHz	380	46.5	55.3	0.07
Spain	Jul 2018	3.6-3.8 GHz	200	€438[6]	517	0.06
Sweden	Jan 2021	3.4-3.7 GHz	320	SEK2,317	277.1	0.07
UK	Apr 2018	3.4-3.6 GHz	150	£1,150	1,610[7]	0.16
UK	Mar 2021	3.6-3.8 GHz	120	£512	707	0.09

Notes: [1]Not every auction is listed as the amounts raised in certain cases were aggregated with payments for other spectrum bands that took place simultaneously; [2]There were 39 blocks in 12 regions, of which a small number were won by regional telcos. Spectrum caps were imposed on the incumbents; [3]Mixed urban and rural blocks; [4]Of the 52 available blocks, only 40 were sold so was only 255 MHz of the available 340 MHz; [5]Of which €60.5 million consisted of up-front payments equivalent to $0.04/MHz/pop and €17.5 million in spectrum usage fees; [6]Adding on such costs as spectrum fees meant that, in total, €1.4 billion was raised; [7]The pound had reached a peak rate against the dollar – it has since subsided considerably; [8]Other sources tend to give slightly different values for entries in this column. It is generally not possible to work out why this is the case as they tend not to provide their underlying data. It may be noted that the euro is often used for comparisons rather than the dollar and that conversions in this table are done at the exchange rates ruling at the time.

Source: Compiled by the authors from a variety of official and internet publications.

Table 4. Illustrative[1] auctions of C-band spectrum outside Europe

Country	Date	Band	MHz Sold	Revenue $ million	$ per MHz per pop
Australia[1]	Dec 2018	3.5-3.7 GHz	125	614	0.196
Canada	Jul 2021	3.4-3.7 GHz	200	7,146	0.937
Chile	Feb 2021	3.4-3.8 GHz	150	347	0.120
Hong Kong	Nov 2019	3.3-3.4 GHz	100	129	0.085
Hong Kong	Jan 2020	3.4-3.6 GHz	200	85	0.110
Nigeria	Dec 2021	3.5-3.8 GHz	200	563	0.130
South Korea	Jun 2018	3.4-3.8 GHz	280	n/a	0.180
Taiwan	Jan 2020	3.4-3.8 GHz	270	4,660	0.730
USA[2]	Aug 2020	3.5-3.8 GHz	70	4,586	0.217
USA[3]	Jan 2021	3.7-4.0 GHz	280	81,114	0.944
USA[4]	Nov 2021	3.4-3.6 GHz	100	21,888	0.661[5]

Notes: [1]Sold by way of 350 regional blocks of 5 MHz apiece; [2]Auction 105 comprising 22,631 licences; [3]Auction 107 comprising 5,604 licences; [4]Auction 110 comprising 4,060 licence; [5]The revenue refers to the post-assignment phase of the auction (Javid, 2021).

Source: Compiled by authors from a variety of publications.

Table 5. C-band launches by licensees as of end-November 2022

Country	Operator	Date	Country	Operator	Date
Austria	Hutchison	Dec 2019	Latvia	Tele2	Jan 2020
	Telekom Austria	Jan 2020		Telia	Sep 2021
	T-Mobile	Mar 2020	Lithuania	Telia	Jan 2022
Belgium	Belgacom	Dec 2020	Luxembourg	Belgacom	Oct 2020
	Telenet	Dec 2021		Post Luxembourg	Oct 2020
	Orange	Feb 2022		Orange	Nov 2020
Bulgaria	Telekom Austria	Nov 2020	Malta	Melita	May 2021
	Telenor	Jun 2021		Epic	Nov 2021
Croatia	Hrvatski Telekom	Aug 2021		GO	Dec 2021
	Telekom Austria	Aug 2021	Monaco	Monaco Telecom	Jul 2019
Cyprus (S)	CyTA	Jan 2021	Montenegro	Crnogorski Telekom	Mar 2022
				PPF Group	Aug 2022
Czech Rep.	Nordic Telecom	Oct 2019	N. Macedonia	Macedonski Telecom	Feb 2022
	PPF Group	Jul 2020	Portugal	Nos	Nov 2021
	Vodafone	Oct 2020		Vodafone	Nov 2021
Denmark	TDC	Sep 2020		Altice	Jan 2022
	Telenor	Jun 2021	Romania	Vodafone	May 2019
	Telia	Jun 2021		RCS&RDS	Jun 2019
	Hutchison	Dec 2021		Orange	Nov 2019
Estonia	Telia	Nov 2020	San Marino	Telecom Italia	Dec 2018
	Elisa	Jun 2022	Slovakia	Orange	Apr 2021
Finland	Elisa	Jun 2019		PPF Group	Sep 2021
	Telia	Oct 2019		4ka	Nov 2021
	DNA	Jan 2020	Slovenia	Telemach	Jun 2021
France	Altice	Nov 2020		Telekom Austria	Sep 2021
	Bouygues	Dec 2020	Spain	Vodafone	Jun 2019
	Iliad	Dec 2020		MásMóvil	Sep 2020
	Orange	Dec 2020		Orange	Sep 2020
Germany	T-Mobile	Sep 2019		Telefónica	Sep 2020
	Vodafone	Jul 2019	Sweden	Tele2	May 2020
	Telefónica	Oct 2020		Telenor	Oct 2020
Greece	OTE	Dec 2020	Switzerland	Sunrise	Apr 2019
	Wind	Dec 2020		Swisscom	Apr 2019
	Vodafone	Jan 2021		Salt	Jan 2021
Hungary	Vodafone	Oct 2019	UK	EE	May 2019
	T-Mobile	Apr 2020		Vodafone	Jul 2019
	PPF Group	Nov 2021		Hutchison	Aug 2019
Ireland	Vodafone	Aug 2019		Telefónica	Oct 2019
	eir	Oct 2019			
	Hutchison	Sep 2020			
Italy[2]	Vodafone	Jun 2019			
	Telecom Italia	Jul 2019			
	Hutchison	Dec 2020			
	Iliad	Dec 2020			

Notes: [1]Inclusive of fully mobile and FWA networks. So far as can be ascertained – operators' announcements are sometimes ambiguously worded – all the entries relate to 'commercial' launches rather than trials, although it has to be said that coverage in the initial stages may have been extremely limited. [2]Fastweb – claiming that it should be regarded as a MNO despite its official status as a MVNO – launched in December 2020. Linkem also launched 5G NSA in December 2020, with a subsequent launch of 5G Standalone – the first in Italy – on 1 October 2021 using the 3.5 GHz band;

Source: Compiled by the authors from a variety of official and internet sources.

Table 6. Spectrum caps 3.4-3.8 GHz[1]

Country	Date	Spectrum caps
Austria	Mar 2019	Telekom Austria & T-Mobile: 150 MHz; Others: 170 MHz If not all bid for, then Telekom Austria & T-Mobile: 160 MHz; Others: 190 MHz
Belgium	June 2022	100 MHz
Bulgaria	Apr 2021	100 MHz
Cyprus (S)	Dec 2020	100 MHz
Czech Republic	Jul 2017	Incumbents: 40 MHz; Others: 80 MHz
Czech Republic	Nov 2020	Incumbents: 60 MHz; Others: 100 MHz If not all bid for then Incumbents: 80 MHz; Others: 120 MHz[4]
Denmark	Apr 2021	160 MHz
Finland[2]	Oct 2018	130 MHz (equivalent to one block)
France[3]	Oct 2020	Incumbents: minimum 50 MHz and maximum 100 MHz
Germany	Jun 2019	No caps
Greece	Dec 2020	Minimum 70 or 100 MHz. Maximum from 90 MHz to 160 MHz[2]
Hungary	May 2016	[5]
Hungary	Mar 2020	Minimum of 20 MHz and maximum of 140 MHz
Ireland	May 2017	150 MHz
Italy	Oct 2018	100 MHz in the auctioned 3.6-3.8 GHz band as well as 100 MHz across the entire 3.4-3.8 GHz band
Latvia	Nov 2017	100 MHz in 3.4-4.2 GHz band
Latvia	Sep 2018	100 MHz in 3.4-4.2 GHz band
Lithuania	Aug 2022	100 MHz
Luxembourg	Jul 2020	120 MHz
Malta	May 2021	100 MHz. But if spectrum not all utilised a further 40% could also be acquired subject to a total cap of 140 MHz.
Norway	Sep 2021	120 MHz
Portugal	Oct 2021	100 MHz
Slovakia	May 2022	Winners to acquire 8 to 10 of the 39 blocks available but could buy up to 14 blocks if any initially left unsold
Slovenia	Apr 2021	160 MHz
Spain	Jul 2018	120 MHz in the 3.4-3.8 GHz band including existing holdings
Sweden	Jan 2021	120 MHz
Switzerland	Feb 2019	120 MHz
UK	Apr 2018	[6]
UK	Mar 2021	[7]

Notes:

1. It has not been possible to establish the existence of spectrum caps in respect of Croatia, North Macedonia and Romania. In the case of Estonia, three licences, each of 130 MHz, were offered sequentially in independent auctions, commencing in May 2022.
2. The cap did not technically exist but with three operators and 390 MHz available, it was always clear that each would acquire 130 MHz.
3. Each bidder was required to bid for at least 40 MHz. The cap applied to the initial award plus spectrum won in the auction
4. Or possibly none, depending upon the number of bidders, bidders' activity and demand.
5. The spectrum comprised 10 blocks of 5 MHz paired in the 3410-3490 MHz band paired with the 3510-3590 MHz band together with 40 blocks of 5 MHz unpaired between 3600 MHz and 3800 MHz. An applicant could bid for at least four and at most six paired blocks, and at least four and at most 20 unpaired blocks with a cap of 100 MHz overall.

6. Each incumbent would be capped at 225 MHz of 'immediately useable' spectrum and at 340 MHz of overall spectrum – equivalent to 37% of all spectrum expected to become useable by 2020 including that involved in the auction and the 700 MHz band. As a result, BT/EE could acquire no more than 85 MHz in the 3.4 GHz band while Vodafone could acquire a maximum of 160 MHz across both bands.
7. The 37% overall spectrum cap above – now equivalent to 416 MHz – would effectively restrict BT/EE to a maximum purchase of 120 MHz across the 700 MHz and 3.6 GHz bands in the combined auction, 3UK to a maximum of 185 MHz and Vodafone to a maximum of 190 MHz, whereas Telefónica would face no limits.

Source: Compiled by the authors from a variety of official and internet sources.

Table 7. Allocations of nationwide spectrum to incumbents (I) and new entrants (NE)[1]

Country	Year	Allocation	Country	Year	Allocation
Belgium	2022	100, 100,100 (I) 50, 20 (NE)	Latvia	2018	50 (I)
Bulgaria	2021	100, 100, 100 (I)	Lithuania	2022	100, 100, 100 (I)
Croatia	2021	120, 100, 100 (I)	Luxembourg	2020	110, 110, 100(I) 10 (NE)
Cyprus (S)	2020	100, 100, 100, 100 (I)	Malta	2021	100, 100, 100 (I)
Czech Repub.	2017	40, 40 (I) 80, 40 (NE)	Nth Macedonia	2021	100, 100 (I)
Czech Repub.	2020	60, 20, 20 (I) 80, 20 (NE)	Norway	2021	120, 100, 100, 40 (I)
Denmark	2021	140, 130, 120 (I)	Portugal	2021	100, 90, 90 (I) 3x40 (NE)
Estonia	2022	130, 130, 130 (I)	Romania	2021	5 (NE)
Finland	2018	130, 130, 130 (I)	Romania	2022	160,, 100, 60 (I)
France	2020	90, 80, 70, 70 (I)	Slovakia	2022	100, 100, 100, 90 (I)
Germany	2019	90, 90, 70 (I) 50 (NE)	Slovenia	2021	140, 140, 100 (I)
Greece	2020	150, 140, 100 (I)	Spain	2018	90, 60, 50 (I)
Hungary	2020	140, 120, 50 (I)	Sweden	2021	120, 100, 100 (I)
Italy	2018	80, 80, 20, 20 (I)	Switzerland	2019	120,100, 80 (I)
Latvia	2017	100 (I)	UK	2018	50, 40, 40, 20 (I)
			UK	2021	40, 40, 40 (I)

Note: 1. Iceland awarded three licences, each of 100 MHz, to the three incumbents in May 2020 without an auction.

Source: Compiled by the authors from a variety of official and internet sources.

Table 8. C-band auction licence duration. May 2016 onwards

Country	Date	Licence Years[1]	Country	Date	Licence Years[1]
Austria	Mar 2019	20	Latvia	Nov 2017	10
Belgium	June 2022	208 months[2]	Latvia	Sep 2018	10
Bulgaria	Apr 2021	20	Lithuania	Aug 2022	20
Croatia	Aug 2021	15 +5	Luxembourg	Jul 2020	15 +5
Cyprus (S)	Dec 2020	20	Malta	May 2021	15 + 5
Czech Republic	Jul 2017	15	Nth Macedonia	Dec 2021	15 +5
Czech Republic	Nov 2020	12	Norway	Sep 2021	242 months
Denmark	Apr 2021	249 months	Portugal	Oct 2021	n/a
Estonia	May 2022	n/a	Romania	Nov 2021	4
Finland	Oct 2018	15	Romania	Nov 2022	22[3]
France	Oct 2020	15 +5	Slovakia	May 2022	[4]
Germany	Jun 2019	20	Slovenia	Apr 2021	15 + 5
Greece	Dec 2020	15 + 5	Spain	Jul 2018	20
Hungary	May 2016	18	Sweden	Jan 2021	[5]
Hungary	Mar 2020	15 +5	Switzerland	Feb 2019	15
Ireland	May 2017	15	UK	Apr 2018	20
Italy	Oct 2018	19	UK	Mar 2021	20

Notes:

1. +5 indicates the possibility of a 5-year extension of the original award.
2. The licences became operational on 1 September 2022 and ran until 6 May 2040.
3. Commencing on 1 January 2026
4. The national licences will run from either end-December 2024 or end-August 2025 to end-December 2049 while the regional licences will run from end-August 2025 to end-December 2045.
5. The licences ran from the date of the award in mid-January 2019 to the end of December 2045, approximately 26 years,although certain licences in the 3.5 GHz band would be shorter to allow for existing licences to expire at end-March 2023.

Source: Compiled by the authors from a variety of official and internet sources.

Abstract

Purpose – To investigate how the licensing of the 3.6 GHz (C-band) has progressed throughout Europe.

Design/methodology/approach – Original databases have been created by the authors covering every aspect of the C-band auctions in Europe, and these have been subjected to analysis to draw out the key themes.

Findings – Although there have been delays in licensing the C-band, the process is now largely complete and the first launches have taken place. However, there has been considerable diversity in the rules underpinning the licences and considerable differences in the amounts raised measured in $/MHz/pop.

Research limitations/implications – It is difficult to make comparisons across a substantial sample of disparate countries because of the need to compare on a like-for-like basis – an issue that is generally glossed over in the literature. This has been addressed in this paper but some issues inevitably remain unresolved.

Practical implications – The development of 5G is highly contingent on the use of the C-band not just in Europe but elsewhere in the world where less-developed countries can learn from the European experience.

Originality/value – While the subject matter has received attention elsewhere, this represents the most up-to-date version with the largest sample of European countries.

Keywords – C-band, Auction, Licensees, Launches, Spectrum caps

Paper type – Research paper