An Coimisiún um
Rialáil Cumarsáide
Commission for
Communications Regulation

Proposed Award process for rights of use in the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz bands:

Benchmarking and minimum prices

a report from DotEcon Ltd

Consultant Report

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Proposed Award process for rights of use in the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz bands: Benchmarking and minimum prices

Prepared for ComReg

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1 Introduction

The Commission for Communications Regulation (ComReg) is considering the award of licences for the use of radio frequencies in some or all of the 700 MHz, 2.1 GHz, 2.3 GHz band and 2.6 GHz bands in Ireland. As ComReg's advisers, in this report we:

- examine the prices at which similar spectrum has been awarded in other countries; and
- provide a recommendation for setting the minimum prices for the spectrum offered in the upcoming auction.

2 Analysis of licence prices from similar awards

2.1 Samples used

The value of spectrum depends on various band-specific factors, such as propagation characteristics, planned use, harmonisation and equipment availability. Therefore, where we have a sufficient number of observations, it is preferable to estimate the market value for spectrum in a band on the basis of observations for that specific band alone. For each of the 2.1 GHz and 2.6 GHz bands, we have more than thirty observations, which should be sufficient for our analysis; therefore, for each of these bands we estimate market value using only observations for that band.

We only have a limited number of observations (less than thirty) for licences in the 700 MHz and 2.3 GHz bands. Therefore, when estimating market value in these bands, we first present summary statistics for that band only, and then consider whether we can use a larger sample pooling data from other similar bands. In the case of

the 700 MHz band, we consider a larger sample, pooling observations from licences in the 800 MHz and 900 MHz bands. In the case of the 2.3 GHz band, we consider a larger sample also including observations from licences in the 2.6 GHz band.

Within each sample we identify outliers as those observations for which the adjusted average per MHz per capita:

- lies more than three standard deviations away from the sample arithmetic mean; and/or
- lie beyond the outer fence (the outer fence is defined as three times the interquartile range from the first and third quartiles respectively) from the median.

We exclude such outliers when calculating summary statistics for the sample.

For each of the samples considered for each band, we also calculate summary statistics the following nested sub-samples:

- **all awards** – uses all of the suitable data available in our database corresponding to the relevant band(s);
- **competitive auctions** – a subsample which includes only observations from awards which use an auction mechanism and in which the price of at least one licence exceeds its reserve price;
- **competitive auctions in the last 10 years** – recent benchmarks are more likely to provide a contemporary view on the value of spectrum as current market conditions and technical developments are more likely to have been considered by operators valuing spectrum in these auctions. This is particularly important for spectrum bands that have only recently been harmonized for wireless broadband use as equipment cost and the potential impact of scale economies are likely to be relevant factors affecting valuations. Therefore, we consider a subsample that only includes awards in the last ten years.[1]
- **competitive auctions in the last 10 years in Europe** – there is a considerable consistency in regulatory policy across Europe,

[1] In some of our previous benchmark reports for ComReg we have considered a shorter timeframe for recent awards, of five years. Partly, our motivation to look only at more recent awards was to remove the effect from prices obtained in spectrum auctions that may have been affected by the dot-com bubble at the start of the millennium, which might have led to inflated prices during the bubble and deflated prices after its burst. However, given the time elapsed since then, the last 10 years are not likely to be affected by this. Therefore, by considering the last 10 years we can still remove the effect of the bubble that might have distorted pre-2008 prices whilst retaining a larger sample size. However, in some instances the number of observations in the last decade is limited, so it is useful to have a larger sample also including earlier observations.

therefore, we would expect greater uniformity in market conditions across Europe compared to the rest of the world.

2.2 Adjustments to enable comparison across awards

In order to obtain price figures that are comparable across awards and to the upcoming award, we have made the following adjustments:

- For each licence in our sample, we have calculated the discounted present value of the stream of fees for the licence (including the upfront fees and any further instalments and annual licence fees). For calculating the NPV of fees we use a real discount rate of 7.13%.[2] We have used a real discount rate as our data gives expected future payments before any indexation for inflation; in many jurisdictions there is an expectation that future payments will increase with inflation (typically CPI).
- For the purposes of reporting our results, we have normalised all licences to a common duration of 15 years, which is close to the proposed duration of licences offered in the proposed award – any further adjustments to reflect the actual duration of each licences are done after obtaining the price estimate for 15-year licences.[3]
- We have converted prices to common currency terms. To do so we have first converted all licence prices to US Dollars using

[2] For our previous benchmarking analysis for ComReg we used ComReg's nominal mobile Weighted Average Cost of Capital (WACC) estimate (8.63%) to discount prices across time. However, we consider that using a real discount rate better takes into account that future annual spectrum usage fees (SUFs) are inflation adjusted, and we have therefore updated our approach accordingly. The discount rate used (7.13%) is based on the estimates provided for the mobile sector WACC in ComReg, 2014, Cost of Capital, Document 14/136 and D15/14: http://www.comreg.ie/_fileupload/publications/ComReg14136.pdf. We estimate the real pre-tax WACC by subtracting the estimated inflation (1.5%) from the estimated nominal pre-tax WACC (8.63%).

[3] To adjust the price for the licence duration we have used the simplifying assumption that the annual value of a licence is constant over the licence duration, but discounted for the purpose of calculating the upfront value of the licence using the same discount rate as for licence payments. The current proposal is to award the spectrum in the 2.1 GHz, 2.3 GHz and 2.6 GHz bands in two time-slices. When making a recommendation for the price of spectrum licences in each time slice we have adjusted our estimate of the price of a 15-year licence (which would be combined duration for a licence covering both time slices) to obtain a price estimate for each time slice using the same approach.

purchasing power parity PPP exchange rates[4] at the time of the corresponding award. We then adjust prices for inflation using the United States Consumer Price Index (CPI) to express prices in 2019 terms, and finally converted them back to Euro (again using PPP exchange rates). Therefore, all prices are expressed in 2019 Euro terms.

Typically, there are many licences sold in each award. We therefore calculate an average price per MHz per capita (i.e. per population covered by the licence) for spectrum in each band in each award.[5] Therefore, each individual band in each award constitutes a single observation.[6]

2.3 Sample distribution and summary statistics

The distribution of the licence price observations does not follow a normal distribution, but rather is positively skewed with a long upper tail of higher values. This is natural as the price in some awards can be (for whatever reason) significantly higher than the rest, but there is limited scope for prices to be much lower than the rest, since prices cannot be negative and are typically bound below by reserve prices.

A consequence of this is that the arithmetic mean of the price observations is likely to be above the median, in which case there will be more observations below the mean than above. Therefore, although using the arithmetic mean as our prediction for the value minimises the expected difference between the prediction and an observation taken at random, it is also more likely that the prediction will be above, rather than below, the actual value of this observation. As a result, if we use the arithmetic mean as our estimate for final auction prices, then we know that, even though we are minimising

[4] Price data is adjusted according to Purchasing Power Parity (PPP) exchange rates to reflect the value of the licence price relative to the value of a basket of comparable goods and services in that country. This allows us to take into account differing levels of cost of living, tax structures and other factors which may affect the general level of prices across countries. PPP exchange rates account for price differences and levels of affluence between countries and are less prone to speculative fluctuation compared to a market exchange rate.

[5] For awards in which regional licences were assigned, the population coverage for each licence is the population in the corresponding region, rather than the country population.

[6] As a consequence, where several licences for the same band were sold in the same award, the observation will only provide the weighted average price across these. However, notice that if two bands of interest were sold in the same award, then these are included as two separate observations.

our prediction error, an observation taken at random is more likely to be above this estimate than below.

The price observations are better fitted by a lognormal distribution than normal distribution. Given this, the geometric mean (which is less affected by extreme upper values) is a better predictor for the central tendency of licence prices. The geometric mean in our samples is below the median. As a result, if we use the geometric mean as our predictor, an observation taken at random is more likely to be above the geometric mean than below, even if our expected prediction error will be greater than if we use the arithmetic mean as the predictor.

Given the above, if we set minimum prices with reference to the geometric mean in the sample we can be more confident that actual clearing prices will be above minimum prices than if we set minimum prices with reference to the arithmetic mean. In line with a conservative approach to setting minimum prices (to ensure that these are not above clearing prices), we consider the geometric mean to provide a good reference for setting minimum prices.

In our analysis below, we present the following sample statistics for each of the sub-samples considered:

- the number of awards included in the sub-sample;
- the arithmetic mean;
- the standard deviation;
- the geometric mean;
- the first quartile;
- the median; and
- the third quartile.

As shown below, in all cases we observe that the arithmetic mean is above the median, whilst the geometric mean is below the median, implying asymmetry of the distribution, with the upper tail being longer than the lower tail.

2.4 The 700 MHz band

We have 25 observations from auctions of 700 MHz spectrum, which are listed in Annex A. We have identified one outlier.[7]

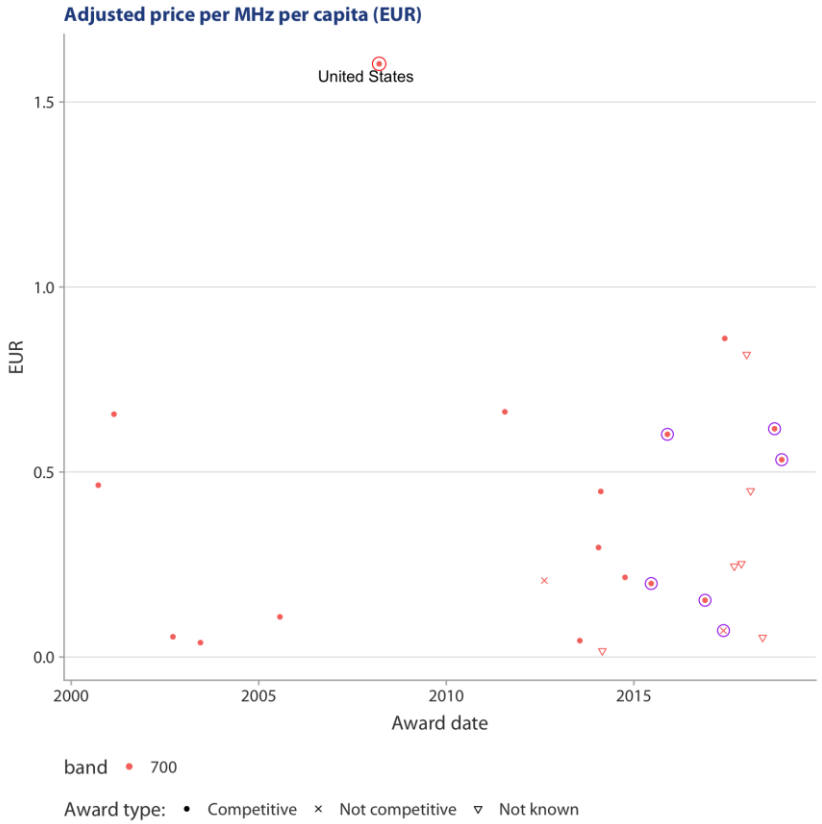
Figure 1 plots the observations (both the adjusted price per MHz per capita for these awards and its log) over time, where:

- competitive auctions are marked as a dot

[7] The price obtained in the US auction in 2008 (Auction 73).

- awards which are not competitive auctions are marked with a cross (x);
- awards where it is not known whether they were a competitive auction or not are marked as a triangle;
- outliers are circled in red; and
- European awards are circled in purple.

Figure 1: Observations from 700 MHz licences



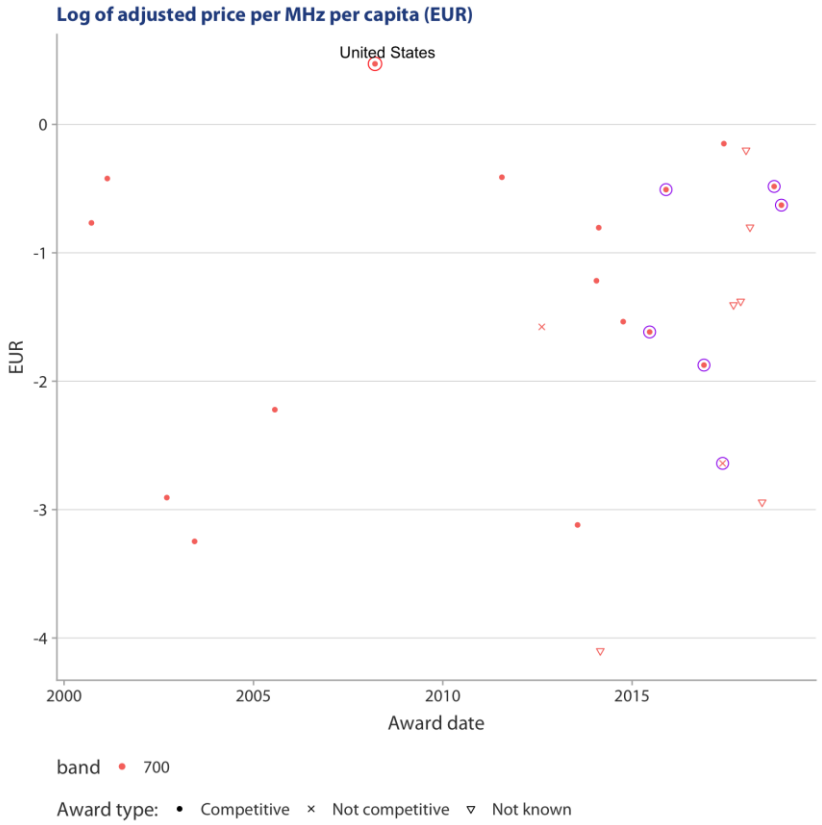


Table 1 reports summary statistics of the adjusted price (Euro per MHz per capita) for the full sample and each of the subsamples considered.

Table 1: Summary statistics for 700 MHz observations

Sub-sample	Num. obs.	Arithmetic mean	Std. dev.	Geometric mean	First quartile	Median	Third quartile
All	24	0.336	0.264	0.214	0.099	0.249	0.550
Competitive	16	0.372	0.265	0.254	0.142	0.372	0.606
Competitive last 10 years	11	0.421	0.256	0.325	0.207	0.447	0.609
Competitive last 10 years European	5	0.421	0.226	0.360	0.199	0.533	0.602

There are relatively few observations in this sample. Therefore, we have expanded the sample by also including observations from licences in the 800 MHz and 900 MHz bands. To check that this is appropriate we have run non-parametric tests to check for structural

differences between 700 MHz and 800 MHz observations, and separately between 700 MHz and 900 MHz observations, on the basis of which we rejected the hypothesis that the observations belong to different distributions even at the 10% significance level.[8]

In total, when pooling data across the three bands, we obtain 100 observations across 92 awards,[9] listed in Annex A. We have identified six outliers.[10] The pooled observations are plotted in Figure 2, using the same legend as in the previous figure, but further distinguishing by the colour of the marker whether the observation is for the price of 700 MHz licences (in blue), 800 MHz licences (in green) or 900 MHz licences (in orange).

[8] Specifically, we have run Wilcoxon rank sum tests to test whether the observations are from the same distribution or not. The probability that our 700 MHz observations have been drawn from the same distribution as our 800 MHz and 900 MHz observations is 0.4 and 0.7 respectively.

[9] For awards of licences in more than one of these bands, the price for each band constitutes a separate observation.

[10] The prices obtained in two US auctions of 900 MHz spectrum in 1994 (Auctions 1 and 3), the price obtained for 900 MHz spectrum in two Indian auctions (the 900 MHz and 1800 MHz auction in 2014 and the 800MHz, 900MHz, 1800MHz and 2100MHz auction in 2015), and the price obtained in the two 900 MHz Thai auctions run in 2015. We note that the observation identified as an outlier when considering only observations from 700 MHz licences is not identified as an outlier when considering this larger sample.

Figure 2: Observations from 700 MHz, 800 MHz and 900 MHz licences

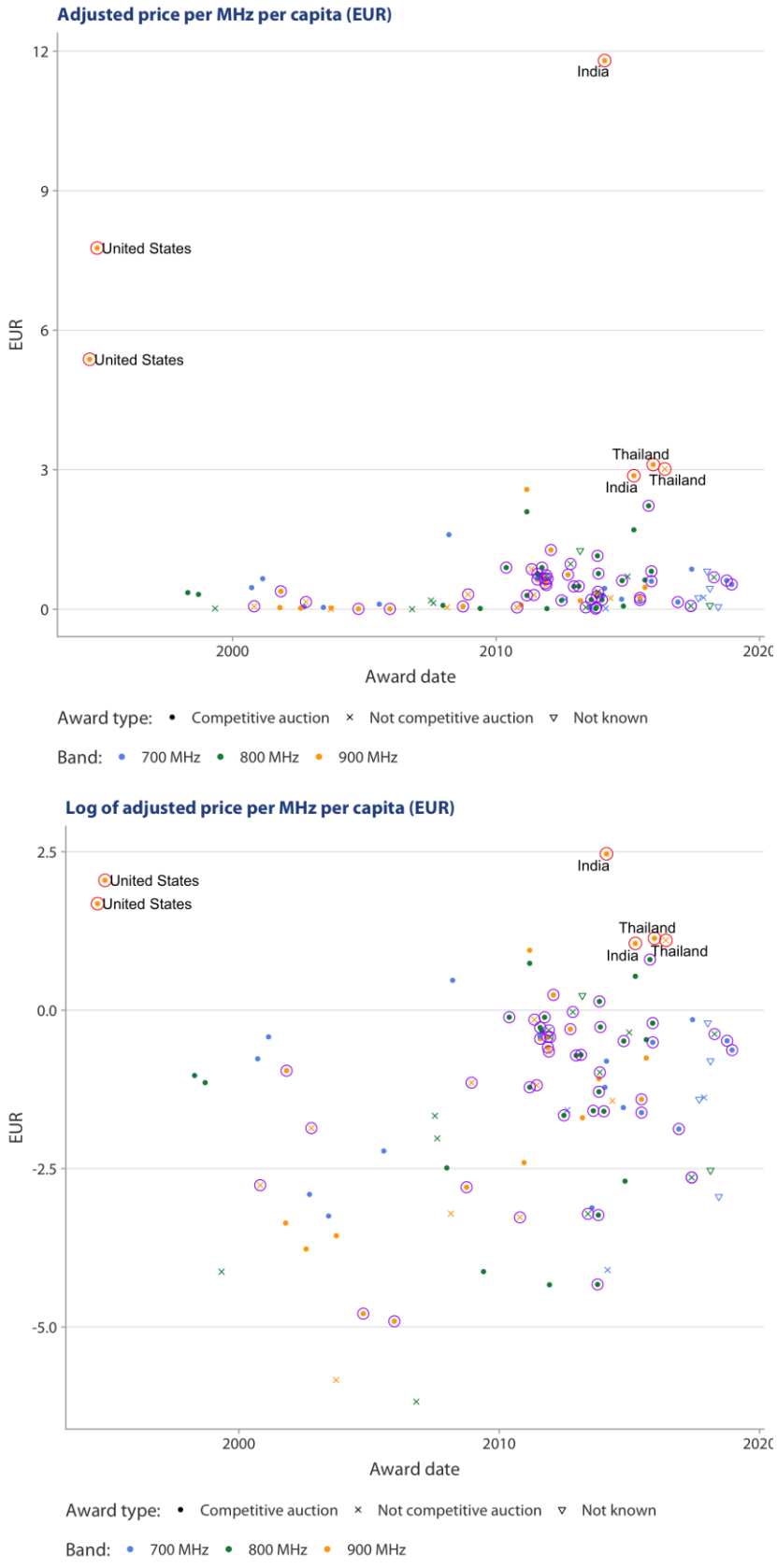


Table 2 reports summary statistics of the adjusted price (Euro per MHz per capita) for this extended sample.

Table 2: Summary statistics for 700 MHz, 800 MHz and 900 MHz observations

Sub-sample	Num. obs.	Arithmetic mean	Std. dev.	Geometric mean	First quartile	Median	Third quartile
All	94	0.455	0.500	0.210	0.071	0.301	0.656
Competitive	62	0.520	0.558	0.251	0.095	0.371	0.661
Competitive last 10 years	48	0.618	0.590	0.352	0.202	0.514	0.762
Competitive last 10 years European	29	0.572	0.456	0.385	0.204	0.557	0.760

Both the arithmetic and geometric mean are greater when using pooled data, for all the subsamples, though the impact on the geometric mean is modest. However, the distribution of observations in the charts do not suggest that prices for 800 MHz and 900 MHz licences are systematically higher, and this is reinforced by the results from the non-parametric tests that reject that prices for 700 MHz licences are from a different distribution to those from 800 MHz or 900 MHz licences. Moreover, the geometric mean for the pooled sample is relatively close to that for the 700 MHz only sample.

Given that we have a relatively large subsample for licences awarded in competitive auctions in the last ten years in Europe, we focus on this group.

On the basis of the observations available on the price of licences with value comparable to that of 700 MHz spectrum, we expect the price per MHz per capita for 700 MHz licences sold in a competitive European award to be typically around (or marginally above) €0.38, though it could be materially higher on average due to some high value outcomes, with an expected mean value of around €0.57.

2.5 The 2.1 GHz band

We have 82 observations from licences of 2.1 GHz spectrum, which are listed in Annex A. We have identified five outliers.[11] The observations are plotted in Figure 3, using the same legend as in earlier figures. In addition, we have circled in green the observations corresponding to the Irish awards of 2.1 GHz licences.

[11] The prices obtained in some of the early 3G awards (UK, Germany, France and Italy) and in a 3G licence upgrade process that took place in Egypt in 2007.

Figure 3: Observations from 2.1 GHz licences

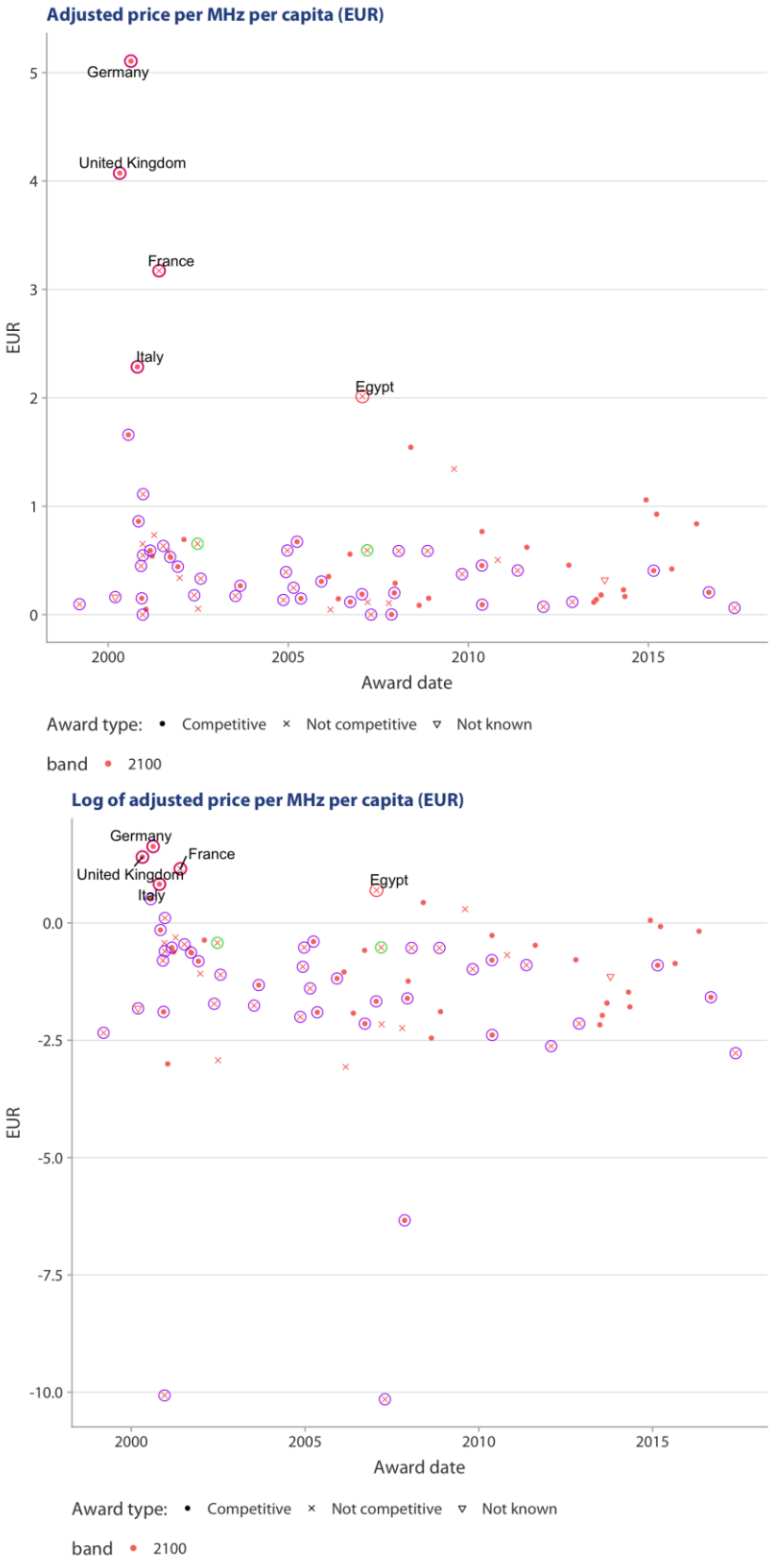


Table 3 reports summary statistics of the adjusted price (Euro per MHz per capita) for the full sample and each of the subsamples considered.

Table 3: Summary statistics for 2.1 GHz observations

Sub-sample	Num. obs.	Arithmetic mean	Std. dev.	Geometric mean	First quartile	Median	Third quartile
All	77	0.411	0.345	0.228	0.149	0.339	0.587
Competitive	37	0.467	0.386	0.303	0.181	0.406	0.621
Competitive last 10 years	17	0.484	0.418	0.333	0.151	0.406	0.766
Competitive last 10 years European	3	0.234	0.159	0.197	0.149	0.205	0.306

With only three observations, we cannot draw reliable conclusions on the basis of the sub-sample that includes only competitive auctions in the last decade in Europe, as this band was already awarded in most jurisdictions during this period. Therefore, it may be preferable to consider a wider group of observations. Amongst the other groups, we favour those that include only competitive awards, where the price is set with reference to the demand expressed by bidders rather than administratively by the agency assigning the licences. Within these, there is little difference, suggesting that the major distortions arising from the dot-com bubble at the start of the millennium are already addressed through the identification of outliers.

On the basis of the observations available, we expect the price per MHz per capita for 2.1 GHz licences sold in a competitive award to be typically around €0.33, though it could be materially higher, with an expected average value of around €0.48. However, there have been very few competitive auctions in Europe in the last decade in which 2.1 GHz licences have been awarded, and in these 2.1 GHz licences have sold on average at a lower price slightly above €0.20 per MHz per capita.

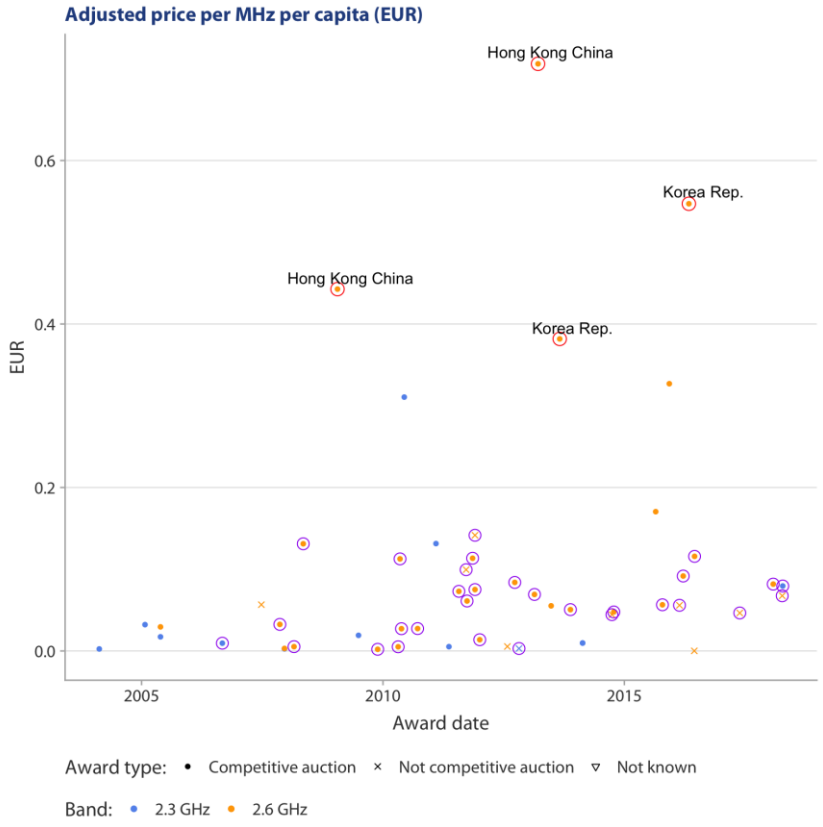
2.6 The 2.3 GHz and 2.6 GHz bands

We have only thirteen observations from licences of 2.3 GHz spectrum, the majority of which are relatively old (only 5 occurred within the last 10 years). However, the 2.3 GHz band should have

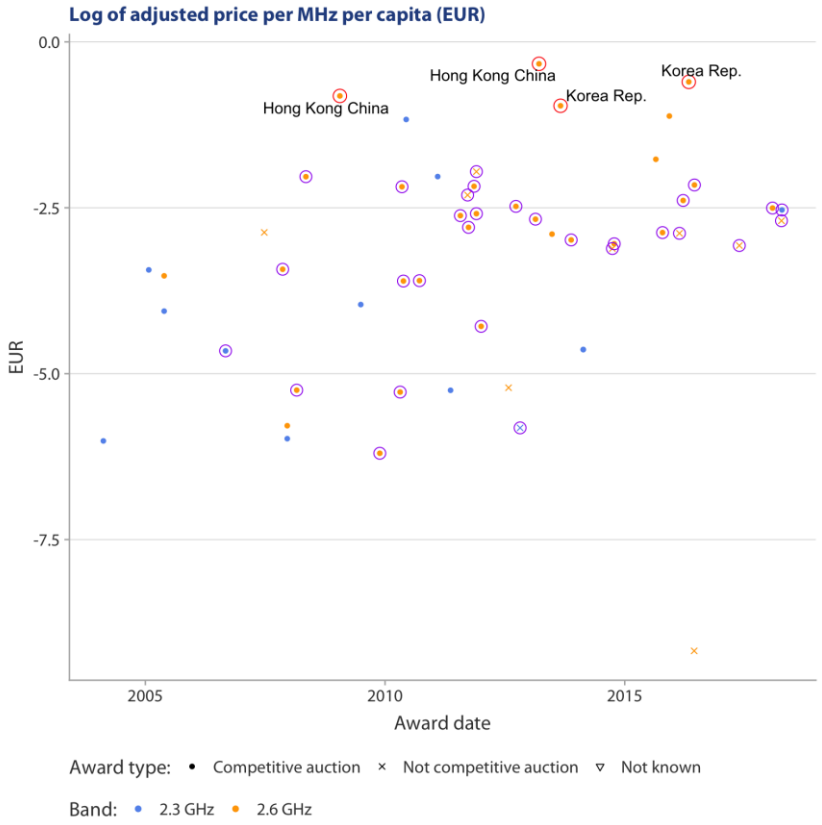
similar characteristics and usage possibilities as the 2.6 GHz band in the very near future and we expect the two bands to be substitutable and of similar value. Therefore we have pooled the observations across the two bands to derive a single price estimate for spectrum in these bands.

For the 2.6 GHz band we have 39 observations, so pooling the data across the two bands gives 52 observations across 49 awards, listed in Annex A. We have identified four outliers.[12] The pooled observations are plotted in Figure 4, using the same legend as in the previous figure, distinguishing by the colour of the marker whether the observation is for the price of 2.3 GHz licences (in blue) or 2.6 GHz licences (in orange).

Figure 4: Observations from 2.3 GHz and 2.6 GHz licences



[12] The prices obtained for 2.6 GHz spectrum in two Hong Kong auctions (the BWA auction in 2009, and the 4G auction in 2013) and in two South Korean auctions (the 1800 MHz & 2.6 GHz auction in 2013, and the multiband auction in 2016). The observations previously identified as outliers when considering only 2.3 GHz licences are not identified as outliers in this wider sample.



Non-parametric tests for structural differences between our 2.3 GHz and 2.6 GHz observations suggest that we cannot rule out that there are structural differences between the two sub-samples.[13] However, this might be due to the fact that most of the few observations we have for 2.3 GHz licences are relatively old, so that licences would have been awarded before there was a clear expectation that the band might be used for IMT, whilst many of the observations for 2.6 GHz licences are from a time where the band had been clearly designated for IMT, and achieved higher prices. In this regard, we note that 2.3 GHz prices appear to have been higher in more recent awards, and that the price achieved in the recent UK award (€0.079) is significantly higher than the arithmetic mean for the whole 2.3 GHz sample (€0.017)). Therefore, structural differences between the two samples might not reflect a difference in value across the bands, but rather the higher value of spectrum in these bands once they have been designated and can be used for IMT. Given this, we consider that the price of 2.3 GHz is likely to be closer to the price

[13] We have run Wilcoxon rank sum tests to check the probability that the observations are from the same distribution or not, and the probability that our 2.3 GHz observations have been drawn from the same distribution as our 2.6 GHz observations is 0.02.

estimate we obtain when using the pooled sample than the price estimate we would obtain when using only older 2.3 GHz band observations.

Table 4 reports summary statistics of the adjusted price (Euro per MHz per capita) for this extended sample.

Table 4: Summary statistics for 2.3 GHz and 2.6 GHz observations

Sub-sample	Num. obs.	Arithmetic mean	Std. dev.	Geometric mean	First quartile	Median	Third quartile
All	48	0.063	0.069	0.029	0.010	0.049	0.082
Competitive	38	0.066	0.075	0.032	0.011	0.049	0.083
Competitive last 10 years	30	0.079	0.079	0.044	0.021	0.065	0.107
Competitive last 10 years European	21	0.063	0.039	0.043	0.027	0.069	0.084

Bothe the arithmetic and geometric means appear to have increased within the last ten years, whilst narrowing the sample to European-only awards has a notable effect on the arithmetic mean but almost negligible on the geometric mean. Given that we have a reasonable number of observations for licences awarded in competitive auctions in the last ten years in Europe, we focus on this group.

On the basis of the observations available, we expect the price per MHz per capita for 2.3 GHz/2.6 GHz licences sold in a competitive award to be typically around €0.04, though it could be materially higher, with an expected average value of around €0.06.

3 Proposed minimum prices

Minimum price for 700 MHz

On the basis of our analysis of observations on the price of 700 MHz licences, we expect that the price of licences would usually be about €0.38-0.39 per MHz per capita. These are fully aligned with the minimum prices set by ComReg for the 800 MHz and 900 MHz bands in 2012 (which were estimated to be approximately €0.38 per MHz per capita), and in the event the final prices of licences assigned in the 2012 MBSA appeared to be materially above minimum prices. In line with these observations, **we propose setting a minimum price of €0.38 per MHz per capita for the available 700 MHz frequencies**.

Minimum price for 2.1 GHz should be different to that for 2.3/2.6 GHz

We believe that the 2.1 GHz, 2.3 GHz and 2.6 GHz bands are likely to be substitutes for this award, given their similar propagation characteristics and the existing device ecosystem for each of the bands. On this basis there is an argument for setting a common minimum price across each of the three bands. In particular, in the long run, we would expect these bands to be of similar value due to their similar propagation characteristics.

However, there is a material difference in the observations of prices for 2.1 GHz licences compared with the other two bands. This is likely to reflect the different historic patterns of use of these bands and that the 2.1 GHz was the initial band for deployment of 3G.

For the 2.1 GHz band, prices appear to typically be around €0.33 per MHz per capita, or slightly lower, at around €0.20 per MHz per capita if we focus only on the very few competitive auctions that have taken place in Europe in the last decade. Conversely, the prices for 2.3 GHz and 2.6 GHz licences appear to be typically around €0.04 per MHz per capita.

Therefore, we recommend setting a different minimum price for the 2.1 GHz band relative to the 2.3 and 2.6 GHz bands. In part, this also reflects the greater uncertainty of the estimates of the market price of the 2.3 and 2.6 GHz bands, However, we consider that it would be appropriate to set the same minimum price for spectrum in the 2.3 GHz and 2.6 GHz bands. Specifically:

- **For the 2.1 GHz band we propose a minimum price of €0.20 per MHz per capita**, which is close to the minimum price used in the 2012 MBSA for 1800 MHz licences (€0.19 per MHz per capita).
- For the 2.3 GHz and 2.6 GHz bands, we propose **a minimum price of approximately €0.04 per MHz per capita**, which is also aligned with the prices achieved in Ireland in 2017 for the 3.6 GHz band (approximately €0.05 per MHz per capita).

These minimum prices are likely to be rather conservative, but they reflect the uncertainty around market values for these bands and the limited available data.

Minimum prices per lot

In table 5 below we set out our current proposals for the minimum prices per lot in each band for each time slice (accounting for differences in start dates and licence duration), including a break-down of these into a minimum spectrum access fee (SAF) and annual

spectrum usage fees (SUFs) per lot.[14] These are based on the provisional lot structure set out in our award design report[15] and a 40:60 split of the minimum fee between the SAF and the total discounted SUFs. The fees for the 2300 – 2330 MHz frequency-specific lot are also adjusted to take account of the reduced geographic coverage that would apply due to Rurtel's regional licences within the band (based on the current extent of the Rurtel network and the required coordination zones).[16]

[14] The fees for each time slice are calculated on the basis that SUF payments would be due in July each year (in line with the proposed start date for 700 MHz, 2.3 GHz and 2.6 GHz licences), and that where a licence does not run for the full part of the year, only a proportion of the SUF for that year would be charged

[15] ComReg Document 19/59a

[16] Plum Consulting estimates that the existing Rurtel network would reduce the population that could be served by the new rights of use by 1,277,000.

Table 5: Proposed minimum prices

Band	Time slice	Licence term	Lot size	Min. price for 15-year licence (€/MHz/Pop.)	Reserve price per lot (€)	Annual SUF per lot (€)
700 MHz	N/A	01 Jul 2020 – 30 Jun 2035	2x5 MHz	0.38	7,540,720	1,168,778
2.1 GHz	1	16 Oct 2022 – 11 Mar 2027	2x5 MHz	0.20	1,376,873	615,147
2.1 GHz	2	12 Mar 2027 – 30 Jun 2035	2x5 MHz	0.20	1,694,275	615,147
2.3 GHz (2300 – 2330 MHz)	1	01 Jul 2020 – 11 Mar 2027	30 MHz	0.04	1,013,427	274,082
2.3 GHz (2300 – 2330 MHz)	2	12 Mar 2027 – 30 Jun 2035	30 MHz	0.04	754,893	274,082
2.3 GHz (2330 – 2390 MHz)	1	01 Jul 2020 – 11 Mar 2027	5 MHz	0.04	227,453	61,515
2.3 GHz (2330 – 2390 MHz)	2	12 Mar 2027 – 30 Jun 2035	5 MHz	0.04	169,428	61,515
2.3 GHz (2390 – 2400 MHz)	1	01 Jul 2020 – 11 Mar 2027	10 MHz	0.04	454,905	123,029
2.3 GHz (2390 – 2400 MHz)	2	12 Mar 2027 – 30 Jun 2035	10 MHz	0.04	338,855	123,029
2.6 GHz Paired	1	01 Jul 2020 – 11 Mar 2027	2x5 MHz	0.04	454,905	123,029
2.6 GHz Paired	2	12 Mar 2027 – 30 Jun 2035	2x5 MHz	0.04	338,855	123,029
2.6 GHz Unpaired	1	01 Jul 2020 – 11 Mar 2027	5 MHz	0.04	227,453	61,515
2.6 GHz Unpaired	2	12 Mar 2027 – 30 Jun 2035	5 MHz	0.04	169,428	61,515

Annex A: Observations included in our analysis

This Annex provides the list of observations included in each of the samples used for our analysis.

700 MHz

Table 6: 700 MHz awards

Country	Award	Year
United States	Auction 33 - Upper 700 MHz Guard Bands	2000
United States	Auction 38 - Upper Guard Bands	2001
United States	Auction 44 - Lower 700 MHz Band	2002
United States	Auction 49 - Lower 700 MHz Band	2003
United States	Auction 60 - Lower 700 MHz Band Auction	2005
United States	Auction 73- 700MHz	2008
United States	USA Auction 92 - 700 MHz band	2011
Bahamas	Bahamas 4G	2012
Fiji	Fiji multiband	2013
New Zealand	New Zealand 700MHz	2014
Canada	Canada 700MHz	2014
Chile	Chile 700MHz	2014
Brazil	Brazil 700MHz	2014
Germany	Germany 700MHz, 900MHz, 1500MHz and 1800MHz	2015
France	France 700MHz	2015
Finland	Finland 700 MHz	2016
Iceland	Iceland Multi-band Award	2017
Saudi Arabia	Saudi Arabia 700 MHz and 1800 MHz auction	2017
Uruguay	700 MHz & 1700/2100 MHz auction	2017
Panama	700 MHz auction	2017
Paraguay	700 MHz auction	2018
Saudi Arabia	Saudi 700 MHz, 800 MHz and 1800 MHz auction	2018
Tanzania	700 MHz auction	2018
Sweden	700 MHz auction	2018
Italy	5G Auction	2018

800 MHz

Table 7: 800 MHz awards

Country	Award	Year
Australia	PCS 800MHz-1800MHz auction	1998
Australia	PCS 800MHz-1800MHz 2nd auction	1998
Australia	PCS 3rd auction 800MHz	1999
Macao China	3G	2006
Nigeria	Nigeria 800MHz Spectrum Auction	2007
Hong Kong China	Hong Kong CDMA	2007
Brazil	2G Licences	2007
Canada	Auction of spectrum for air-ground services	2009
Germany	Auction of spectrum in the 800MHz, 1800MHz, 2.1GHz and 2.6GHz bands	2010
Hong Kong China	850MHz, 900MHz and 2GHz bands auction	2011
Sweden	800MHz	2011
Spain	Spain 800MHz, 900MHz and 2.6GHz bands	2011

Korea Rep.	Korean 800MHz,1800MHz & 2.1GHz	2011
Italy	Italian 4G Auction	2011
Portugal	Portuguese 4G Multiband Auction	2011
Brazil	Brazil leftover 800 MHz,1800MHz	2011
France	French 4G auction (800MHz)	2011
Denmark	800MHz auction	2012
Croatia	Croatia 800MHz auction	2012
Netherlands	Dutch Multiband	2012
United Kingdom	UK 4G Auction	2013
India	India 800MHz	2013
Estonia	Estonia 800MHz - first block	2013
Estonia	Estonia 800MHz - second block	2013
Lithuania	Lithuanian 800MHz auction	2013
Latvia	Latvia 800MHz auction	2013
Finland	Finland 800MHz	2013
Croatia	Croatia remaining 800MHz auction	2013
Belgium	Belgian 800MHz auction	2013
Czech Republic	Czech 4G Auction 800MHz 1800MHz and 2.6GHz	2013
Estonia	Estonia 800MHz - third block	2014
Greece	Greece 800MHz and 2.6GHz	2014
Argentina	Argentina 3G,4G	2014
Georgia	Georgia 800MHz	2014
India	India 800MHz, 900MHz, 1800MHz and 2100MHz	2015
Turkey	Turkey 4.5G (4G) Auction	2015
Poland	Poland 800MHz and 2.6GHz	2015
Serbia	Serbia 800MHz	2015
Iceland	Iceland Multi-band Award	2017
Saudi Arabia	Saudi 700 MHz, 800 MHz and 1800 MHz auction	2018
Malta	Malta 800 and 2600 MHz	2018

900 MHz

Table 8: 900 MHz awards

Country	Award	Year
United States	Auction 1 - Nationwide Narrowband (PCS)	1994
United States	Auction 3 - Regional Narrowband (PCS)	1994
Switzerland	Additional GSM 900MHz frequencies	2000
United States	Auction 41 Narrowband PCS	2001
Norway	E-GSM Auction	2001
New Zealand	Auction 5 WLL and LMP and Cellular	2002
Austria	GSM 2002 Auction	2002
United States	Auction 51 Regional Narrowband PCS	2003
United States	Auction 50 Narrowband PCS	2003
Austria	GSM 2004 Auction	2004
Ireland	WDM Auction	2005
Singapore	Public Cellular Mobile Telecommunications Services Auction	2008
Austria	900 MHz Auction	2008
Poland	E-GSM	2008
Denmark	900MHz	2010
Brazil	Brazil 1900/2100MHz and leftover 800MHz, 900MHz, 1800MHz	2010
Hong Kong China	850MHz, 900MHz and 2GHz bands auction	2011
Malta	Malta 900MHz and 1800MHz	2011
Spain	Spain beauty contest	2011
Spain	Spain 800MHz, 900MHz and 2.6GHz bands	2011

Spain	Spanish 4G second auction	2011
Greece	Greek 900 and 1800	2011
Portugal	Portuguese 4G Multiband Auction	2011
Hungary	Hungarian 900MHz Auction	2012
Romania	Romania 4G 800 MHz, 900 MHz, 1800 MHz and 2600 MHz band auction	2012
Uruguay	Uruguay 900MHz, 1900MHz, AWS	2013
Taiwan	Taiwan multiband auction	2013
India	India 900MHz & 1800MHz	2014
Dominican Republic	Dominican Republic 900 and 2100MHz	2014
India	India 800MHz, 900MHz, 1800MHz and 2100MHz	2015
Germany	Germany 700MHz, 900MHz, 1500MHz and 1800MHz	2015
Turkey	Turkey 4.5G (4G) Auction	2015
Thailand	Thai 900MHz auction	2015
Thailand	Thai 900MHz re-auction	2016

2.1 GHz

Table 9: 2.1 GHz awards

Country	Award	Year
Finland	3G	1999
Spain	3G	2000
United Kingdom	3G Auction	2000
Netherlands	3G Auction	2000
Germany	3G Auction	2000
Italy	3G Auction	2000
Austria	3G Auction	2000
Norway	3G	2000
Switzerland	3G Auction	2000
Korea Rep.	3G	2000
Sweden	3G	2000
Portugal	3G	2000
Poland	3G	2000
New Zealand	Auction 3: 1710 - 2300 MHz	2001
Belgium	3G Auction	2001
Australia	3G Auction	2001
Singapore	3G Auction	2001
France	3G	2001
Greece	3G Auction	2001
Korea Rep.	Second 3G award	2001
Denmark	3G Auction	2001
Hong Kong China	3G Auction	2001
Czech Republic	3G Auction	2001
Israel	2G/3G Auction	2001
Taiwan	3G Auction	2002
Luxembourg	3G Award	2002
Ireland	3G	2002
Malaysia	3G	2002
France	3G 2nd Award	2002
Luxembourg	3G Award 2	2003
Norway	3G Auction 2	2003
Romania	3G	2004
Hungary	GSM and 3G	2004
Croatia	2G and 3G	2004

Czech Republic	3G Auction 2	2005
Bulgaria	3G Auction	2005
Poland	3G	2005
Denmark	3G Auction 2	2005
Indonesia	3G auction	2006
Malaysia	Malaysia 3G round 2	2006
Georgia	3G Auction	2006
United States	Auction 66 - Advanced Wireless Services	2006
Slovenia	3G tender 2	2006
Estonia	3G Tender	2007
Egypt	3G licence upgrade	2007
Ireland	2nd 3G	2007
Nigeria	3G Auction	2007
Russian Federation	3G	2007
Kenya	Kenya 3G licence	2007
Norway	2.6 GHz	2007
Norway	3G 4th licence	2007
Brazil	3G	2007
Macedonia FYR	3G	2008
Canada	AWS auction	2008
United States	Auction 78 - AWS1	2008
Macedonia FYR	3G 2	2008
Turkey	3G	2008
Jordan	First 3G licence	2009
France	Fourth 3G licence	2009
France	Remaining mobile 3G France	2010
India	3G auction	2010
Germany	Auction of spectrum in the 800 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz bands	2010
Singapore	3G Spectrum Rights	2010
Belgium	3G Auction	2011
Korea Rep.	Korean 800 MHz,1800 MHz & 2.1 GHz	2011
Hungary	Fixed price spectrum for entrant in Hungarian 9000 MHz auction	2012
Thailand	Thailand 3G	2012
Norway	2 GHz auction	2012
Colombia	Columbia 4G	2013
Peru	Peru AWS	2013
Bangladesh	Bangladesh 3G auction	2013
Bangladesh	Bangladesh admin award at 3G auction price	2013
Algeria	Algeria 3G	2013
Pakistan	Pakistan 3G&4G	2014
Dominican Republic	Dominican Republic 900 and 2100 MHz	2014
Hong Kong China	Hong Kong 2.1 GHz	2014
Ukraine	Ukraine 2100 MHz	2015
India	India 800 MHz, 900 MHz, 1800 MHz and 2100 MHz	2015
Turkey	Turkey 4.5G (4G) Auction	2015
Korea Rep.	Korean multi-band	2016
Iceland	Icelandic Multi-band	2017

2.3 GHz

Table 10: 2.3 GHz awards

Country	Award	Year

Canada	2300 & 3500 MHz Auction	2004
Canada	Residual 2300 & 3500 MHz Auction	2005
Singapore	Wireless Broadband Auction	2005
Norway	2.3 GHz Auction	2006
New Zealand	2.3 and 2.5 GHz auction	2007
Canada	Residual Spectrum Licences in the 2300 MHz and 3500 MHz bands	2009
India	BWA Auction	2010
Hong Kong China	2.3 GHz Auction	2011
Australia	Australia residual 2.3 GHz auction	2011
Latvia	Latvia 2.3 GHz	2012
Nigeria	Nigeria 2.3 GHz	2014
Nigeria	Nigeria 2.3 GHz	2014
United Kingdom	2.3 and 3.4 GHz award	2018

2.6 GHz

Table 11: 2.6 GHz awards

Country	Award	Year
Singapore	Wireless Broadband Auction	2005
Taiwan	Wimax auction	2007
Norway	2.6 GHz	2007
New Zealand	2.3 and 2.5 GHz auction	2007
Norway	Residual 2.6GHz	2008
Sweden	2.6GHz	2008
Hong Kong China	BWA Auction	2009
Finland	2.6GHz	2009
Netherlands	2.6 GHz band	2010
Denmark	2.5GHz auction	2010
Germany	Auction of spectrum in the 800MHz, 1800MHz, 2.1GHz and 2.6GHz bands	2010
Austria	2.6GHz auction	2010
Spain	Spain 800MHz, 900MHz and 2.6GHz bands	2011
France	French 4G auction (2.6 GHz)	2011
Italy	Italian 4G Auction	2011
Spain	Spanish 4G second auction	2011
Portugal	Portuguese 4G Multiband Auction	2011
Belgium	Belgian 4G Auction	2011
Latvia	Latvia 2.6GHZ	2012
Chile	Chile 4G	2012
Romania	Romania 4G 800 MHz, 900 MHz, 1800 MHz and 2600 MHz band auction	2012
United Kingdom	UK 4G Auction	2013
Hong Kong China	Hong Kong 4G	2013
Colombia	Columbia 4G	2013
Korea Rep.	Korea 1800MHz & 2.6GHz	2013
Czech Republic	Czech 4G Auction 800MHz 1800MHz and 2.6GHz	2013
Hungary	Hungary 800, 900, 1800MHz, 2.6 and 26GHz	2014
Greece	Greece 800MHz and 2.6GHz	2014
Turkey	Turkey 4.5G (4G) Auction	2015
Poland	Poland 800MHz and 2.6GHz	2015
Taiwan	Taiwan 2.6GHz	2015

Russian Federation	Russia 2.6GHz	2016
Spain	Spain 2.6 GHz and 3.5 GHz	2016
Korea Rep.	Korean multi-band	2016
Nigeria	Nigeria 2.6GHz	2016
Czech Republic	Czech remaining 1800MHz and 2.6GHz	2016
Iceland	Iceland Multi-band Award	2017
Ukraine	Ukraine 2600 MHz	2018
Malta	Malta 800 and 2600 MHz	2018