Annex 10 - Summary of analysis of differences between frequencies

Introduction

A10.1 This Annex summarises our refined analysis of the differences that may arise after liberalisation between operators with different spectrum holdings if liberalised spectrum is used for UMTS (3G) networks. These differences are measured in terms of differences in costs incurred and/or quality differences in the mobile broadband services provided. The measures of quality include data rate and coverage.

A10.2 There are two different bands being considered for liberalisation, 900 MHz and 1800 MHz. Options being considered for each of these bands include liberalisation of spectrum in the hands of the incumbent holders, and mandatory spectrum release, so that some liberalised spectrum ends up in the hands of a third party. It is also possible that spectrum will be redistributed not because we mandate it, but as a result of secondary market trading.

A10.3 In order to inform the choice between options, this annex answers the following high level questions:

- If we liberalise in the hands of incumbents, and there is no trade that changes the current distribution of 900MHz and 1800 MHz spectrum, what speed and coverage differences could arise between mobile broadband services as a result of operators having different spectrum holdings?
- If we liberalise in the hands of incumbents, and there is no trade that changes the current distribution of 900MHz and 1800 MHz spectrum, what would be the differences in costs for operators to provide the same mobile broadband services using different spectrum?
- What savings would be achieved for an operator initially without 900 MHz spectrum who acquires one block (2x5MHz) of this spectrum?

A10.4 These questions reflect that operators with higher frequency spectrum might provide the same service as operators with lower frequency spectrum, possibly at additional cost, or provide a lower quality service. We cannot be certain of which of these will be the most likely strategy; hence we consider both cases.

A10.5 The rest of this annex is structured as follows:

- An ***overview of the analysis***
- The ***scenarios covered in the analysis***
- ***Differences in the coverage and speed of mobile broadband services*** that may arise between operators with different spectrum holdings
- ***Cost differences*** that may arise between operators with different spectrum holdings, ***in more densely populated areas***

- ***The potential benefits of intervention*** to release a single block of 900MHz spectrum
- Results for ***cost differences*** that may arise between operators with and without liberalised spectrum, ***in less densely populated areas***
- A ***summary of findings***

Overview of the analysis

A10.6 Since the 2007 consultation we have refined and updated our analysis of the differences between bands. The main changes are:

- We have updated the range of market scenarios considered to take account of market developments since our previous consultation
- We have revised the methodology and parameters for our technical analysis in light of responses to the consultation and subsequent input from the mobile network operators
- We have taken into account the increased likelihood that it will be possible to provide services with 800MHz spectrum that are able to compete with services provided with 900MHz spectrum, at a comparable cost. To reflect this, we now focus on the case where operators without 900 MHz spectrum acquire, and subsequently use, 800 MHz spectrum to offer services comparable to those using 900 MHz spectrum, and focus on differences that arise during that interim period (ie the period between 900 MHz and 800 MHz providing benefits to consumers). However, as this outcome is not certain, we also calculate results for the case where this does not happen.

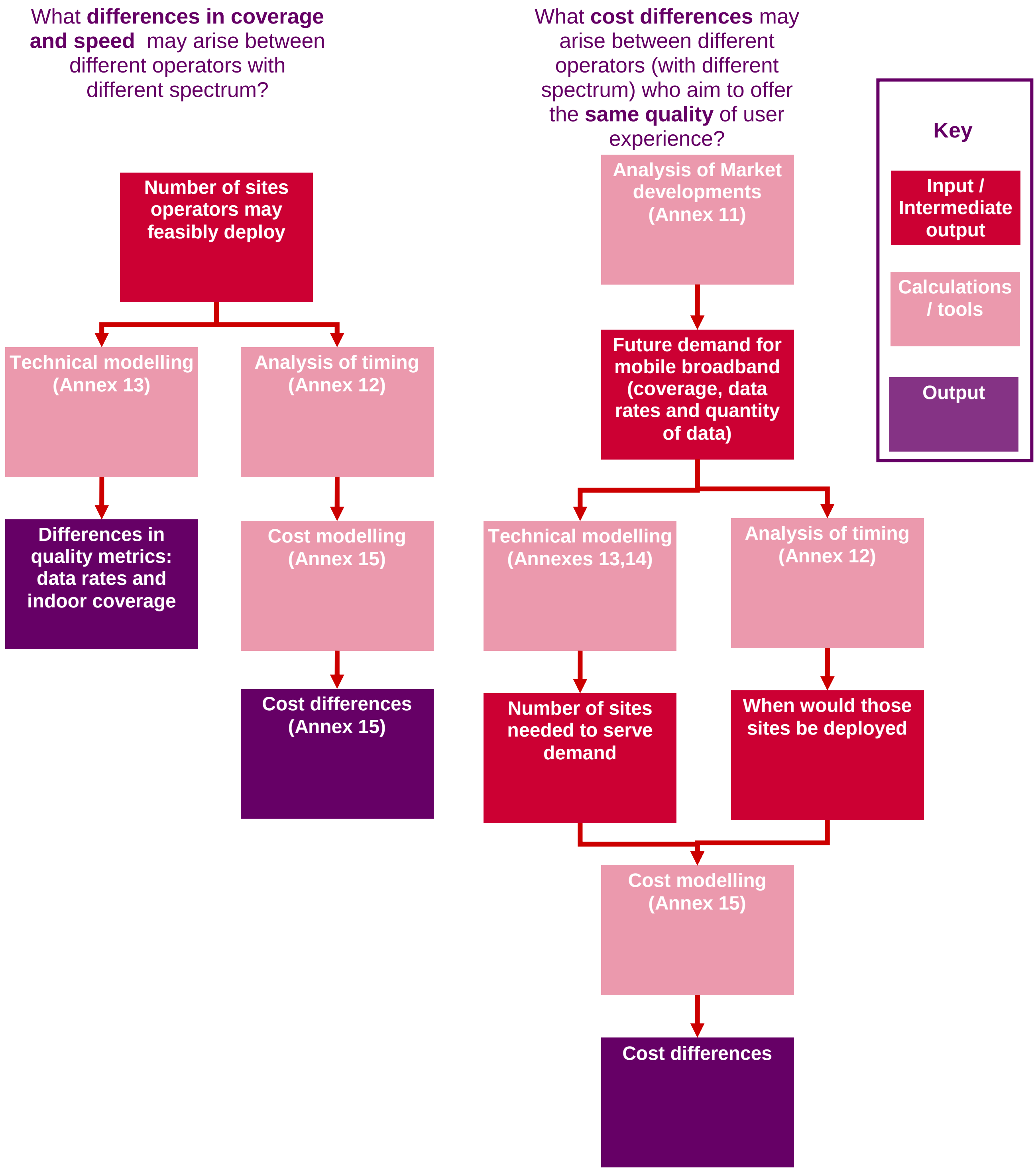
A10.7 Our refined analysis comprises:

- **Market scenario analysis**. This looks at the future demand for mobile data services that may be provided using the liberalised spectrum. This is presented in detail in Annex 11.
- **Technical modelling of the differences between operators**. Given a market scenario and other inputs, our technical modelling work estimates the number of sites[1] needed for different operators. Alternatively the model can also be used to derive the data rates (throughput), indoor coverage and volumes of data that are likely to be supported by an operator with a given number of sites. The technical calculations are performed separately for densely populated areas, and less densely populated areas. This is presented in Annexes 13 and 14..
- **Timing analysis.** Presents ranges of likely timings for the deployment of mobile broadband technologies in the frequency bands of interest, and roll out profiles for deployment of mobile broadband networks matched to the range of market scenarios.
- **Cost modelling**. Given a difference in sites and a roll out profile, we calculate a resulting cost difference, as a present value (PV) over a 20 year period. This is presented in Annex 12.

[1] In general, sites here refer to macro sites. There are other types of sites, such as micro sites and femtocells. The way we take this into account is explained in detail in Annex 10

A10.8 The way we use these tools to answer different questions is illustrated below in Figure 1.

Figure 1: How different question are answered



A10.9 The process shown above is explained in more detail below for each of the questions.

What speed and coverage differences could arise between mobile broadband services as a result of operators having different spectrum holdings?

A10.10 To answer this question we consider how many sites operators could plausibly deploy over the next few years before 800 MHz spectrum starts to offer an effective alternative to 900 MHz spectrum. Given a range of possible network deployments, we estimate potential differences in the speed and indoor coverage of mobile broadband services between operators holding liberalised 900MHz spectrum and those without. The calculation is detailed in Annex 13. We also show the cost difference between operators that is incurred in addition to the quality difference.

What would be the differences in costs for operators with different spectrum holdings to provide the same mobile broadband services?

A10.11 This analysis calculates the cost of providing a given level of service for operators with different spectrum portfolios. The sequence of analysis undertaken for more densely populated areas (where 80% of the population lives) is:

- A range of plausible relevant levels of service is derived from market scenarios in Annex 11.
- The technical modelling (Annexes 13 and 14) provides the number of sites needed for serving this range of demand scenarios, if one is to use traditional macro sites. These results are also used to check the initial range of market scenarios so that we avoid considering scenarios that seem impractical for any operator to provide using macro sites.[2]
- Annex 12 derives roll out profiles, based on the total number of sites required for a given demand scenario, at different bands. It takes into account timing inputs related to the availability of spectrum and equipment for the technologies of interest.
- These roll out profiles are then used to calculate differences in costs between operators with different spectrum holdings (Annex 15).

A10.12 A greatly simplified version of this process is applied for calculations for less densely populated areas, beyond the area where 80% of the population lives. Although liberalisation can provide significant benefits for services in less densely populated areas, there are many fewer sites deployed or needed in these areas than in more densely populated areas. The level of detail of analysis undertaken in the two areas reflects this.

What saving would be achieved for operators who acquire one block of 900 MHz spectrum?

A10.13 The previous question is concerned with the cost difference between operators if spectrum holdings are unchanged following liberalisation.. A related question is whether operators who currently does not have 900 MHz spectrum would realise an equivalent cost saving if they acquired some 900 MHz spectrum.

[2] Note that some additional volume of demand may be served via alternative means of delivery, other than traditional macrocell networks. This analysis focus on the proportion of total traffic that is served via macrocell networks, which is where the impact of liberalised spectrum may occur. This is explained in more detail in Annex 12.

A10.14 In order to answer this, we follow the same analysis as described for the previous question and adjust some inputs to reflect any differences in the position of an acquirer of 900 MHz spectrum compared to an incumbent holder of 900 MHz spectrum.

Scenarios covered in the analysis of more densely populated areas

A10.15 The values of several variables used in the analysis are subject to some uncertainty. This includes the nature of future data traffic, technical inputs, and some cost inputs. However, most of the variation in the range of cost stems from the nature of the data traffic that mobile networks will serve in the future, in particular the level of coverage and data rates provided. We have therefore used a range of plausible scenarios to capture this uncertainty. These scenarios are informed by our analysis of market developments and are considered in more detail in Annex 11.

A10.16 In addition, we also consider the practicality of deploying different networks within particular timescales, and the spectrum holdings and use of spectrum by different operators.

A10.17 The range of demand scenarios being considered now is wider, and higher in terms of data volumes and speeds, than that used at the time of the 2007 consultation. Table 1 below summarises the parameters for the scenarios at the highest and lowest end of the range considered – “lower demand” and “higher demand”. Annexes 13 and 15 also explore intermediate scenarios and some scenarios with parameters beyond these ranges.

Table 1 - Demand scenarios

Scenario	**Speed** (minimum data rate consistently provided whilst in coverage)	**Depth of Coverage** (in 80% population area)	**Data quantity** (average volume downloaded per user per day)
Lower demand	384 kbps	Depth 1 (shallower)	1 megabyte
Higher demand	2.4 Mbps	Depth 2 (deeper)	30 megabytes

A10.18 Each of the parameters in Table 1is discussed in more detail in Annex 11. In summary:

- **Data rates.** This variable measures the minimum data rate (specifically the throughput) that users can consistently get whilst within coverage. In any mobile network, data rates vary a lot from location to location and for this reason, we focus on the minimum data rates that can be expected consistently, rather than on the maximum rates achievable.

- **Quantity of data traffic.** This variable measures the average volume (in MBs) of data that is downloaded per mobile user per day. The measure used is an average across all mobile users, not just those who subscribe to mobile broadband services, to enable this variable to capture uncertainty over the level of mobile broadband take-up as well as level of use. The relevant data traffic is the traffic delivered using traditional 'macrocell' networks. We also examine volumes greater than 30 MB to understand the extent to which networks may face capacity constraints.

- **Indoor coverage**. This variable measures how good indoor coverage is for mobile broadband services. We have modelled networks providing indoor coverage, such that consumers can reliably get mobile broadband service whilst indoors. Two levels of indoor coverage are examined, and named depth 1 and 2. Depth 2 is a more consistent service level across the area of a building and depth 1 is a shallower service level but still provides a measure of in-building service. Both sets of parameters are meant to reflect industry practice.

A10.19 The relevant time period for these scenarios is the point at which mobile broadband networks using 900 MHz spectrum could have been deployed and could be widespread use by consumers, but before networks using 800 MHz spectrum are likely to be in widespread use. The year 2015 is used as an approximate reference to this point (see timing analysis in Annex 12 for more details) . Uncertainty surrounding future data traffic levels in particular is very high, and the range of forecasts used could fit equally well the years just before, or just after 2015. We use 2015 as a reference point to make the presentation of the analysis simpler. This does not imply that we expect some definite milestone to occur in 2015.

A10.20 We also have considered whether it is practical for operators to provide these levels of service within this period given the number of sites that would be required with particular spectrum holdings. In particular we consider the practical constraints that may limit a network operator's ability to expand their network sufficiently fast to provide the services defined by these scenarios:

- For the cost difference analysis, we considered the maximum number of sites that a network could practically deploy year by year, taking account of limitations in acquiring new sites and our understanding of some examples of real world business plans. This is detailed in Annex 12. We concluded that the full range of demand scenarios examined can plausibly be met by an operator using UMTS 900, so no demand scenarios were discarded on this account.

- For the analysis about differences in the coverage and speed of mobile broadband services, we formulated scenarios about the total number of sites that operators interested in mobile data are likely to deploy, within the time of interest for this analysis. We project forward for a few years ahead levels of deployment that are similar to those observed in the market today.

A10.21 The scenarios shown here describe the difference between operators that deploy UMTS 900 (as well as retaining their existing UMTS 2100 networks) and operators without 900 MHz spectrum who continue to rely on their existing UMTS 2100 networks.

A10.22 We do not present explicit comparisons for operators who deploy UMTS1800 networks because technical analysis shows that 1800 MHz has little advantage (and sometimes small disadvantages) in relation to 2100 MHz spectrum, in terms of number of sites needed, if all things are equal. Even if more spectrum were employed at 1800 MHz than at 2100 MHz, and traffic volumes grew significantly, no significant advantage appears to arise. For example, using 4 carriers of 1800 MHz spectrum compared to 2 carriers of 2100 MHz spectrum seems to reduce the requirement in number of sites by only 3%[3] even in a high traffic volume scenario (as detailed in Annex 13). In addition, if greater mobile broadband capacity were needed in the future, there are a number of other means of expanding capacity (for instance, by acquiring additional spectrum).

A10.23 We focus on scenarios where any advantage from holding liberalised 900MHz spectrum is only temporary because operators without 900 MHz spectrum have the opportunity to gain access to 800 MHz spectrum. However, as there are some uncertainties over the availability and future use of 800MHz spectrum we also calculate results for the case where this does not happen.

Differences in the coverage and speed of mobile broadband services

A10.24 This section provides answers to our first question: what speed and coverage differences could arise between different operators, as a consequence of different spectrum holdings following liberalisation in the hands of the incumbents. This is measured by comparing the speeds (throughput) and indoor penetration provided by different networks that may plausibly be deployed in the next few years, before 800 MHz becomes available and widely used. The results are for the more densely populated areas where 80% of the population lives.

A10.25 The comparisons are between:

- Operator with 900 MHz deploying UMTS 900 at higher demand and an operator without 900 MHz who does not attempt to match this using UMTS2100.
- Operator with 900 MHz deploying UMTS 900 at higher demand and an operator without 900 MHz who does attempt to match this using UMTS2100.

A10.26 The operator with 900 MHz deploys in this comparison 7,300 sites with UMTS 900. This is sufficient to meet the “higher demand” scenario. We believe that this number of sites can feasibly be deployed in the period between now and 2015 or before, as detailed in Annex 12.

A10.27 The number of UMTS 2100 sites deployed by the operator without 900 MHz varies with each comparison. They either:

- ***Do not try to fully match the UMTS 900 operator***. To represent this case, we used a scenario where they reach a total of 9,000 sites between now and 2015.
- ***Attempts to match the UMTS 900 operator.*** To represent this case, we used a scenario where the operator without 900 MHz deploys 15,000 sites, as detailed in Annex 12. We believe that this is close to the maximum that is feasible to achieve in the timeline of interest.

A10.28 We present results for an operator with 900 MHz using one UMTS 900 carrier[4]. The operator without 900 MHz uses two 2100 MHz carriers[5].

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[3] This result is based on a comparison between a network with 2 carriers at 2100 MHz and one with 4 carriers at 1800 MHz, providing 2.4Mbps, good indoor coverage, and 30 MB/user/day.

[4] Because of limitations of our modelling techniques, the results shown here use a simplified model that only reflects one band of spectrum at a time. It does not take into account the fact that the UMTS 900 operator would also have 2100 MHz spectrum. However the technical results show that if we were to take this into account, there would be no significant impact n the results. We establish this by increasing the amount of 900 MHz spectrum available to the UMTS 900 operator, and observing that

A10.29 Data volumes used were fixed at 3 MB/user/day. The detailed results in Annex 13 suggest that these results would change very little even if data volumes were chosen to be much higher.

A10.30 We have focused on indoor coverage when measuring differences between networks. This is because provision of indoor coverage is technically challenging, and because much of the current use of mobiles occurs indoors (also see Annex 11)

A10.31 We compared data rates (throughput) that users may experience across a range of indoor locations. The figure below shows the results of this comparison. The horizontal axis shows indoor locations on the ground floor of a typical building.

A10.32 Starting from the left hand side, the chart shows first the data rates achieved in the best 5% of locations (those with the best mobile reception). The chart shows the gradual degradation in speeds as a user moves from the best locations to the worst locations within the typical building. Note that not all buildings will receive the same quality of coverage; some will see better performance than this, but others worse.

A10.33 Moving along the horizontal axis from left to right, the advantage of 900MHz spectrum is reflected in the ability to deliver higher data rates to a larger proportion of indoor locations. The 2100MHz operator can increase the data rate it can offer at indoor locations by adding sites, increasing them from 9,000 to 15,000. But, even so, the 900MHz operator can offer higher data rates to a proportion of indoor locations.

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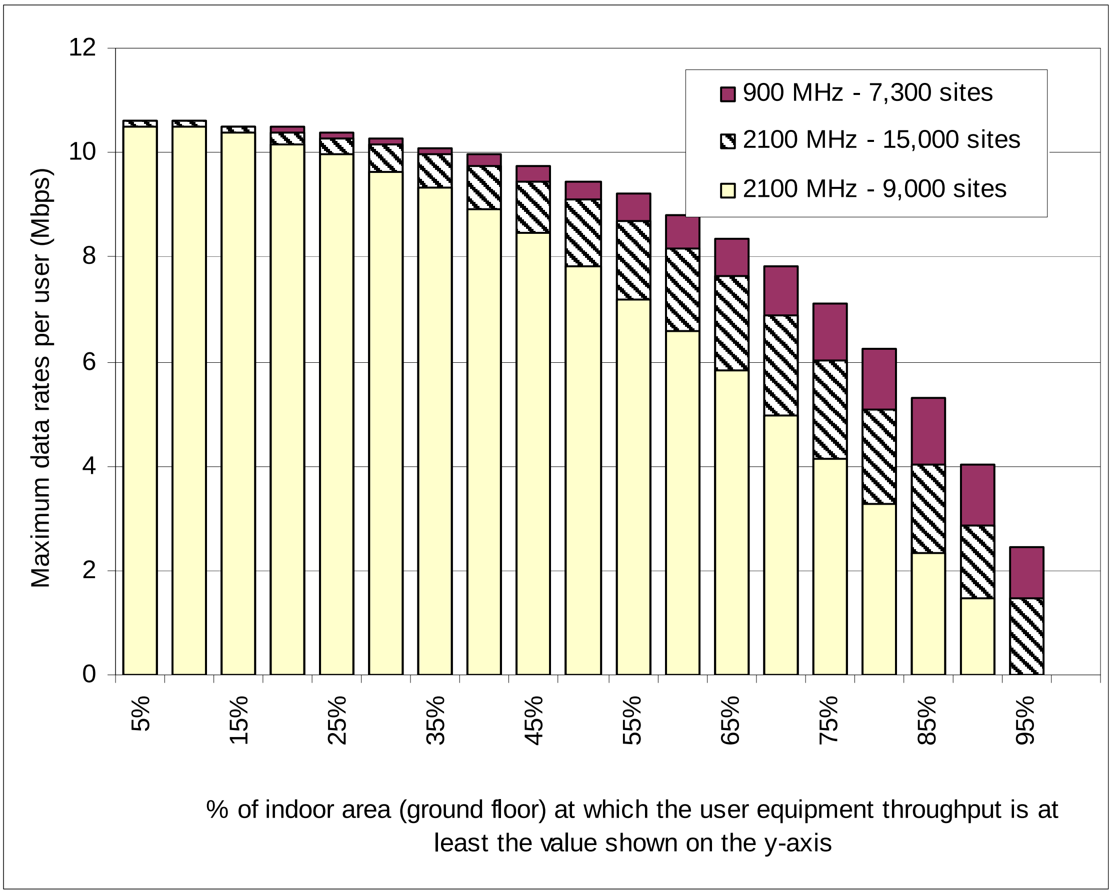
the resulting increase in speeds is smaller than 0.1% in 37 out of 38 data points used to draw the chart shown. This shows that the results are not sensitive to additional 900 MHz spectrum. Additional 2100 MHz will be less beneficiary than additional 900 MHz spectrum, because of the latter better propagation. Therefore, if we were able to add 2100 MHz spectrum to the UMTS 900 operator, any improvement would be even smaller than the one described above.] This makes intuitive sense as normally low frequencies are used for coverage, and higher frequencies for capacity.

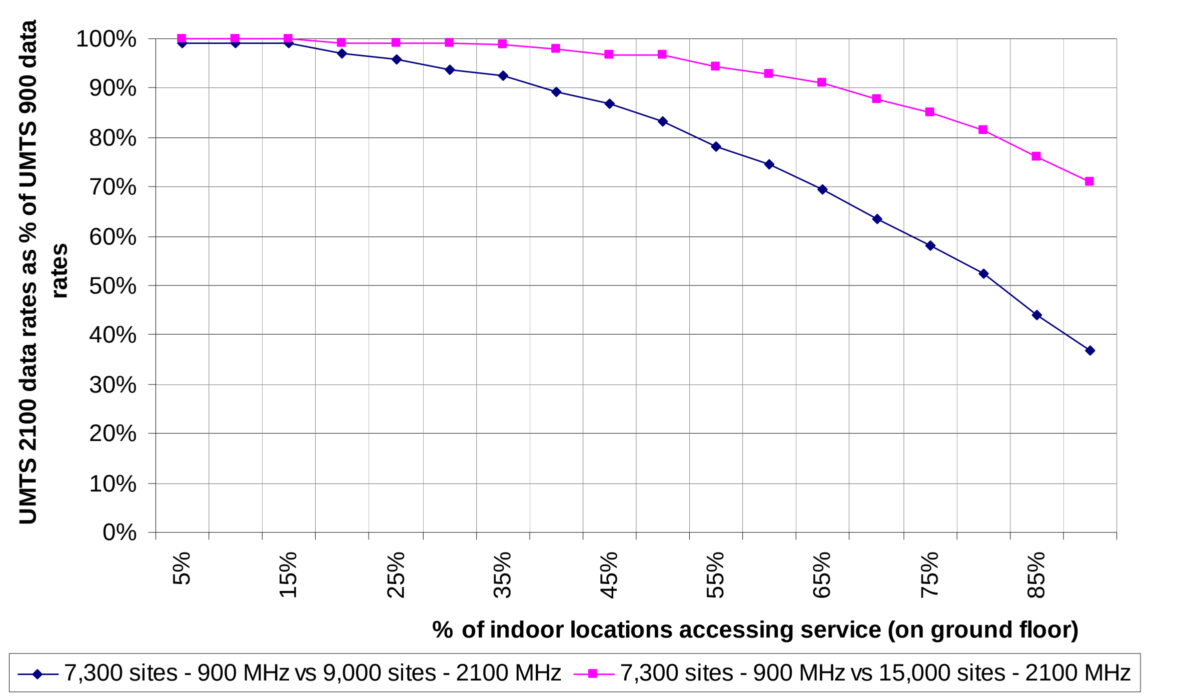
[5] Some operators have three 2100 MHz carriers, but the technical modelling shows that the impact of a third carrier is very small for this comparison because the comparisons below will be coverage constrained (more details in Annex 10).

Figure 2 - Data rates achieved by different networks, as seen from different indoor locations



A10.34 Figure 3 below shows the difference between UMTS 900 and UMTS 2100 networks in terms of a percentage difference in data rates.

Figure 3 - Speed difference between UMTS 900 and UMTS 2100 networks, as seen from different locations



A10.35 In the first comparison (when the operator without 900 MHz does not try to match the operator with 900 MHz), the figures above show that:

- For users in the best 55% of locations, who get the fastest speeds (7-10.5Mbps with 2100MHz), there are relatively small differences between the data rates experienced on the UMTS 2100 network and the UMTS 900 network - speeds on the UMTS 2100 network are less than 20% slower.

- For the next 20% of locations the difference is greater: UMTS 2100 speeds are 25-40% slower than UMTS 900, but the UMTS 2100 network still provides a good rate compared to what is currently marketed for mobile broadband. For example a user of the UMTS 2100 network might get around 8 Mbps compared to 5 Mbps in the UMTS 900 network.

- For the next 15% of locations, rates provided by the UMTS 2100 network are around half, or less than half those at the UMTS 900 network.

- Finally, for the last 5% of locations at which either network provides service, UMTS 2100 customers get service at very low data rates, or practically no service at all (below 0.1 Mbps), while UMTS 900 customers still get good data rates (2 to 3 Mbps).

A10.36 In order to give a sense of the impact of these differences in speed, we show below an example of the difference in download times under a variety of situations as experienced by UMTS 900 and UMTS 2100 customers. As discussed above, the difference is small in around half of indoor, ground floor locations (ie, the top 50% places with the best reception). The comparison is intended to be representative of what would happen in the other half of locations (and therefore reflects speeds at the third quartile of indoor places).

Table 2 - Examples of expected additional wait for a UMTS 2100 customer, when downloading different files

	A 5 minute video clip [6]	A 50 MB attachment	A 45m TV show
Users in third quartile of ground floor indoor locations; 7 Mbps vs 4 Mbps)	**22s** additional wait (UMTS 900 user waits **29s**; UMTS 2100 user waits **51s**)	**43s** additional wait (**57s** vs **1m40s**)	**2m51s** additional wait (**3m49s** vs **6m40s**)

A10.37 In the case where the operator without 900 MHz does attempt to match the operator with 900 MHz by deploying 15,000 sites, the differences are much smaller, and are always less than 30%, as shown in

[6] Sizes: 26 MB for a 5 minute clip; 200 MB for a 45 minute TV show. Sources: Vodafone.co.uk online calculator and Apple http://support.apple.com/kb/HT157, "itunes store: download times will vary"

Figure 3.

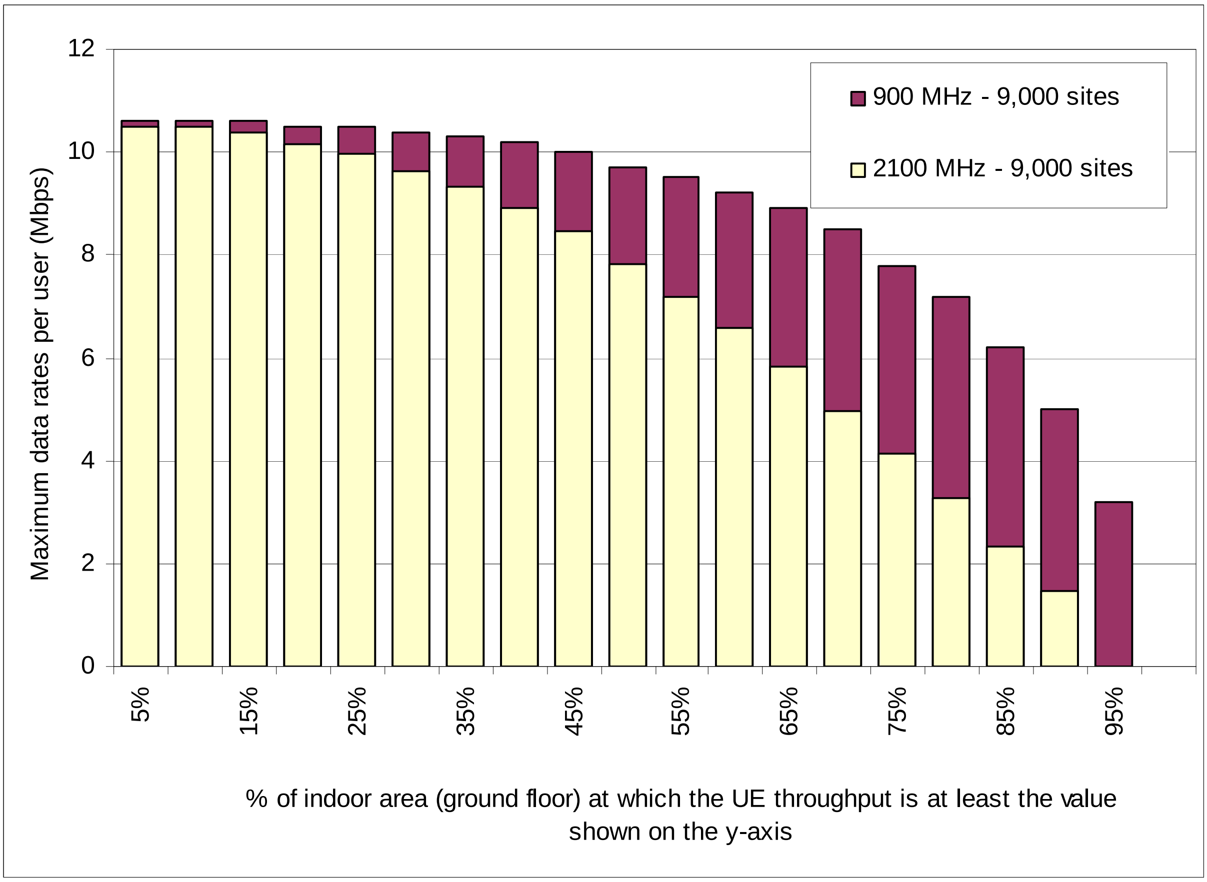
A10.38 In addition to the quality differences above, there are also costs differences in deploying these networks using 2100 MHz compared to 900 MHz spectrum. This is summarised in Table 3.

Table 3 - Cost difference in addition to quality differences

	UMTS 900 operator	UMTS 2100 operator	Cost difference
Number of sites	7,300	9,000	£50m
Number of sites	7,300	15,000	£700m

A10.39 Finally, we show below a comparison where both operators deploy 9,000 sites:

Figure 4 - Data rates achieved by networks with the same number of sites and different spectrum bands, as seen from a range of indoor locations



Cost differences in more densely populated areas

A10.40 This section provides answers to our second question: If we liberalise in the hands of incumbents and there is no trade that changes the current distribution of spectrum, what would be the difference in costs for operators to provide the same mobile broadband services using spectrum at different frequencies?

A10.41 The comparisons show the difference in costs for an operator with 900 MHz spectrum that deploys UMTS 900 with one 5 MHz carrier versus an operator without 900 MHz spectrum that continues to rely on only UMTS 2100 with two carriers. We do not show comparisons for operators with 1800 MHz spectrum deploying UMTS 1800 for the reasons explained earlier in this Annex.

A10.42 A cost difference can be interpreted as a financial barrier for the UMTS 2100 operator to match the service offered by an operator with UMTS 900. It is possible that there may be a non-financial barrier as well in some cases. This would be the case when there is difficulty in acquiring sites at the required pace. In order to show the full amount of the financial barrier separately from the non-financial barrier, we measured the costs of the full number of sites that would need to be acquired, even if the acquisition of sites at that pace may be impractical.

Table 4 - Number of sites required in densely populated areas

Operator	Lower demand Service provided: - Minimum of 384 kbps - shallower indoor coverage - 1 MB / subscriber / day	Higher demand Service provided: - Minimum of 2.4 Mbps - deeper indoor coverage - 30 MB / subscriber / day
Operator with 900 MHz spectrum deploying UMTS 900	2,900	7,300 sites
Operator using only UMTS2100	8,600	21,100

Table 5 - Additional costs for an operator using only UMTS2100 compared to an operator deploying UMTS900 (assuming the same service is provided) (NPV at 3.5%)

Cost difference	Lower demand (384 kbps / shallower indoor penetration) 1 MB / subscriber / day	Higher demand (2.4 Mbps / deeper indoor penetration) 30 MB / subscriber / day
Single UMTS2100 operator (who acquires 800 MHz)	£50m	£1.6bn

Network sharing UMTS2100 operator (who acquires 800 MHz)	No cost advantage for 900MHz operator arising from liberalisation	£1.0bn
Single UMTS2100 operator (who does not acquire 800 MHz)	£250m	£2.2bn
Network sharing UMTS2100 operator (who does not acquire 800 MHz)	£50m	£1.4bn

A10.43 These results use our baseline assumptions for many parameters related to the cost modelling and technical model. We also present several sensitivities that show the impact of flexing these parameters in Annexes 13 and 15. The uncertainty over technical parameters expands the above range. Using one extreme of the range of parameters, results suggests no cost advantage derived from use of liberalised spectrum. If the parameters on the opposite extreme are used, the cost difference grows as large as £4.5bn for a single operator.

The potential benefits of intervention

A10.44 This section presents the cost savings for an operator originally without 900 MHz spectrum who acquires one block of that spectrum following a regulatory intervention to mandate spectrum release. The cost saving is defined as the difference in costs for an operator originally without 900 MHz spectrum between the following two outcomes:

a) 900 MHz is liberalised in the hands of incumbents (and kept by the incumbents); the operator without 900 MHz spectrum matches the quality of the UMTS 900 network; and

b) One block of 900 MHz spectrum is acquired by the operator, following intervention to mandate release. The operator matches the quality of the incumbent 900 MHz operator.

A10.45 The calculation is very similar to the cost difference calculation used in the previous section. We discuss the parameters used below.

A10.46 **Relevant spectrum holdings.** The relevant spectrum holdings of such an operator would be similar to those used in the calculations presented in the previous section: they would have use of one block of 900 MHz and 2 or 3 blocks of 2100 MHz spectrum.

A10.47 **Timing.** There may be a delay in use of the 900 MHz spectrum if we do intervene (for more details on timing see Annex 9). Even if the delay in spectrum release were to cause a delay in use of UMTS 900, this would not result in any additional costs for the acquirer of the spectrum. Delaying the expenditure in deploying of a UMTS 900 network would only reduce its Present Value (PV).

A10.48 **Unit site costs.** The relevant change in parameters for this case is related to unit site costs. An incumbent 900 MHz operator already has 900 MHz antennas and other frequency-specific equipment, and may be able to re-use them when upgrading to UMTS 900, which leads to cost savings. These savings will not be available to an operator acquiring 900 MHz spectrum.

A10.49 We have calculated a wide range for this effect, varying the savings resulting from re-use of 900 MHz equipment from 0% to 50% of the cost of an upgrade. As a result, the cost saving achievable by an acquirer of 900MHz spectrum varies between 90% and 100% of the cost advantage that an existing holder of 900MHz spectrum would be likely to enjoy.

Table 6 – Cost difference for an operator without 900 MHz, if they acquire a 900 MHz block

	Without 900 MHz	Acquiring a 900 MHz block
Higher demand scenario	£1.6bn	£150m

Results for cost differences in less populated areas

A10.50 Annex 11 explains the technical calculations for less densely populated areas. It is a simplified calculation for the costs of extending a basic level of 3G data coverage from areas where 80% of the population lives to areas currently covered by 2G networks. This indicates that an operator deploying UMTS2100 would face costs £20m to £60m higher than an operator deploying UMTS900, depending on the speed of roll out.