Research into linkages between the 700MHz, 1452-1492MHz and 2100MHz bands

Final report for Ministry of Economic Affairs

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1 Executive summary

This report has been prepared by Aetha Consulting Limited (Aetha) for the Directorate General for Energy, Telecommunications and Competition of the Ministry of Economic Affairs (the Ministry) as a summary of Aetha's research on linkages between the 700MHz, 1452-1492MHz and 2100MHz bands, with regard to plans to award spectrum in these bands.

1.1 Background and study objectives

The Ministry is in the process of developing its plans for the award of spectrum in the 700MHz, 1452-1492MHz and 2100MHz bands and wishes to understand the optimum timing and conditions for the award of the spectrum:

- The 700MHz band comprises frequencies in the range from 694MHz to 790MHz and is currently utilised for digital terrestrial television but, in line with European Union proposals[1] and an Implementing Decision of the European Commission[2], this spectrum will be available in the Netherlands for other uses from 1 January 2020. The spectrum comprises a 'core' 2×30MHz band (703-733/758-788MHz) for which technical usage conditions suited for mobile broadband services are being harmonised across Europe and additional non-core spectrum which includes the 'duplex gap' (733-758MHz) between the paired spectrum blocks and spectrum at the bottom end of the band (694-703MHz). A variety of uses are being considered for this non-core spectrum.

- The 1452-1492MHz band (also commonly referred to as 'L-Band') is potentially available for assignment in the Netherlands immediately. This band has been harmonised by the European Commission[3] for use as a supplemental downlink band. Here the intention is the band would be combined with a paired frequency band which results in additional capacity being available for the downlink in line with the asymmetric nature of mobile data traffic (downlink data traffic is several multiples of uplink traffic as a consequence of the take-up of audio visual streaming and download services).

- The 2100MHz band refers to the paired frequencies between 1920 – 1980 MHz and 2110 – 2170 MHz that are currently assigned for electronic communications services in the Netherlands. These existing spectrum rights are due to expire at the end of 2020, so an assignment process will be undertaken for the new rights commencing from 1 January 2021. The spectrum is currently used by the mobile

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1 European Commission, 'Interinstitutional File: 2016/0027 (COD)', Council of the European Union, 13 May 2016, submitted in response to 'Proposal for a Decision of the European Parliament and of the Council on the use of the 470-790MHz frequency band in the Union', 2 February 2016.

2 European Commission, 'Commission Implementing Decision (EU) 2016/687 of 28 April 2016 on the harmonisation of the 694-790 MHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services and for flexible national use in the Union', published in the Official Journal of the European Union, 4 May 2016.

3 European Commission, 'Commission Implementing Decision (EU) 2015/750 of 8 May 2015 on the harmonisation of the 1 452-1 492 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Union (notified under document C(2015) 3061)', published in the Official Journal of the European Union, 8 May 2015.

operators primarily for the deployment of 3G networks but has started to be re-farmed for use for 4G (LTE).

The Ministry has previously announced that it plans to auction spectrum in the 700MHz and 2100MHz bands in 2019 and also that it plans to auction spectrum in the 1452-1492MHz band.

The primary objective of this project is to assess the strengths of linkages between the three bands in order to ascertain whether the spectrum should be awarded through one combined auction or two (or more) separate auction processes. This also includes consideration of the timing over which each of the three spectrum bands will start to be used/become available in order to identify the optimum timing of the award(s).

To undertake this assessment, we have undertaken background research on several underlying technological and economic questions and have also held telephone discussions with several industry stakeholders to discuss their own perspectives on the demand for spectrum in each band and strength of linkages between the bands.

1.2 Demand for the spectrum

1.2.1 Mobile communications services

We spoke to stakeholders comprising existing mobile operators, potential new mobile market entrants and equipment manufacturers. Unsurprisingly, all stakeholders highlighted the need for additional spectrum to be made available to support the growth in mobile data traffic levels. In relation to interest in each of the specific frequency bands under study:

- **700MHz**: The underlying propagation benefits of this band were repeatedly highlighted by stakeholders in view of providing indoor coverage and wide area coverage across less populated areas, It was noted that there is a shortage in the amount of low frequency (sub 1GHz) spectrum currently available and the fact that this is not evenly distributed across the operators. The expectation was that, given the timing of availability, this band is likely to be used for 5G technology though it is also largely universally noted that 5G in bands below 3GHz is most likely to be an evolution of the 4G (LTE) technology rather than a completely new radio interface. Interest in spectrum outside the core 2×30MHz paired part of the band was limited – several stakeholders mentioned that there may be challenges in making use of the 'duplex gap' for mobile broadband services (for example to support supplementary downlinks) but in the event that these issues could be resolved then interest in this spectrum may rise for such use.

- **1452-1492MHz**: The degree of interest in this band was varied, primarily in view of concerns regarding the availability of handsets supporting this band. At the time of undertaking our research, no handsets compatible with this band had been released. Stakeholders expressed a wide variety of views of when the band could start to be used effectively in view of the time required for supporting user devices to become widely available – this ranged from 2018 to beyond 2020. We expected that interest in the band and forecast timing of usefulness of the spectrum might differ between those organisations that hold 800MHz spectrum assignments and those that do not since the 800MHz/1452-1492MHz band combination was expected to be the first that is implemented in handsets – in fact, however, we found quite a range of views amongst the three operators holding 800MHz spectrum.

- **2100MHz**: The three operators with existing assignments in this band all stressed that the spectrum is an important component of their overall network operations today – primarily for 3G but increasingly

for 4G. The operators also stressed the need for the band to be re-configured at the time of re-assignment in order to ensure that each operator winning spectrum has spectrum in a single contiguous block.

Possible new market entrants were potentially interested in spectrum across all three bands – but with the expectation that prices for the core 2×30MHz in the 700MHz would be high, interest was greatest in the 2100MHz band and potentially the other parts of the 700MHz band (including the 'duplex gap'), especially if the usage conditions could be made to be compatible with TDD use of the spectrum. One organisation expressed general interest in the use of TDD in all bands if this could be accommodated in the usage conditions.

We reviewed current plans for the development of 3GPP standards for the combinations of different bands for carrier aggregation in user devices. We noted the combinations of bands for which specifications had already been developed and those bands for which specifications were under development. Unfortunately device manufacturers are not willing to provide specific details of their roadmaps for supporting individual bands/band combinations - the development of specifications by 3GPP is by no means a guarantee that the functionality will appear in user devices or of the timing that such functionality will become available in devices. It is purely an indicator of current interest.

The main issue arising from our review of carrier aggregation combinations is that of carrier aggregation with the 1452-1492MHz band. Development work to-date has focused on the combination of the 800MHz and 1452-1492MHz bands and, shortly before the finalisation of this report, Google announced the launch of, and released the technical specifications for, the Google Pixel handset[4], the first handset which supports the 1452-1492MHz band – in combination with the 800MHz band. Further standardisation work is ongoing by 3GPP for combinations of the 1452-1492MHz and 800MHz band with other bands (specifically 1800MHz and 2600MHz). Consequently we believe it is likely that user devices supporting these three band combinations will become available before user devices supporting two band combinations involving the 1452-1492MHz band with bands other than the 800MHz band (for example the 700MHz and 900MHz, 1800MHz and 2600MHz bands). This would mean that organisations holding 800MHz spectrum are in a stronger position in the short-term in respect of their ability to utilise the 1452-1492MHz band, compared to organisations not holding 800MHz spectrum.

One further technical linkage issue that we identified between the 700MHz and 1452-1492MHz bands was that of a risk of interference in user devices in the case where both bands are simultaneously used. The second harmonic of the 700MHz uplink band (1406-1466MHz) overlaps with the 1452-1492MHz band which is used for downlinks which means that the second harmonic of the 700MHz signal produced in the power amplifier of a handset could cause interference to reception of signals in the 1452-1492MHz range. This issue needs further investigation. One potential solution is to ensure that the assignments held by an individual operator in both the 700MHz and 1452-1492MHz bands are in parts of each of the bands which are compatible with one another.

As part of our assessment of interest in the three spectrum bands for use for mobile broadband services, we developed a high-level model to predict the future demand for spectrum for mobile communications services under two alternative traffic scenarios. We found that under our low traffic scenario, the amount of available spectrum (once the 700MHz band and 1452-1492MHz band are included) would be sufficient for forecast modelled traffic until 2025. Under our high traffic scenario, around an additional 140MHz of

[4] See https://madeby.google.com/intl/en_uk/phone/specs/

spectrum will need to be made available to support downlink traffic by 2025 – the additional demand over and above the 700MHz and the 1452-1492MHz bands arises from 2024 onwards.

1.2.2 Internet of Things/Machine to Machine communications (IoT/M2M)

Of the three bands under study, the 700MHz band is primarily of interest to stakeholders interested in deploying low power wireless access networks. Up to now such networks have been deployed using proprietary technologies such as Sigfox and LoRa in licence-exempt spectrum (in particular the 868MHz band). Under 3GPP Release 13, the mobile industry has now standardised several technologies including Narrowband IoT (NB-IoT) which utilise a mobile operator's existing licensed spectrum assets to provide a specialised solution for IoT devices.

Our discussions with mobile operators indicated that several are actively considering the deployment of NB-IoT. This is likely to be in the 800MHz and 900MHz band initially and with the expectation that 5G will incorporate IoT functionality, the 700MHz band is also likely to be used for wide area coverage IoT applications from 2020 onwards. Other organisations were also interested in possible use of the 700MHz band for IoT applications – potentially utilising technologies that currently operate in licence-exempt spectrum bands. This interest was mainly in spectrum outside the core 2×30MHz band. One challenge raised was that M2M applications currently envisaged in the European Commission's Implementing Decision[20] are expected to make use of the 733-736/788-791MHz range – however this does not currently facilitate use by TDD technologies which were of interest to some stakeholders. It is also possible that other parts of the 'duplex gap' spectrum could be used for IoT TDD technologies but this may need legal clarification in respect of compliance with the Implementing Decision as it is currently written. Furthermore, compatibility studies would need to be undertaken.

1.2.3 Public Protection and Disaster Relief (PPDR)

Our discussions indicated that the government will be considering a range of options for providing broadband communications services to emergency service users including:

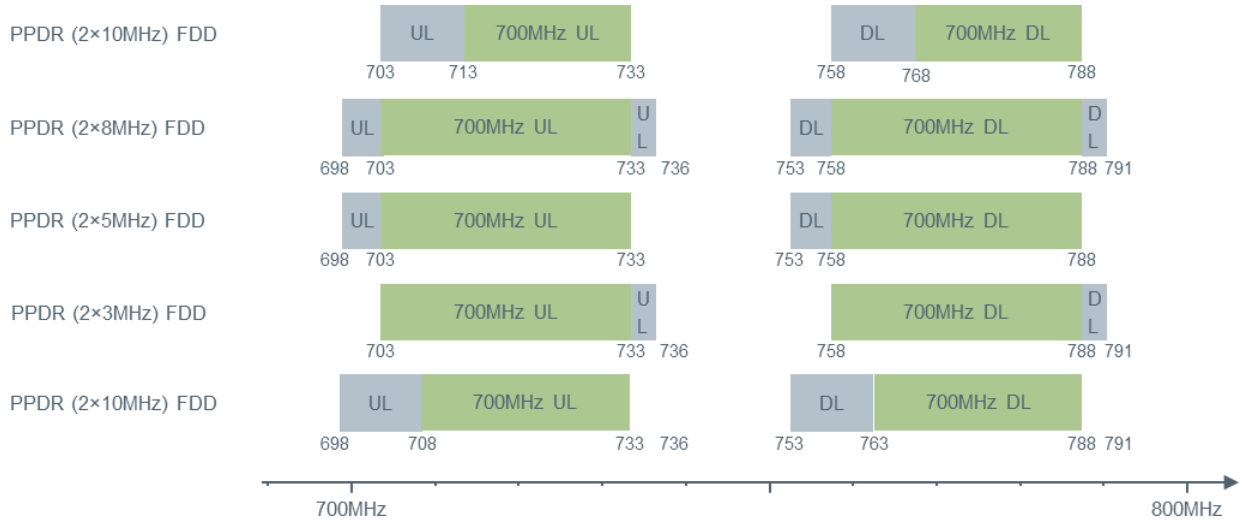
- Purchase of network capacity from one or more commercial mobile operators. This is the approach that has been adopted in the UK with EE being awarded a contract by the UK Government.
- Deployment of a dedicated mobile broadband network using dedicated spectrum. We understand that Germany is considering deploying such a dedicated network on a nationwide basis. Additionally the Swedish government is examining this possibility with a report on the topic due to be delivered to the government in February 2017.
- Hybrid options including:
  - Deployment of a dedicated network in key geographic areas with use of commercial networks in other areas. The French government has announced plans to deploy such a network making use of spectrum in the 700MHz band (698-703/753-758 MHz and 733-736/788-791MHz) for the dedicated network.
  - Provision of dedicated spectrum to one or more commercial network operators which then supplement this spectrum with further capacity from the spectrum they utilise for commercial purposes when this is required (this could be from the 2×30MHz of spectrum in the core 700MHz band but also supplemented with capacity from other bands held by the mobile operator(s)).

In respect of the spectrum requirements for PPDR, ECC Report 199[5] estimated that 2×10MHz of spectrum was needed to meet the needs for emergency service users. ECC Report 218[27] identified a number of alternative bandplan options for PPDR in the 700MHz band. These include:

- Use of spectrum from the core 2×30MHz part of the band i.e. 703-733/758-788MHz e.g. the bottom 2×10MHz (703-713/758-768MHz)
- Use of the 698-703/753-758MHz band and the 733-736/788-791MHz band (i.e. a total of 2×8MHz of spectrum). This is the option adopted by the French government. We understand this is also being considered by Germany.
- Use of the 698-703/753-758MHz band only
- Use of the 733-736/788-791MHz band only
- Use of the 698-703/753-758MHz band combined with 2×5MHz from the core 2×30MHz band (703-708/758-763MHz.

These options are illustrated in Figure 1-1.

Figure 1-1: Options for providing dedicated spectrum for PPDR from 700MHz band



Some commentators have indicated that the 698-703/753-758MHz band is less likely to be used for PPDR than the 733-736/788-791MHz band in view of the equipment availability as a result of the challenges of developing the filters required to protect digital terrestrial television broadcasting in the adjacent band (Channel 48), whereas equipment supporting the 733-736/788-791MHz spectrum is already available since this falls within the 700MHz band that has been adopted in Asia and South America (the so-called APT700 bandplan).

In respect of the Netherlands, it is not clear how much spectrum will be required for PPDR since there are no decisions yet in respect of the approach the Netherlands government will follow for providing

[5] CEPT ECC, 'ECC Report 199: User requirements and spectrum needs for future European broadband PPDR systems (Wide Area Networks)', May 2013.

broadband communications services to the emergency services community. We understand that a decision on which approach to follow is unlikely to be made by the government for another 3-4 years.

1.2.4 Programme Making and Special Events (PMSE)

The PMSE community makes extensive use of the UHF (470-870MHz) band for wireless audio systems including wireless microphones, in-ear monitors and audio links in support of programme making and other cultural events including theatre productions and musicals. Because of the latency associated with digital systems, these microphones continue to be based on analogue technology and require spectrum in line with the audio bandwidth they wish to cover.

Several European reports have identified PMSE as a potential use of spectrum in the 'duplex gap' of the 700MHz band (733-758MHz) and spectrum in the 694-703MHz range. Our discussions with stakeholders representing PMSE spectrum users suggested that this spectrum would be of interest, though as 'duplex gap' and 'guard band' spectrum there are constraints on the extent to/ways in which the spectrum could be used so it is not ideal. Nonetheless stakeholders clearly recognised this spectrum would be considerably better than the option of no additional spectrum.

In June 2016, the European Commission requested[6] the Radio Spectrum Policy Group to provide an Opinion on the long-term strategy for providing sufficient spectrum for wireless audio and video PMSE applications. This work is likely to result in further assessment of the potential for utilising the 694-703MHz and 733-758MHz bands for PMSE at a European level and could have implications for the demand from PMSE stakeholders for spectrum in these frequency ranges as well as the harmonised conditions to apply to use of these frequency ranges. The final draft of the Opinion is scheduled to be released in November 2017 for public consultation and any subsequent proposals for European Commission Decisions could follow in 2018.

1.2.5 Summary of demand

Figure 1-2 summarises our overall assessment of demand for spectrum in the 700MHz, 1452-1492MHz and 2100MHz bands for the different potential uses of the spectrum.

[6] European Commission, 'Request for an Opinion from the Radio Spectrum Policy Group on a long-term strategy on spectrum requirements facing the future needs and use of wireless audio and video PMSE applications', 8 June 2016.

Figure 1-2: Summary of demand for spectrum in 700MHz, 1452-1492MHz and 2100MHz bands

Use/user	700MHz (2×30)	700MHz (Other)	1452-1492MHz	2100MHz
Existing mobile operators	High demand	No/Low demand	Medium demand (timing varies from 2018 to beyond 2020)	High demand
Potential mobile entrants	Low demand[7]	Low demand (unless TDD technologies can be accommodated)	Low demand (unless TDD technologies can be accommodated)	High demand
PPDR	Possibly Medium[8]	Possibly High[8]	None	None
IoT/M2M	None[9]	Medium	None	None
PMSE	Not applicable[10]	Medium/High	None	None

1.3 Combined award vs separate award

A number of factors need to be taken into consideration when deciding whether to award spectrum bands separately or simultaneously, including:

- The timing of the availability of the different spectrum bands
- The extent to which the bands are complimentary – of greater value in combination than individually
- The extent to which the bands are substitutes – alternatives that an operator would ideally want to choose between on the basis of relative price
- The added complexity of a combined award process as compared with separate, sequential, award processes.

Where a number of spectrum bands will become available at the same time, and those bands are either strong compliments or close substitutes for at least some likely potential bidders, then there is a good case for holding a single combined award process (e.g. auction) since this will be more likely to lead to an efficient assignment than will a number of separate, sequential, award processes. This does however have to be balanced against the added complexity of a combined award process.

However, where there are differences in the timing of the availability of the different spectrum bands under consideration, as there are here between the 1452-1492MHz and the 700MHz and 2100MHz bands, it is very important to consider the potential impacts that holding an earlier or later award of all the spectrum (in a single combined award) might have, as compared with separate awards at different times:

From our assessment of demand for the spectrum and economic linkages between the bands, including discussions with stakeholders we concluded that:

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7 Demand constrained due to expected high prices for this spectrum.

8 Depends on approach chosen by government – demand shown is if a dedicated PPDR network solution is chosen.

9 No demand for specific spectrum dedicated for IoT/M2M use in this band in view of expected high prices for this spectrum. Spectrum assignments made to mobile operators in this band could be used for providing IoT/M2M services using 3GPP technologies such as NB-IoT.

10 No interest from PMSE in this band since spectrum has been harmonised with the technical characteristics set primarily for use for wireless broadband networks.

- Interest in the 700MHz spectrum outside the core 2×30MHz band is mostly separate from interest in the core 2×30MHz spectrum and interest in spectrum in the 1452-1492MHz and 2100MHz bands. Furthermore the allocation and potentials uses of the other 700MHz spectrum is not clear, particularly in view of the question of whether any spectrum needs to be reserved for PPDR and what further harmonisation efforts may be made at the European level in relation to this spectrum, for example in relation to PMSE. These issues may take some time to resolve. As indicated above, the uncertainties may also have different impacts on different types of organisation and could result in an inefficient award of the spectrum. For these reasons, **we recommend that the award of the non-core 700MHz spectrum is undertaken through a separate process from the other spectrum bands**. The parameters of this award process (timing, spectrum packaging etc) can be determined at a later date once the government's plans for PPDR become clear and any further harmonisation steps are undertaken for the band at the European levels, for example in relation to use of the spectrum for PMSE.

- At the same time, **it does appear to be appropriate to delay the award of the 2×30MHz core block of 700MHz spectrum whilst the government makes a decision over how to meet the broadband connectivity needs of PPDR users.** Looking at the approach taken by other countries, even if the government in the Netherlands decides to deploy a dedicated PPDR network or hybrid dedicated/commercial solution, in all likelihood it will make use of spectrum outside the core 2×30MHz band i.e. spectrum in the 698-703/753-758MHz or/and the 733-736/788-791MHz ranges. We do not detect any widespread movement across Europe to set aside part of the core 2×30MHz block for dedicated PPDR networks – in fact those countries which are most advanced in respect of the planning of dedicated/hybrid PPDR networks (namely France and Germany) have already awarded all of the 2×30MHz spectrum to commercial operators.

- Stakeholders differ in respect of the strength of linkages between the core 700MHz, 1452-1492MHz and 2100MHz bands. Across mobile operators there are differences in view of the strength of linkages between the bands and the ability of the operator to value spectrum in a particular band without knowing its holdings in the other bands. Most operators however felt that a combined auction was necessary in view of these linkages, even if the direct linkages across all three bands together was limited, there were sufficient linkages between two of the different pairs (700MHz and 1452-1492MHz, 700MHz and 2100MHz) meaning that the three bands need to be considered together. Most organisations felt the linkages between the 700MHz and 2100MHz band were strongest – with the linkages between the 1452-1492MHz band and other bands being weaker – but stronger with the 700MHz band than the 2100MHz band. We note that holders of 800MHz spectrum have a potential advantage in valuing 1452-1492MHz spectrum over other organisations which might to some degree be reliant on an acquisition of spectrum in another band (for example the 700MHz band) to maximise the value they can obtain from the 1452-1492MHz band.

- The main priority of potential new entrants is to avoid a complex award process as this places them at a disadvantage as they may not have as much access as the larger operators to expert advice.

- Although the 1452-1492MHz band is theoretically currently available for use, in reality the current lack of available handsets supporting this band means that no economic benefit is currently being lost due to the lack of assignment. This will change as handsets supporting the band become available.

For the core 700MHz spectrum and the 1452-1492MHz and 2100MHz bands, the ideal solution would be to hold a combined award for the spectrum in early 2018 (rather than 2019) since this would allow the organisations who believe there are linkages between the various bands to express these linkages (e.g.

through package bidding) but also potentially enable the economic benefits from use of the 1452-1492MHz band to start to be realised in 2018, subject to the availability of compatible user devices (e.g. handsets).

However the Authority for Consumers and Markets (ACM) is due to undertake an extensive analysis of the mobile market in 2017 in order to advise the Ministry on the state of the market and, if required, on potential remedies to ensure market competitiveness. This advice is due in early 2018. Such remedies could have implications for the award of the spectrum for example in relation to matters such as the setting of spectrum caps, reservations of spectrum etc. The implication of this is that a combined auction could not take place until 2019 in order to allow sufficient time for finalisation and implementation of ACM's advice into the final auction rules. We understand from the Ministry that it could take 18 months between the initial publication of auction legislation (in the beginning of 2018) and the holding of the auction (mid 2019).

Nonetheless, it may be possible for the Ministry to consider awarding the 1452-1492MHz band separately at an earlier date i.e. through a separate auction process, provided that the strength of linkages between the 1452-1492MHz band and the 700MHz and 2100MHz bands for different organisations would not result in the risk of an inefficient outcome arising from holding a separate auction - which could then has an impact on the market environment.

We therefore considered two alternative options for the award of the core 700MHz spectrum and the 1452-1492MHz and 2100MHz bands:

- Option A: Combined auction of the 700MHz, 1452-1492MHz and 2100MHz bands in 2019
- Option B: Auction of 1452-1492MHz band in 2017/18 and auction of 700MHz and 2100MHz bands in 2019.

When considering the impacts of the two award options, we concluded that the comparison of the options primarily comes down to a consideration of:

- Could an inefficient assignment of the 1452-1492MHz band arise as a result of separating the award of this band from the awards of the 700MHz and 2100MHz bands?
- Would the award of the 1452-1492MHz band ahead of the completion of the ACM's market assessment be appropriate?
- How much economic benefit would be gained from the use of 1452-1492MHz spectrum prior to 2019? Specifically to what extent would the 1452-1492MHz band be put into use in 2018 and how much economic benefit would arise from this?

In respect of the possibility of an inefficient outcome arising from a separate award of the 1452-1492MHz band, we concluded that any loss of efficiency from an inefficient outcome arising from a separate award of 1452-1492MHz spectrum is likely to be small; however this is a potential issue of fairness (non-discrimination) across the different market participants. The potential loss of efficiency arises in a scenario in which some bidders discount their valuations for 1452-1492MHz spectrum to account for the risk they may not acquire 700MHz spectrum under which circumstances the 1452-1492MHz spectrum is less valuable. However we believe any such 'discount' to valuations is likely to be modest given the possibility of future pairings of the 1452-1492MHz band with other alternative bands (e.g. 900MHz, 1800MHz) and consequence any market inefficiency that results will also be modest. However an inefficient outcome could have an impact on the overall competitive position of an individual operator relative to others, and

therefore there is a question over whether the holding of a separate award of the 1452-1492MHz band would be fair (i.e. non-discriminatory) in respect of its impact on different market participants.

Regarding the issue of the appropriateness of holding an award of the 1452-1492MHz band in advance of the ACM's market assessment, we concluded that there could be strong benefits from the ACM concluding its review of market competitiveness and identifying potential remedies in advance of the award of spectrum in any of the three bands. The main competitive impact of the 1452-1492MHz band is that the band will have stronger short-benefits for organisations that hold 800MHz spectrum assignments than for those organisations that do not. This benefit arises independently of whether the 1452-1492MHz spectrum is auctioned separately or together with other frequency bands. However the ACM may wish to consider whether this issue could have a material impact on long-term market competitiveness in advance of the award of the 1452-1492MHz spectrum (as well as the 700MHz and 2100MHz bands) since if the ACM determined this was an issue that could affect long-term market competitiveness, it may wish to consider advising on market remedies which affect several of the bands being auctioned – for example possible spectrum caps that apply across multiple bands. Furthermore, if the 1452-1492MHz award is held in advance of the award of the 700MHz and 2100MHz bands, the ACM is likely to need to undertake a further market assessment following the award of the 1452-1492MHz band, which, once any advice is considered and acted upon by the Ministry, may lead to a delay in the timing of the subsequent 700MHz and 2100MHz auction.

In respect of the potential economic benefits arising from use of the 1452-1492MHz band in 2018, overall we concluded that there is potentially a small amount of economic benefit for citizens from use of the band in 2018, however the probability of this benefit being fully realised is low given the current device ecosystem for the 1452-1492MHz band. The potential benefit might arise in the form of high data bundle package sizes for mobile subscribers in 2018 instead of 2019 however it is not clear whether/how many operators would actually deploy the 1452-1492MHz band in 2018 in view of the timescale over which a choice of user devices compatible with the band are likely to become available and taken-up by a sufficient number of each operator's subscribers[11] and also the intention expressed by some organisations to only make upgrades to existing base station sites once there is certainty over spectrum holdings in all three bands (700MHz, 1452-1492MHz and 2100MHz).

Our overall judgement is that the benefits of a combined award in 2019 outweigh the benefits of separate awards in late 2017/early 2018 and 2019 since:

- Any consumer benefits from making the 1452-1492MHz band available in 2018 instead of 2019 are likely to be limited, and there is no certainty these benefits will in any case be fully realised in 2018 given the timescale for widespread adoption of user devices supporting the band.
- A combined auction is fair to all organisations as each organisation can take full account of any linkages that exist between bands when placing bids for spectrum, thereby resulting in a more efficient outcome.
- The award of spectrum in all three bands will be able to reflect the findings/recommendations from the ACM's market competitiveness study.

[11] We note that whilst Google has recently announced the Google Pixel phone which supports the 1452-1492MHz band, the major recent new handset releases from the two largest manufacturers – namely Apple (iPhone 7) and Samsung (Galaxy Note 7) - have not included support for the 1452-1492MHz band. However we expect that the new handsets launched by these firms in 2017 are likely to include support for the 1452-1492MHz band.

- In practical terms, one single auction should have lower administrative costs/require less preparatory time overall for both organisers of the auction and participants, compared with the holding of two separate auctions.

- A combined auction would also be able to take account of the possible need for ensuring that assignments of spectrum in the 700MHz and 1452-1492MHz bands to each individual operator minimise the risk of harmful interference occurring in user devices when both bands are used simultaneously. Separate auctions could lead to strategic bidding by organisations in the 700MHz auction knowing that their competitors would be seeking to avoid certain frequencies which are incompatible with the competitors' assignments in the 1452-1492MHz band. There may potentially be scope for the auction rules to take account of this by automatically excluding any 700MHz assignments which are incompatible with the existing 1452-1492MHz holdings of each of the bidders, but this would add complexity to the auction.

We therefore recommend that the Ministry holds a combined award for the core (2×30MHz) of 700MHz spectrum, the 1452-1492MHz band and the 2100MHz band in 2019. We also advise that the Ministry strives to make the combined auction as simple as possible in order to maximise market interest (particularly assisting smaller/niche organisations that may not have as much access to expert advice as larger organisations). We have sought to support this objective of simplicity in our spectrum packaging recommendations.

1.4 Spectrum packaging

We considered how spectrum in each of the three bands should be packaged taking account of the potential uses and demand for the spectrum, any views expressed about packing by stakeholders and also any lessons that could be drawn from previous auctions in the same/similar bands across the European Union.

In respect of the 2×30MHz of spectrum in the 700MHz band, the view of stakeholders and experience from the majority of European auctions in the 700MHz and 800MHz bands, suggests that a minimum assignment of 2×10MHz is required to make efficient use of the spectrum. For this reason, we recommend the following two options for the packaging of spectrum in this band:

- Six lots each of 2×5MHz with the auction design ensuring no organisation that wins spectrum in this band is left with less than a minimum of 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design.

- Or, alternatively, if there would be a significant reduction in the overall complexity of the auction, the spectrum could be pre-packaged into three lots of 2×10MHz, with each organisation only able to acquire a maximum of one of these lots, since it is highly likely that this will be the eventual outcome of the auction in any case.

With reference to the 1452-1492MHz band, the limited number of primary assignments (in Germany and Italy) and a secondary transaction (in the UK) have resulted in assignments of 20MHz to individual organisations. Stakeholders indicated that a minimum assignment of 10MHz would be economically efficient and technically network equipment and user devices that support 10MHz and 20MHz channel bandwidths should also be able to support 15MHz channel bandwidths. For these reasons our recommendation is for the spectrum to be packaged in 5MHz blocks but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that this requirement for

a minimum acquisition of 10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn as the valuations of spectrum by bidders will probably lead to a minimum block size of 10MHz for each successful bidder anyway

In relation to the 2100MHz band, spectrum as typically been packaged in 2×5MHz lots however successful bidders typically acquired larger packages (at least 2×10MHz, with many buyers ending the auction with 2×15MHz and 2×20MHz of spectrum).Our discussions with stakeholders suggested a minimum assignment of 2×10MHz would be useful for economic efficiency reasons and so we concluded that the auction should be left to determine the spectrum holdings over a minimum package size of 2×10MHz. Our recommendation is that the spectrum is packaged as 2×5MHz blocks, but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that this requirement for a minimum acquisition of 2×10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn as the valuations of spectrum by bidders will probably lead to a minimum block size of 2×10MHz for each successful bidder anyway.

1.5 Other recommendations and areas for further study

As we undertook our research, a number of related issues arose which we believe should be considered by the Ministry as it develops its plans for the auction:

- **Auction complexity**. Many stakeholders commented on the complexity of the multi-band auction in 2012 including concerns of lack of transparency about what the final cost of any spectrum licences is likely to be. Smaller organisations stressed the need for the auction to be as simple as possible as they may not have the same expert resources available to them as larger organisations.

- **Coverage obligations**. Should any coverage obligation be included in the conditions of use of the spectrum, several stakeholders have suggested that these should not be band specific i.e. the licensee can use any of/a combination of the spectrum bands that it holds to meet the coverage obligation.

- **Contiguous assignments in the 2100MHz band**. The mobile operators with existing assignments in the 2100MHz band all expressed a strong wish for the re-assignment process to be used to ensure that each winner receives spectrum in a contiguous block to enable deployment of the widest possible LTE carrier.

- **Incorporation of PPDR requirements in 700MHz licence conditions**. The mobile industry expressed concern at the potential for the 700MHz licence conditions to include mandatory wholesale access for PPDR users and any requirement for 'hardening' of base stations believing any such requirements should be contracted for by the government as part of its overall process for providing broadband wireless connectivity services to emergency services users.

Furthermore, we recommend that the Ministry undertakes (or encourages European institutions to undertake) further assessments in the following areas:

- **Possible 700MHz and 1452-1492MHz interference issues in user devices**. As discussed above, the second harmonic of the 700MHz uplink band (1406-1466MHz) overlaps with the 1452-1492MHz band which is used for downlinks which means that the second harmonic of the 700MHz signal produced in the power amplifier of a handset could cause interference to reception of signals in the 1452-1492MHz range. This could have implications for the auction in that it would be desirable to ensure that incompatible assignments across both bands are not available as options to bidders.

- **PMSE co-existence issues in the 700MHz band**. Additional compatibility assessments may be needed in respect of PMSE's potential use of spectrum in the 694-703MHz and 733-758MHz bands in respect of compatibility with mobile broadband using the 703-733/758-788MHz band and other services using the 694-703MHz and 733-758MHz bands. It is possible these issues may already be plans for further study at the European level prompted by the Radio Spectrum Policy Group's work on developing an Opinion for the long-term strategy for providing sufficient spectrum for PMSE[6].

- **Potential for use of the TDD technologies in the 694-703MHz and 733-758MHz bands**. Interest has been expressed by stakeholders in the potential use of this spectrum for TDD technologies for both mobile broadband services (using the TDD variant of LTE) and for low power wireless access networks for the Internet of Things (using a range of possible technologies). Such use is probably not currently compatible with the European Commission's Implementing Decision for use of the 700MHz band[2] and work would need to be undertaken at the European level to examine such scope for usage, assess compatibility issues and, if appropriate, update the Implementing Decision to allow such usage.

2 Introduction

This report has been prepared by Aetha Consulting Limited (Aetha) for the Directorate General for Energy, Telecommunications and Competition of the Ministry of Economic Affairs (the Ministry) as a summary of Aetha's research on linkages between the 700MHz, 1452-1492MHz and 2100MHz bands, with regard to plans to award spectrum in these bands.

2.1 Background

The Ministry is in the process of developing its plans for the award of spectrum in the 700MHz, 1452-1492MHz and 2100MHz bands and wishes to understand the optimum timing and conditions for the award of the spectrum:

- The 700MHz band comprises frequencies in the range from 694MHz to 790MHz and is currently utilised for digital terrestrial television but, in line with European Union proposals[12] this will be available in the Netherlands for use for electronic communications services from 1 January 2020.
- The 1452-1492MHz band (also commonly referred to as 'L-Band') is potentially available for assignment in the Netherlands immediately.
- The 2100MHz band refers to the paired frequencies between 1920 – 1980 MHz and 2110 – 2170 MHz that are currently assigned for electronic communications services in the Netherlands. These existing spectrum rights are due to expire at the end of 2020, so an assignment process will be undertaken for the new rights commencing from 1 January 2021.

The Ministry has previously announced that it plans to auction spectrum in the 700MHz and 2100MHz bands in 2019 and also that it plans to auction spectrum in the 1452-1492MHz band.

The current assignments of mobile spectrum are summarised in Figure 2-1.

Figure 2-1: Current mobile spectrum holdings [Source: ECO[13]]

Frequency Band	Vodafone	KPN	T-Mobile	Tele2	Zum
800MHz	2 × 10MHz	2 × 10MHz		2 × 10MHz	
900MHz	2 × 10MHz	2 × 10MHz	2 × 15MHz		
1800MHz	2 × 20MHz	2 × 20MHz	2 × 30MHz		
2100MHz	2 × 20MHz	2 × 20MHz	2 × 20MHz		
2100MHz (TDD)	5MHz	5MHz	20MHz		
2600MHz	2 × 10MHz	2 × 10MHz	2 × 5MHz	2 × 20MHz	2 × 20MHz
2600MHz (TDD)		30MHz	25MHz		

[12] European Commission, 'Interinstitutional File: 2016/0027 (COD)', Council of the European Union, 13 May 2016, submitted in response to 'Proposal for a Decision of the European Parliament and of the Council on the use of the 470-790MHz frequency band in the Union', 2 February 2016.

[13] European Communications Office (ECO), 'ECO Report 03: The licensing of "mobile bands" in CEPT', 03 March 2016.

2.2 Project objectives and approach

The primary objective of this project is to assess the strengths of linkages between the three bands in order to ascertain whether the spectrum should be awarded through one combined auction or two (or more) separate auction processes. This also includes consideration of the timing over which each of the three spectrum bands will start to be used/become available in order to identify the optimum timing of the award(s).

To undertake this assessment, we have undertaken background research on several underlying technological and economic questions and have also held telephone discussions with several industry stakeholders to discuss their own perspectives on the demand for spectrum in each band and strength of linkages between the bands.

The organisations that we spoke to during the course of the study were

Ericsson	Ministry of Security and Justice	Venus and Mercury
Huawei	PMSE.nl	Vodafone
IP Specials	Tele2	Ziggo
KPN	T-Mobile	

We would like to take this opportunity to thank all of the above stakeholders for participating in the study. We gained a considerable amount of information and insight from each of our calls as a result of all participants' willingness to openly answer the questions we raised. As agreed with the Ministry and the participants, we present the findings of our discussions in this report in an anonymised way i.e. we do not attribute points made to any specific participant in order to protect commercial confidentiality.

2.3 Structure of this document

The remainder of this document is structured as follows:

- Section 3 provides further details on the available spectrum in each of the three bands and any applicable European harmonisation measures
- Section 4 discusses the potential uses of and amount of demand for spectrum from each of the uses
- Section 5 presents our assessment of the strengths of linkages between the bands
- Section 6 discusses the relative merits of a combined award versus separate awards
- Section 7 presents our views regarding the packaging of spectrum in each of the bands
- Section 8 discusses other issues relating to the award of spectrum that have arisen during this study
- Section 9 contains a summary of our recommendations.

In addition, Annex A provides details of our approach to the modelling of the future demand for spectrum for mobile services.

Within this report we have answered the list of technical and economic questions included in the original scope of work[14] for the study. For the Ministry's convenience, we outline below in which sections of the report answers to each of the questions that were raised can be found.

Technological questions	Section(s) of report
Alternative uses of each of the bands and growth profile for each technology and alternative technologies	4
700MHz: Mix of commercial and public applications, shared use and uses for the unpaired spectrum	3.1, 4
L-Band: development of ecosystem for core band and possible extension bands	3.2, 4.1
Complementary and/or supplementary linkages between bands. Synergies from use of multiple bands.	4.1, 5
Can L-Band be used with 700MHz and/or 2100MHz bands? What is the timeline for aggregation of these frequencies?	3.2.3, 4.1
Can these frequencies be used in flexible ways? What is the impact of carrier aggregation?	4.1
Do the bands (also) show complementarities with other frequency bands? (800, 900, 1800 and 2600 MHz specifically)? Specific advantages and disadvantages of the 700 MHz, 2100 MHz and L-Band in comparison with these bands?	4.1, 3
Are other spectrum bands available for applications for possible niche players and new entrants?	4.2, 4.3, 4.4
To what extent do the bands offer coverage and capacity?	3, 4.1
Identify logical sizes of lots and licenses – taking account of any relevant evidence from auctions in other countries	7
Provide per band an overview of the compatibility issues and possible solutions	3.1.4, 3.2.4, 3.3.4

Economic and market-related questions	Section(s) of report
How much spectrum does the mobile industry need in the next coming years for continued service offerings, to enable the growth in demand and capacity and for setting up entirely new services?	4.1, Annex A
Looking at the existing nationwide operators and possible new entrants, what are the differences in spectrum-needs between fully converged (fixed-mobile) players and mobile-only players?	4.1, Annex A A.3.3
On the basis of these questions, prioritise the spectrum needs of the different types of market players	4.1, Annex A A.3.3

[14] Directorate General for Energy, Telecommunications and Competition of the Ministry of Economic Affairs, 'Request for Proposal (RFP) on "Research into Linkage Frequency bands" – Reference 201605310913'.

3 Available spectrum and harmonisation measures

In this section we provide further background on the spectrum available in each of the three frequency bands and present an overview of the technical harmonisation and compatibility studies that have been undertaken in relation to potential uses of each band.

3.1 700MHz band

The 694-790MHz (700MHz) band is currently used for terrestrial television broadcasting across the European Union, including in the Netherlands, but from 2020 onwards the band will be used for the provision of wireless broadband communications services. As well as services from commercial mobile operators which are primarily anticipated to use a 'core' band of 2×30MHz of paired spectrum, other spectrum in this band could be used for a variety of services including additional spectrum for commercial mobile services, use for public protection and disaster relief (PPDR), use for Programme Making and Special Events (PMSE) and use for Machine to Machine (M2M) communications.

700MHz spectrum is regarded as being highly valuable as radio signals using these frequencies are able to propagate through walls (i.e. provide good indoor coverage) and reach extended regions of rural areas (meaning that fewer numbers of base station sites are needed to provide coverage in less populated areas).

3.1.1 European harmonisation of the band

During the World Radiocommunications Conference in 2012 (WRC-12), an agreement was reached (subject to confirmation in WRC-15) to make a Primary allocation to wireless broadband alongside broadcast services in the 694-790MHz[15] band from 2015 across the whole of ITU Region 1 (covering Europe, the Middle East and Africa). This band was allocated to the mobile service across ITU Regions 2 (covering the Americas) and 3 (Asia-Pacific) in WRC-07.

As a consequence of this provisional decision, European countries began work on developing a suitable band plan for use of this band for mobile services. On 11 March 2013 the European Commission issued a mandate to CEPT to develop harmonised technical conditions for the 700MHz band. In response to this mandate, CEPT issued Report 53[16] on 28 November 2014 and Report 60[17] on 1 March 2016.

CEPT's work initially resulted in the identification of 2×30MHz of spectrum (comprised of 6 individual 2×5MHz channels) that could be used for mobile broadband services and would also align with the 700MHz band plan adopted in the Asia-Pacific region (the so-called APT700 bandplan – this has been standardised in 3GPP as Band 28). This would mean that equipment compatible with the APT700 band

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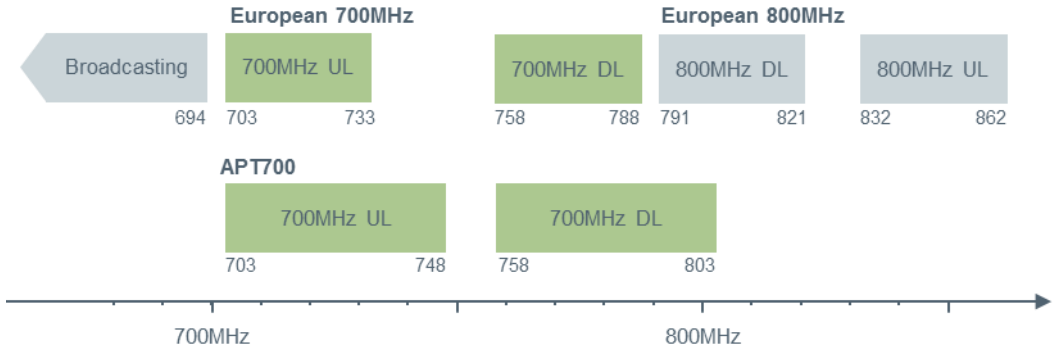
[15] Note that the lower edge of this band was to be confirmed as part of WRC-15.

[16] CEPT ECC, 'CEPT Report 53: Report A from CEPT to the European Commission in response to the Mandate "To develop harmonised technical conditions for the 694-790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband band other uses in support of EU spectrum policy objectives', 28 November 2014.

[17] CEPT ECC, 'CEPT Report 60: Report B from CEPT to the European Commission in response to the Mandate "To develop harmonised technical conditions for the 694-790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband band other uses in support of EU spectrum policy objectives', 01 March 2016.

plan (being adopted across Latin America, some countries in the Middle East and Africa as well as the Asia-Pacific region) could be used in Europe as the 2×30MHz would align with the lower 2×30MHz of the overall 2×45MHz of spectrum in the APT700 bandplan and use the lower duplexer in the radio. This alignment is shown in Figure 3-1.

Figure 3-1: Overview of paired spectrum in European 700MHz bandplan and overlap with APT700 bandplan



CEPT also considered potential alternative uses of the remaining spectrum in the band including:

- Use for Supplemental Downlinks (SDL). Here the spectrum in the 'duplex gap' (spectrum in the range 733-758MHz which lies between the uplink and downlink blocks which form the core 2×30MHz of spectrum) could be used to provide additional downlink capacity (transmissions from base stations) when combined with paired spectrum. The additional capacity that supplemental downlinks provide is particularly important with the increased adoption of data services on mobile communications networks since much of the increased traffic is downlink traffic (e.g. streaming of audio visual content) whereas voice calls required equal amounts of uplink and downlink capacity.

- Programme Making and Special Events (PMSE). It is envisaged that PMSE could use the 694-703MHz guard band as well as the duplex gap spectrum. The main use would be for wireless audio systems (including radio microphones and in-ear monitors) which currently operate in the 'white space' spectrum allocated for television broadcasting services in the 470-694MHz range.

- Public Protection and Disaster Relief (PPDR). As discussed in Section 4.3, solutions are being sought for the provision of broadband data communications to emergency service users and other associated government/quasi-government bodies involved in public safety. Options in respect of dedicated spectrum could include one or more (i.e. combinations) of the following:

  – 2×5MHz of paired spectrum in the range 698-703/753-758MHz (i.e. just below the main 2×30MHz paired block)

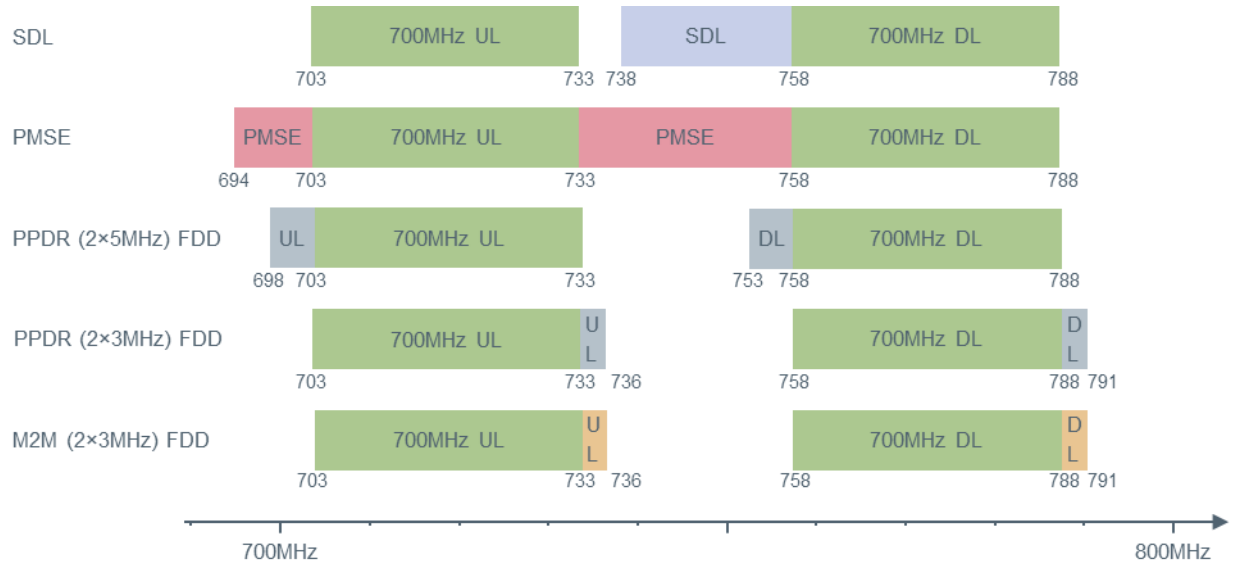
  – 2×3MHz of paired spectrum in the range 733-736/788-791MHz (i.e. just above the main 2×30MHz paired block)

  – Use of any part of the main 2×30MHz paired block (using the channelisation arrangements shown in Figure 3-1 above).

- Machine to Machine (M2M) communications. It was envisaged these could be used in the 733-736/788-791MHz range.

Figure 3-2 summarises the bandplan options for these alternative potential uses of the remaining spectrum in the 700MHz band as envisaged in CEPT Report 53 and Report 60. Please note that the options shown below are not necessarily exclusive and could potentially be combined.

Figure 3-2: Alternative uses of 700MHz band as envisaged by CEPT Report 53 and Report 60



WRC-15 (held in November 2015) decided to allocate the 694-790MHz band to the mobile service in ITU Region 1.

On 2 February 2016, the European Commission adopted a proposal[18] for a Decision of the European and Parliament and the Council on the use of the 700MHz band which proposed that the band should be assigned to wireless broadband services by 30 June 2020 in all EU member states. On 26 May 2016, the Council of the European Union agreed with this general approach and adopted the main measures in the Commission's proposals[19]. The European Parliament is scheduled to vote on this issue on 13 October 2016.

On 28 April 2016, the European Commission adopted an implementing decision[20] for the technical parameters governing the harmonisation of the 694-790MHz band for use for wireless broadband services. This incorporated the recommendations from CEPT Report 53 and CEPT Report 60.

The European Commission strong interest in this band is partially as it is seen as a potential band for the introduction of 5G. In February 2016 the European Commission announced[21] the development of a 5G Action Plan to ensure that Europe takes a leading role in 5G and that European companies are ready to start

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[18] European Commission, 'Proposal for a Decision of the European Parliament and of the Council on the use of the 470-790MHz frequency band in the Union', 2 February 2016.

[19] European Commission, 'Interinstitutional File: 2016/0027 (COD)', Council of the European Union, 13 May 2016.

[20] European Commission, 'Commission Implementing Decision (EU) 2016/687 of 28 April 2016 on the harmonisation of the 694-790 MHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services and for flexible national use in the Union', published in the Official Journal of the European Union, 4 May 2016.

[21] European Commission, 'Press release: EU and Brazil to work together on 5G mobile technology', 23 February 2016.

offering 5G products and services in 2020. In June 2016 the Radio Spectrum Policy Group (RSPG) published a draft opinion[22] on spectrum bands for 5G which indicated that 5G would need to be deployed in bands below 1GHz, "including particularly the 700MHz band".

On 14 September 2016, the European Commission published a series of documents including an updated proposal for the Electronic Communications Code[23] (which would update the framework for regulating electronic communications services) and the 5G Action Plan[24]. The proposed Electronic Communications Code includes a number of proposed measures on spectrum including giving national regulatory authorities decision-making powers in relation to regulatory and market shaping aspects of spectrum assignment, a requirement for the national regulators to notify their draft measures to other regulatory authorities in the European Union through BEREC[25] for the purposes of 'peer review' and providing the Commission with the power in respect of certain elements of spectrum assignment (for example, the duration of spectrum assignments). The 5G Action Plan's aim is to facilitate the deployment of 5G across the European Union from 2018 onwards and the document makes reference to the 700MHz band as being one of the "pioneer spectrum bands for the initial launch of 5G services" and also highlights the availability of the 700MHz band as "being critical for 5G success".

3.1.2 Use in the Netherlands

In common with much of Europe, the 700MHz band is currently used in the Netherlands for the provision of digital terrestrial television services. The commercial licence for offering this service is held by KPN and the current licence is due to expire on 1 February 2017. The Ministry held a competition for a new licence to continue operating DTT until 2030 and it was announced in June 2016 that the licence was won by KPN after an unnamed second bidder pulled out of the auction. As part of the licence conditions, KPN is required to clear the 700MHz band from DTT usage by 1 January 2020 and fund any costs associated with channel relocation and technological upgrading that is needed to enable the clearance.

3.1.3 Equipment availability

As shown in Figure 3-3 below, as of June 2016, 372 LTE user devices are available which support the APT700 band – which, as indicated above, incorporates the European 700MHz band. This number is expected to grow rapidly over the coming years as the band starts to be used more widely across the Asia-Pacific region, Latin America and Africa and the Middle East as well as Europe. Our discussions with equipment manufacturers indicated that network equipment is available for European 700MHz deployments – including antennas specifically designed for covering the 700MHz band.

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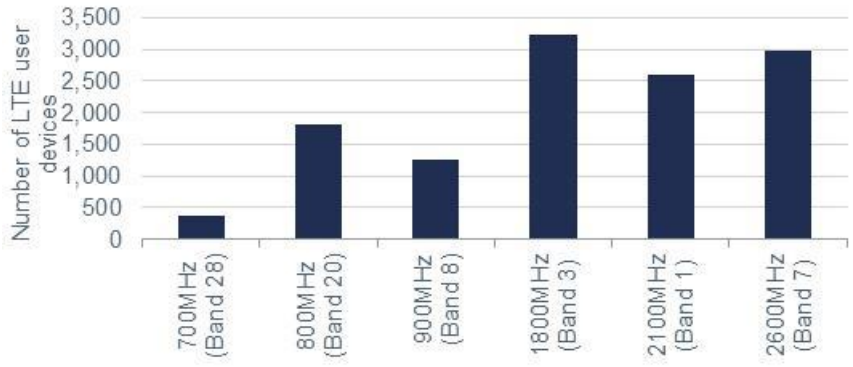
[22] Radio Spectrum Policy Group, 'Strategic roadmap towards 5G for Europe: DRAFT RSPG Opinion on spectrum related aspects for next generation wireless systems (5G)', Reference RSPG16-031 FINAL, 8 June 2016.

[23] European Commission, 'Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code (Recast)', Reference COM(2016) 590 final, 14 September 2016.

[24] European Commission, 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 5G for Europe: An Action Plan', Reference COM(2016) 588 final, 14 September 2016.

[25] The Body of European Regulators for Electronic Communications – see berec.europa.eu

Figure 3-3: Availability of LTE user devices by band, June 2016 [Source: GSA[26]]



3.1.4 Compatibility studies

The Annex to the European Commission's Implementing Decision[20] specifies the usage parameters for different systems operating in the 700MHz band. These have mainly been derived from CEPT Report 53 and CEPT Report 60.

CEPT Report 53 includes:

- the appropriate channelling arrangements for the 694-790MHz band including for alternative uses of the non-paired spectrum/guards bands such as Programme Making and Special Events, Public Protection and Disaster Relief and Machine 2 Machine Communications
- an initial draft of the least restrictive technical conditions for use of the 694-790MHz band for wireless broadband communications services which will minimise the risk of harmful interference being caused to broadcasting and PMSE services operating below 694MHz
- an assessment of interference issues between mobile/fixed communications network in the 694-790MHz band and broadcasting below 694MHz
- an assessment of interference from broadcasting to mobile/fixed communications networks and compatibility with the harmonised conditions for use of wireless broadband in the 790-862MHz range.

CEPT Report 60 provides:

- an updated version of the least restrictive technical conditions for use of the 694-790MHz band for wireless broadband communications services which will minimise the risk of harmful interference being caused to broadcasting and PMSE services operating below 694MHz
- additional information on potential band plans for use for broadband PPDR services.

ECC Report 218[27] presents several options for the configuration of PPDR in the 700MHz band (see Section 4.3 of this report for further details) and considers the compatibility issues. It is noted that if PPDR or M2M services use the 733-736MHz band for uplink services, there is only 2MHz of separation with the 738MHz-743MHz block which could be used for supplementary downlink services and interference issues

[26] Global mobile Suppliers Association, 'Evolution to LTE report: 4G Market and Technology Update', 28 July 2016.

[27] CEPT ECC, 'ECC Report 218: Harmonised conditions and spectrum bands for the implementation of future European Broadband Public Protection and Disaster Relief (BB-PPDR) systems', October 2015.

could arise which require mitigating measures. Some of the analysis presented in ECC Report 218 originates from ECC Report 239[28] which investigated the compatibility issues for broadband PPDR systems operating in the 700MHz band.

Additionally from our discussions with stakeholders, we understand there may be a problem with use of the 698-703/753-758MHz band for PPDR in that the filtering requirements to protect neighbouring television broadcasting transmissions (Channel 48) are very tight and device manufacturers have shown a reluctance to develop equipment in line with this specification. This is not a major issue in the Netherlands as Channel 48 is only used in small parts of the country however this issue has to be resolved in other countries to enable this band to be used across several countries and therefore the equipment ecosystem (particularly user terminals) supporting this band becomes available. Additional research in this area may be required before any final decisions are made regarding use of the 698-703MHz band for uplink transmissions. For such equipment availability reasons, some commentators believe that the 698-703/753-758MHz band is less likely to be used for PPDR than the 733-736/788-791MHz band.

ECC Report 221[29] examines the compatibility issues between PMSE audio applications (wireless microphones) in the 700MHz frequency band with mobile communications services. The study concludes that there may be a need for a setup procedure for the audio PMSE equipment in order to ensure interference-free operation for the required quality of service. To reduce interference between indoor wireless PMSE audio equipment and mobile communications networks using adjacent bands, additional mitigation solutions could be implemented including the potential need for a guard band[30] meaning that it may not be possible to utilise the entire 700MHz 'duplex gap' for PMSE.

The analysis in ECC Report 221 was undertaken on the basis that the entire 733-758MHz band is being used for PMSE. In the event that part of this band is used for other applications (e.g. supplementary downlinks on mobile networks) this could result in greater levels of interference and the need for additional mitigation measures. Further study of this would be required in the event that this was an option being considered by the Ministry.

ECC Report 242 examines the compatibility issues between M2M applications in the 733-736/788-791MHz band with other services (mobile broadband networks in the 700MHz and 800MHz bands, PMSE and PPDR[31]). The M2M applications considered in the interference assessment are those based on narrowband LTE and GSM technologies which occupy a bandwidth of 200kHz. If other M2M/Internet of Things technologies (see Section 4.2 for further details) are to be used in the 700MHz band, additional

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[28] CEPT ECC, 'ECC Report 239: Compatibility and sharing studies for BB PPDR systems operating in the 700 MHz range', 30 September 2015.

[29] CEPT ECC, 'ECC Report 221: Adjacent band compatibility between MFCN and PMSE audio applications in the 700 MHz frequency band', September 2014.

[30] The need for the guard band may arises as a consequence of interference to mobile reception (from unwanted emissions from PMSE terminals and also receiver blocking) in scenarios when PMSE equipment is in close proximity to a mobile terminal - for example, when using handheld or body worn PMSE devices indoors. For outdoor use of PMSE, interference to mobile reception is primarily a problem when the narrowband variant of LTE is used (3MHz) – for 10MHz LTE transmissions interference was manageable.

[31] Note that the assessment assumes either M2M or PMSE utilises the 733-736/788-791MHz band – not both. In the unlikely event that the Ministry were to consider allocating this band to both services, additional technical compatibility work would be required.

compatibility studies will be required. These could cover (for example) the use of M2M technologies that utilise Time Division Duplex (TDD) as the transmission mode.

Since the publication of CEPT Report 53 and CEPT Report 60, we understand the mobile industry is increasingly concerned about the practical challenges of supporting supplementary downlinks in the 700MHz band in view of:

- The technical challenges of adding 700MHz SDL as a new band in multi-band terminals (especially as the uplink of the full Band 28 overlaps with the SDL band), especially given the limited market size for this (essentially Europe).
  - In LTE, downlink-only bands are supported through carrier aggregation with a paired band. The implementation of carrier aggregation in a terminal involves a separate RF chain for each band to be aggregated. In the standard implementation of a multi-band terminal, the RF signal to/from its antenna is separated into two paths using a diplexer, for bands below and above 1GHz , each with its own RF transmitter and receiver chains (because of the limited frequency range of one RF chain). As a consequence, carrier aggregation of the combination of any one band below 1GHz with any one band above 1GHz can be supported without adding complexity to the RF subsystem. The great majority of smart phones (if not all) should therefore support this type of carrier aggregation.
  - The two paths for below and above 1GHz each comprise a matrix of filters and switches, linking the transmitter and receiver ports of the RF chain to the antenna, and keeping the two ports isolated from each other. If carrier aggregation of two or more bands below 1GHz or above 1GHz is to be supported, the relevant path will need additional RF chain(s), and the matrix of filters and switches will become more complicated. Each supported combination of bands needs to be considered individually in the design process. Some combinations are more challenging than others, and some are not feasible (for example, aggregation of 700MHz paired with 700MHz SDL may not be possible).
  - There is a limit to the overall complexity of the RF subsystem of a terminal, based on feasibility of implementation and considerations of cost and performance (which inevitably degrades with an increase in the number of supported bands). This 'envelope' of complexity is increasing in size quite rapidly due to advances in technology, but it is not catching up with the number of new mobile bands being released and licensed around the world. Therefore, terminal manufacturers are forced to make difficult choices on the bands and combinations of bands for carrier aggregation that their products will support. They are likely to choose bands with the greatest global use, and ones for which there is widespread co-ordinated deployment (most often, when there is a coordinated licence award process for a band and the band is brought into use immediately after the licence award).
  - If a downlink-only carrier is aggregated with a paired carrier, then the downlink traffic can be shared dynamically between the two carriers. However, the control channels and the uplink traffic must be supported by the paired carrier (i.e. it is the primary carrier). Therefore, the performance of the aggregated combination is largely determined by the characteristics of the paired carrier - and particularly its frequency. The market scale of 700MHz SDL may not be sufficient for it to be supported in terminals as a dedicated combination with the 800MHz and/or 900MHz bands. However a 700MHz SDL channel could inherently be aggregated with any band above 1GHz (in practice, this means a band around 2GHz or 2.6GHz). However this would result in the 700MHz

SDL channel effectively being limited to the coverage area of the 2GHz band i.e. not fully utilising the underlying propagation characteristics of the spectrum.

- The difficulties for mobile operators of adding 700MHz SDL to cell sites that are already supporting up to three bands below 1GHz:
  - The 700MHz SDL band is immediately below the 700MHz band paired downlink, which is separated from the 800MHz band downlink by a gap of only 3MHz. This makes a total of 83MHz of almost continuous downlink spectrum, with 5MHz separation to uplink below and 11MHz separation above. This may be beyond what is feasible for a single duplex filter in a base station. The gap of 3MHz between 700MHz and 800MHz band is too narrow to comfortably split it into two frequency ranges with the transition between the two duplexers in the 3MHz gap. It is therefore likely that supporting this frequency range will require two bandpass filters, with a transition that falls within the 700MHz or 800MHz band (but away from the spectrum used by the operator in question). This means that the base station filters will need to be specific to each operator and the spectrum that it has in each country. This becomes an even greater challenge in situations where two operators share sites and antennas.
  - For some operators, the 700MHz SDL band might increase the number of its channel groups below 1GHz to four. This greatly increases the likelihood of intermodulation products desensitising a receive channel, or the difficulty of acquiring spectrum in different bands that have frequency relationships such that this does not occur. This problem is compounded when operators share sites and antennas, because the number of channel groups is higher.

An alternative potential use of the 'duplex gap' spectrum could be to support wireless broadband TDD technologies. Although it may be challenging for a mobile operator with paired spectrum in the 700MHz and 800MHz bands and perhaps the 900MHz band, to introduce TDD in the centre gap – perhaps even more challenging than introducing SDL, this would not be the case for a potential new entrant or existing holder of spectrum that does not hold any spectrum below 1GHz. Such use of the centre gap for TDD technology is not currently supported by the Commission's Implementing Decision. This would therefore need to be modified and compatibility studies undertaken, however:

- For the central 15MHz of spectrum in the duplex gap, such compatibility assessments could be undertaken fairly quickly since existing studies already provide the necessary technical information to define the parameters for TDD for this frequency range. For example, the Commission's Implementing Decision for the 700MHz band[20] contains parameters for Frequency Division Duplex (FDD) downlink and for co-existence between uplink and downlink with 5MHz separation (between the paired uplink at 733MHz and below and SDL at 738MHz and above). These together are sufficient to define the parameters for FDD downlink in the middle 15 MHz of the centre gap. CEPT's studies on the 2500 - 2690MHz band[32] also provide insight into the use of the centre gap of a paired frequency arrangement.
- Studies could also consider the extent to which the remaining two 5MHz blocks in the duplex gap could be used for TDD as "restricted blocks".

[32] For example, CEPT ECC, 'CEPT Report 002: Report from CEPT to the European Commission on the 5th Mandate on IMT-2000/UMTS: Harmonisation of the frequency usage within the additional frequency band of 2500-2690 MHz to be made available for IMT-2000/UMTS systems in Europe'; 12 November 2004.

Any compatibility work on mobile broadband TDD technologies in the 700MHz band could also consider the use of M2M TDD technologies.

3.2 1452-1492MHz band

The 1452-1492MHz band has been allocated to wireless broadband services for providing a supplementary downlink when combined with a paired frequency band. The spectrum is currently available for assignment in the Netherlands but whilst compatible network equipment is widely available, at the time of finalising this report, only one handset supporting the band had just been announced[33] – though this situation is expected to change with further handsets becoming available during 2017 and 2018.

3.2.1 European harmonisation of the band

In 2002, the 1452-1479.5MHz part of the band was harmonised for the deployment of terrestrial DAB (Digital Audio Broadcasting) technology across Europe, with frequencies above this band also being potentially available for satellite audio broadcasting. However due to the relatively poor propagation characteristics of the band (compared to the VHF spectrum historically used for radio broadcasting) there was limited interest in this use and very few countries actually deployed any DAB transmitter sites in this band.

In view of the band being underutilised, the whole 1452-1492MHz band was identified as a potential band that could be made available for other uses (e.g. electronic communications services) as part of the inventory of spectrum[34] undertaken under the Radio Spectrum Policy Programme[35].

A variety of alternative uses of the band were considered by CEPT and Report 188[36] concluded that the most appropriate regulatory framework for the band would be one which supported supplementary downlinks for mobile communications networks. The intention is the band would be combined with a paired frequency band which results in additional capacity being available for the downlink supporting the asymmetric nature of mobile data traffic (downlink data traffic is several multiples of uplink traffic as a consequence of the take-up of audio visual streaming and download services).

In March 2014 the European Commission issued CEPT with a mandate to develop the harmonised technical conditions for use of the band. In November 2014 CEPT responded with Report 54[37] which proposed harmonisation of the band for wireless broadband supplemental downlink use and included the technical criteria for use of the band whilst incorporating measures to protect existing T-DAB services in

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[33] Details of the Google Pixel were released on 4 October 2016 and the phone will become available to customers in Australia, Canada, Germany, United Kingdom and the United States of America on 20 October 2016.

[34] European Commission, 'Report from the Commission to the European Parliament and the Council on the Radio Spectrum Inventory – Reference COM(2014) 536 final', 1 September 2014.

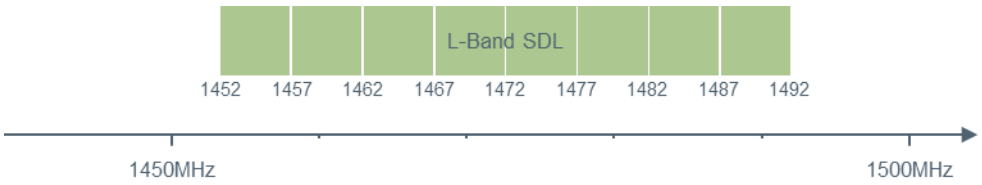
[35] European Commission, 'Decision No 243/2012/EU of the European Parliament and of the Council of 14 March 2012 establishing a multiannual radio spectrum policy programme', published in the Official Journal of the European Union, 21 March 2012.

[36] CEPT ECC, 'ECC Report 188: Future harmonised use of 1452-1492MHz in CEPT', February 2013.

[37] CEPT ECC, 'CEPT Report 54: Report from CEPT to the European Commission in response to the Mandate "To develop harmonised technical conditions in the 1452-1492MHz frequency band for wireless broadband electronic communications services in the EU', 28 November 2014.

the same band as well as users of adjacent spectrum bands. The recommended bandplan (8 channels each of 5MHz bandwidth) is shown in Figure 3-4.

Figure 3-4: Bandplan for 1452-1492MHz band



In May 2015 the European Commission issued an implementing decision[38] for the harmonisation of the 1452-1492MHz band across the European Union, This required member states to make the band available on the basis of the conditions set out in the decision (which were based on the CEPT Report 54 recommendations) within six months of the date of the notification of the Decision. Member states were also required to report on the application of the Decision no later than nine months after the date of notification.

So far the 1452-1492MHz band has been auctioned in Germany, Italy and the UK. The spectrum was originally auctioned in the UK in 2007 under different licence conditions but these conditions were revised[39] in May 2015 to align with the Commission Implementing Decision.

One particular benefit of pairing the 1452-1492MHz band with a low frequency band (sub 1GHz) is that the technical usage conditions of the 1452-1492MHz band sometimes allow higher power transmissions than are allowed for lower frequency bands by national administrations. The coverage of mobile frequency bands is typically limited by the uplink channel and consequently by pairing a higher power supplemental downlink channel in the 1452-1492MHz band, the resulting coverage is not that different from the coverage of a lower frequency band (e.g. 800MHz) since this is determined by the coverage of the uplink. Effectively pairing the 1452-1492MHz band with a lower (sub 1GHz) frequency band results in the additional downlink capacity being available across most of the coverage area supported by the sub-1GHz frequency band.

WRC-15 identified the wider 1427-1518MHz band globally for mobile broadband services. The exact timing of when additional spectrum may become available in this band in Europe is highly uncertain.

3.2.2 Use in the Netherlands

The 1452-1492MHz spectrum is currently available for assignment in the Netherlands.

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[38] European Commission, 'Commission Implementing Decision (EU) 2015/750 of 8 May 2015 on the harmonisation of the 1 452-1 492 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Union (notified under document C(2015) 3061)', published in the Official Journal of the European Union, 8 May 2015.

[39] See Ofcom, 'Variation of the spectrum access licence for 1452-1492 MHz and changes to fixed link use in the paired bands 1350-1375MHz and 1492-1517MHz',

3.2.3 Equipment availability

The 1452-1492MHz band was designated by 3GPP as Band 32. Specifications were originally developed for combining the 1452-1492MHz band with:

- The 900MHz band (Band 8) and 2100MHz band (Band 1) for 3G (UTRA)
- The 800MHz band (Band 20) and 1800MHz bands (Band 3) for 4G (EUTRA).

However the rapid move of the market to 4G has resulted in developments all focusing on the latter combinations – and, in particular, the combination of the 1452-1492MHz band with the 800MHz band.

Network equipment/software upgrades are available to support this combination of bands, however at the timing of undertaking our initial research no compatible handsets had been released. We spoke to a variety of organisations (including the stakeholders listed in Section 2.2) to understand when handsets are likely to become available and widely adopted by consumers. Unfortunately there was no clear answer on this – estimates ranged from initial handsets being available from later this year (2016) with moderate levels of adoption in the Netherlands in 2018 through to handsets not becoming available in volume until 2020 and perhaps beyond.

In respect of the technical complexity of adding support for the 1452-1492MHz band to the handset, we do not believe there are any specific major challenges:

- Chipsets are available supporting the frequency ranges for the Japanese 1500MHz bands[40] and it should therefore not be too challenging to adapt these to cover the 1452-1492MHz band.
- The RF chain in the handset only needs a receiver (since the 1452-1492MHz band is downlink-only)
- The 1452-1492MHz band can share an antenna with GPS.

The issue is therefore primarily one of market demand – and terminal manufacturers having the certainty of demand from their customers (the mobile operators) which in turn depends on governments and regulators being clear about when the spectrum will become available.

Qualcomm has indicated that its chip roadmap will support supplemental downlinks in the 1452-1492MHz band[41].

Shortly before the finalisation of this report, Google released the technical specifications for the new Google Pixel handset[42] and this indicated that the handset will support the combination of the 1452-1492MHz band (Band 32) with the 800MHz band (Band 28). The major recent new handset releases from Apple (iPhone 7) and Samsung (Galaxy Note 7) have not included support for the 1452-1492MHz band,

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[40] The Japanese 1500MHz bands have downlinks in the vicinity of the 1452-1492 MHz band – specifically the lower 1500MHz band (Band 11) covers the frequency range 1427.9-1447.9/1475.9-1495.9MHz whilst the upper 1500MHz band (Band 21) covers the frequency range 1447.9-1462.9/1495.9-1510.9MHz.

[41] See, for example, Qualcomm response to Agcom consultation, 'Consultazione pubblica sulle procedure e regole per l'assegnazione e utilizzo delle frequenze disponibili nella banda 1452 – 1492 MHz per sistemi terrestri di comunicazioni elettroniche: Risposta Qualcomm', March 2015.

[42] See https://madeby.google.com/intl/en_uk/phone/specs/

however we expect that the new handsets launched by these firms in 2017 are likely to include support for the 1452-1492MHz band.

In respect of the combination of the 1452-1492MHz band with other bands:

- Combination with 1800MHz (Band 3): This combination is included in the workplan for 3GPP Release 14 and was also discussed in a technical report[43] on combining two downlink carriers under the 3GPP Release 14 timescale.
- Combination with 2600MHz (Band 7): This combination is included in the workplan for 3GPP Release 14 and was also discussed in the same technical report[43] on combining two downlink carriers under the 3GPP Release 14 timescale.
- Combination with 900MHz (Band 8): This combination is included in the workplan for 3GPP Release 14 but the combination was not discussed in the technical report suggesting it is low priority for Release 14, probably as a consequence of Bands 3 and 7 being used more widely for LTE at present.
- Combination with 700MHz (Band 28): This combination has not been included in the workplan for Release 14.

It therefore appears unlikely that handsets supporting the combination of the 1452-1492MHz band with any sub 1GHz band other than the 800MHz band will become available any time in the near future. At present it appears likely that the next bands that will be supported are the 1800MHz and 2600MHz bands.

In relation to the extended L-Band spectrum (1427-1518MHz) identified for mobile at WRC-15, it will be some time before terminals are available to work across this band since:

- The channel numbering scheme for the carrier centre frequencies (EARFCNs) outside the 1452-1496MHz band has not been defined The EARFCNs for the wider band will not be contiguous, because the adjacent number ranges have already been used for other bands. Furthermore, it is unlikely that 3GPP will define these number ranges until it receives firm input from regulators on the frequency ranges to be supported - i.e. the size of any guard band between the SDL band and radio astronomy below 1427MHz and between the SDL band and MSS above 1518MHz.
  - The lower sub-band of 1427-1452MHz is 25MHz wide, which leads to two likely alternatives; 20MHz mobile spectrum with 5MHz guard band or 25MHz with a substantial geographic exclusion for the lower 5MHz around radio astronomy stations using this band.
  - The upper sub-band of 1492-1518MHz is 26MHz wide, which leads to two likely alternatives; 20MHz mobile spectrum with 6MHz guard band or 25MHz with 1MHz guard band. Studies prior to WRC-15 indicate that the limiting factor is likely to be the blocking performance of mobile satellite system terminals. The studies on coexistence between mobile and MSS are continuing post-WRC-15.
  - It is unlikely that 3GPP will commence the development of specifications for the wider L-Band until these studies are complete and CEPT has defined the frequency range of the wider band – or until an individual administration starts a national licence award process.

[43] See 3GPP, '3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; LTE Advanced inter-band CA for 2DL/1UL (Release 14)', Reference 3GPP TR 36 .714-02-01 V0.2.0, June 2016.

- The 91MHz of spectrum across this band corresponds to 6% of centre frequency at L-Band. This is at the upper limit of the bandwidth that can be achieved for a bandpass filter using the technologies available for terminals. Even so, not all vendors may be able to achieve this, and there may be compromises in insertion loss and steepness of the edges. However:
  - Filter technology is advancing quite rapidly, so these challenges may reduce significantly within a few years.
  - The services below and above the wider L-Band will be radio astronomy and mobile satellite service space-to-earth transmissions. As neither of these have terrestrial transmissions, there is no possibility of receiver blocking of L-Band mobile terminals. This might allow a relaxation of the terminal filtering - which would reduce its complexity and cost. However interference between mobile base stations and radio astronomy may be an issue and a guard band may be required.
- For all of these reasons, terminal vendors are likely to wait before starting to develop the specifications for the wider L-Band.

3.2.4 Compatibility studies

The Annex to the European Commission's Implementing Decision for the 1452-1492MHz band[38] specifies the usage parameters for supplemental downlink use as well as the parameters for providing protection to existing broadcasting services using the band. The usage parameters have been derived from CEPT Report 54[37] which also sets out technical conditions and principles for cross-border coordination between wireless broadband, terrestrial sound broadcasting and aeronautical telemetry services in the 1452-1492MHz band. ECC Reports 202[44] and 227[45] provide further details of the interference assessments that were undertaken in support to the development of these usage parameters.

In relation to the potential future pairing of the 1452-1492MHz band with the 700MHz band (Band 28), The Ministry will need to give consideration to a particular complication that arises between these bands. The second harmonic of the 700MHz uplink band (1406-1466MHz) overlaps with the 1452-1492MHz band which is used for downlinks. This means that the second harmonic of the 700MHz signal produced in the power amplifier of a handset will desensitise the handset's 1452-1492MHz receiver (i.e. increase the noise floor) for the corresponding channels at double the frequency and also, to some extent, the adjacent channels. This will complicate both the definition of the specifications (some frequency combinations cannot be tested) and the implementation (in order to minimise the desensitisation of the adjacent channels). For this reason the assignment process for 700MHz and 1452-1492MHz spectrum should take account of this to ensure that an individual operator does not have a combination of 700MHz and 1452-1492MHz band frequencies that will cause this harmonic relationship to arise. In a combined award of the two bands, the auction could be designed to ensure that incompatible assignments across both bands are not available as options to bidders. If the two bands were awarded separately, for example the 1452-1492MHz band in advance of the 700MHz band, then there is a risk that bidders in the 700MHz auction could engage in strategic bidding with the aim of forcing competitors to bid higher amounts to avoid assignments that are incompatible with the competitors' 1452-1492MHz holdings. There may potentially

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[44] CEPT ECC, 'ECC Report 202, Out-of-band emission limits for mobile/fixed communications network (MFCN) supplemental downlink (SDL) operating in the 1452-1492MHz band', September 2013.

[45] CEPT ECC, 'ECC Report 227: Compatibility studies for mobile/fixed communications networks (MFCN) supplemental downlink (SDL) operating in the 1452-1492MHz band', January 2015.

be scope for the auction rules to take account of this by automatically excluding any 700MHz assignments which are incompatible with the existing 1452-1492MHz holdings of each of the bidders, but this would add complexity to the auction.

One stakeholder that we spoke to expressed interest in using the 1452-1492MHz band for TDD variants of mobile broadband technologies. Although this potential use was considered as one of the options and evaluated in CEPT Report 188[36], and whilst this assessment was on the basis of various regulatory criteria which included the potential for interference with existing services, we are not aware of detailed evaluations being undertaken of the compatibility of use of TDD technologies with services in adjacent bands. This option would not be compatible with the European Commission's Implementing Decision for the 1452-1492MHz band and should the Ministry wish to consider the feasibility of the option to use TDD technologies in this band, it will need to negotiate this at the European Union level and further compatibility studies will need to be undertaken. We are not aware of any equipment that is currently available supporting the deployment of the TDD variant of LTE in the 1452-1492MHz or any existing plans to incorporate such an option in the 3GPP standards.

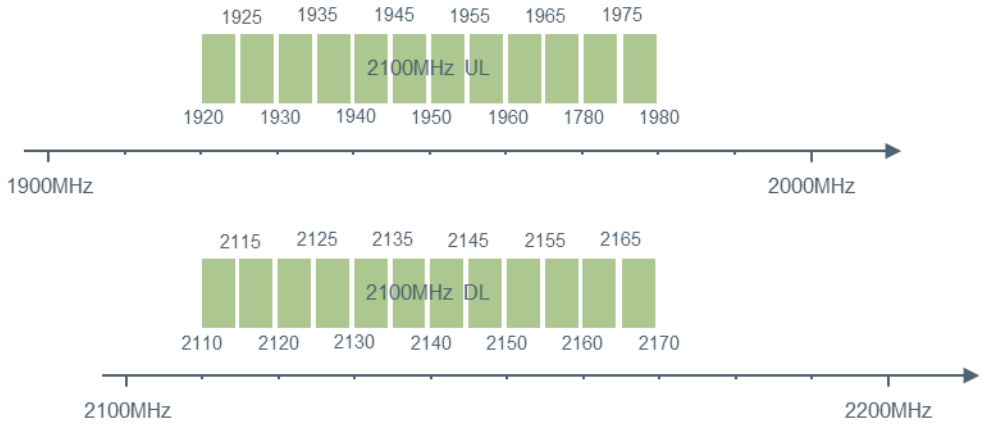
3.3 2100MHz band

The 2100MHz band is currently assigned to mobile operators in the Netherlands and is primarily used for deploying 3G networks – and on some sites some of the spectrum is used for deploying LTE technology. The existing licences are due to expire at the end of 2020.

3.3.1 European harmonisation of the band

In 1998, the European Parliament and Council adopted a decision[46] harmonising the frequency bands 1900-1920MHz, 1920-1980/2110-2170MHz and 2010-2025MHz were harmonised for the introduction of UMTS services from 1 January 2002 at the latest. This defined the band plan for the spectrum as shown in Figure 3-5.

Figure 3-5: Bandplan for 2100MHz band



[46] European Commission, 'Decision 128/1999/EC on the coordinated introduction of a third-generation mobile and wireless communications systems (UMTS) in the Community', published in the Official Journal of the European Community on 22 March 1999.

Over time the usage conditions for the band have been made more neutral allowing the band to be used for new technologies e.g. LTE. In particular in November 2012 the Commission issued an implementing decision[47] which set out new usage conditions for the band using the block edge mask principles applied to other bands. Member states were required to implement the new usage parameters by 30 June 2014 at the latest.

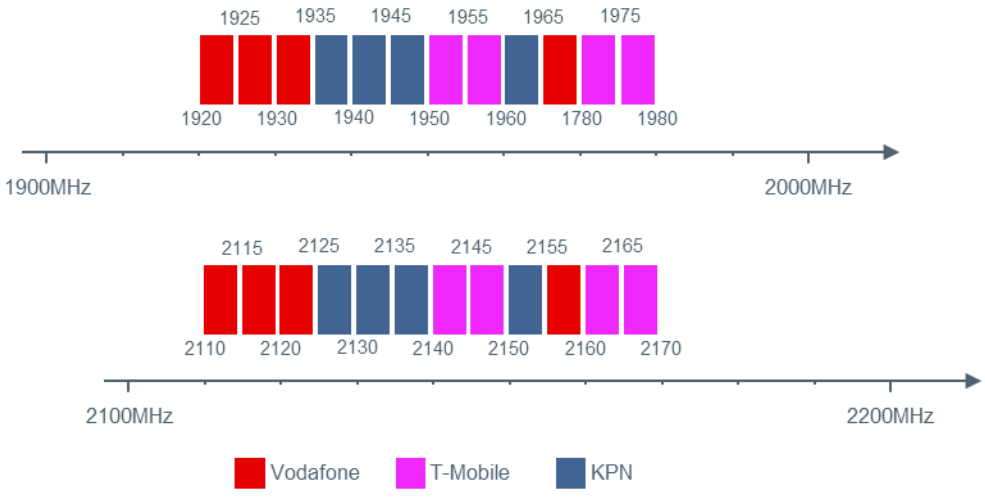
The band has been standardised by 3GPP as Band 1.

The unpaired bands (1900-1920MHz and 2010-2025MHz) have remained largely unused. Work is being undertaken in Europe to define new uses for these bands – the latest expectation is that the 2010-2025MHz will be used for PMSE (wireless video cameras). In respect of the 1900-1920MHz band, interest was initially in use of the band for broadband direct air-to-ground communications (DA2GC) however this appears to be diminishing and this band is increasingly being considered for use for licence-exempt short range devices – including the possibly providing additional spectrum for digital cordless telephones (e.g. using the DECT technology standard). We do not consider these unpaired bands further in this report since they are likely to be allocated through a completely separate process once European harmonisation decisions are made regarding their use.

3.3.2 Use in the Netherlands

As indicated above, the band is currently assigned to mobile operators as shown in Figure 3-6. It can be seen that the current holdings of individual operators are fragmented and during our stakeholder discussions this was raised as a major issue preventing the bands from being used most efficiently e.g. to deploy 20MHz LTE carriers. Stakeholders expressed a strong desire for the band to be re-configured as part of the new assignment process in order to create one contiguous paired block of spectrum assigned to each operator.

Figure 3-6: Existing spectrum assignments in 2100MHz band



[47] European Commission, 'Commission Implementing Decision (EU) of 5 November 2012 on the harmonisation of the frequency bands 1 920-1 980 MHz and 2 110-2 170 MHz for terrestrial systems capable of providing electronic communications services in the Union (notified under document C(2012) 7697) (2012/688/EU)', published in the Official Journal of the European Union, 7 November 2012.

The spectrum is primarily used for the deployment of UMTS (3G) technology however 4G has been deployed on some sites and this trend is expected to continue over the coming years as subscribers acquire 4G terminals and 4G traffic volumes increase whilst 3G traffic volumes fall. Over time it is likely that the band will be migrated for use with 5G technology.

The current assignments are due to expire at the end of 2020. These were originally due to expire on 1 January 2017 but in a Ministerial Decree of December 2014, the licences were extended until 1 January 2021 in order, amongst other reasons, to accommodate the possibility of awarding this spectrum in combination with the 700MHz band in a combined auction in 2019.

3.3.3 Equipment availability

Network equipment and user devices supporting the 2100MHz band for 3G and LTE are widely available. As of June 2016, as previously shown in Figure 3-3, over 2600 LTE devices support the 2100MHz band. Only the 1800MHz and 2600MHz bands have higher levels of device support, despite operator deployments of LTE in the 2100MHz band being (up to now) relatively limited.

3.3.4 Compatibility studies

The European Commission's implementing decision[47] of 2012 set out the criteria for the usage of the band. These were developed from CEPT Report 39[48] which identified the technical conditions which would manage the risk of harmful interference between neighbouring networks at both a national and cross-border level without imposing any particular type of technology, but based on optimised parameters for the most likely use of the band.

We are not currently aware of any specific additional compatibility issues that need to be investigated in relation to the future use of the 2100MHz band. However the future introduction of 5G technology in this band could mean that new investigations need to be undertaken.

[48] CEPT ECC, 'CEPT Report 39: Report from CEPT to the European Commission in response to the Mandate to develop least restrictive technical conditions for 2GHz bands', 25 June 2010.

4 Uses of and demand for spectrum

In this section we consider potential alternative uses of the three spectrum bands, building on the initial discussions in Section 3. Our assessment includes an assessment of the amount of spectrum sought for each of the uses across the bands, including a general forecast of future spectrum demand for mobile broadband services.

4.1 Mobile communications services

With the rapid rise in data traffic that is being experienced by mobile operators, additional capacity to serve this demand is being provided through a combination of the following:

- deployment of new more spectrally efficient technologies – for example LTE (4G) and, over time, 5G
- deployment of new sites – in particular small cells
- deployment of new spectrum bands.

Unsurprisingly, all mobile industry stakeholders that we spoke to discussed the need for additional spectrum to be made available to support mobile broadband services. In relation to interest in each of the specific frequency bands under study:

- **700MHz**: The underlying propagation benefits of this band were repeatedly highlighted by stakeholders in view of providing indoor coverage and wide area coverage across less populated areas, It was noted that there is a shortage in the amount of low frequency (sub 1GHz) spectrum currently available and the fact that this is not evenly distributed across the operators. The expectation was that, given the timing of availability, this band is likely to be used for 5G technology though it is also largely universally noted that 5G in bands below 3GHz is most likely to be an evolution of the 4G (LTE) technology rather than a completely new radio interface so it may be that if 5G is delayed, the latest available variant of 4G could be deployed initially. Interest in spectrum outside the core 2×30MHz paired part of the band was limited – several stakeholders mentioned that there may be challenges in making use of the 'duplex gap' for mobile broadband services but in the event that these issues could be resolved then interest in this spectrum may rise for such use.

- **1452-1492MHz**: This band is primarily of interest for supplementary downlinks. The degree of interest in this band was varied, primarily in view of concerns regarding the availability of handsets supporting this band. There were a wide variety of views of when the band could start to be used effectively in view of the time required for supporting handsets to arise – this ranged from 2018 to beyond 2020. We expected that interest in the band and forecast timing of usefulness of the spectrum might differ between those organisations that hold 800MHz spectrum assignments and those that do not in view of the 800MHz/1452-1492MHz band combination being likely to be the first to be implemented in handsets – in fact, however, we found quite a range of views amongst the three operators holding 800MHz spectrum.

- **2100MHz**: The three operators with existing assignments in this band all stressed that the spectrum is an important component of their overall network operations today – primarily for 3G but also some spectrum on some sites is already starting to be re-farmed over to 4G as a result of falling levels of 3G traffic. The operators also stressed the need for the band to be re-configured at the time of re-assignment in order to ensure that each operator winning spectrum has spectrum in a single contiguous

block – this is particularly important for use of the band for LTE in order to allow the maximum LTE carrier bandwidth to be deployed. We expect that several of the mobile operators may choose to eventually migrate the remainder of their 3G traffic to the 900MHz enabling all of the 2100MHz band to be used for LTE – and in the longer-term, 5G.

Possible new market entrants were potentially interested in spectrum across all three bands – but with the expectation that prices for the core 2×30MHz in the 700MHz would be high, interest was greatest in the 2100MHz band[49] and potentially the other parts of the 700MHz band (including the 'duplex gap'), especially if the usage conditions could be made to be compatible with TDD use of the spectrum. One organisation expressed general interest in the use of TDD in all bands if this could be accommodated in the usage conditions. A question was also raised as to whether the mobile operators do actually need all of the spectrum that is currently assigned to them as well as additional spectrum bands – we explore this issue below in our assessment of future spectrum demand.

One key issue raised by many of the stakeholders was the issue of carrier aggregation combinations across different spectrum bands. Carrier aggregation is the combination of two or more LTE carriers, so that traffic can be dynamically shared between them. There are three technological aspects:

- Signalling: The signalling for LTE carrier aggregation has been supported in 3GPP standards from the outset since this was necessary to demonstrate the support of 100MHz channel bandwidth needed for the development of IMT-Advanced. It supports any combination of up to five bands.

- Base station: The RF (radio frequency) requirements for a base station supporting multiple bands are the same, whether they are used independently or jointly with carrier aggregation.

- Terminals: Carrier aggregation can have a substantial impact on the architecture of terminals, because of the need to support more than one downlink carrier, and perhaps more than one uplink carrier. This increase in complexity, and possible degradation in performance, depends substantially on the specific combination of bands. Therefore, the support of a carrier aggregation for a particular combination of bands is determined by the inclusion of the radio frequency requirements for that combination in the 3GPP specification for terminals (TS 36.101).

There are three basic types of carrier aggregation from the terminal perspective:

- **Intra-band aggregation**: Two or more carriers within the same band, which may or may not be adjacent.

- **High band / low band aggregation**: The standard RF architecture for an LTE terminal has completely separate RF chains for the bands below 1GHz (low band) and above 1.7GHz (high band). These two frequency ranges are separated by a diplexer, which is the final component in the path to the antenna. As a result, there is generally little added complexity in aggregating any one band below 1GHz with any one band above 1.7GHz, because the separate RF components to do this already exist in the terminal. We understand that when the 1452-1492MHz band is added to a terminal, the diplexer transition frequency will be changed from 1.7GHz and set to be below 1452MHz, which means that the 1452-1492MHz band will count as a 'high band'.

[49] Use of the 2100MHz band on its own would enable a new entrant to offer services in urban/suburban areas and potentially make use of WiFi connectivity and fixed broadband connections (e.g. in the home) for providing voice and data service connectivity indoors.

- **Other inter-band aggregation combinations**: Any combination of two high bands, or two low bands, or more than two bands, will require extra filtering to separate the signals for different bands (called duplexers), and switches change the configuration depending on the band combination being used. The complexity of these extra components, and the extra attenuation of the signals passing through them, will depend on the frequency relationship between the bands. Therefore, the performance requirements for each band combination need to be studied separately and are therefore individually specified in TS 36.101.

We understand that the main carrier aggregation scenarios relating to the 700MHz, 1452-1492MHz and 2100MHz bands for which the 3GPP terminal specifications have been developed are as follows:

- 700MHz paired spectrum (Band 28):
  - 2 x Downlink with 800MHz (Band 20), 900MHz (Band 8), 1800MHz (Band 3), 2100MHz (Band 1), 2600MHz (Band 7)
  - 3 x Downlink with 1800MHz & 2100MHz (Bands 1 and 3), 1800MHz & 2600MHz (Bands 3 and 7) & 2100MHz & 2600MHz (Bands 1 and 7), 2600MHz & 2600MHz[50] (Bands 7 and 7)
  - 4 x Downlink with 1800MHz, 2600MHz & 2600MHz (Bands 3, 7 and 7)
  - 5 x Downlink with 1800MHz, 1800MHz 2600MHz & 2600MHz (Bands 3, 3, 7 and 7), 1800MHz, 2100MHz 2600MHz & 2600MHz (Bands 3, 1, 7 and 7)
  - 2 x Uplink with 2100MHz (Band 1), 2600MHz (Band 7)
  - Combined multi-carrier uplink and downlink combinations have also been standardised

- 700MHz 'duplex gap' (Band 67):
  - 2 x Downlink with 800MHz (Band 20)

- 1452-1492MHz (Band 32):
  - 2 x Downlink with 800MHz (Band 20)

- 2100MHz (Band 1):
  - 2 x Downlink with 700MHz (Band 28) 800MHz (Band 3), 900MHz (Band 8), 2600MHz (Band 7)
  - 3 x Downlink with 700MHz and 1800MHz (Bands 28 and 3), 700MHz and 2600MHz (Bands 28 and 7), 800MHz and 1800MHz (Bands 20 and 3), 800MHz and 2600MHz (Bands 20 and 7), 900MHz and 1800MHz (Bands 8 and 3), 900MHz and 2600MHz (Bands 8 and 7), 1800MHz & 1800MHz (Bands 3 and 3), 1800MHz & 2600MHz (Bands 3 and 7), 1800MHz & 2600MHz TDD (Bands 3 and 41), 2600MHz TDD and 2600MHz TDD (Bands 41 and 41)
  - 4 x Downlink with 800MHz, 1800MHz and 2600MHz (Bands 20, 3 and 7), 900MHz, 1800MHz and 1800MHz (Bands 8, 3 and 3), 900MHz, 1800MHz and 2600MHz (Bands 8, 3 and 7), 1800MHz, 2600MHz and 2600MHz (Bands 3, 7 and 7)
  - 5 x Downlink with 700MHz, 1800MHz, 2600MHz and 2600MHz) (Bands 28, 3, 20, and 20)
  - 2 x Uplink with 700MHz (Band 28), 900MHz (Band 8) and 1800MHz (Band 3)
  - Combined multi-carrier uplink and downlink combinations have also been standardised.

The specifications for many other combinations are under ongoing development by 3GPP. Some examples include:

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[50] Please note that multiple mentions of an individual band are to enable the support of multiple carriers within that band in view of the maximum carrier size of LTE being set at 20MHz. Therefore 2600MHz and 2600MHz would enable the inclusion of two 2600MHz carriers (each up to 20MHz bandwidth each).

- 700MHz paired spectrum (Band 28):
  - 3 x Downlink with 900MHz and 2600MHz TDD (Bands 8 and 41), 1800MHz and 2600MHz TDD (Bands 3 and 41), 2100MHz and 2600MHz TDD (Bands 1 and 41)

- 1452-1492MHz (Band 32):
  - 2 x Downlink with 1800MHz (Band 3)
  - 3 x Downlink with 800MHz and 1800MHz (Band 20 and 3), 800MHz and 2600MHz (Band 20 and 7).

The pace of development (and relative priority) is uncertain – in reality it can depend on which individuals and organisations are taking the lead on the standardisation work and the importance of the band combination to those organisations. Furthermore the development of specifications by 3GPP is by no means a guarantee that the functionality will appear in user devices or of the timing that such functionality will become available in devices. It is purely an indicator of current interest.

Overall, given the large number of supported carrier aggregation combinations, we do not believe any of the mobile operators is at a potential advantage or disadvantage to their competitors in respect of the adoption of carrier aggregation band combinations in terminals, other than:

- Obviously if an individual operator has less spectrum/fewer spectrum bands than another operator, then clearly there will be fewer options for combining bands and the overall peak data rates and network capacity that can be supported. However the spectrum that is held by such operators is in frequency bands which are widely supported in existing user devices and the standards development processes for carrier aggregation combinations.

- The key exception relates to carrier aggregation with the 1452-1492MHz band since, as discussed in Section 3.2.3, operators holding 800MHz spectrum are at an advantage to organisations not holding 800MHz spectrum since the development of user devices appears to be primarily focusing on the combination of the 800MHz and 1452-1492MHz bands at this time – and, as indicated in Section 3.2.3, the first handset supporting this combination (Google Pixel) has now been announced. Furthermore standardisation work is ongoing by 3GPP for combinations of the 1452-1492MHz and 800MHz band with other bands (specifically 1800MHz and 2600MHz) and we believe this it is likely that user devices supporting these three band combinations will become available before user devices supporting two band combinations involving the 1452-1492MHz band with any band other than the 800MHz band (specifically the 700MHz and 900MHz and 1800MHz bands). This would mean that organisations holding 800MHz spectrum are in an even stronger position in respect of their ability to utilise the 1452-1492MHz band in the short-term compared to organisations not holding 800MHz spectrum.

Future demand for spectrum

We have developed a model to forecast the amount of spectrum required for mobile communications services over the next 10 years, in the light of the predicted growth in data traffic levels. This has been constructed to consider a ‘generic’ network operator (with 5000 sites across the Netherlands, serving 25% of mobile customers in the Netherlands) and the spectrum demand of this operator has been scaled up (i.e. multiplied by 4) to calculate the overall market demand for spectrum.

As the Netherlands currently has relatively low usage levels of data traffic, we have run our models under two alternative traffic scenarios:

- Low traffic. Here traffic is assumed to follow the annual growth levels predicted in third party forecasts.
- High traffic. Here traffic is assumed to converge to the Western European average (per mobile subscriber) by 2020 and after this period is then assumed to grow at the same annual rate as for the low scenario.

Full details of our modelling approach, assumptions and results can be found in Annex A.

In summary we found that:

- Under the low traffic scenario, the amount of available spectrum (once the 700MHz band and 1452-1492MHz band are included) would be sufficient for forecast modelled traffic until 2025. In such a scenario it may be that the 2.6GHz band does not get fully utilised until the 2020s (assuming it is the least preferred of all bands in view of its poorer propagation characteristics).
- Under the high traffic scenario, as shown in Figure 4-1 and Figure 4-2, around an additional 140MHz of spectrum will need to be made available to support downlink traffic by 2025 – the additional demand over and above the 700MHz and the 1452-1492MHz bands arises from 2024 onwards.
- In the low traffic scenario, the 1452-1492MHz band would start to be deployed in a small number of sites from 2019 onwards, with more widespread deployment in the mid-2020s. In the high traffic scenario, the 1452-1492MHz band would start to be deployed in a small number of sites in 2018, with more widespread development occurring from 2020 onwards. Please note that our modelling work assumed that the 1452-1492MHz band would theoretically be available for use from 2017 onwards and would be deployed as required based on forecast traffic levels from users, without taking account of whether there is a sufficiently large base of handsets compatible with the 1452-1492MHz band in any given year to make deployment by an operator worthwhile.

Figure 4-1: LTE/5G spectrum demand for a generic operator under high traffic demand scenario

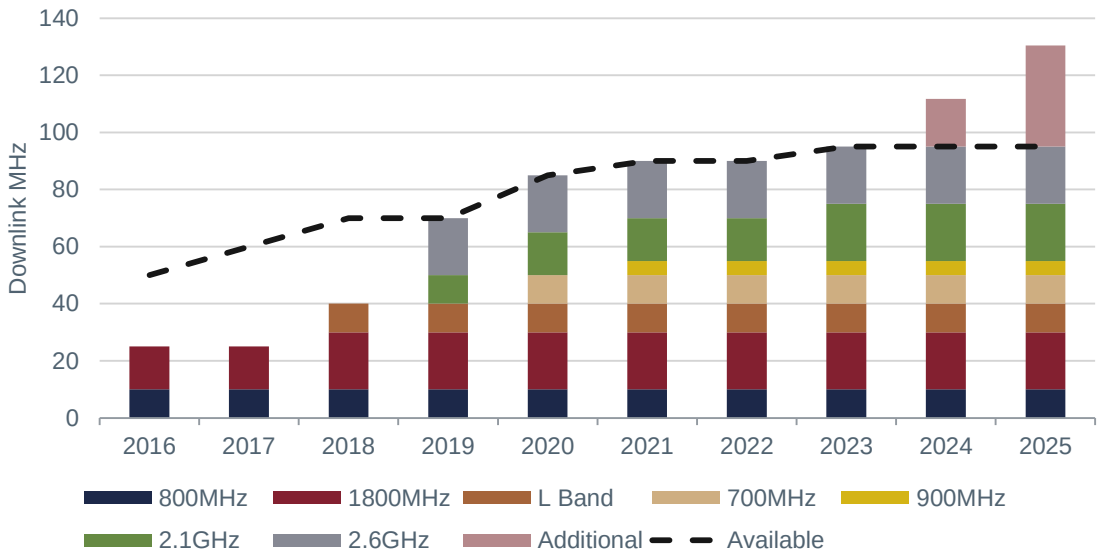
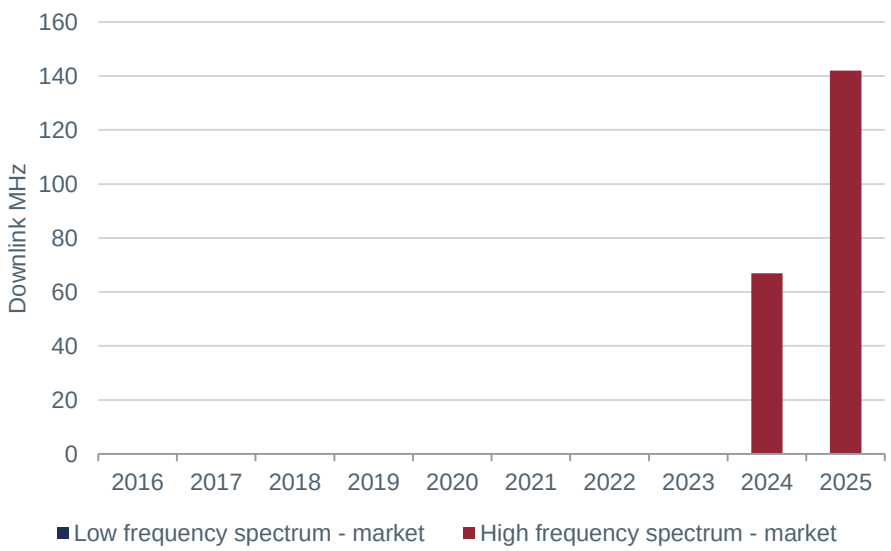


Figure 4-2: Additional downlink spectrum required for whole market under high traffic demand scenario



We also considered how the spectrum requirements may vary between a converged fixed-mobile operator and a mobile only operator. For modelling purposes we considered that the mobile only operator might need to carry extra traffic as a result of not being able to off-load as much traffic onto the fixed network (e.g. on the home broadband connection of a friend when visiting their house). Under an assumption that a converged fixed-mobile operator is on average able to off-load 20% more traffic than a mobile only operator, we projected spectrum demand for the different types of operator under both low and high traffic scenarios. These are shown in Figure 4-3 and Figure 4-4, respectively. As expected the demand for spectrum from a mobile only operator is likely to be higher – what is uncertain is the extent to which a mobile only operator will be able to derive additional customer revenues from carrying the additional traffic over its mobile network if it is carried by the converged fixed-mobile operator over a fixed connection at no additional cost to the end customer.

Figure 4-3: LTE/5G spectrum demand for downlink traffic – low traffic scenario

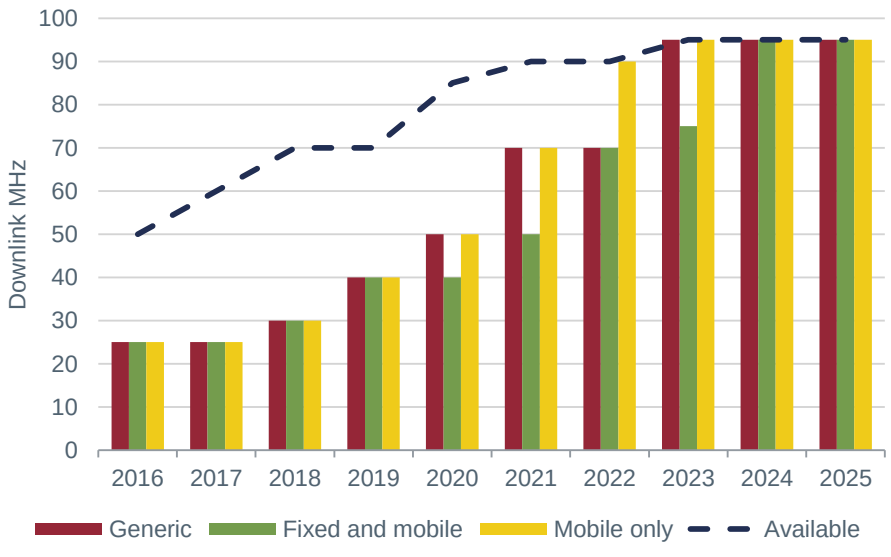
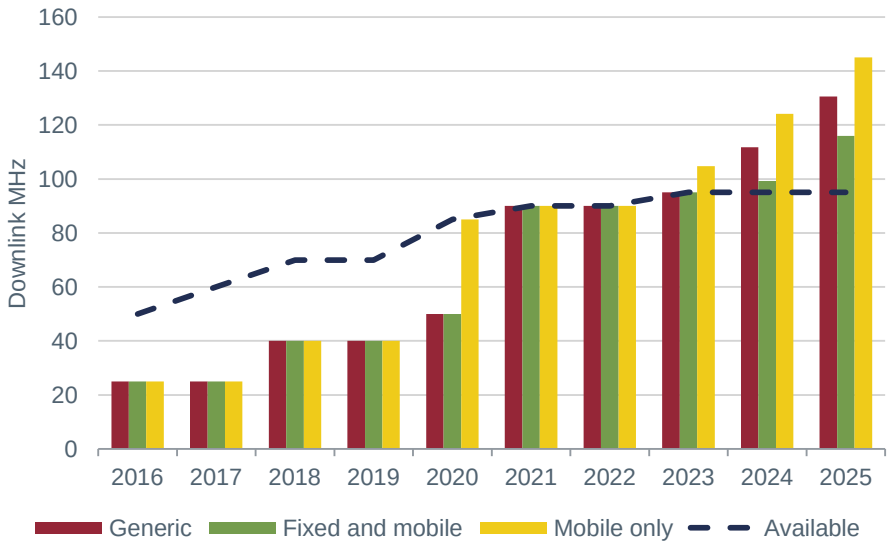


Figure 4-4: LTE/5G spectrum demand for downlink traffic – high traffic scenario



4.2 Internet of Things/Machine to Machine communications

The Internet of Things (IoT)/Machine to Machine (M2M) communications refers to the connection of billions of devices (including sensors) facilitating the transmission of data for intelligent processing. The term covers a vast array of potential applications including (but by no means limited to):

- Smart energy – intelligent integration of decentralized applications measuring energy production and consumption, including widespread adoption of smart meters in homes
- Smart transport – advanced applications providing innovative services relating to different modes of transport and traffic management including supporting autonomous self-driving vehicles
- Smart homes – Advanced application systems allowing private and public buildings to be equipped with lighting, heating, and electronic devices that can be controlled remotely
- Smart health – medical and public health and personal wellness practices supported by advanced applications.

The wide variety of potential uses also have differing connectivity needs:

- Large amounts of data may need to be continuously transmitted over short-ranges in real-time. A good example of this is communications between connected cars.
- Very small bursts of data may need to be occasionally sent – but over long distances in order to reach central nodes. A good example of this is the transmission of meter readings from smart meters in homes.

The spectrum bands under consideration in this study are more suited to the second of the above categories (providing wide area communications) and consequently we focus on these types of IoT uses in the remainder of this report. The first type of communications is likely to make use of higher frequency bands – for example the 5875-5905MHz band which is designated for Intelligent Transport Services.

The requirement for low data rate wide area communications has to-date primarily been met through the deployment of specialised technologies:

- Sigfox was founded in 2009 in France and has developed a technology suitable for a low power wide area network and subsequently deployed the technology in several countries including France, Ireland, the Netherlands, Portugal and Spain. In several countries Sigfox's deployment is in conjunction with a local partner – Aerea in the case of the Netherlands. Several major telecom operators are investors in Sigfox including NTT DoCoMo, SK Telecom and Telefonica,

- LoRa is a specification for a low power wide areas network that was primarily developed by Semtech, a semiconductor company. The LoRa Alliance has been established to encourage the development of a wide and open ecosystem for the technology and its members include Bouygues Telecom, KPN, SK Telecom, Softbank and Swisscom. During 2016 KPN deployed a LoRa network across the Netherlands. Nationwide networks have also been deployed in Germany and South Korea.

Additionally HaLow is being developed by the WiFi Alliance as an alternative low power solution based on IEEE802.11ah technology.

All of the above technologies make use of licence-exempt spectrum – principally the 868MHz band. The narrow bandwidth of the technologies means that even low transmit powers can result in very high coverage. They are suitable for devices which make infrequent transmissions of small amounts of data.

In response the mobile industry has developed specifications for three low power wide area technologies as part of 3GPP Release 13:

- Narrowband IoT (NB-IoT) has gained the most interest to date. It utilises one resource block of LTE (i.e. the equivalent of 180kHz of spectrum) and supports data rates of up to 250kbps. NB-IoT is gaining increasing traction and Vodafone has announced plans for a widespread deployment of the technology in 2017.

- Extended coverage GSM IoT (EC-GSM-IoT) makes use of GSM's existing 200kHz channels. This is essentially a development of the EDGE standard and supports data rates of up to 140kbps.

- Enhanced Machine Type Communications (eMTC) will utilise the narrowest channel bandwidth in LTE (1.4MHz). eMTC is designed for higher throughput applications (supporting data rates of up to 1Mbps).

All three technologies make use of a mobile operator's licensed spectrum holdings can be deployed by operators with modern base station sites by means of a software upgrade. In the Netherlands, Vodafone estimates 95% of its existing base stations can support NB-IoT with a 'straight-forward software upgrade'.

Our discussions with the mobile operators in the Netherlands indicated that several are actively considering the deployment of NB-IoT. This is likely to be in the 800MHz and 900MHz band initially and with the expectation that 5G will incorporate IoT functionality, the 700MHz band is also likely to be used for wide area coverage IoT applications from 2020 onwards. Other organisations were also interested in possible use of the 700MHz band for IoT applications – potentially utilising technologies that currently operate in licence-exempt spectrum bands. This interest was mainly in spectrum outside the core 2×30MHz band. One challenge raised was that M2M applications currently envisaged in the European Commission's Implementing Decision[20] are expected to make use of the 733-736/788-791MHz range – however this does not currently facilitate use by TDD technologies which was of interest to some stakeholders. It is also possible that other parts of the 'duplex gap' spectrum could be used for IoT TDD technologies but this may need legal clarification in respect of compliance with the Implementing Decision as it is currently written. Furthermore, compatibility studies would need to be undertaken.

In respect of alternative bands, CEPT ECC is currently undertaking work on the harmonisation of the 870-876/915-921MHz bands for sharing between GSM-R and low power systems (e.g. short range devices, RFIDs etc). The 915-921MHz spectrum has the possibility of being harmonised on an international basis.

Another possibility could be the allocation of part of the 700MHz 'duplex gap' spectrum on a licence-exempt basis which could be used as additional spectrum to supplement the 868MHz band for IoT applications, although we understand that the Radiocommunications Agency has recently commissioned a consultancy study[51] which concluded there was no need for additional spectrum to be allocated for low power wireless access IoT uses in the short to medium-term.

In respect of the amount of spectrum required for low power wireless access applications, our discussions with stakeholders suggested that the use of the 3GPP technologies such as NB-IoT would use the spectrum available to mobile operators and this demand has already been considered in Section 4.1 above. For a new network using one of the other technologies, stakeholders indicated that less than 1MHz of spectrum in the 700MHz band would be required. If there were multiple providers of networks, then the spectrum requirement could be greater than 1MHz in the event that the providers used incompatible technologies that required the creation of guard bands.

4.3 Public Protection and Disaster Relief

The emergency services community has historically made use of dedicated networks for emergency services communications using dedicated spectrum. In Europe, spectrum in the 380-400MHz band was harmonised for the deployment of networks based on the TETRA and Tetrapol standards. Whilst these networks were very suited to meeting the voice communications needs of the emergency services, the supported data rates are very basic and the emergency services are seeking access to broadband communications services.

There is considerable debate over the best way to provide this service both across countries and within countries. It is generally agreed that use will be made of commercial LTE technology with overlay applications providing additional security and functionality (e.g. for voice, group call, push to talk and priority and pre-emption services). However the means of providing the underlying network has several alternatives:

- Purchase of network capacity from one or more commercial mobile operators. This is the approach that has been adopted in the UK with EE being awarded a contract by the UK Government.
- Deployment of a dedicated mobile broadband network using dedicated spectrum. We understand that Germany is considering deploying such a dedicated network on a nationwide basis. Additionally the Swedish government is examining this possibility with a report on the topic due to be delivered to the government in February 2017.
- Hybrid options including:
  - Deployment of a dedicated network in key geographic areas with use of commercial networks in other areas. The French government has announced plans to deploy such a network making use of

[51] Dialogic, 'The wireless Internet of Things: Spectrum utilisation and monitoring', Publication number 2016.032-1618 v1.100, 19 August 2016.

spectrum in the 700MHz band (698-703/753-758 MHz and 733-736/788-791MHz) for the dedicated network.

– Provision of dedicated spectrum to one or more commercial network operators which then supplement this spectrum with further capacity from the spectrum they utilise for commercial purposes when this is required (this could be from the 2×30MHz of spectrum in the core 700MHz band but also supplemented with capacity from other bands held by the mobile operator(s)).

In the Netherlands the government has yet to make a decision about the approach it wishes to take so all these options are possibilities. From our discussions with stakeholders we understand that it may take 3-4 years before the government makes a decision on this matter.

In respect of the spectrum requirements, ECC Report 199[52] estimated that 2×10MHz of spectrum was needed to meet the needs for emergency service users. It was not possible to identify this amount of spectrum from the existing 380-400MHz allocation and so the 700MHz band was considered as a potential source of spectrum. We understand from stakeholders that if directional antennas are used with the 700MHz band at the existing base station sites where the emergency services TETRA network was deployed in the Netherlands, the coverage of a 700MHz LTE network would not be that different from the coverage of the TETRA network using 380-400MHz spectrum.

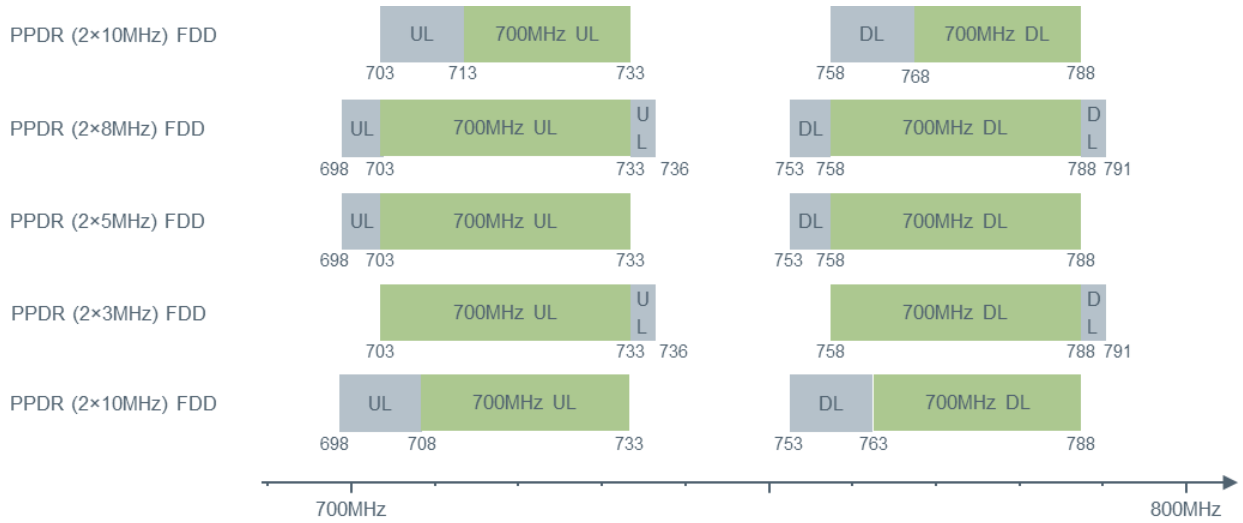
ECC Report 218[27] identified a number of alternative bandplan options for PPDR in the 700MHz band. These include:

- Use of spectrum from the core 2×30MHz part of the band i.e. 703-733/758-788MHz e.g. the bottom 2×10MHz (703-713/758-768MHz)
- Use of the 698-703/753-758MHz band and the 733-736/788-791MHz band (i.e. a total of 2×8MHz of spectrum). This is the option adopted by the French government. We understand this is also being considered by Germany.
- Use of the 698-703/753-758MHz band only
- Use of the 733-736/788-791MHz band only
- Use of the 698-703/753-758MHz band combined with 2×5MHz from the core 2×30MHz band (703-708/758-763MHz.

These options are illustrated in Figure 4-5.

[52] CEPT ECC, 'ECC Report 199: User requirements and spectrum needs for future European broadband PPDR systems (Wide Area Networks)', May 2013.

Figure 4-5: Options for providing dedicated spectrum for PPDR from 700MHz band



As discussed in Section 3.1.4, some commentators have indicated that the 698-703/753-758MHz band is less likely to be used for PPDR than the 733-736/788-791MHz band in view of the equipment availability as a result of the challenges of developing the filters required to protect digital terrestrial television broadcasting in the adjacent band (Channel 48), whereas equipment supporting the 733-736/788-791MHz spectrum is already available since this falls within the APT700 bandplan.

In respect of the Netherlands, it is not clear how much spectrum will be required for PPDR since there are no decisions yet in respect of the approach the Netherlands government will follow for providing broadband communications services to the emergency services community. The mobile operators generally expressed strong concerns about any of the core 2×30MHz of 700MHz band spectrum being set aside/reserved for a dedicated emergency services network. Stakeholders indicated that discussions were being held regarding the possible requirement for winners of 700MHz spectrum to be mandated to provide capacity to PPDR users or being required to 'harden' some of their base stations (for example installation of power generators and battery back-up facilities, installation of duplicate backhaul connections for redundancy purposes) as one of the obligations in the licence for use of the 700MHz spectrum. Mobile operators generally felt that any such requirements/obligations should be undertaken in a separate process by the government as part of its procurement of the overall solution for emergency services broadband communications.

4.4 Programme Making and Special Events

The PMSE community makes extensive use of the UHF (470-870MHz) band for wireless audio systems including wireless microphones, in-ear monitors and audio links in support of programme making and other cultural events including theatre productions and musicals. Because of the latency associated with digital systems, these microphones continue to be based on analogue technology and require spectrum in line with the audio bandwidth they wish to cover.

The wireless audio devices historically operated in the 'white spaces' between terrestrial television transmission networks (areas of the country where the frequency was not needed for reception of television services but where signals may still propagate meaning that it could not be used for another high power broadcasting transmitter). With the move to digital terrestrial television, the overall amount of spectrum allocated to broadcasting has reduced (initially to accommodate the 800MHz mobile band created as part

of the digital dividend and now also to accommodate the new 700MHz band) – this has meant that the amount of spectrum allocated to television broadcasting in the UHF band has fallen by almost 45%. Additionally digital terrestrial television transmissions can be made on adjacent channels from the same transmitter site (this was not possible when analogue transmissions were used) and this has further reduced the amount of spectrum available for PMSE. The issue of a potential shortage of spectrum for PMSE as a result of the migration to digital broadcasting was recognised in CEPT Report 32[53], published in October 2009, which noted that PMSE's demand for spectrum would continue to rise in the medium-term at the same time as use of the UHF would need to be adapted in view of the creation of the 800MHz band and that new frequency bands would need to be found for PMSE wireless audio systems in addition to the 470-790MHz UHF band.

As a consequence of this, the European Commission issued a mandate to CEPT[54] in December 2011 to investigate technical conditions for harmonisation conditions for wireless radio microphones as well as cordless video cameras. In response CEPT Report 50[55] recommended that the 821-832MHz and 1785-1805MHz bands (which are duplex gaps within the mobile 800MHz and 1800MHz bands) could be harmonised for use for wireless audio applications.

A Commission Implementing Decision[56] was issued in September 2014 which required member states to make the 823-832MHz and 1785-1805MHz bands available under harmonised conditions for use for PMSE wireless audio applications within 6 months of the date of the Decision. Furthermore the Implementing Decision required member states to make at least an additional 30MHz of spectrum available for PMSE wireless audio equipment use within this period, though the exact frequencies could vary by member state.

As discussed in Section 3.1.1, CEPT Report 53[16] and CEPT Report 60[17] identified PMSE as a potential use of spectrum in the duplex gap of the 700MHz band (733-758MHz) and spectrum in the 694-703MHz range. Our discussions with stakeholders representing PMSE spectrum users suggested that this spectrum would be of interest, though as 'duplex gap' and 'guard band' spectrum there are constraints on the extent to/ways in which the spectrum could be used so it is not ideal. Nonetheless stakeholders clearly recognised this spectrum would be considerably better than the option of no additional spectrum. The stakeholders indicated that there was a need in the Netherlands to find an additional 30MHz of spectrum to meet future PMSE demand for wireless audio applications. Furthermore stakeholders were keen to highlight the extent to which the 700MHz range frequencies are currently being utilised for PMSE – potentially thousands of

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53 CEPT ECC, 'CEPT Report 32: Report from CEPT to the European Commission in response to the Mandate on "Technical considerations regarding harmonisation options for the digital dividend in the European Union. Recommendation on the best approach to ensure the continuation of existing Program Making and Special Events (PMSE) services operating in the UHF (470-862MHz), including the assessment of the advantage of an EU-level approach"', 30 October 2009.

54 European Commission, 'Mandate to CEPT on technical conditions regarding spectrum harmonisation options for wireless radio microphones and cordless video-cameras (PMSE equipment)', 15 December 2011.

55 CEPT ECC, 'CEPT Report 50: Report A from CEPT to the European Commission in response to the Mandate "On technical conditions regarding spectrum harmonisation options for wireless radio microphones and cordless video-cameras (PMSE equipment)" Technical conditions for the use of the bands 821-832MHz and 1785-1805MHz for wireless radio microphones in the EU', 8 March 2013.

56 European Commission, 'Commission Implementing Decision of 1 September 2014 on harmonised technical conditions of radio spectrum use by wireless audio programme making and special events equipment in the Union', published in the Official Journal of the European Union on 3 September 2014.

different systems each day supporting the development of programme, live broadcasts, theatre/musical productions and other events.

There was little interest in the 1452-1492MHz and 2100MHz bands for PMSE as it was recognised that the bands had been harmonised for use for wireless broadband communications. Nonetheless the PMSE stakeholders were keen to stress that identifying spectrum in the 2GHz range is very important to support wireless video (including mobile camera applications) – candidate bands for such applications included the 2.3-2.4GHz and 2.7-2.9GHz ranges.

In respect of the compatibility of use of PMSE in the 700MHz band with other applications, as discussed in Section 3.1.4, ECC Report 221[29] recommended mitigation measures to ensure the compatibility of use of PMSE with other services. Such measures include:

- The potential need for some power restrictions on PMSE transmissions.
- The possible need for a guard band to protect against harmful interference being caused to mobile signal reception.
- The need for PMSE to undertake a quality of service check in the radio environment before use.

In June 2016, the European Commission requested[57] the Radio Spectrum Policy Group to provide an Opinion on the long-term strategy for providing sufficient spectrum for wireless audio and video PMSE applications. This work is likely to result in further assessment of the potential for utilising the 694-703MHz and 733-758MHz bands for PMSE at a European level and could have implications for the demand from PMSE stakeholders for spectrum in these frequency ranges as well as the harmonised conditions to apply to use of these frequency ranges. The final draft of the Opinion is scheduled to be released in November 2017 for public consultation and any subsequent proposals for European Commission Decisions could follow in 2018.

4.5 Summary of demand

Figure 4-6 summarises our overall assessment of demand for spectrum in the 700MHz, 1452-1492MHz and 2100MHz bands for the different potential uses of the spectrum.

[57] European Commission, 'Request for an Opinion from the Radio Spectrum Policy Group on a long-term strategy on spectrum requirements facing the future needs and use of wireless audio and video PMSE applications', 8 June 2016.

Figure 4-6: Summary of demand for spectrum in 700MHz, 1452-1492MHz and 2100MHz bands

Use/user	700MHz (2×30)	700MHz (Other)	1452-1492MHz	2100MHz
Existing mobile operators	High demand	No/Low demand	Medium demand (timing varies from 2018 to beyond 2020)	High demand
Potential mobile entrants	Low demand[58]	Low demand (unless TDD technologies can be accommodated)	Low demand (unless TDD technologies can be accommodated)	High demand
PPDR	Possibly Medium[59]	Possibly High[59]	None	None
IoT/M2M	None[60]	Medium	None	None
PMSE	Not applicable[61]	Medium/High	None	None

In addition, our assessments indicate that potentially around an additional 140MHz of downlink spectrum will need to be identified for use for mobile broadband services in the early to mid-2020s in the event that the high data traffic growth scenario arises. We note that this demand for additional high frequency spectrum could be met from use of spectrum in the 3.5GHz range which we have not included in our forecasts. This is a European harmonised band for wireless broadband communications however it cannot currently be used for wireless broadband services across all of the Netherlands due to existing uses.

[58] Demand constrained due to expected high prices for this spectrum.

[59] Depends on approach chosen by government – demand shown is if a dedicated PPDR network solution is chosen.

[60] No demand for specific spectrum dedicated for IoT/M2M use in this band in view of expected high prices for this spectrum. Spectrum assignments made to mobile operators in this band could be used for providing IoT/M2M services using 3GPP technologies such as NB-IoT.

[61] No interest from PMSE in this band since spectrum has been harmonised with the technical characteristics set primarily for use for wireless broadband networks.

5 Linkages in demand across frequency bands

In this section we consider the strength of linkages between the bands in respect of the business cases of potential users of the spectrum. This includes consideration of whether the bands are complementary in that the success of the business case for one band is strongly dependent on having spectrum holdings in the other band and also the degree to which the bands are close substitutes (the degree to which the bands are alternatives to each other) in which case there are likely to be benefits in awarding the bands together to avoid any artificial scarcity issues.

5.1 Assessment of linkages across band combinations

5.1.1 Linkages within the 700MHz band

As discussed in Sections 3 and 4, there are several potential uses of spectrum in the 700MHz band. As there are differences in the maturity of standardisation and identifications of uses/demand for the different parts of the 700MHz band (the core 2×30MHz and the other spectrum), we start our analysis of linkages by considering the extent of linkages within the overall 700MHz band.

We undertake this assessment by considering the linkages for different potential uses and users of the spectrum:

- Use for mobile broadband services. Here the core 2×30MHz band is of considerable interest to existing mobile operators and some interest to potential new entrants. The other 700MHz spectrum could be used for supplementary downlinks, which would lead to a strong linkage between this spectrum and the core 700MHz band, though this is increasingly looking unlikely. As an alternative this spectrum could be used for TDD technologies in which case there may be a linkage for mobile operators wishing to acquire spectrum in both parts of the 700MHz band though our initial technical assessments suggest that challenges in implementing this combination in handsets may mean the spectrum may be of more interest to organisations that have not acquired any of the core 700MHz band spectrum. If the spectrum can be used for TDD, there may be a linkage as the bands could be substitutable to some extent for the mobile operators and also potential new entrants (though this also depends on relative prices of spectrum in different parts of the 700MHz band).

- Use for Public Protection and Disaster Relief. Whether any dedicated spectrum needs to be allocated to PPDR and in which parts of the 700MHz band is highly uncertain. There could be significant linkages between the core 2×30MHz and the remaining spectrum in the event that PPDR requires a mix of spectrum. The mobile industry is generally against any of the 2×30MHz of spectrum being allocated to PPDR and the current trend across other countries in Europe is also against this.

- Use for Internet of Things/Machine to Machine. Interest is essentially in spectrum outside the core 2×30MHz band mostly as a result of expectations around the cost of this spectrum. There is therefore no particular linkage within the 700MHz band for this use.

- Use for Programme Making and Special Events. The interest in the 700MHz band for PMSE is limited to spectrum outside the core 2×30MHz block – in particular the 694-703MHz and 733-758MHz blocks. This is primarily due to an acceptance that the technical conditions for use of the 2×30MHz of

spectrum have been developed for mobile broadband use. So there are no linkages within the 700MHz band.

Overall we have not identified any significant linkages within the 700MHz band with the possible exception of PPDR which is subject to a future decision by the government on the overall approach for procuring broadband data services for the emergency services community. At this time we suggest the core 2×30MHz of spectrum in the 700MHz band can be considered separately from the other spectrum in the 700MHz band.

5.1.2 Linkages between non-core 700MHz band spectrum and 1452-1492MHz and 2100MHz bands

In this section we consider the linkages between the non-core 700MHz band spectrum and other bands.

From our assessments and discussions with stakeholders, PPDR and IoT/M2M interest in the 700MHz band is primarily as a result of the propagation characteristics of this frequency range and does not generally extend to other higher frequency bands such as the 1452-1492MHz or the 2100MHz bands. In the case of PMSE, there is little interest in the 700MHz paired block, 1452-1492MHz and 2100MHz bands given the bandplans and harmonised conditions for use of each of these bands are designed to support mobile broadband services and the interest of PMSE stakeholders is focused on the other (non-core) 700MHz spectrum. Consequently we conclude there are no particular economic linkages between the non-core 700MHz band spectrum and the 1452-1492MHz/2100MHz bands in the case of PPDR, IoT/M2M and PMSE uses of the spectrum.

In respect of possible mobile use of non-core 700MHz spectrum (e.g. for TDD use), this could lead to potential linkages with higher frequency spectrum, in particular for any potential new entrants seeking a portfolio of low frequency spectrum for coverage and higher frequency spectrum for capacity. The linkages are likely to be mainly with the 2100MHz band since the 1452-1492MHz is harmonised for use for supplementary downlinks so is most suitable for being linked with low frequency paired spectrum. There could be stronger linkages in the event that TDD technology could be used in the 1452-1492MHz band, but this appears to be unlikely.

Given the uncertainties of whether the non-core 700MHz spectrum will be used for mobile services, we do not see any strong linkages at this time and, again, given the overall uncertainties over the future use of the non-core 700MHz spectrum, we do not see any reason why the non-core 700MHz spectrum could not be considered separately from the 1452-1492MHz and 2100MHz bands.

5.1.3 Linkages between core 700MHz band and 1452-1492MHz band

Over time it is expected that handsets will become available which support the combination of the core 700MHz band (Band 28) and the 1452-1492MHz band (Band 32). Although this combination does not appear to be in the current 3GPP workplan for Release 14, we expect that specifications will be developed at some point in the future.

For those organisations that do not hold spectrum in the 800MHz band, there may therefore be a linkage between their interest/business case for the 1452-1492MHz band and the 700MHz band. The other potential low frequency option for linkage with the 1452-1492MHz band is the 900MHz band – although this is included in the workplan for 3GPP Release 14, it does not appear to be a priority. The 1452-1492MHz band could also be combined with spectrum in higher frequency bands such as the 1800MHz band and 2600MHz band.

Additionally some of the existing mobile operators have indicated to us that they require the certainty over their future spectrum holdings in these bands prior to deploying new equipment on base station sites so that such an upgrade can be undertaken on individual sites for all acquired bands together. For example, the operators will seek to purchase a new antenna for deployment on existing base station sites that can cover the 1452-1492MHz band, the 700MHz band or both the 1452-1492MHz and 700MHz bands, depending on the new spectrum that is acquired.

Overall, we conclude that some organisations have economic linkages between the core 700MHz and 1452-1492MHz bands.

5.1.4 Linkages between core 700MHz and 2100MHz bands

Although the two bands are different in terms of propagation characteristics and are therefore not substitutes, in speaking to stakeholders we have identified instances where there may be a relatively strong economic linkage between the bands in terms of complementarity. For some organisations including potential new entrants, interest in the 2100MHz band for additional capacity may depend on acquiring sufficient 700MHz spectrum for a network coverage layer. We have however also heard from other potential new entrants who have a different strategy and are only interested in capacity spectrum i.e. their business case for 2100MHz is independent of 700MHz spectrum acquisition.

In respect of the existing mobile operators, different views have been expressed ranging from the valuation of the bands can be undertaken relatively independently through to valuations can only be made knowing how much spectrum the organisation has in the other bands.

Essentially here there are very different views on the strengths of linkages between the 700MHz and 2100MHz band amongst different stakeholders but it seems a large number do believe there are linkages between these bands.

5.1.5 Linkages between 1452-1492MHz and 2100MHz bands

It was originally anticipated that the 1452-1492MHz band could be paired with the 2100MHz band as a means of providing a supplementary downlink for 3G. However interest moved quickly onto supplementary downlinks with 4G and also the focus was on pairing with low frequency bands (below 1GHz) and, in particular, the 800MHz band as previously discussed.

Some potential new entrants have indicated interest in the 1452-1492MHz band in the event it could be used for TDD technologies. This could create both a complementary and a potential substitute relationship with the 2100MHz band but given the low likelihood overall of the 1452-1492MHz being made available for TDD technologies, we overall conclude that there is no particular linkage between the 1452-1492MHz and 2100MHz bands.

5.1.6 Linkages between core 700MHz, 1452-1492MHz and 2100MHz bands

The linkages across all three bands are limited – and primarily are in relation to the valuation of spectrum in each band in view of the general substitutability of capacity.

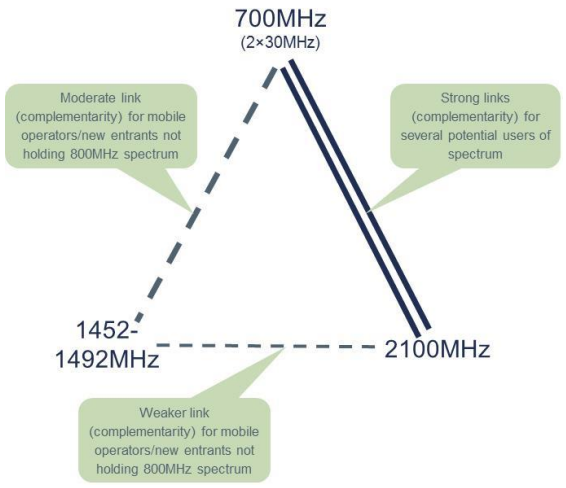
5.2 Summary of assessment of economic linkages

Overall we conclude that:

- The non-core spectrum in the 700MHz band (i.e. spectrum other than the core 2×30MHz block) can be treated separately from the 2×30MHz core block in the 700MHz band. The exception to this may be for PPDR but this is highly uncertain and is dependent upon a decision from the government on its overall approach to providing broadband connectivity services to PPDR users including which spectrum (if any) it wishes to allocate to PPDR.
- Additionally there are no particularly strong linkages between the non-core 700MHz spectrum and the 1452-1492MHz and 2100MHz bands.
- The linkages between the core 2×30MHz in the 700MHz band and the 1452-1492MHz and 2100MHz band vary considerably by stakeholder:
  - The strongest relationships are in relation to the 700MHz and 2100MHz band where for some stakeholders there is a complementarity relationship (no interest in the 2100MHz unless 700MHz is acquired)
  - The strengths of linkages between the 1452-1492MHz band and other bands (700MHz, 2100MHz) vary considerably by organisation. For example, for organisations not holding 800MHz spectrum, there is potentially a complementary linkage between interest in the 1452-1492MHz spectrum and acquisition of 700MHz spectrum.

A diagram summarising the linkages between the bands is shown in Figure 5-1.

Figure 5-1: Summary of linkages between the 700MHz, 1452-1492MHz and 2100MHz bands



Although there is a very limited linkage across all three bands (700MHz, 1452-1492MHz and 2100MHz) which mainly relates to the substitutability of capacity, the three bands are still inter-connected through the existence of two linkage pairs for some stakeholders:

- a linkage between the 700MHz and 2100MHz band (for some stakeholders this linkage is strong)
- a linkage between the 700MHz and 1452-1492MHz band (although this linkage is weaker for some stakeholders than the 700MHz/2100MHz linkage).

6 Combined award vs separate awards

In this section we discuss the relative benefits and drawbacks of undertaking a combined award of all three spectrum bands compared to holding two or more separate awards for the spectrum.

6.1 Benefits and drawbacks of combined auction process

A number of factors need to be taken into consideration when deciding whether to award spectrum bands separately or simultaneously, including:

- The timing of the availability of the different spectrum bands
- The extent to which the bands are complimentary – of greater value in combination than individually
- The extent to which the bands are substitutes – alternatives that an operator would ideally want to choose between on the basis of relative price
- The added complexity of a combined award process as compared with separate, sequential, award processes.

Where a number of spectrum bands will become available at the same time, and those bands are either strong compliments or close substitutes for at least some likely potential bidders, then there is a good case for holding a single combined award process (e.g. auction) since this will be more likely to lead to an efficient assignment than will a number of separate, sequential, award processes. This does however have to be balanced against the added complexity of a combined award process.

However, where there are differences in the timing of the availability of the different spectrum bands under consideration, as there are here between the 1452-1492MHz and the 700MHz and 2100MHz bands, it is very important to consider the potential impacts that holding an earlier or later award of all the spectrum (in a single combined award) might have, as compared with separate awards at different times:

- An early award of all the available spectrum allows the spectrum to be used as soon as possible after it becomes available. A later award might mean that some of the spectrum (e.g. the 1452-1492MHz spectrum) cannot be used for some time after it has become available, as the award of the spectrum has not yet taken place. There may therefore be a loss of economic benefit in the latter case, as some spectrum that could have been used remains idle waiting for an award to happen.

- By contrast, an early award of the entire available spectrum may result in an assignment of some of the spectrum that subsequently proves to be less than fully efficient (and may also generate less auction revenue than a later award). Bidders in an early award need to make predictions about the future value of spectrum that may not become available for a number of years. Such future values are of course inherently uncertain. To the extent that any such uncertainty impacts all bidders equally then this may not be of particular concern. But where this uncertainty impacts some bidders more than others – for example new entrants or niche players as compared with existing established operators – and in particular if it impacts a particular class of bidder more adversely, then it has the potential to disadvantage certain types of bidder in an early auction, and thereby lead to a less efficient outcome. (Bidders are also likely to bid less for spectrum where there is significant uncertainty about its future value, and hence auction prices are likely to be lower).

6.2 Assessment of situation

From our assessment of demand for the spectrum and linkages between the bands, including discussions with stakeholders we conclude that:

- Interest in the 700MHz spectrum outside the core 2×30MHz band is mostly separate from interest in the core 2×30MHz spectrum and interest in spectrum in the 1452-1492MHz and 2100MHz bands. Furthermore the allocation and potentials uses of the other 700MHz spectrum is not clear, particularly in view of the question of whether any spectrum needs to be reserved for PPDR and what further harmonisation efforts may be made at the European level in relation to this spectrum, for example in relation to PMSE. These issues may take some time to resolve. As indicated above, the uncertainties may also have different impacts on different types of organisation and could result in an inefficient award of the spectrum. For these reasons, we recommend that the award of the non-core 700MHz spectrum is undertaken through a separate process from the other spectrum bands.

- At the same time, it does appear to be appropriate to delay the award of the 2×30MHz core block of 700MHz spectrum whilst the government makes a decision over how to meet the broadband connectivity needs of PPDR users. Looking at the approach taken by other countries, even if the government in the Netherlands decides to deploy a dedicated PPDR network or hybrid dedicated/commercial solution, in all likelihood it will make use of spectrum outside the core 2×30MHz band i.e. spectrum in the 698-703/753-758MHz or/and the 733-736/788-791MHz ranges. We do not detect any widespread movement across Europe to set aside part of the core 2×30MHz block for dedicated PPDR networks – in fact those countries which are most advanced in respect of the planning of dedicated/hybrid PPDR networks (namely France and Germany) have already awarded all of the 2×30MHz spectrum to commercial operators.

- Stakeholders differ in respect of the strength of linkages between the core 700MHz, 1452-1492MHz and 2100MHz bands. Across mobile operators there are differences in view of the strength of linkages between the bands and the ability of the operator to value spectrum in a particular band without knowing its holdings in the other bands. Most operators however felt that a combined auction was necessary in view of these linkages, even if the direct linkages across all three bands together was limited, there were sufficient linkages between two of the different pairs (700MHz and 1452-1492MHz, 700MHz and 2100MHz) meaning that the three bands need to be considered together. Most organisations felt the linkages between the 700MHz and 2100MHz band were strongest – with the linkages between the 1452-1492MHz band and other bands being weaker – but stronger with the 700MHz band than the 2100MHz band. We note that holders of 800MHz spectrum have a potential advantage in valuing 1452-1492MHz spectrum over other organisations which might to some degree be reliant on an acquisition of spectrum in another band (for example the 700MHz band) to maximise the value they can obtain from the 1452-1492MHz band.

- The main priority of potential new entrants is to avoid a complex award process as this places them at a disadvantage as they may not have as much access as the larger operators to expert advice.

- Although the 1452-1492MHz band is theoretically currently available for use, in reality the limited availability of handsets supporting this band means that no economic benefit is currently being lost due to the lack of assignment. This will change as increasing numbers of handsets supporting the band become available – however there are differences in view as to when compatible handsets will become sufficient in number in respect of subscriber take-up to make deployment of 1452-1492MHz band economically viable – these views range from 2018 through to beyond 2020.

- Whilst there is huge uncertainty over what 5G will be, an industry consensus is occurring that the technology deployed in the 700MHz and 2100MHz bands will essentially be a further evolution of LTE rather than a completely new radio interface (as is expected to be the case for bands above 3GHz). LTE is already being deployed in the 2100MHz band and if the development of 5G is delayed, it may be the case that LTE is deployed in the 700MHz band as well prior to the deployment of 5G. Consequently the risks associated with the use and assessment of the value of the 700MHz band (and also regarding 5G in the 2100MHz band) are lower than for other potential bands above 3GHz that will be used for 5G. Consequently we believe it should be possible for auction participants to reliably (or as reliably as is ever anyway possible in respect of 15+ year licences) assess the value of the 700MHz band in any auction even if all details for 5G are not known, since it is increasingly likely that the 5G deployed in this band will be a further evolution of LTE. The successful award of the 700MHz band spectrum in France and Germany in 2015 illustrates that organisations are able to assess the value of the spectrum. With a further 2+ years to go until any auction for the 700MHz band in the Netherlands, additional information will become available and the uncertainty should further reduce. Additionally it is clear that the 700MHz spectrum will be available for deployment in the Netherlands for mobile services from 2020 onwards – in other countries there is more uncertainty over the availability date as it may be beyond 2020.

6.3 Assessment of options for the award of spectrum

6.3.1 Identification of options

As indicated above, we recommend that the non-core 700MHz spectrum is awarded separately from the core 2×30MHz in the 700MHz band and the spectrum in the 1452-1492MHz and 2100MHz bands. The parameters of this award process (timing, spectrum packaging etc) can be determined at a later date once the government's plans for PPDR become clear and any further harmonisation steps are undertaken for the band at the European levels, for example in relation to use of the spectrum for PMSE.

For the core 700MHz spectrum and the 1452-1492MHz and 2100MHz bands, the ideal solution would be to hold a combined award for the spectrum in early 2018 (rather than 2019) since this would allow the organisations who believe there are linkages between the various bands to express these linkages (e.g. through package bidding) but also potentially enable the economic benefits from use of the 1452-1492MHz band to start to be realised in 2018, subject to widespread availability of compatible user devices (e.g. handsets).

However it will not be possible to hold a combined auction in 2018. Following earlier advice from the Authority for Consumers and Markets (ACM), the Minister decided in 2015 to extend the validity of the existing 2100MHz assignments and to probably combine the award of the 2100MHz band with the 700MHz band. The main reason for the extension of the 2100MHz assignments was that the ACM thought it was too early to assess the market situation – a prerequisite for the Ministry in forming its spectrum award policy – at that time and suggested it undertake an extensive analysis of the mobile market in 2017 with proposals on potential remedies (if required) to ensure market competitiveness. This advice is due in early 2018. Such remedies could have implications for the award of the spectrum for example in relation to matters such as the setting of spectrum caps, reservations of spectrum etc. The implication of this is that a combined auction could not take place until 2019 in order to allow sufficient time for finalisation and implementation of ACM's advice into the final auction rules. We understand from the Ministry that it could take 18 months between the initial publication of auction legislation (in the beginning of 2018) and the holding of the auction (mid 2019).

One key question is whether the 1452-1492MHz band can be awarded at an earlier date, given that this spectrum is currently available for use. In this section we therefore consider two alternative options for the award of the core 700MHz spectrum and the 1452-1492MHz and 2100MHz bands:

- Option A: Combined auction of the 700MHz, 1452-1492MHz and 2100MHz bands in 2019
- Option B: Auction of 1452-1492MHz band in 2017/18 and auction of 700MHz and 2100MHz bands in 2019.

6.3.2 Initial review of options

A combined auction in 2019 (Option A) would:

- Allow all organisations who believe there are linkages between the various bands to express these linkages (e.g. through package bidding):
  - With particular reference to Option B, it would allow organisations that currently do not hold any 800MHz spectrum to take account of the acquisition of 700MHz spectrum when bidding for 1452-1492MHz spectrum.
- Enable the auction rules for all three bands to take account of the outcome of ACM's assessment of competition in the mobile market and incorporate any remedies relating to spectrum.
- Be more administratively straightforward for both the Ministry and spectrum applicants to implement/participate in one single auction rather than two separate auctions – subject to the complexity of a combined auction for all three bands over that of a combined auction for two bands.

Separate auctions in 2017/18 and 2019 (Option B) would:

- Potentially enable the economic benefits of use of the 1452-1492MHz spectrum to be realised in advance of 2019.
- Mean that the award of the 1452-1492MHz band is undertaken in advance of the completion of the earlier mentioned ACM's market assessment and therefore could not incorporate any specific remedies arising from this assessment in relation to the 1452-1492MHz band.

When considering the impacts of the two award options, we concluded that the comparison of the options primarily comes down to consideration of:

- Could an inefficient assignment of the 1452-1492MHz band arise as a result of separating the award of this band from the awards of the 700MHz and 2100MHz bands?
- Would the award of the 1452-1492MHz band ahead of the completion of the ACM's market assessment be appropriate?
- How much economic benefit would be gained from the use of 1452-1492MHz spectrum prior to 2019? Specifically to what extent would the 1452-1492MHz band be put into use in 2018 and how much economic benefit would arise from this?

We consider each of these three issues in turn in the sections below.

6.3.3 Risk of an inefficient assignment of 1452-1492MHz spectrum

In relation to whether an inefficient economic assignment of the 1452-1492MHz band could arise from a separate award, we note that several stakeholders have highlighted linkages between the 1452-1492MHz band and the 700MHz and 2100MHz bands. These include the need to have certainty over future spectrum holdings across all three bands when planning future network upgrades and also concerns over whether spectrum in any of the three bands can be valued without consideration of holdings in the other two bands. Furthermore in relation to the valuation of spectrum in the 1452-1492MHz band, we note that the availability of user devices supporting the 1452-1492MHz band will initially focus on the combination of the 800MHz and 1452-1492MHz bands (both two carrier combinations together initially and then also three carrier combinations with other bands such as the 1800MHz and 2600MHz bands). Two carrier combinations of the 1452-1492MHz band with other bands (e.g. 700MHz, 900MHz and 1800MHz) are expected to follow at a later date. Consequently any organisation not holding 800MHz spectrum may benefit from a combined auction since the certainty of knowing whether the organisation had acquired 700MHz spectrum could lead to an increase in the bids the organisation is willing to place on 1452-1492MHz spectrum. Nonetheless we expect this difference in bids may be relatively modest, particularly if the organisation also holds spectrum in other bands that could be paired with the 1452-1492MHz band (for example spectrum in the 900MHz band or/and 1800MHz bands).

We have a specific concern that an inefficient outcome could arise from a separate auction for the 1452-1492MHz band since:

- We would expect that KPN would be likely to have (relatively) higher valuations for the 1452-1492MHz spectrum than the other mobile operators in view of the ratio of KPN's share of existing spectrum holdings to its share of subscribers, although we also note KPN's ability to carry some indoor traffic over the fixed network (e.g. over WiFi connected to the home broadband connections of its subscribers).
- We would expect that Tele2 would be likely to have (relatively) lower valuations for the 1452-1492MHz spectrum than the other mobile operators in view of the size of its subscriber base relative to its share of existing spectrum assignments.
- However our expectation is that T-Mobile and Vodafone could have relatively similar underlying valuations of the 1452-1492MHz spectrum since:
  - Current low frequency (sub 1GHz) spectrum holdings for the two operators are broadly in line with their market shares.
  - Both T-Mobile and Vodafone hold assignments of 1452-1492MHz spectrum in other countries and therefore both organisations will directly benefit from synergies (e.g. knowledge sharing, work on 3GPP standards etc) from use of this band in their other operations internationally.
  - As Vodafone holds 800MHz spectrum, it is likely to be able to make use of the 1452-1492MHz band ahead of T-Mobile in view of handset availability – which will increase the value to Vodafone relative to T-Mobile.

  - However T-Mobile is likely to need to carry a relatively higher share of indoor traffic compared to a potentially integrated Vodafone/Ziggo[62] – and would therefore have a higher value for low frequency spectrum.

- In the absence of knowing whether it will obtain 700MHz spectrum, there is a possibility that T-Mobile may reduce its bid in a separate auction for 1452-1492MHz spectrum to account for the risk it may not acquire 700MHz spectrum in the future (under these circumstances the 1452-1492MHz spectrum could be less valuable):

  - However any such reduction is likely to be limited since T-Mobile has assignments of 2×15MHz of 900MHz spectrum and 2×30MHz of 1800MHz spectrum either of which could also be paired with the 1452-1492MHz band and user devices supporting pairing with the 1800MHz band may become available ahead of devices supporting pairing with the 700MHz band.

As a consequence of the above, we believe there is a possibility that an inefficient auction outcome may arise in respect of the amounts of spectrum acquired by T-Mobile and Vodafone in the event that a separate award of the 1452-1492MHz band was held. However we also conclude that any loss of efficiency from an inefficient outcome arising from a separate award of 1452-1492MHz spectrum is likely to be small. Since the reason a potentially inefficient outcome arises is that of the valuations of spectrum by specific organisations being very similar/finally balanced, it also follows that an inefficient outcome should not have a material impact on the overall economic benefits from use of the spectrum. However an inefficient outcome could have an impact on the overall competitive position of an individual operator relative to others, and therefore there is a question over whether the holding of a separate award of the 1452-1492MHz band would be fair (i.e. non-discriminatory) in respect of its impact on different market participants.

6.3.4 Appropriateness of an award of 1452-1492MHz spectrum in advance of the ACM's market assessment

The second key issue to be considered is whether it is possible to hold the 1452-1492MHz award ahead of the completion of the ACM's market assessment? The main competitive impact of the 1452-1492MHz band is that the band will have stronger short-term benefits for organisations that hold 800MHz spectrum assignments than for those organisations that do not. This benefit arises independently of whether the 1452-1492MHz spectrum is auctioned separately or together with other frequency bands. However the ACM may wish to consider whether this issue could have a material impact on long-term market competitiveness in advance of the award of the 1452-1492MHz spectrum (as well as the 700MHz and 2100MHz bands) since if the ACM determined this was an issue that could affect long-term market competitiveness, it may wish to consider advising on market remedies which affect several of the bands being auctioned – for example possible spectrum caps that apply across multiple bands.

In such an instance, organisations may wish to optimise their spectrum portfolio across the three different frequency bands and this could only occur in a combined auction. As a theoretical example, if the ACM were to advise the Ministry to place an overall cap on total spectrum holdings below 1500MHz (including both existing holdings and any spectrum acquired in the auction), it would be undesirable to have a

[62] We note that the European Commission recently cleared the proposed creation of a joint venture in the Netherlands between Vodafone and Liberty Global - see European Commission, 'Press release: 'Mergers: Commission clears Vodafone/Liberty Global telecoms joint venture, subject to conditions; rejects referral request by Dutch competition authority', 3 August 2016.

situation where the ACM undertook a market assessment after a separate 1452-1492MHz auction which then led to the identification of such a potential remedy as this could affect the winners of the 1452-1492MHz spectrum in relation to their scope for acquiring (for example) 700MHz spectrum when such organisations may have had a preference for acquiring 700MHz spectrum over the 1452-1492MHz spectrum if they had been aware of the remedy prior to both awards of spectrum.

The likelihood of a further market assessment needing to be undertaken after a separate award of the 1452-1492MHz spectrum is an argument for holding a combined award since the undertaking of this further market assessment and the time required for the Ministry to consider and act upon its findings could cause a delay in the timing of the subsequent 700MHz and 2100MHz auction and potentially the date on which the 700MHz band could start to be used for mobile broadband services (including 5G).

Overall, we conclude that there could be strong benefits from the ACM concluding its review of market competitiveness and identifying potential remedies in advance of the award of spectrum in any of the three bands.

6.3.5 Economic benefits from use of the 1452-1492MHz band in 2018

In respect of the potential economic benefits arising from use of the 1452-1492MHz band in 2018:

- We note that the widespread adoption of user devices (e.g. handsets) compatible with the 1452-1492MHz band in 2018 is highly uncertain. Stakeholders expressed very different views over when compatible handsets would be adopted in sufficient volumes to make use of the 1452-1492MHz band worthwhile – these ranged from 2018 to beyond 2020. We note that although the first handset (Google Pixel) supporting the band has now been announced, the band has not been supported in handsets recently launched by the two largest manufacturers – namely the Apple iPhone 7 and the Samsung Galaxy Note 7. We expect that the 1452-1492MHz band will be incorporated into new handsets launched by these manufacturers during 2017, but given handset replacement cycles, the number of mobile subscribers in the Netherlands with handsets compatible with the 1452-1492MHz band will be limited during 2018.

- Utilising our model for the assessment of future spectrum demand, we consider the extent to which the additional capacity from the 1452-1492MHz band is required by the mobile industry in 2018. Overall we concluded that there is a possibility that the 1452-1492MHz spectrum could be needed on a small number of sites in 2018 in the event of realisation of the high traffic scenario.

- Some organisations have indicated that in the event of the 1452-1492MHz band being awarded ahead of the 700MHz and 2100MHz bands, they would be unlikely to deploy new base station equipment on sites until both auctions had completed in view of the need to minimise the cost of upgrading base station sites. Detailed network planning and procurement of sites upgrades would therefore only occur once the organisations had a clear view of its overall spectrum holdings.

- We also considered what practical difference deployment of the 1452-1492MHz band in 2018 instead of 2019 would make to mobile subscribers, assuming sufficient adoption of compatible user devices. Our conclusion was that the availability and deployment of the band could enable operators to increase the data bundle package sizes (i.e. date usage levels) one year earlier than would otherwise have been the case. We note that this additional data would have used for ‘lowest value’ uses i.e. the incremental value of this additional data is less than the average economic value of the data package that would be supported without use of the 1452-1492MHz band.

Overall we conclude that there is potentially a small amount of economic benefit for citizens from use of the 1452-1492MHz band in 2018, however the probability of this benefit being fully realised is low given the current device ecosystem for the 1452-1492MHz band.

6.4 Conclusion

Our overall judgement is that the benefits of a combined award in 2019 outweigh the benefits of separate awards in late 2017/early 2018 and 2019 since:

- Any consumer benefits from making the 1452-1492MHz band available in 2018 instead of 2019 are likely to be limited, and there is no certainty these benefits will in any case be fully realised in 2018 given the timescale for widespread adoption of user devices supporting the band.
- A combined auction is fair to all organisations as each organisation can take full account of any linkages that exist between bands when placing bids for spectrum, thereby resulting in a more efficient outcome.
- The award of spectrum in all three bands will be able to fully reflect the findings/recommendations from the ACM's market competitiveness study.
- In practical terms, one single auction should have lower administrative costs/require less preparatory time overall for both organisers of the auction and participants, compared with the holding of two separate auctions.
- A combined auction would also be able to take account of the possible need for ensuring that assignments of spectrum in the 700MHz and 1452-1492MHz bands to each individual operator minimise the risk of harmful interference occurring in user devices in a scenario when both bands are used simultaneously. This potential problem is discussed further in Section 3.2.4 of this report and in Section 9.3 we recommend that work is undertaken to investigate this issue. Separate auctions could lead to strategic bidding by organisations in the 700MHz auction knowing that their competitors would be seeking to avoid certain frequencies which are incompatible with the competitors' assignments in the 1452-1492MHz band. There may potentially be scope for the auction rules to take account of this by automatically excluding any 700MHz assignments which are incompatible with the existing 1452-1492MHz holdings of each of the bidders, but this would add complexity to the auction.

We therefore recommend that the Ministry holds a combined award for the core (2×30MHz) of 700MHz spectrum, the 1452-1492MHz band and the 2100MHz band in 2019. We also advise that the Ministry strives to make the combined auction as simple as possible in order to maximise market interest (particularly assisting smaller/niche organisations that may not have as much access to expert advice as larger organisations). We have sought to support this objective of simplicity in our spectrum packaging recommendations.

The award of the other spectrum in the 700MHz band should be undertaken separately. As indicated earlier, the parameters of this award process (timing, spectrum packaging etc) can be determined at a later date once the government's plans for PPDR become clear and any further harmonisation steps are undertaken for the band at the European levels, for example in relation to use of the spectrum for PMSE.

7 Spectrum packaging

In this section we consider how the spectrum in each frequency band should be packaged. As part of this we consider the uses and demand for spectrum, any views expressed about packaging by stakeholders and also see whether there are any lessons that we can draw from previous auctions in the same/similar bands. We consider auctions from European Union countries, which share regulatory framework and set of frequency allocations to that of the Netherlands.

Typically there is a balance to be drawn between providing maximum flexibility in the auction for operators to acquire different amounts of spectrum and the overall complexity of the auction process. Pre-packaging of spectrum in larger blocks can result in significant simplification of auctions at the cost of reducing operator flexibility. We consider this balance when developing our recommendations.

We present our recommendations for the packaging of spectrum for each band in turn. Please note that we have not considered developing any cross-band packages of spectrum since the extent of linkages between the bands vary across the different stakeholders and the design of a multi-band auction can enable different operators to acquire packages of spectrum (whether single band or across multiple bands) to suit their own requirements.

7.1 700MHz band – 2×30MHz of paired spectrum

Stakeholders have indicated that they require a minimum of 2×10MHz of spectrum in this band to make efficient use of the spectrum. This matches Aetha's own experience in respect of valuing spectrum that will be used for LTE. The difference between 2×10MHz of spectrum and 2×5MHz of spectrum is a doubling of capacity and peak data rates whereas the main cost difference is simply additional software/licence fees and some extra operating costs (e.g. power) – the core base station hardware and antennas will be the same cost. Additionally we typically find that 2×5MHz of spectrum only provides sufficient capacity to delay the building of additional sites rather than preventing the building of new sites in the long-run. For these reasons we typically find that the value of 2×10MHz of spectrum is considerably more than double the value of 2×5MHz of spectrum.

Our discussions with stakeholders also indicated that there was a general expectation that three organisations would each acquire 2×10MHz of spectrum from the auction.

Looking at recent European auctions, we have considered both 700MHz auctions which have taken place (specifically France and Germany) and also the 800MHz auctions since this band is similar to the 700MHz band in terms of the total quantity of spectrum available (2×30MHz) and its underlying technical characteristics (e.g. propagation). A summary of the 800MHz auctions is shown in Figure 7-1 and a summary of the 700MHz auctions is shown in Figure 7-2. Both figures show how the spectrum was originally packaged in each auction, the number of competing operators, the outcome of the auction and any specific additional points regarding the auction that may have led to that outcome (e.g. spectrum caps/restrictions).

Figure 7-1: Spectrum packaging in recent 800MHz auctions in Europe

Auction	Operators	Spectrum packaging	Caps / restrictions	Auction outcome	Comments
Germany, 2010 (SMRA)	4	6 lots of 2×5MHz	Sub-1GHz: 2×20MHz	DTE: 2×10MHz TEF: 2×10MHz VOD: 2×10MHz	
Sweden, 2011 (SMRA)	4	6 lots of 2×5MHz	800MHz: 2×10MHz	HUT: 2×10MHz TSN: 2×10MHz N4M: 2×10MHz	Coverage obligation attached to highest block
Spain, 2011 (SMRA)	4	6 lots of 2×5MHz	Sub-1GHz: 2×20MHz	ORA: 2×10MHz TEF: 2×10MHz VOD: 2×10MHz	
Italy, 2011 (SMRA)	4	6 lots of 2×5MHz	Sub-1GHz: 2×25MHz	TIT: 2×10MHz VOD: 2×10MHz WIN: 2×10MHz	
Portugal, 2011 (SMRA)	3	6 lots of 2×5MHz	800MHz: 2×10MHz 800MHz + 900MHz: 2×20MHz	NOS: 2×10MHz TMN: 2×10MHz VOD: 2×10MHz	
France, 2011 (Sealed Bid)	4	2 lots of 2×5MHz 2 lots of 2×10MHz	800MHz: 2×15MHz	BOY: 2×10MHz ORA: 2×10MHz SFR: 2×10MHz	Additional hosting obligations attached to purchase of more than one lot
Switzerland, 2012 (CCA)	3	6 lots of 2×5MHz	Sub-1GHz: 2×25MHz	SCM: 2×10MHz ORA: 2×10MHz SUN: 2×10MHz	
Denmark, 2012 (CCA)	4	4 lots of 2×5MHz 1 lot of 2×10MHz	800MHz: 2×20MHz	TDC: 2×20MHz TTN: 2×10MHz	The 2×10MHz lot had reduced coverage obligation
Romania, 2012 (Package Clock Auction)	4 (+1)	6 lots of 2×5MHz	800MHz: 2×10MHz Sub-1GHz: 2×20MHz	ORA: 2×10MHz VOD: 2×10MHz COS: 2×5MHz	One 2×5MHz lot unsold due to high reserve price
Netherlands, 2012 (CCA)	4	6 lots of 2×5MHz	2 lots reserved for 'newcomers'	KPN: 2×10MHz TEL: 2×10MHz VOD: 2×10MHz	Two lots reserved for newcomers
Ireland, 2012 (CCA)	4	6 lots of 2×5MHz	Sub-1GHz: 2×20MHz	MET: 2×10MHz TEF: 2×10MHz VOD: 2×10MHz	
United Kingdom, 2013 (CCA)	4 (+1)	4 lots of 2×5MHz 1 lot of 2×10MHz	Sub-1GHz: 2×27.5MHz	TEF: 2×10MHz VOD: 2×10MHz HUT: 2×5MHz EE: 2×5MHz	5MHz licences arose from reservation of minimum portfolio of spectrum for a 4th national operator
Norway, 2013 (Sealed Bid)	4	4 lots of 2×5MHz 1 lot of 2×10MHz	800MHz: 2×10MHz	TNR: 2×10MHz TSN: 2×10MHz ICE: 2×10MHz	

Figure 7-2: Spectrum packaging in recent 700MHz auctions in Europe

Auction	Operators	Spectrum packaging	Caps / restrictions	Auction outcome	Comments
Germany, 2015 (SMRA)	3	6 lots of 2×5MHz	None	DTE: 2×10MHz TEF: 2×10MHz VOD: 2×10MHz	
France, 2015 (Clock Auction)	4	6 lots of 2×5MHz	700MHz: 2×15MHz 700MHz + 800MHz + 900MHz: 2×30MHz	BOY: 2×5MHz SFR: 2×5MHz ORA: 2×10MHz ILA: 2×10MHz	

Of the 15 auctions presented in Figure 7-1 and Figure 7-2, all of the auctions packaged at least a proportion of the 700MHz/800MHz bands in lots of 2×5MHz. Indeed, the majority of the auctions packaged the entirety of the band in six lots of 2×5MHz, with the remaining auctions using a combination of 2×5MHz and 2×10MHz lot sizes. Including 2×5MHz lot sizes in the packaging arrangement of the spectrum provides greatest flexibility in how the spectrum is assigned between operators, facilitating the possibility of four operators each acquiring spectrum in the band for example. Such an outcome would not be possible if the band was packaged as three lots of 2×10MHz.

However the outcomes of the auctions studied have generally been for three operators to each acquire 2×10MHz of spectrum. This implies a strong preference from operators for acquiring 2×10MHz of spectrum over 2×5MHz. In a four operator market, an outcome where three bidders acquire 2×10MHz indicates that the fourth bidders' valuation for a single 2×5MHz lot was lower than the incremental value of the second 2×5MHz lot to the winning bidders.

There have been exceptions to this outcome where bidders have acquired a single 2×5MHz lot. In Romania's multiband auction of 2012, Cosmote acquired one 2×5MHz lot in the 8000MHz band with the remaining 2×5MHz lot left unsold. This outcome is likely to have been the result of high reserve prices for the 800MHz spectrum and Cosmote perhaps having an overall budget constraint. Whilst the publicly available results from the packaged clock auction prevent the price of each block being known, the total amounts paid by the operators imply that the spectrum was sold for little above the reserve price.

The United Kingdom multiband auction of 2013 resulted in two operators each acquiring a single 2×5MHz lot in the 800MHz band (3 and EE). This outcome was partly a result of Ofcom's decision to specify a series of minimum spectrum packages for a fourth national wholesale operator. As a consequence 3 acquired this reserved lot at the reserve price. Similarly, France's 2015 clock auction resulted in two operators each acquiring a single 2×5MHz lot in the 700MHz band (Bouygues Telecom and SFR). This result would seem to suggest that both operators had significant valuations for a single 2×5MHz lot – the final price per lot was EUR466 million. However, we note that this auction outcome may have been a consequence of the auction mechanism used by ARCEP. In each round of the auction, bidders had the option to either maintain their bid from the previous round or reduce their bid by a single lot. Therefore a bidder that wanted to reduce its demand from two lots (2×10MHz) to zero lots would have had to bid on one lot (2×5MHz) as an intermediate step. It is possible that one or both of Bouygues Telecom and SFR bid on one lot simply as an intermediate step, and had not intended to acquire a single lot by itself.

A further departure from the outcome whereby three buyers each acquire 2×10MHz, is Denmark's 800MHz auction in 2012. This auction resulted in TDC acquiring 2×20MHz and Telia/Telenor acquiring

2×10MHz of spectrum. The large quantity of spectrum acquired by TDC was partly a result of limited participation in the auction and the caps allowing one operator to acquire 2×20MHz of spectrum in total.

In summary, all of the auctions studied have used packaging arrangements for the 700MHz/800MHz bands that include at least some 2×5MHz lots. Whilst these smaller lots enable greater flexibility in the auction outcome, the majority of the auctions have resulted in the successful buyers acquiring 2×10MHz packages.

In view of the combination of the views expressed by stakeholders and the experience from European auctions, we recommend the following two options for the packaging of spectrum:

- Six lots each of 2×5MHz with the auction design ensuring no organisation that wins spectrum in this band is left with less than a minimum of 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design.
- Or, alternatively, if there would be a significant reduction in the overall complexity of the auction, the spectrum could be pre-packaged into three lots of 2×10MHz, with each organisation only able to acquire a maximum of one of these lots, since it is highly likely that this will be the eventual outcome of the auction in any case.

7.2 700MHz band – other spectrum

In view of the uncertainty over whether part of this spectrum will need to be reserved for PPDR and over whether further plans will be developed at the European level for harmonised use of this spectrum, we believe it is too early to make any recommendations regarding the packaging of this spectrum. We also note that no awards of this spectrum have taken place in Europe to date so no information is available in this respect.

Consequently we limit our recommendations at this time to simply highlighting various points that should be considered when spectrum packaging decisions are made for this band after reflecting any spectrum that needs to be set aside for PPDR:

- IoT/M2M users may seek very small amounts of spectrum in this band and so some of this spectrum should be made available in small blocks e.g. 1MHz.
- In the event that TDD technologies can be supported in this spectrum (e.g. for mobile broadband services, machine to machine communications), the spectrum packaging and usage conditions for the band should reflect this.

7.3 1452-1492MHz band

Stakeholders expressing interest in this band indicated they sought a minimum of 10MHz of spectrum in this band – for similar reasons as the 700MHz band, 5MHz of spectrum is typically not so cost effective to deploy.

Looking at European auctions, so far the 1452-1492MHz band has been auctioned in Germany, Italy and the United Kingdom. The United Kingdom auctioned this spectrum band back in 2008, where it was acquired by the chip manufacturer Qualcomm. Qualcomm subsequently sold the spectrum in a secondary market transaction to Vodafone and 3. This sale was not made by public auction, so it is not possible to observe how the spectrum was packaged for sale. However the final outcome was announced with the two buyers acquiring 20MHz of spectrum each. In 2015, Germany and Italy assigned the 1452-1492MHz

spectrum at auction. From these auctions, both the packaging arrangement for the lots and the quantities acquired by each buyer is observable, as summarised in Figure 7-3.

Figure 7-3: Spectrum packaging in 1452-1492MHz auctions in Europe

Auction	Operators	Spectrum packaging	Caps / restrictions	Auction outcome	Comments
United Kingdom, 2008 (SMRA)	5	16 lots of 1.7MHz 1 lot of 12.5MHz	None	QCM: 40MHz	
Germany, 2015 (SMRA)	3	8 lots of 5MHz	None	DTE: 20MHz VOD: 20MHz	
United Kingdom, 2015	4	Not known	Not known (probably none)	VOD: 20MHz HUT: 20MHz	Secondary transaction – sale by Qualcomm
Italy, 2015 (SMRA)	4	2 lots of 20MHz	1452-1492MHz band: 20MHz	TIT: 20MHz VOD: 20MHz	

Across the three primary market auctions shown in Figure 7-3, a wide range of spectrum packaging arrangements have been used. The United Kingdom's 2008 auction packaged the spectrum into 17 lots, most of which had a bandwidth of only 1.7MHz. This arrangement is reflective of the bandplan in operation at the time which was developed when the band was harmonised for terrestrial audio broadcasting. Indeed at the time it was anticipated that the spectrum might be used for a technology broadcasting TV services to mobile devices e.g. DVB-H, MediaFLO.

By the time of the German and Italian auctions, which followed the European Commission's implementing decision to harmonise the 1452-1492MHz band in May 2016, it was clear that the band would be used for mobile broadband services. The German and Italian auctions used lots sizes of 5MHz and 20MHz respectively.

With respect to the Netherlands future auction, the three transactions from 2015 are the most instructive regarding the outcome of the assignment processes. In each of these three transactions, two buyers acquired 20MHz of spectrum each. In the case of the Italian auction where the spectrum was sold in lots of 20MHz, this outcome gives little information about the operators' preference for spectrum bandwidth in the 1452-1492MHz. However, in the German auction where smaller lot sizes were used, and to some extent the United Kingdom's secondary market transaction, the outcome implies a preference for spectrum holdings of 20MHz in the 1452-1492MHz band.

Given that several organisations may have interest in the 1452-1492MHz spectrum in the Netherlands and that stakeholders have not strongly suggested a likely division of the spectrum into 20MHz blocks (as they did for 2×10MHz blocks in the 700MHz band), we do not believe it would be appropriate to pre-judge the outcome of the auction and package the spectrum into 20MHz blocks. However we do believe the packaging/auction should reflect the efficiencies that arise from having a minimum of 10MHz of spectrum.

The spectrum packaging should also allow organisations to potentially acquire 15MHz of spectrum in the band – and not just multiples of 10MHz. The carrier aggregation combinations with the 1452-1492MHz that have currently been defined all include support for 5MHz and 15MHz channel bandwidths as well as 10MHz and 20MHz channel bandwidths.

Consequently our overall recommendation is for the spectrum to be packaged in 5MHz blocks but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 10MHz.

Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that this requirement for a minimum acquisition of 10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn as the valuations of spectrum by bidders will probably lead to a minimum block size of 10MHz for each successful bidder anyway.

7.4 2100MHz band

Stakeholders have indicated there is strong interest in this band – primarily from existing licensees but also some from other organisations. The existing licensees each have 2×20MHz of spectrum in this band, but on a non-contiguous basis. Over time the band will be refarmed from 3G to 4G and the existing licensees are keen to deploy full 20MHz LTE carriers in this band.

In respect of European auctions of this band, the band was originally auctioned for 3G services in several European countries in the early 2000s. However since UMTS technology was focused on 5MHz carriers and since in many countries the spectrum was pre-packaged to reflect the number of desirable market participants, we do not believe these outcomes are so relevant to determining the spectrum packaging for this band for licences that will start on 1 Jan 2021. Instead we therefore consider instances where the 2100MHz band has been auctioned upon reaching the end of the original licence period i.e. a similar situation to the Netherlands or where part of the band was not originally assigned (for example in Belgium and France). These results are shown in Figure 7-4.

Figure 7-4: Spectrum packaging in recent 2100MHz auctions in Europe

Auction	Operators	Spectrum packaging	Caps / restrictions	Auction outcome	Final holdings
Germany, 2010 (SMRA)	4	4 lots of 2×5MHz	None	KPN: 2×10MHz TEF: 2×5MHz VOD: 2×5MHz	KPN: 2×20MHz VOD: 2×15MHz TEF: 2×15MHz DTE: 2×10MHz
France, 2010 (Sealed Bid)	4	2 lots of 2×5MHz	None	ORA: 2×5MHz SFR: 2×5MHz	ORA: 2×20MHz SFR: 2×20MHz BOY: 2×15MHz ILD: 2×5MHz
Belgium, 2011 (SMRA)	4	1 lots of 2×15MHz	Reserved for candidates that did not hold a 3G licence	TNT: 2×15MHz	PRX: 2×15MHz ORA: 2×15MHz TNT: 2×15MHz
Switzerland, 2012 (CCA)	3	12 lots of 2×5MHz	2100MHz: 2×50MHz	SCM: 2×30MHz ORA: 2×20MHz SUN: 2×10MHz	SCM: 2×30MHz ORA: 2×20MHz SUN: 2×10MHz
Norway, 2012 (Clock Auction)	4	9 lots of 2×5MHz	2100MHz: 2×20MHz	TSN: 2×20MHz TNR: 2×20MHz NOR: 2×5MHz	TSN: 2×20MHz TNR: 2×20MHz NOR: 2×20MHz

Across the auctions shown in Figure 7-4, spectrum has generally been packaged into lots of 2×5MHz. The only exception to this packaging arrangement is the Belgium auction of 2011, in which a single lot of 2×15MHz was auctioned but existing operators who already held 2100MHz spectrum licences were not eligible to bid for this. The outcomes of the auctions show a wide range of spectrum quantities being acquired by operators. In several auctions, operators acquired as little as 2×5MHz of spectrum in the band. However, as the spectrum auctioned generally represented a subset of the 2×60MHz of spectrum in the band, it is more instructive to consider the buyers' total spectrum holdings at the end of the auction. From this perspective all buyers ended with at least 2×10MHz, with many buyers ending the auction with

2×15MHz and 2×20MHz. For example, in the French auction of 2010 SFR and Orange, who both had existing holdings of 2×15MHz in the 2100MHz, each acquired an additional 2×5MHz in the band.

As for the 700MHz and 1452-1492MHz band, we believe there is little value for an operator in acquiring 2×5MHz of spectrum in the 2100MHz band. Noting that there is interest in this band from both existing licensees and other organisations, we believe an auction should be left to determine the spectrum holdings over a minimum package size of 2×10MHz.

Our overall recommendation therefore is that the spectrum is packaged as 2×5MHz blocks, but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that this requirement for a minimum acquisition of 2×10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn as the valuations of spectrum by bidders will probably lead to a minimum block size of 2×10MHz for each successful bidder anyway.

8 Other award issues

In this section we briefly discuss a number of other issues relating to the award of the 700MHz, 1452-1492MHz and 2100MHz band that have arisen during our research and discussions with stakeholders. These issues are discussed in turn below.

- **Auction complexity**. Many stakeholders commented on the complexity of the multi-band auction in 2012 including concerns of lack of transparency about what the final cost of any spectrum licences is likely to be. Smaller organisations stressed the need for the auction to be as simple as possible as they may not have the same expert resources available to them as larger organisations.

- **Coverage obligations**. Should any coverage obligation be included in the conditions of use of the spectrum, several stakeholders have suggested that these should not be band specific i.e. the licensee can use any of/a combination of the spectrum bands that it holds to meet the coverage obligation.

- **Contiguous assignments in the 2100MHz band**. The mobile operators with existing assignments in the 2100MHz band all expressed a strong wish for the re-assignment process to be used to ensure that each winner receives spectrum in a contiguous block to enable deployment of the widest possible LTE carrier. It was indicated that previous reconfiguration of a GSM band was achieved in a period of 6 months as a result of all of the mobile operators working together in a constructive manner.

- **Incorporation of PPDR requirements in 700MHz licence conditions**. As discussed in Section 4.3, the mobile industry expressed concern at the potential for the 700MHz licence conditions to include mandatory wholesale access for PPDR users and any requirement for 'hardening' of base stations believing any such requirements should be contracted for by the government as part of its overall process for providing broadband wireless connectivity services to emergency services users.

9 Summary of recommendations

In this section we provide a summary of the main recommendations arising from our assessments.

9.1 Award process and timing

We recommend that the non-core 700MHz spectrum (i.e. the 694-703MHz and 733-758MHz spectrum) is awarded separately from the core 2×30MHz in the 700MHz band and the spectrum in the 1452-1492MHz and 2100MHz bands. The parameters of the award process (timing, spectrum packaging etc) for the non-core 700MHz spectrum can be determined at a later date once the government's plans for PPDR become clear and any further harmonisation steps are undertaken for the band at the European level, for example in relation to use of the spectrum for PMSE.

We do not believe that the Ministry should delay the award of the core 700MHz spectrum (703-733/758-788MHz) whilst the government makes a decision over how to meet the broadband connectivity needs of PPDR users. Looking at the approach taken by other European countries, even if the government in the Netherlands decides to deploy a dedicated PPDR network or hybrid dedicated/commercial solution, in all likelihood it will make use of spectrum outside the core 2×30MHz band i.e. spectrum in the 698-703/753-758MHz or/and the 733-736/788-791MHz ranges.

For spectrum in the core 700MHz, 1452-1492MHz and 2100MHz bands, we recommend that the Ministry holds a combined award for the core (2×30MHz) of 700MHz spectrum, the 1452-1492MHz band and the 2100MHz band in 2019. We also advise that the Ministry strives to make the combined auction as simple as possible in order to maximise market interest (particularly assisting smaller/niche organisations that may not have as much access to expert advice as larger organisations). We have sought to support this objective of simplicity in our spectrum packaging recommendations.

9.2 Spectrum packaging

We recommend that the core 2×30MHz of spectrum in the 700MHz band is packaged as follows:

- Six lots each of 2×5MHz with the auction design ensuring no organisation that wins spectrum in this band is left with less than a minimum of 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design.
- Or, alternatively, if there would be a significant reduction in the overall complexity of the auction, the spectrum could be pre-packaged into three lots of 2×10MHz, with each organisation only able to acquire a maximum of one of these lots.

We recommend that spectrum in the 1452-1492MHz band is packaged as 5MHz blocks but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that this requirement for a minimum acquisition of 10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn.

We recommend that spectrum in the 2100MHz band is packaged as 2×5MHz blocks, but for the auction design to ensure that no organisation obtaining spectrum in this band can acquire less than 2×10MHz. Such a 'spectrum floor' would need to be integrated into the overall auction design. However in the event that

this requirement for a minimum acquisition of 2×10MHz resulted in a disproportionate amount of complexity in the auction, it could be withdrawn.

9.3 Areas requiring further technical study

We recommend that the Ministry undertakes (or encourages European institutions to undertake) further assessments in the following areas:

- **Possible 700MHz and 1452-1492MHz interference issues in user devices**. As discussed in Section 3.2.4, the second harmonic of the 700MHz uplink band (1406-1466MHz) overlaps with the 1452-1492MHz band which is used for downlinks. This means that the second harmonic of the 700MHz signal produced in the power amplifier of a handset could desensitise the handset's 1452-1492MHz receiver (i.e. increase the noise floor) for the corresponding channels at double the frequency and also, to some extent, the adjacent channels. This could have implications for the award process in that it would be desirable to ensure that incompatible assignments across both bands are not available as options to bidders.

- **PMSE co-existence issues in the 700MHz band**. Additional compatibility assessments may be needed in respect of PMSE's potential use of spectrum in the 694-703MHz and 733-758MHz bands in respect of compatibility with mobile broadband using the 703-733/758-788MHz band and other services using the 694-703MHz and 733-758MHz bands. It is possible these issues may already be plans for further study at the European level prompted by the Radio Spectrum Policy Group's work on developing an Opinion for the long-term strategy for providing sufficient spectrum for PMSE[57].

- **Potential for use of the TDD technologies in the 694-703MHz and 733-758MHz bands**. As discussed in Section 4.1 and Section 4.2, interest has been expressed by stakeholders in the potential use of this spectrum for TDD technologies for both mobile broadband services (using the TDD variant of LTE) and for low power wireless access networks for the Internet of Things (using a range of possible technologies). Such use is probably not currently compatible with the European Commission's Implementing Decision for use of the 700MHz band[20] and work would need to be undertaken at the European level to examine such scope for usage, assess compatibility issues and, if appropriate, update the Implementing Decision to allow such usage.

Annex A Approach to modelling future demand for spectrum for mobile services

As part of this project we developed a model which calculates how much spectrum, in addition to what is currently available in the market (including future 700MHz and 1452-1492MHz band awards), if any, is required by the mobile market in the Netherlands over the next 10 years in view of the forecast growth in data traffic.

A.1 Modelling approach

As indicated above, the objective of the model is to quantify the additional spectrum required to satisfy the traffic demand. We do this by modelling the spectrum requirements of a hypothetical operator with 25% market share and broadly a 25% share of the spectrum available for mobile services and then scale up the resulting spectrum demand to calculate the requirements of the whole market.

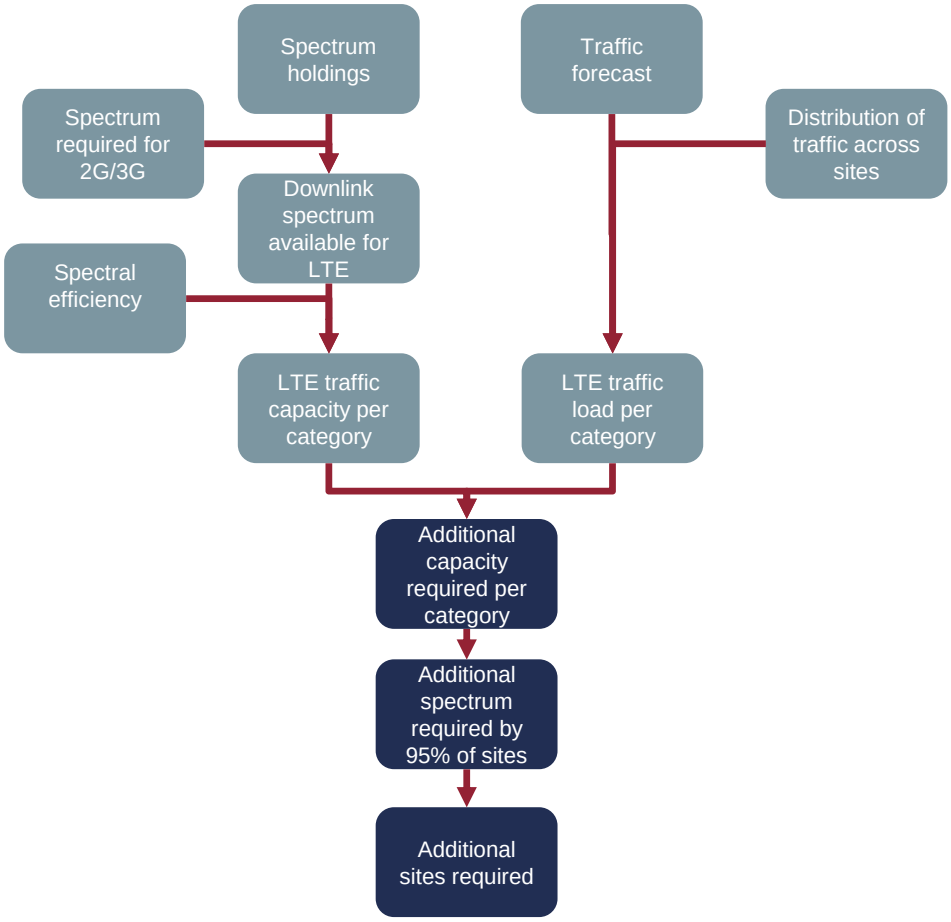
To model the requirements of the operator, we split the total number of physical sites deployed by the operator into 100 equal categories and then we use a traffic distribution curve to distribute the total network traffic over each category. We then, using a traffic usage forecast, determine the traffic load per base station site for each category of sites in each year. Then, using an assumption of the spectrum holdings of the operator and of the spectral efficiency, we calculate the total capacity available per site. We model traffic capacity and demand on the downlink traffic since we expect this to be the limiting factor in view of the increasing use of streaming and downloaded audio-visual content. As traffic is rapidly migrating to LTE, we model LTE traffic and separately make assumptions about the amount of spectrum needed for 2G and 3G services over the modelling period.

From the comparison of traffic demand and capacity at a site, we can calculate how much extra capacity is required at the site and moreover, how much additional spectrum. These calculations are undertaken both for the total traffic to be carried by a site but also for the proportion of traffic that can only be carried using low frequency spectrum in view of the more limited range of higher frequencies.

We have considered the level of additional spectrum to be required to be the amount such that 5% of sites require more than that amount of additional spectrum. i.e. it is the additional spectrum required by the 6th busiest of our categories of sites. This means that, if this additional spectrum is obtained, 95% of sites will have enough capacity to meet demand. The other 5% of sites may require extra sites to be built in order to meet demand. This is undertaken in order to avoid an unrealistic assessment of the demand for spectrum – if it is only required on a limited number of sites, it may be more cost effective in practice for the mobile operator to deploy additional sites rather than to pay for additional spectrum.

A flow chart summarising our modelling approach is shown in Figure A-1 below.

Figure A-1: Modelling approach



A.2 Key assumptions

In this section we outline the key assumptions used for our assessment.

A.2.1 Market assumptions

We assume that the population of the Netherlands is 16.9 million in 2015 (Source: Central Bureau of Statistics Netherlands), increasing linearly to 17.5 million in 2025[63]. Further, we assume that mobile penetration remains flat at 103%[64].

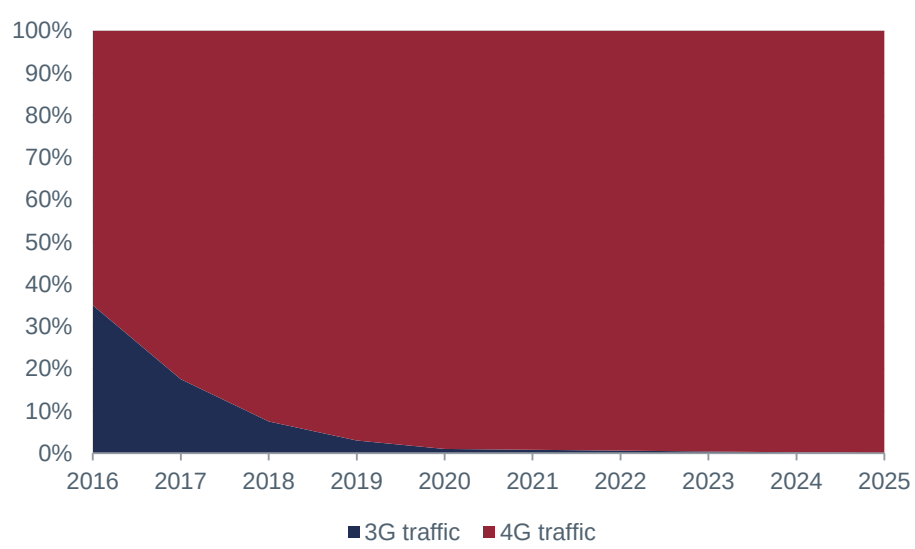
For simplicity we assume that the operator's market share remains constant at 25% throughout the modelling period

Our assumptions regarding the migration of data traffic from 3G to 4G technology is shown in Figure A-2 below:

[63] Source: Central Bureau of Statistics Netherlands

[64] Sources: Ovum, World Cellular Information Service.

Figure A-2: Migration of data traffic from 3G to 4G



We have developed two alternative data traffic forecasts:

- Low traffic case: We start with 2015 data usage[65] use the annual growth rates in the Cisco VNI forecasts[66] to project traffic until 2020 and then extrapolate this curve to 2025.
- High traffic case: We project that data usage in the Netherlands will grow to become equal to that of the Western European average data usage[66] by 2020 (from 2020 to 2025, the annual % increase is equal to that of the low traffic case).

In addition we consider how traffic levels may vary depending on the type of mobile operator:

- A 'generic' operator view, where the operator's data usage per user is equal to that of the market
- A 'fixed and mobile' operator view, where the operator's data usage per user is less than that of the market due to a higher percentage of traffic being offload to fixed networks (in comparison to the market, which has an offload % of 51% in 2016 rising to 55% in 2020[66])
- A 'mobile only' operator view, where the operator's data usage is greater than that of the market, due to a lower percentage of traffic being offloaded to fixed networks.

This results in a total of six data usage forecasts, as shown in Figure A-3 below. We assume that the percentage of data off-loaded by a combined fixed-mobile operator is 20% greater (1.2 times as much, as opposed to 20 percentage points larger) than the traffic off-loaded by a mobile only operator.

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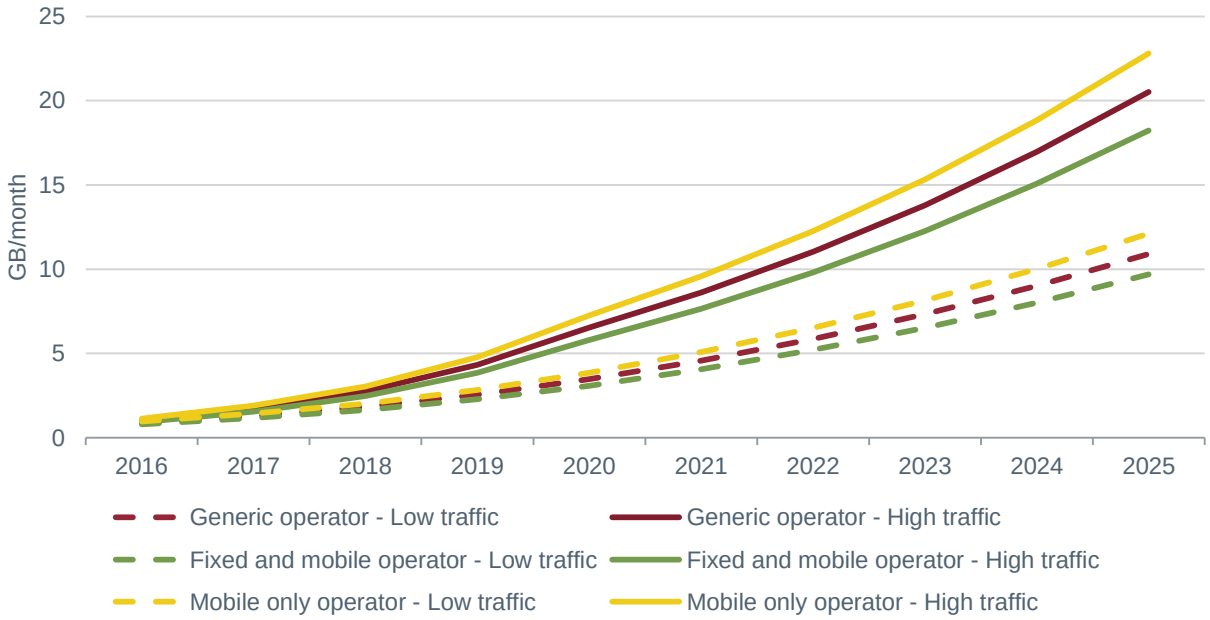
[65] Source: Acm.nl. (2016). *Nederlandse consument heeft thuis steeds vaker snel internet | ACM.nl*. [online] Available at: https://www.acm.nl/nl/publicaties/publicatie/15731/Nederlandse-consument-heeft-thuis-steeds-vaker-snel-internet/.

[66] Cisco, 'Visual Networking Index: Forecast and Methodology, 2015-2020', 1 June 2016, p. 21.

Figure A-3: Forecast growth in data usage per mobile subscriber



A.2.2 Network assumptions

We consider the generic operator to have spectrum holdings as shown in Figure A-4 below. This broadly equates to 25% of the total spectrum available for mobile services.

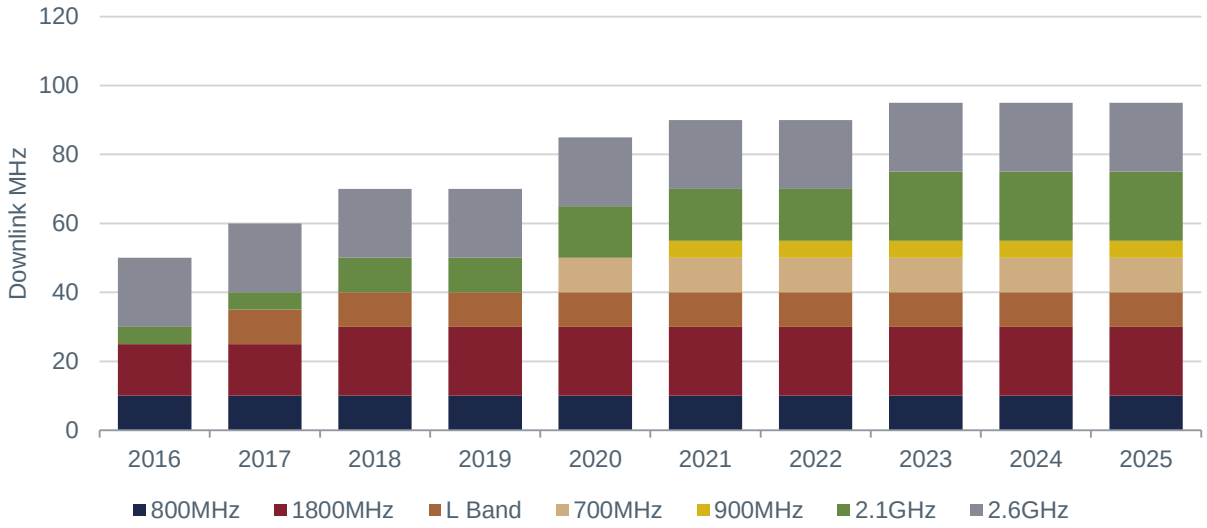
Figure A-4: Spectrum holdings of the operator

Frequency band	Amount of spectrum (MHz)	Year spectrum available from
800MHz	2×10	2016
1800MHz	2×20	2016
L Band	2×10	2017[67]
700MHz	2×10	2020
900MHz	2×10	2016
2.1GHz (paired)	2×10	2016
2.1GHz (unpaired)	10	2016
2.6GHz	2×20	2016

As discussed in the methodology section, we are modelling downlink LTE traffic (and in turn, downlink LTE capacity) – and so we then consider how much spectrum is required for 2G and 3G services, to obtain the spectrum available for use by LTE, which is shown in Figure A-5 below.

[67] We use 2017 as the earliest date to which the 1452-1492MHz spectrum could be put to use. The model itself then determines the date at which the spectrum could be usefully deployed on the generic operator's sites. Please note however that our analysis does not take account of the timing over which sufficient numbers of devices compatible with the 1452-1492MHz band will become available from manufacturers and taken up by subscribers to make deployment by an operator worthwhile.

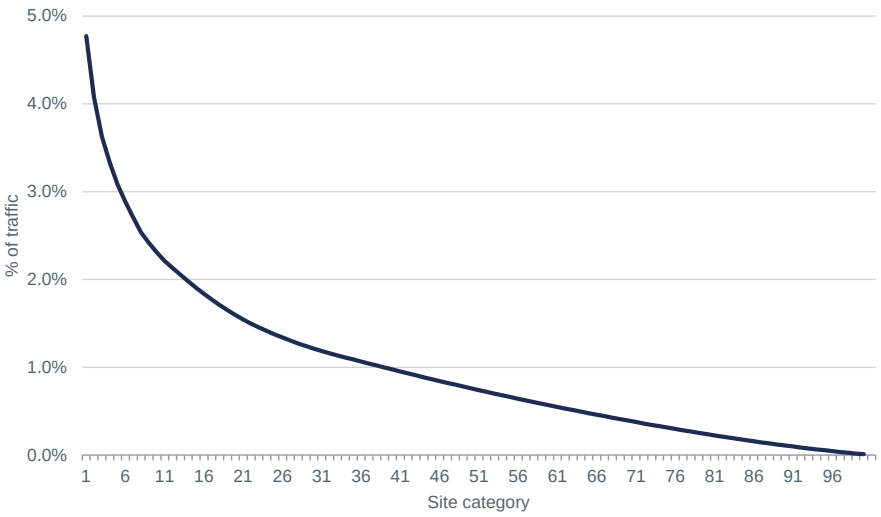
Figure A-5: Spectrum available for use by LTE



We assume that the operator, in 2016, has 5000 physical sites in total and assume the operator has deployed LTE-800 carriers on 3500 sites and LTE-1800 carriers on 1500 sites. We assume that the operator will build 50 sites a year for 5 years (from 2017 to 2021, inclusive) for general coverage and capacity improvement e.g. deployment of small cells.

For the distribution of total traffic across sites, we use a distribution function that is in line with measurements we have seen from operators of their own networks – this function has been used for similar network sizing calculations in other regulatory studies[68]. This function gives the proportion of traffic carried by each category of sites. We split the 5000 total sites into 100 equal categories of 50 sites each. This is shown in Figure A-6 below.

Figure A-6: Traffic distribution across 100 categories of sites



[68] For example see Analysys Mason, 'Assessment of the benefits of a change of use of the 700MHz band to mobile', 22 May 2014, p. 41.

In relation to the traffic carried by each site, we assume that:

- 90% of the data traffic is downlink and the network is dimensioned to cater for downlink traffic since this is the limiting factor
- 10% of traffic occurs in the network busy hour
- 55% of a site's traffic is handled by the busiest sector.

Our assumptions for spectral efficiency are shown in Figure A-7. Please note that these represent the maximum average throughput that can be achieved during the busy hour before a site needs to be upgraded. We note that this is lower than theoretical peak speeds. Over time we forecast that spectral efficiency will increase due to the adoption of new releases of the 3GPP standards for LTE and IMT-Advanced (5G) both in network equipment and in handsets as well as the adoption of 4×4 MIMO in handsets.

Figure A-7: Spectral efficiency assumptions

Year	2015	2025
LTE spectral efficiency (bit/s per Hz)	0.90	1.40

Note: We assume linearity in between these years

For the dimensioning of traffic at each individual site, we utilise two frequency zones – low frequencies (700MHz to 1500MHz) and all frequencies (700MHz to 2.6GHz) to account for the limited propagation of higher frequency bands. Within each frequency zone, traffic is compared to the existing capacity provided by bands which can serve traffic in this frequency zone. If the current capacity is inadequate to serve the traffic demand, new bands will be installed on existing sites. If this is not possible (e.g. all frequency bands within a zone have been fully utilised), then new sites will be deployed to provide the additional capacity.

Figure A-8: Traffic addressability by frequency zone

Band	Zone 1 (LF)	Zone 2 (HF)
800MHz	✓	✓
1800MHz	✗	✓
L Band	✓	✓
700MHz	✓	✓
900MHz	✓	✓
2.1GHz	✗	✓
2.6GHz	✗	✓

We assume that low frequency traffic accounts for 25% of all traffic for the generic operator. However in the cases where we separately model a fixed-mobile converged and mobile only operator, since the forecast differences in traffic levels arises from the extent of off-loading that takes place, we adjust the low frequency traffic proportion to account for 50% of this traffic difference being needed to be carried using low frequency spectrum as it is mostly generated indoors.

In respect of the order of deployment of new frequency bands, once traffic levels at a site exceeds existing capacity, bands are installed in order of the amount of spectrum available in the band since this is a

determinant of the amount of bandwidth that will become available from the deployment of this band. This order is as shown in Figure A-8, from top to bottom.

A.3 Results

We present the results of our modelling initially for the generic operator, then the spectrum demand for the overall market and finally we show how the demand for spectrum may vary between a fixed-mobile converged operator and a mobile only operator.

We show the results from using both the low traffic and high traffic scenarios for each case.

A.3.1 Generic operator

A.3.1.1 Low traffic

Figure A-9 shows the number of sites that each LTE band is installed on.

Figure A-9: Number of sites with each LTE band installed

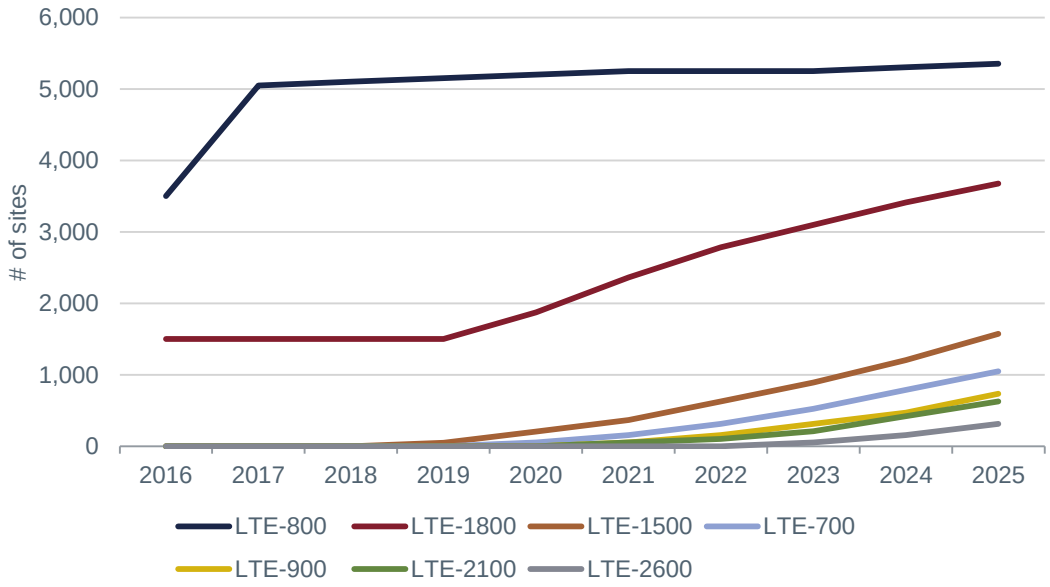
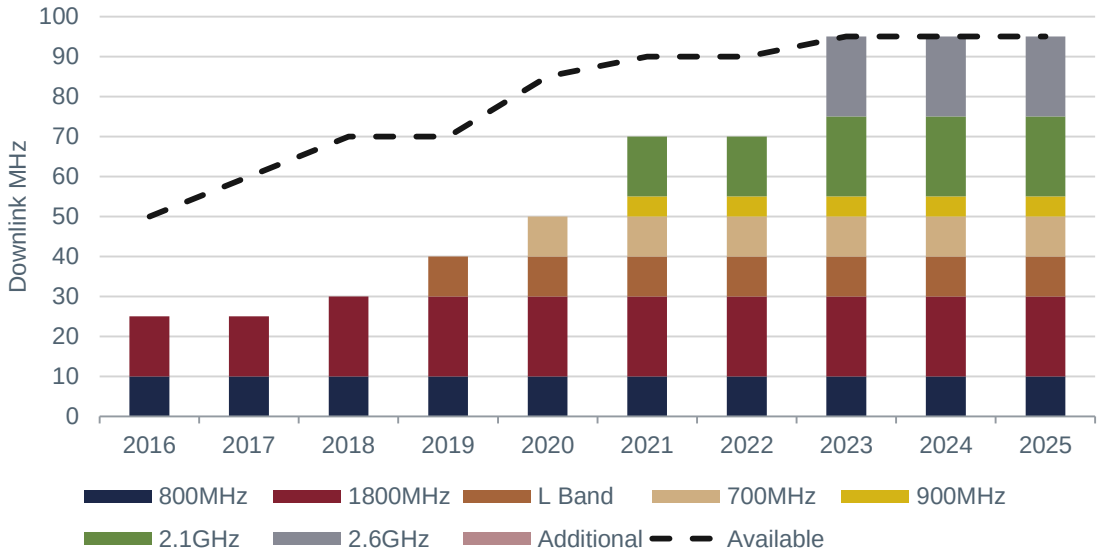


Figure A-10 shows how the spectrum is being used over time. The spectrum used means any spectrum that is required to satisfy any site's capacity requirement, up to the amount of 'available spectrum'. For spectrum beyond this amount, this is assessed as the spectrum needed to meet the capacity demands on 95% of sites (with the assumption that an operator would build more sites rather than buy more spectrum simply to serve demand for the 5% busiest sites).

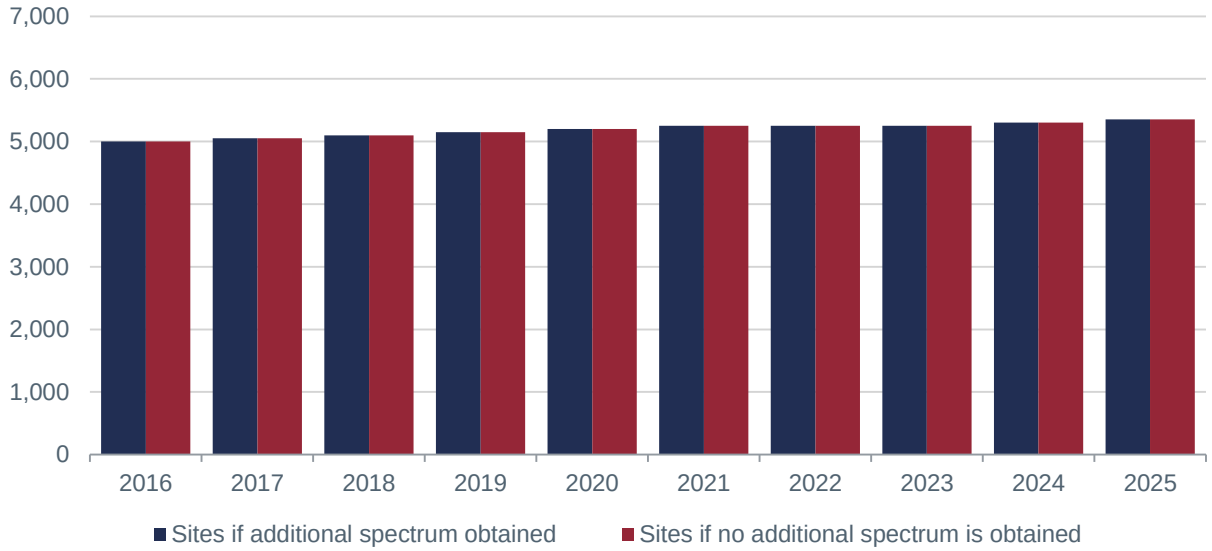
Figure A-10: Spectrum used by operator for LTE



In the low traffic case, no additional spectrum (over and above the 700MHz and 1452-1492MHz bands) is required over the modelling period.

Figure A-11 shows the total number of physical sites required over time to meet demand. It also shows the sites required if the additional spectrum is obtained.

Figure A-11: Number of sites



A.3.1.2 High traffic

Figure A-12 shows the number of sites that each band is installed on.

Figure A-12: Number of sites with each LTE band installed

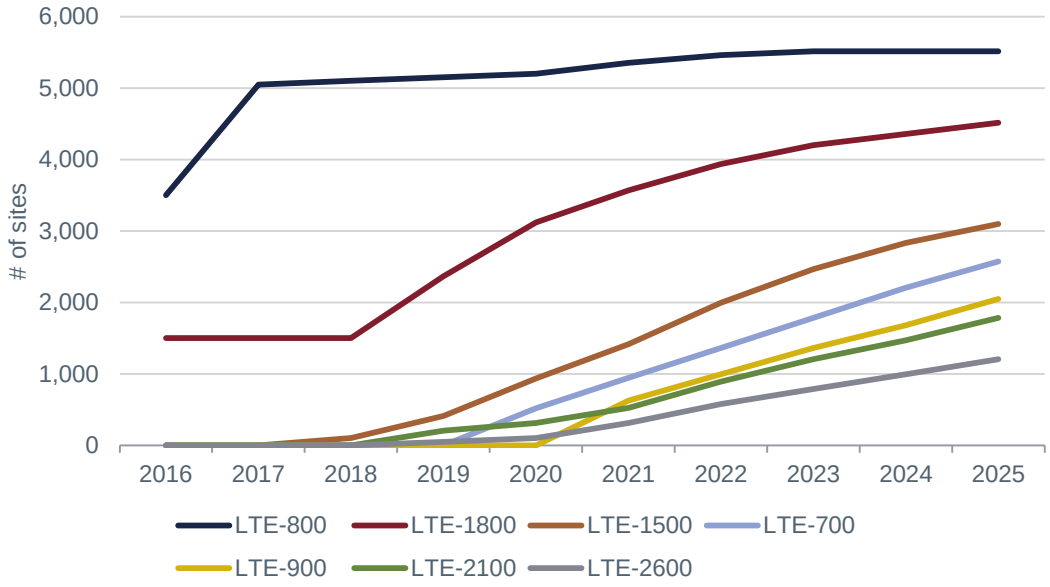


Figure A-13 shows how the spectrum is being used over time, including the amount of additional spectrum that would be used if it was available to the operator.

Figure A-13: Spectrum used by operator for LTE

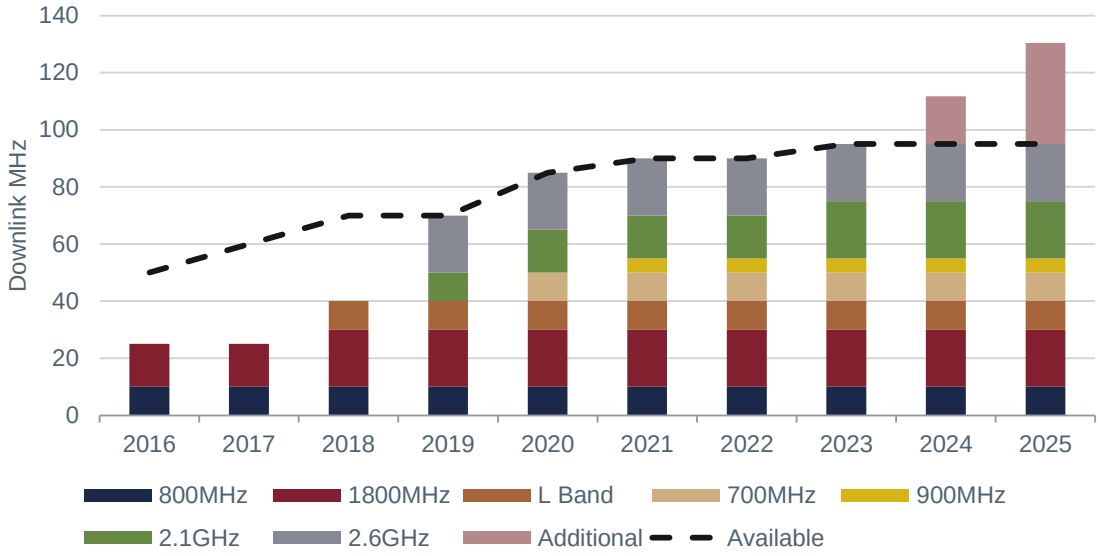


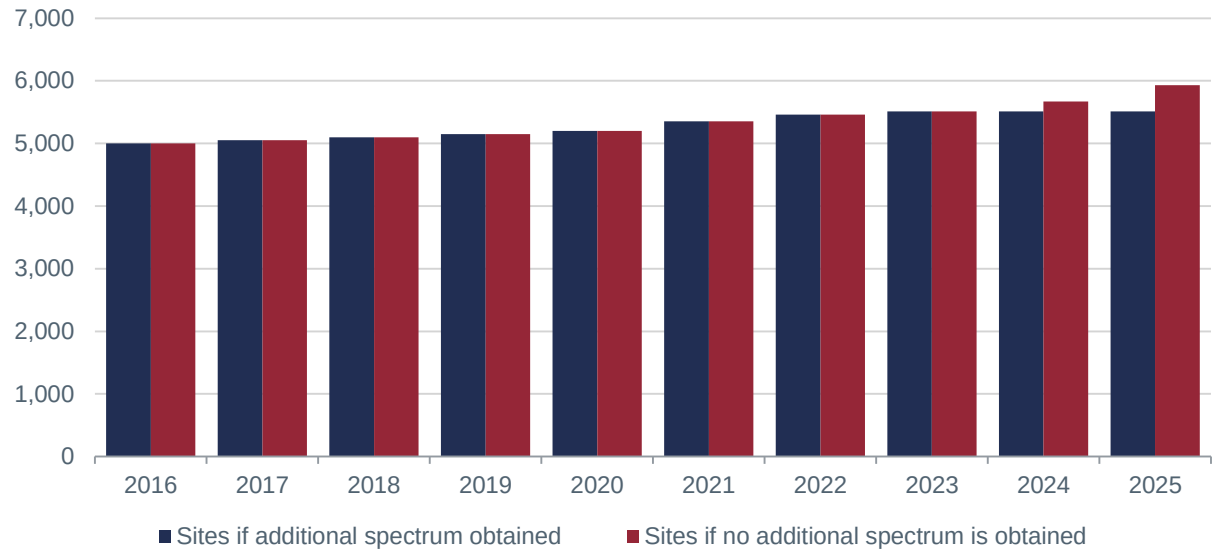
Figure A-14 shows the amount of additional downlink spectrum required by the operator over time.

Figure A-14: Additional downlink spectrum required by operator

This shows that in 2024, 17MHz of additional downlink spectrum is required. This increases to 35MHz in 2025. No additional low frequency spectrum is required.

Figure A-15 shows the total number of physical sites required over time to meet demand. It also shows the sites required if the additional spectrum is obtained.

Figure A-15: Number of sites



A.3.2 Overall market

We scale the spectrum requirement for the generic operator to the whole market by multiplying the spectrum required by the operator by 4 (as the operator has 25% market share), thus giving the total downlink spectrum required by the market.

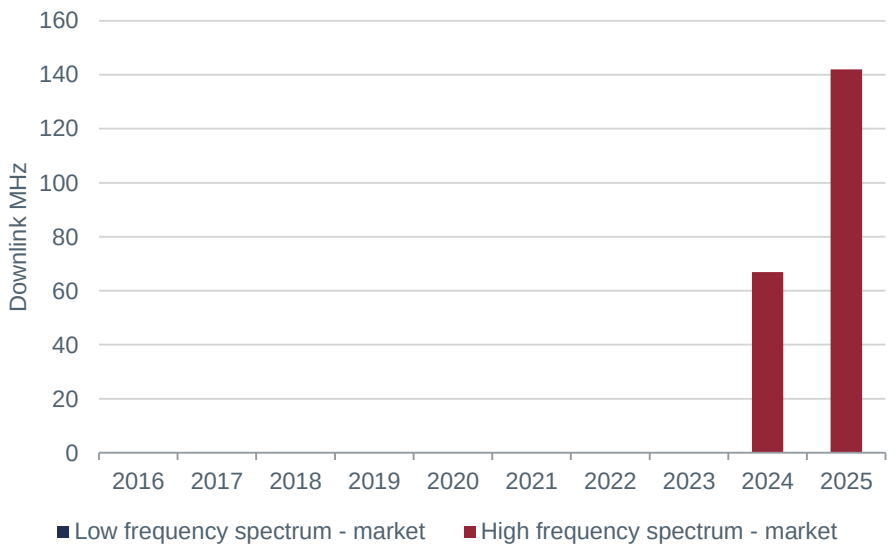
A.3.2.1 Low traffic

In the low traffic case, no additional spectrum is required.

A.3.2.2 High traffic

The additional downlink spectrum required is shown in Figure A-16.

Figure A-16: Additional downlink spectrum required by market



This shows that in 2024, 67MHz of additional downlink spectrum is required. This increases to 142MHz in 2025. As above, no additional low frequency spectrum is required.

A.3.3 Difference in spectrum demand between different types of operator

As discussed previously, we consider two different types of operator (fixed-mobile converged operator and mobile only operator) and see how the spectrum demand varies between these. For illustration purposes we compare these results with those of the generic operator previously modelled.

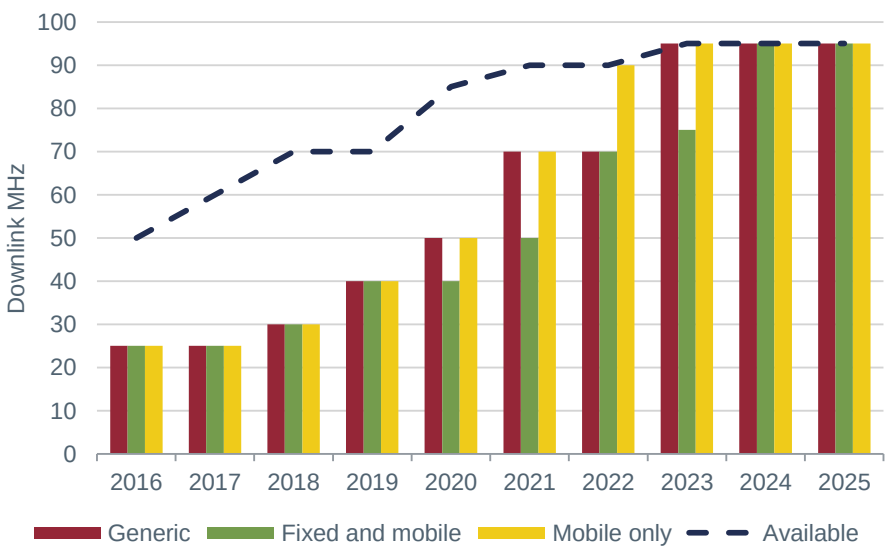
The spectrum available, marked on the charts, is that of the generic operator as detailed above. In reality, each individual operator (whether fixed-mobile converged or mobile only) will have a different spectrum portfolio and different amounts of spectrum available for LTE in any given year.

As before, results are shown for both the low and high traffic scenarios.

A.3.3.1 Total demand for spectrum

For the low traffic case, the downlink spectrum required for LTE is shown in Figure A-17 below.

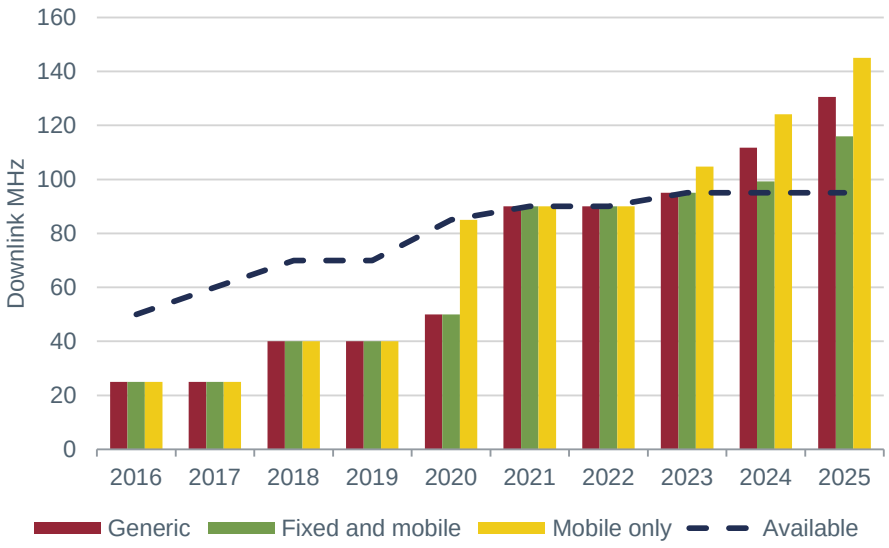
Figure A-17: Total downlink spectrum used to meet demand – low traffic



In the low traffic case, no additional spectrum is required by any of the operators.

For the high traffic case, the downlink spectrum required for LTE is shown in Figure A-18 below.

Figure A-18: Total downlink spectrum used to meet demand – high traffic



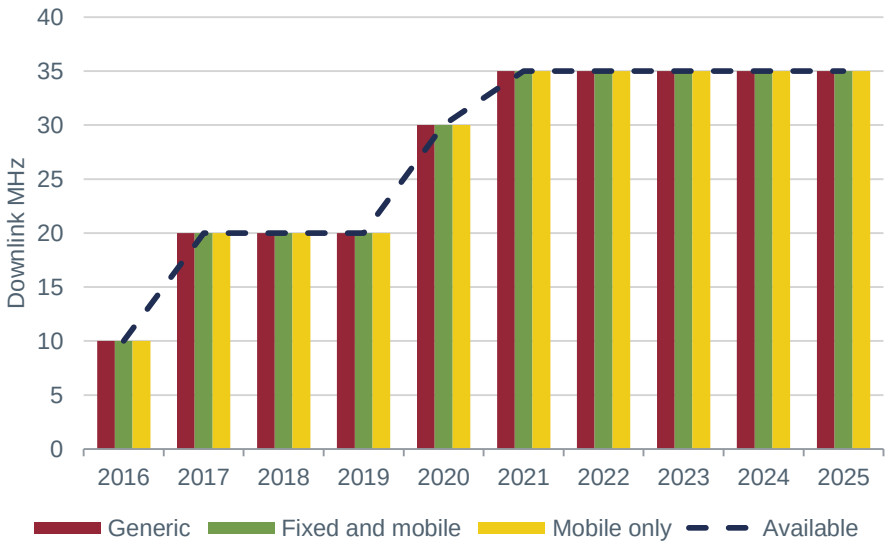
This shows that, by 2025, a generic operator requires an additional 35MHz of downlink spectrum. This compares to 21MHz for a fixed and mobile operator and 50MHz for a mobile only operator.

In this scenario, additional low frequency spectrum is required by a mobile only operator. We show the amount of low frequency spectrum required for the downlink for both low and high traffic scenarios to enable comparison across the scenarios.

A.3.3.2 Demand for low frequency spectrum

For the low traffic case, the low frequency downlink spectrum required for LTE is shown in Figure A-19 below.

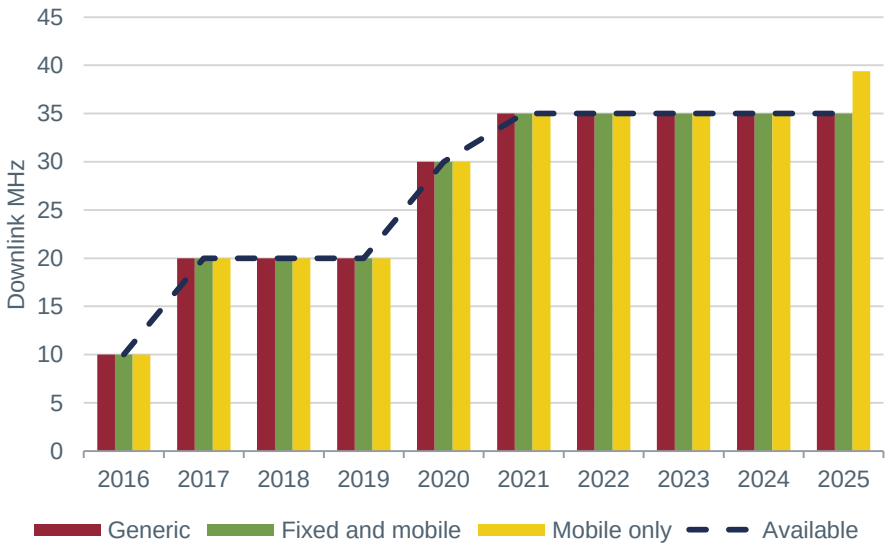
Figure A-19: Low frequency downlink spectrum used to meet demand – low traffic



As indicated earlier, in the low traffic case, no additional low frequency spectrum is required by any of the operators.

For the high traffic case, the low frequency downlink spectrum required for LTE is shown in Figure A-20 below.

Figure A-20: Low frequency downlink spectrum used to meet demand – high traffic



This shows that in 2025, 4MHz of additional low frequency downlink spectrum is required by the mobile only operator. The converged fixed and mobile operator and generic operator do not require any additional low frequency spectrum during the modelling period.