Memorandum

To:	EE
From:	CEG Europe
Date:	17 April 2015
Subject:	**Cost modelling of the value of 1800 MHz spectrum**

1. EE has requested that CEG prepare this memorandum to provide information for Ofcom in relation to the cost modelling undertaken by CEG in relation to Ofcom's *Annual licence fees for 900 MHz and 1800 MHz spectrum: Provisional Determination and Consultation* released on 19 February 2015. In particular, this memorandum provides details on the approach applied to estimate the market value of 1800 MHz spectrum based on the costs that would be saved from the UK operators gaining an increment of 1800 MHz spectrum and the additional costs that would be incurred by the UK operators losing an increment of 1800 MHz spectrum.

1.1 The use of cost modelling to determine the market value of spectrum

2. The Authorisation Directive requires that any fees set for rights of use for radio frequencies must "*reflect the need to ensure the optimal use of these resources*". Prices that reflect opportunity cost will generally promote the efficient use of spectrum. In particular, such prices will generally provide the right incentives for users of spectrum with relatively low values for spectrum at the margin to release spectrum to users with higher values for additional spectrum. A price level that is consistent with all efficiency enhancing spectrum trades taking place can also be considered to be the value of spectrum in a well functioning market.

3. The value of spectrum at the margin to an operator can be assessed by estimating what would be the change in costs to the operator in gaining or losing an increment of spectrum while assuming that the operator maintains the same output and service quality.

4. We have used Ofcom's 2015 Mobile Call Termination (MCT) Model released on 17 March 2015 to capture the relationship between spectrum holdings and network costs. As Ofcom notes in its MCT Statement: "*the model projects the least cost means of delivering existing services using known technology, but recognising where an efficient national network would start from in terms of legacy network deployments.*"[1] In particular, the model calculates the efficient level of network costs that would be incurred by an operator to provide forecast traffic, coverage and

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[1] Ofcom, MCT Market Review 2015-18 Statement, para. A7.13.

service quality levels given particular input parameters including spectrum holdings.

5. The modelled operator in the 2015 MCT model uses a varied portfolio of spectrum holdings to serve approximately 25% market share. Ofcom assumes that the modelled operator:

- operates a 2G network using 2 x 30 MHz of 1800 MHz spectrum;

- operates a 3G network using 2 x 15 MHz of 2100 MHz spectrum; and

- operates a 4G network using:

  - 2 x 10 MHz of 800 MHz spectrum;

  - 2 x 10 MHz of 1800 MHz spectrum, refarmed from the 2G network; and

  - 2 x 10 MHz of 2600 MHz spectrum.

6. We have sought to estimate the value of 1800 MHz spectrum through assessing the network cost that an operator would save by gaining an increment of 1800 MHz spectrum to be used to provide 4G services. The use of spectrum for 2G and 3G services is held constant (including assumed refarming of 1800 MHz spectrum) and an increment of 1800 MHz spectrum is added for use in the 4G network. We have similarly estimated the change in network costs for operators that would result from the loss of an increment of 1800 MHz spectrum.

1.2   Spectrum holdings

7. We model the actual spectrum holdings of the existing UK mobile operators and we assume all operators have a long-term market share of 25%. This is consistent with Ofcom's assumptions in MCT modelling and was also applied by Ofcom in undertaking cost modelling to value 900 MHz spectrum in Ofcom's August 2014 consultation on annual licence fees for 1800 MHz and 900 MHz spectrum.

8. We further assume the release of an additional 190MHz of 2.3GHz/3.4GHz spectrum in 2016, 1452-1492 MHz spectrum in 2018 and 2x30 MHz of 700 MHz spectrum in 2022. We have assumed that the newly released spectrum will be used for providing 4G services. The 1452-1492 MHz spectrum is likely to be downlink only. While this spectrum can be used efficiently in conjunction with existing holdings, for ease of modelling we have assumed that it is equivalent to 4 lots of 5 MHz of paired spectrum. We have assumed that the 2.3GHz/3.4GHz spectrum is equivalent to 90 MHz of paired 2.6 GHz spectrum. We note that there is some uncertainty over whether 3.4 GHz spectrum will be deployed in the small cell layer or the macro layer, where there is also potential interest. While the availability of 3.4 GHz spectrum will be expected to reduce the value of 1800 MHz spectrum, given the uncertainty over how to best model this spectrum we have also presented scenarios excluding 3.4 GHz spectrum.

9. Table 1 shows the modelled spectrum holdings, including assumed future holdings of new spectrum releases. Round brackets indicate 1800 MHz spectrum that is refarmed for use in the 4G network. The different allocations of new spectrum across the operators reflect the assumption that the operators with the highest valuation for spectrum will receive the most spectrum. In the scenarios where we exclude 3.4 GHz, we assume that H3G and Telefonica each acquire 2x10 MHz of 2.3 GHz spectrum, while EE and Vodafone do not acquire 2.3 GHz spectrum.

Table 1: Modelled spectrum holdings (paired MHz equivalent)

Operator	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz	2.3/3.4 GHz *from 2016*	1452 MHz *from 2018*	700 MHz *from 2022*
Base case	10	0	30 (10)	15	10	20	5	5
EE	5	0	45 (20)	20	35	10	5	5
H3G	5	0	15 (5)	15	0	35	5	10
Telefónica	10	17.5	5.75 (5)	10	0	35	5	10
Vodafone	10	17.5	5.75 (5)	15	30*	10	5	5

* Vodafone has 20 MHz of paired and 25 MHz of unpaired 2600 MHz spectrum

1.3 Joint venture

10. Ofcom's MCT Model assumes that the modelled operator enters joint venture arrangements with another party with identical traffic and spectrum characteristics. The joint venture arrangements begin to take partial effect in 2013/14 and take full effect by 2015/16.

11. The MCT Model captures the increase in spectrum attained through joint venture arrangements through the use of 'spectrum multipliers'. The spectrum multiplier increases from 1.00 in 2012/13 to 2.00 in 2015/16 to capture this effect.

12. This method of capturing joint venture arrangements will not be appropriate for partners with asymmetric spectrum holdings, or for holdings that will change over time. For 2G and 4G network design we make amendments to the MCT Model to explicitly model separately the spectrum holdings of the modelled operator and its joint venture partner and how these change over time. This includes:

- for the 2G network, separate assumptions about refarming 1800 MHz to 4G; and

- for the 4G network, application of Ofcom's assumptions about different sharing assumptions across geotypes, including no sharing in urban areas, 25% sharing in suburban 1 and full sharing in other geotypes.

13. For 3G, spectrum holdings are assumed not to change over time. The effect of different spectrum holdings is captured by adjusting the 3G spectrum multiplier.

1.4 LTE spectral efficiency

14. Research undertaken by Analysys Mason (AM) for Ofcom in its assessment of the benefits of the change of use for 700 MHz spectrum suggests that the spectral efficiency of LTE is expected to increase significantly into the future.[2] In practical terms this means that the same amount of spectrum will be able to be used to carry more traffic in the future.

15. Figure 3.9 from AM's report shows a range for the expected path of spectral efficiency improvements.[3] This information is reproduced in Table 2 below, which shows that LTE spectral efficiency is expected to triple by around 2025, along with series for alternative low and high cases of efficiency improvements over time.

Table 2: Spectral efficiency assumptions

Standard	Spectral efficiency (bits per second per hertz per sector)			Relative spectral efficiency (100% = MCT model efficiency)			Adoption
	Low	Mid	High	Low	Mid	High	
LTE R8-10	1.57	1.57	1.57	100%	100%	100%	2012
LTE R11	2.30	2.30	2.30	68%	68%	68%	2015
LTE R12	3.45	3.45	3.45	46%	46%	46%	2017
LTE R13	3.73	3.92	4.01	42%	40%	39%	2019
LTE R14	3.95	4.32	4.53	40%	36%	35%	2021
LTE R15	4.02	4.54	4.85	39%	35%	32%	2023
LTE R16	4.08	4.70	5.10	38%	33%	31%	2025
LTE R17	4.09	4.79	5.27	38%	33%	30%	2027
LTE R18	4.10	4.85	5.40	38%	32%	29%	2029
LTE R19	4.10	4.89	5.49	38%	32%	29%	2031
LTE R20	4.10	4.92	5.56	38%	32%	28%	2033
LTE R21	4.10	4.94	5.60	38%	32%	28%	2035
LTE R22	4.10	4.95	5.64	38%	32%	28%	2037

Source: Analysys Mason

16. The 2015 MCT Model is currently not configured to apply spectral efficiencies to the provisioning of the 4G radio network. It does contain an input for capturing these effects but they are not applied. A note in the model states that spectral efficiencies:

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[2] Analysys Mason, *Assessment of the benefits of a change of use of the 700 MHz band to mobile*, 27 October 2014, pp. 25-30

[3] Ibid, p. 27

Can be used to adjust 4G data traffic for dimensioning: switched off here since voice and data are carried together in LTE.

17. Because improvements in spectral efficiency are assumed to relate to the carriage of data (and not voice), and data and voice are bundled together in the traffic input for 4G, changing the spectral efficiencies in the model does carry the implication that the efficiencies are also assumed to apply to voice. However, we note that the impact of this assumption will not be significant as the vast majority of traffic carried on the 4G network is data traffic. Based on Ofcom's medium traffic assumptions in its MCT Model, less than 0.5% of traffic on the 4G network is voice, based on an equivalent volume basis. This proportion would be expected to be even less under alternative assumptions that increase the amount of data traffic beyond that in the MCT Model.

1.5 Demand

18. We adopt Low, Mid and High Case assumptions for data traffic presented by AM in assessing the benefits of change of use of 700 MHz spectrum. These assumptions are only presented graphically in the AM report and in Ofcom's 2015 MCT Statement. We construct estimates of the forecasts as:

   ▪ Low, Mid and High Case traffic is taken from Ofcom MCT Model volumes up to and including 2013, which appear to be based on actuals;

   ▪ Mid Case traffic from 2014 to 2025 are based on a manual read of Figure A7.19 from Ofcom's 2015 MCT statement (the line called "700 MHz CBA");

   ▪ Mid Case traffic from 2026 to 2039 is based a straight line interpolation between the 2025 figure and an estimate for 2039 based on Figure 3.6 of the AM 700 MHz paper, assumed to be 4,600 PB per operator for a total of 18,400 PB for the market. This gives a ratio of 2030 to 2012 traffic of 68, similar to the 65 noted by AM for the Mid Case in Figure 3.7.

   ▪ High Case traffic is assumed to be 12.3% higher than Mid Case traffic in 2030 in line with Figure 3.7. We assume that the percentage difference between Mid Case traffic and High Case traffic increases at a constant rate through to 2030 and beyond, starting from zero in 2013.

   ▪ Similarly, Low Case traffic is assumed to be 13.8% lower than Mid Case volumes in 2030 in line with Figure 3.7. We assume that the percentage difference between Mid Case traffic and Low Case traffic increases at a constant rate through to 2030 and beyond, starting from zero in 2013.

19. To apply these assumptions to the model, we identify the total 4G data traffic separately from other data traffic in the MCT model. We assume that the difference between each of the 700 MHz data traffic and total data traffic is attributable to additional 4G data traffic. Dividing this difference by Mid Case 4G data traffic

estimates the uplift that needs to be applied to Mid Case 4G data traffic in each year in order to achieve the 700 Mid, Low and High case data traffic scenarios.

1.6 Size of the increment and measuring the savings/costs

20. We assess the value of network cost savings based on gaining a 5 MHz paired increment of 1800 MHz spectrum and the additional network costs in losing a 5 MHz paired increment of 1800 MHz spectrum.

21. We use increments in lots of 5 MHz because in the model this is consistent with the size of a 4G channel. While Ofcom's MCT model does not restrict the 4G spectrum assumptions to multiples of 5 MHz and can deal in part channels, we understand that in practice a multiple of 5 MHz is standard in the industry.

22. While we assess both the network savings generated by gaining a spectrum increment and the additional costs caused by losing a spectrum increment, we note that the results generated in scenarios where a spectrum increment is lost may overstate value for some operators. This is because 1800 MHz spectrum is assumed in the MCT Model to be utilised as coverage spectrum in urban areas. For increments in which an operator does not have access to 1800 MHz spectrum to be used as coverage spectrum, this fundamentally changes the relationship between spectrum and costs so as to increase the valuation of spectrum.

23. This issue does not affect the additional costs that EE would incur in losing an increment of 1800 MHz, because EE has more than 5 MHz of 1800 MHz spectrum available to it for 4G use. We consider that an estimate on this basis would be reliable. Conceptually, ALFs set above this value would be sufficient to lead to EE releasing an increment of spectrum to other operators.

24. We also believe that the estimated values to operators in gaining an increment of spectrum are also reliable. Conceptually, ALFs should not be set above the highest value to operators in gaining an increment. If they were, spectrum could be released by an operator and then left idle because no other operator would want to acquire the increment of spectrum with ALFs greater than the network cost savings that would realised from gaining the increment. Indeed the danger in setting ALFs too far above the lowest value of operators in losing an increment is that it could lead to two increments being released but only one increment being acquired by another operator. This risk can be reduced by ALFs not being set above the second highest value for an operator gaining an increment. This is consistent with the general recommendation in the Indepen, Aegis, Warwick Business School report on spectrum pricing for Ofcom:

"If there is a use with a marginal private value higher than the current use then set the AIP between the two values, but towards the bottom end of the range."[4]

25. Network savings/costs are measured as the present value of total capital and operating expenditure between 2015/16 and 2034/35 inclusive, deducting line items that relate to spectrum costs.[5] We use a pre-tax cost of capital of 9.1% in line with Ofcom's own assumption in the MCT Model. The valuation is measured as:

   ▪ the total present value network costs measured after the spectrum increment; less

   ▪ the total present value network costs measured prior to the spectrum increment; divided by

   ▪ the total spectrum increment (in unpaired MHz).[6]

1.7   4G network costs

26. The balance of costs for 4G radio network of more spectrum relates to:

   ▪ saved costs of base station sites and equipment no longer needed due to the greater amount of spectrum available; but

   ▪ greater carriers required per site in order to carry greater traffic per site.

27. Ofcom's MCT model is built to model up to 12 carriers per site. This is sufficient to accommodate the assumptions used in the mobile termination scenarios.

28. These scenarios are more demanding because some include much more spectrum and much more traffic. Some scenarios have much more traffic per site than the mobile termination scenario. This means that 12 carriers per site are not sufficient to capture the carrier requirements in the model. Without adjustments, the model will overstate the value of spectrum because it will not fully capture the offsetting higher costs of carriers if it cannot model past the twelfth carrier per site.

29. We have made adjustments to the model to accommodate up to thirty carriers per site. In practice however, even more might be required in some scenarios. This may mean that some scenarios with high amounts of spectrum and demand may tend to overstate spectrum valuations for this reason.

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[4] Indepen, Aegis, Warwick Business School, *An economic study to review spectrum pricing*, 2004, p.6.

[5] Although it is only the 1800 MHz spectrum costs that are actually changing.

[6] That is, where the increment is 5 MHz paired, we divided by 10 MHz to capture the value of each MHz separately.

1.8   Scenarios

30.   We have modelled three scenarios and have then carried out sensitivity analysis in relation to the third scenario.

31.   The three scenarios are:

i.   The MCT Model with the additions of the 2.3 and 3.4 GHz spectrum (to be released in early 2016) and the 1452-1492 MHz spectrum (assumed to be released in 2018). This can be considered a scenario with a high degree of certainty in relation to spectrum releases as it is restricted to only the releases planned for the next few years. We have assumed the AM Mid Case traffic forecasts. This will overstate reasonable value as it assumes the full traffic forecasts of the AM CBA 700 MHz Model but not the full spectrum releases that would be necessary to achieve that traffic.

ii.   Our central case. This has the spectrum releases of the first scenario but now also includes the release of 700 MHz spectrum in 2022. In addition, consistent with a longer-term approach, we have also assumed AM's Mid Case for assumed spectral efficiency gains in technology over time.

iii.   A modified version of our central case in which we have excluded 3.4 GHz spectrum from the scenario.

32.   Table 3 shows the results of these scenarios for each modelled operator, as well as 2017/18 site numbers.   The table also shows a sensitivity analysis by presenting results for:

iv.   A Low Value case based on the AM Low Case traffic, the 3 spectrum awards (1452-1492 MHz, 2.3/3.4 GHz and 700 MHz) and the AM High case for spectral efficiency gains; and

v.   A High Value case based on the AM High Case traffic, only the 2 awards of the next few years (1452-1492 MHz, 2.3 GHz) but excluding 3.4 GHz spectrum (and also excluding the 700 MHz award) and with the AM Low Case for spectral efficiency gains over time.

Table 3: Modelled spectrum valuation (£m per MHz) and starting site numbers

Modelled operator	(i)	(ii)	(iii)	Low Case	High Case
	MCT model +AM Mid Case traffic +1452MHz +2.3/3.4 GHz	(i) + with 700 MHz + AM Mid spectral gains	(ii) but excluding 3.4 GHz spectrum	(ii) but AM Low traffic and AM High spectral gains	(ii) AM High traffic, no 700 MHz, no 3.4GHz and AM Low Case spectral gains
Increment = +5 MHz					
EE	2.76	1.03	1.57	0.89	2.48
H3G	5.48	1.47	2.84	1.09	6.47
Telefónica	5.53	1.46	2.81	1.09	5.91
Vodafone	5.15	1.52	2.31	1.10	3.69
Increment = -5 MHz					
EE	2.91	1.21	1.77	0.96	2.83
H3G	7.00	2.19	4.74	1.92	10.09
Telefónica	6.45	2.23	4.00	1.85	8.38
Vodafone	5.77	2.45	3.31	1.93	5.21
2017/18 sites					
EE					
H3G			[✂] [Redacted]		
Telefónica					
Vodafone					