Technical licence conditions for 800MHz and 2.6GHz spectrum

Response by Vodafone to the Ofcom consultation

11 August 2011

1 Introduction

Vodafone welcomes the opportunity of commenting on another in the plethora of Ofcom consultations relating to the award of spectrum in the 800 MHz and 2.6GHz bands. This process started for the 800MHz band with the Digital Dividend Review of December 2006, and for the 2.6GHz band with CEPT Report 19 of December 2007 and Commission Decision 2008/477/EC of June 2008. In December 2010, the Government instructed Ofcom[1] to provide for an auction of licences for the 800MHz and 2.6 GHz bands "as soon as reasonably practicable".

This consultation provided the opportunity for Ofcom to bring closure on the technical licence conditions for these bands, because almost everything that is necessary has already been defined in Decisions of the European Commission. Instead, Ofcom's curiosity has led it to continue to propose partially developed new concepts. This consultation follows so soon after the previous one[2] that the comments of stakeholders on low power shared access cannot have been taken into account in this consultation. The parallel consultation on 800MHz coexistence[3] proposes additional technical licence conditions, which appear to be in conflict with the Commission Decision. If Ofcom chooses to pursue these concepts, it will take at least one further consultation to bring them to a satisfactory completion.

Vodafone urges Ofcom to move rapidly towards the award of licences for the 800MHz and 2.6 GHz bands. To achieve this, it needs to focus on implementing the technical parameters in the Commission Decisions, together with the types of network for which they were developed (i.e. high power networks in 2.6GHz paired spectrum).

2 General comments

Technical licence conditions (TLCs) are an important element of any spectrum licence, because they set the framework for the effective use of spectrum. This consultation makes proposals for the technical licence conditions for the licence awards for two important mobile bands, and modifications to the conditions for two others.

Most of the TLCs proposed in this consultation are drawn from European Commission Decisions; these have been correctly implemented in this consultation. The Decision for the 800MHz band defines a range for base station transmit powers, and the Decision for 900 MHz and 1800 MHz does not define a power limit. Ofcom does not provide a rationale for these power limits, which for 900 MHz and 1800 MHz are different from the ones in the existing licences. The Decision for

[1] SI 2010 no. 3024; The Wireless Telegraphy Act 2006 (Directions to OFCOM) Order 2010

[2] Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues; 22 March 2011

[3] Coexistence of new services in the 800 MHz band with Digital Terrestrial TV; 2 June 2011

800 MHz gives three options for the emissions level below 790MHz, and we believe that Ofcom's proposal to apply the most stringent throughout the UK is not consistent with the intention of the Decision, and not proportionate.

The TLCs for Ofcom's proposed low power shared access spectrum do not provide adequate protection of the "standard power" spectrum from interference, because the block edge masks were developed for macrocell deployments. Ofcom has already concluded (in the context of TV white spaces) that its proposal for hybrid (shared standard power and low power) spectrum does not work.

We agree with Ofcom's conclusions on short range devices. The deployment of mobile services in the 800 MHz band will not result in a significant change in the radio environment for these devices (relative to existing transmissions in the same band and other neighbouring bands), in the context of the non-interference/non-protected basis on which this spectrum is made available.

3 Response to specific questions

1: Do you have any comment on the proposal to apply the limits defined in Case A of Commission Decision 2010/267/EU for out-of-block emissions from base stations into all frequencies in the range 470 to 790 MHz, as set out in Table 4.4?

This is not an accurate summary of Ofcom's proposals for technical licence conditions, because in its consultation on Coexistence in the 800 MHz band, Ofcom proposes different (tighter) limits "in certain geographic areas". We comment on this proposal in detail in our response to that consultation, but in summary Vodafone believes that these limits are not justified as a licence condition and are not consistent with Commission Decision 2010/267/EU.

Application of Case A

In this consultation, Ofcom proposes to apply the "Case A" emissions at all locations. The justification given for this is "to retain flexibility for DTT channels to be brought into use at a later date", but there is no explanation of the reasons why this flexibility might be needed. The Commission Decision (quoted in the consultation response) states that "Cases A and B reserve the option of bringing relevant broadcasting channels into use for digital terrestrial broadcasting at a future date", and Ofcom does not provide any explanation as to why it has chosen Case A.

The Case A emissions limit is substantially below the limits specified in the LTE product standards[4]. For TV channels ~58 and below, we expect that all base stations will meet these limits inherently, due to the performance of the duplexer filter. However, to meet these emission limits for channel 59 and especially channel 60, an extra filter of a higher performance filter will be required, especially for the lower blocks in the 800MHz band, which must be located inside the base station cabinet[5]. This could require special modifications to base station product lines, or even preclude certain types of base station such as remote radio heads and active antennas. The impact of this would be far greater than the cost of the filters themselves.

[4] These emissions are defined in ETSI TS 136.104 and EN 301 908-14. These are defined at the antenna port, so need to be adjusted by the net antenna gain.

[5] It must be inside the base station cabinet because a bandpass filter needs to be located between the transmitter output and the duplexer filter, or be part of the functionality of the duplexer filter. This duplex filter will already be larger than for other bands, because of the lower frequency and narrow duplex separation.

We understand that the channel switches to clear TV channels 61 and 62 are now defined, and there are no other significant changes on the horizon for the UK national TV channel plan. Ofcom has proposed to make "interleaved spectrum" available for local television, and it consulted on its proposals in February 2010[6], including an indicative list of transmission sites and frequencies. Only three of these frequencies are on channel 58 or higher; Mendip and Waltham (one of two available channels) and Winter Hill (one of three available channels). It is extremely unlikely that there will be demand for more than one multiplex (around six programme channels), so the impact of not using interleaved spectrum in channels 58 and higher for broadcasting will be very low.

Vodafone therefore suggests that the following emissions limit would be an appropriate balance between effective use of spectrum below 790 MHz and the cost of infrastructure in the 790 – 862 MHz band:

Baseline requirements – base station out-of-block EIRP limits over frequencies below 790MHz			
TV channel	**Emissions limit in coverage areas of a national multiplex**	**Emissions limit outside coverage areas of a national multiplex**	**Interleaved spectrum** (availability for local TV)
21-57	Case A	Case A	Available for use
58-59	Case A	Case B	Not available
60	Case A	Case C	Not available

Editorial comment

The requirements in Table 4.4 in the consultation document depend on the parameter 'base station in-block EIRP', which is defined in dBm/10MHz. There is an ambiguity as to whether this is the power measured in a bandwidth of 10MHz or a power spectral density. We believe that the former is intended, because of the nature of the interference mechanisms and because 10MHz is a very unusual bandwidth in which to define a power spectral density. We suggest that this is clarified by a note in the technical licence conditions, as follows:

Table 4.4: Baseline requirements – base station out-of-block EIRP limits over frequencies below 790 MHz

Frequency range of out-of-block emissions	**Condition on base station in-block EIRP, P dBm/10 MHz[1]**	**Maximum mean out-of-block EIRP**	**Measurement bandwidth**
470 to 790 MHz	P ≥ 59	0 dBm	8 MHz
	36 ≤ P < 59	(P-59) dBm	8 MHz
	P < 36	-23 dBm	8 MHz

[1] This is the power measured in a bandwidth of 10MHz.

[6] Digital dividend: 600 MHz band and geographic interleaved spectrum; Consultation on potential uses; 18 February 2010. The list is on pages 21 and 22.

2: Do you have any comment on the proposal to set an in-block emission limit of 61dBm/(5 MHz) for base stations in the 800 MHz band?

The previous consultation discusses at some length the coverage of mobile broadband using bands below 1GHz. The maximum permitted base station power clearly affects the coverage, so the impact of the proposed limit needs to be assessed; the only explanation given in the consultation document for the proposed in-block emission limit of 61dBm/(5 MHz) is that it is within the range defined in the Commission decision:

> An in-block EIRP limit for base stations is not obligatory. However, Member States may set limits and, unless otherwise justified, such limits would normally lie within the range 56 dBm/5 MHz to 64 dBm/5 MHz.

The transmit power clearly also has the potential to affect the interference to TV reception. However, the modelling undertaken by Ofcom[7] shows that filtering at the DTT receiver cures almost every case. Therefore, in this case an increase in the base station power would have negligible impact on TV reception.

Therefore, it would be appropriate for Ofcom to consider increasing the in-block emission limit for base stations in areas where the top few TV channels are not used, provided that filters are provided for DTT reception. In this case, there could well be a justification for raising the limit above 64 dBm/5 MHz.

It should also be noted that DTT is planned to cover 98.5% of the UK population, which means that around 1.5% of the population cannot be affected at all by interference to DTT reception. This likely to be the same part of the population that stand to benefit most from improved coverage of mobile broadband.

3: Do you agree with the proposed conditions on antenna placement that would permit the use of the alternative block-edge mask for restricted unpaired blocks? If not, please explain your reasoning and your alternative proposals, bearing in mind the need to remain consistent with the framework provided in Commission Decision 2008/477/EC.

No comment.

4: Meeting the conditions on the use of the alternative block edge mask for restricted TDD blocks would require certain licensees to share information about the locations of their base stations. Do you agree with this proposed approach?

No comment.

5: We welcome comments on stakeholders' preference for the dedicated or hybrid options for low-power shared access as discussed above.

Vodafone does not support either the dedicated or hybrid options for low power shared access in paired spectrum. In our response to the previous consultation we highlighted the lack of any analysis by Ofcom of the potential of low power shared access to become an optimal use of valuable mobile spectrum.

We believe that it would be a more optimal use of spectrum for the low power shared access to be located in the unpaired 2.6 GHz spectrum. This is discussed in our response to question 6.

[7] Technical analysis of interference from mobile network base stations in the 800 MHz band to digital terrestrial television; Ofcom; 10 June 2011

The hybrid approach, as described in this consultation would result in only 2 X 50MHz of exclusive paired spectrum in the 2.6GHz band[8]. This could make it impossible for four operators to obtain 2 X 20MHz of contiguous spectrum in order to provide high quality mobile broadband services.

The feasibility of the hybrid approach is fundamentally dependent on the adequacy of the technical licence conditions in preventing interference between high power and low power networks sharing the same spectrum. We are therefore concerned by the comment in para. 7.60 that "We are not in this consultation proposing the detail of these additional technical licence conditions…". Without these, it is impossible to give final view on the technical feasibility of the hybrid option.

However, it seems that Ofcom has already reached a conclusion on the feasibility of the hybrid approach, because in para. 7.5 is concludes: The complete low-power underlay approach was shown to present considerable challenges not only in terms of protection to the overlapping standard-power operator, but also in terms of ensuring low-power operators could provide an adequate level of service in areas of overlapping deployment. The hybrid approach is the same as the complete underlay approach, but applied to 2 X 10 MHz of spectrum instead of the whole band. Accordingly, Ofcom should logically reach the same conclusion: it should not be considered further.

See also the comment in response to question 8.

6: We welcome comments on the appropriate frequency placement for low-power spectrum blocks.

The most appropriate frequency placement for low-power shared access spectrum blocks is within the unpaired spectrum.

Ofcom has not provided any rationale, either this consultation or the earlier one of March 2011, for its proposal to locate low power shared access in paired spectrum. The unpaired spectrum would seem to be more suited to this application than paired, because of the restricted blocks. These blocks already have a power limit that is comparable to what is proposed for the low power shared access networks[9]. Therefore, locating the low shared access in unpaired spectrum would result in less loss of spectrum suitable for high power networks. This would be equivalent to using the spectrum of "licensee 2" in figure 8.8 of the March 2011 consultation for low power shared access.

Equipment is available for both TDD and FDD technologies for the 2.6GHz band, so there is no justification for needing to use valuable paired spectrum for this application.

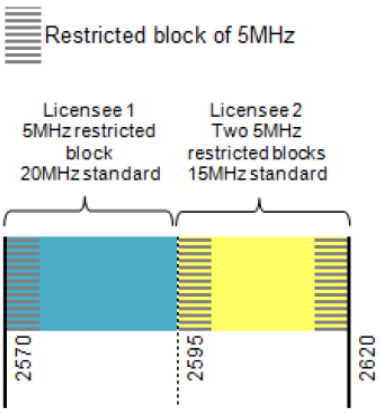

Figure 8.8 from the Ofcom March 2011 consultation

[8] In para. 7.53 of the consultation, Ofcom states that it has not even "decided on the relative priority for access to spectrum shared between standard-power networks and low-power networks".

[9] The power limit proposed in this consultation document for lower power shared access base stations is 30dBm EIRP total (Table 7.2). The power limit defined for unpaired restricted blocks is 25dBm/5MHz. If 15MHz of unpaired spectrum is allocated to low power shared access and the central block has the same power limit as the two restricted blocks, then the maximum power would be 30dBm EIRP total. However, the power limit in the central block could probably be increased.

See also the comment in section 6 of this response.

7: Do you agree with our proposed technical licence conditions for low-power access?

No.

The proposed conditions would allow the low-power access base stations to cause interference to the neighbouring block(s) that could cause substantial loss of service in the areas in which the low power networks are deployed.

The consultation document only considers the in-block power of the low-power networks in the context of interference. However, for the limits defined in Table 6.3 of the document, the out-of block emissions would cause far more interference to terminals operating on other networks in the adjacent channel[10] than the in-block power.

The out-of-block edge EIRP limits in Table 6.3 apply to both high power and low power networks, and are copied from Commission Decision 2008/477/EC. These are inadequate for low power shared access networks. This is because the base stations will inherently be far nearer to terminals of other networks than was assumed in the CEPT studies that defined the block edge masks[11], by virtue of the lower transmit power.

It is envisaged that high power FDD networks in the 2.6GHz band will use LTE; the product specifications for LTE include appropriate emissions masks for both high and low power base stations, so in practice interference will not occur if the operators of these networks also use low power base stations. However, the potential applications for low power shared access are very unclear, so it cannot be assumed that they will use LTE. The operators of low power networks would not have any reciprocal interference in preventing interference, and for some business models in might even be beneficial.

The table below shows the emissions mask proposed by Ofcom for base stations in the "DECT Guard Band" 1781.7-1785 MHz paired with 1876.7-1880 MHz[12]. These might be an appropriate starting point for definition an appropriate emissions mask for the 2.6GHz band.

Offset from edge of block	**Maximum permitted level**	**Measurement bandwidth**
0 MHz to 0.3 MHz	-103 × Δ*f* dBc	30 kHz
0.3 MHz to 0.5 MHz	-17.5 - (45 × Δ*f*) dBc	30 kHz
0.5 MHz to 1.1 MHz	-40 dBc	30 kHz
1.1 MHz to 1.7 MHz	-43 dBc	30 kHz
1.7 MHz to 6 MHz	-45 dBc	100 kHz

where Δ*f* is the frequency offset in MHz

[10] The maximum permitted EIRP for the adjacent block is around +10dBm, which corresponds to an ACLR (adjacent channel leakage power ratio) of 20dB for a maximum mean in-block power of 30dBm EIRP. In contrast, the specified minimum ACS (adjacent channel selectivity) of an LTE terminal is 33dB.

[11] These studies are described in CEPT Report 19; Report from CEPT to the European Commission in response to the Mandate to develop least restrictive technical conditions for frequency bands addressed in the context of WAPECS, 21 December 2007.

[12] See para. 6.22 and Table 6.1 of the Ofcom consultation document "Award of available spectrum: 1781.7-1785 MHz paired with 1876.7-1880 MHz"; 16 September 2005

and the block edges are defined as 1876.9 MHz and 1879.9 MHz.

However, implementing such an emissions mask in a UK licence for the 2.6GHz band would presumably require some amendment to Commission Decision 2008/477/EC[13].

8: We welcome comments from stakeholders on the additional restrictions and technical measures we have outlined for the management of interference under the hybrid approach, and the technical licence conditions that would be necessary to implement them

The hybrid option relies on the low power network sensing the high power one. This is the same concept that has been proposed for while space devices operating in UHF TV spectrum. In its Statement on cognitive access[14], Ofcom concluded:

> "However, we note that implementation of detection-only devices is likely many years away and hence there is little advantage in rapidly making the necessary regulations to licence-exempt such devices."

It is unclear why Ofcom is proposing a solution for the 2.6GHz band which it has already concluded "is likely many years away" – which was for a band and deployment scenarios that have been studied far more intensely than the 2.6GHz band.

Furthermore, Ofcom's proposals for the hybrid approach are inherently not technology neutral. The studies by Real Wireless have assumed LTE for both high power and low power networks, and as Ofcom notes in para. 7.49 "these additional technical licence conditions … are likely to depend on the specific technology choices licensees make…".

It is unclear what would happen if the operator of the high power network were to decide to change technology.

9: Do you agree that a Code of Practice on Engineering Coordination, as outlined, is the appropriate approach to manage the coexistence between low-power Licences

No comment.

10: Do you agree that we should proceed with the approach that terminal stations complying with the relevant technical parameters be exempted from the requirement for individual licensing?

Vodafone agrees with this approach.

The Harmonised Standards EN 301 908-1, EN 301 908-2 and EN 301 908-13 are the appropriate standards to reference for UMTS/HSPA and LTE in the Interface Requirements documents, for all four of the bands addressed by this consultation. These standards demonstrate presumption of conformity to the in-block requirements described in Section 8 of the consultation document (although the numerical values are in some cases slightly different due to the test method employed). These standards also demonstrate conformity to the relevant emissions limits described in ECC Decisions and CEPT Reports for the respective bands.

Editorial comment

[13] Commission Decision of 13 June 2008 on the harmonisation of the 2 500-2 690 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community.

[14] Digital dividend: cognitive access; Statement on licence-exempting cognitive devices using interleaved spectrum; 1 July 2009, para. 1.9.

In para. 8.9, the technical conditions for exemption of LTE and WiMAX terminals should not refer to EN 301 908-14 and EN 301 908-22, because these standards are for base stations not terminals.

4 Comments on the proposed changes to the 900 MHz and 1800 MHz licences

The consultation document does not ask any specific questions on the proposals for the 900 MHz and 1800 MHz band. However, in the context of Ofcom's proposals for spectrum below 1 GHz, the proposed changes for 900 MHz are just as important as the proposals for 800 MHz

We can understand the logic behind making the in-block limit the same for the 800 MHz and 900 MHz bands, but Ofcom does not provide any explanation for the limit that it proposes for LTE in these bands[15]. Vodafone suggests that it would be more appropriate to align the EIRP limit for LTE in the 900 MHz and 1800 MHz bands with the limit for UMTS, i.e. 32 dBW/(5MHz).

In the consultation on the variation of licences the for 2.1GHz band[16], Ofcom said:

> Operators are free to request an increase of the in-band power limit for UMTS in other bands if they wish. Any such request will be considered on its merits at the time.

As the 900 MHz and 1800 MHz licences are due to be revised, this might be an appropriate time to consider this change, and to apply the same change to LTE.

Editorial Comments

The 4th bullet of the proposed additions to paragraph 7 contains a typo; it should refer to WiMAX, not LTE.

The term "channel edge", used in the 2nd and 4th bullets added to paragraph 7, is defined in the LTE specifications. However, it is not defined in the WiMAX specifications, and is only used in these specifications in relation to receiver performance. It is therefore suggested that the definition from the LTE specification is included in the licence:

> "Channel edge" shall mean the lowest and highest frequency of the carrier, separated by the channel bandwidth.

5 Comments on the proposed technical licence conditions for the 2.6 GHz band

The consultation document does not ask any specific questions on proposed technical licence conditions for the 2.6 GHz band. These are drawn from the Commission Decision on the 2.6GHz band[17].

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[15] We suspect that the origin of the +61dBm/5MHz EIRP limit is Commission Decision 2008/477/EC for the 2.6 GHz band. However, this limit is related to coexistence between TDD and FDD basestations in this band (as described in CEPT Report 19, Annex 4), and is not applicable to the 900 MHz or 1800 MHz bands.

[16] Notice of proposed variation of 900 MHz and 1800 MHz Wireless Telegraphy Act licences; 28 October 2010; para. 3.11.

[17] Commission Decision of 13 June 2008 on the harmonisation of the 2 500-2 690 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community; 2008/477/EC

Vodafone proposes that the unrestricted base station in-block EIRP limit should be raised by 1dB to 62 dBm/(5 MHz) EIRP for base stations equipped with MIMO, which would allow an alignment with the power limit for other frequency bands and technologies. This is justified because the effect of blocking to a terminal from a base station equipped with MIMO is around 1dB below that for a base station with a single transmit antenna.

The 'Base Station in-block e.i.r.p. BEM' is defined in Table 2 of the annex of the Commission Decision. A note to this table states:

> NB: Member States can relax this limit to 68 dBm/5 MHz for specific deployments e.g. in areas of low population density provided that this does not significantly increase the risk of terminal station receiver blocking.

In this case, the specific deployment is MIMO, and an increase of 1dB in the EIRP limit will not significantly increase the risk of terminal station receiver blocking. This can be implemented in Table 6.2 of the consultation document as follows:

Table 6.2: Block specific requirements – unrestricted base station in-block EIRP limit

Frequency range of in-block emissions	Support for MIMO	Maximum mean in-block power
Paired downlink frequencies	Without MIMO	61 dBm/(5 MHz) EIRP
	With MIMO	62 dBm/(5 MHz) EIRP
Downlink use of standard unpaired frequencies	Without MIMO	61 dBm/(5 MHz) EIRP
	With MIMO	62 dBm/(5 MHz) EIRP

Terminal station blocking from base station transmissions

The Commission Decision defines terminal station receiver blocking as the criterion for relaxation of 'base station in-block e.i.r.p. BEM'. It is clear from CEPT Report 19 (section A4.4.2) that the base station EIRP limit was derived for a base station with a single antenna per sector.

A terminal station that might be subject to blocking from a base station will typically be in a Rayleigh fading environment, in which the power of the signal fluctuates due to multipath propagation. Receiver blocking is caused by several mechanisms (which are difficult to analyse quantitatively), but we estimate that this will typically start to occur when the power threshold for blocking to occur is exceeded for around 5-10% of time.

If a base station is equipped with MIMO, the terminal is subject to two signals with independent Rayleigh fading, each with a mean power 3dB below the signal for a base station with a single antenna. It is found that, for percentiles greater than around 70%, the power at the terminal is lower for MIMO base stations than one for a single antenna. The results for the 90%ile and 95%ile cases (corresponding to the power being exceeded for 10% of time and 5% of time respectively) are given in the table below:

Number of MIMO Transmit Antennas	Reduction in Instantaneous Power	
	90^{th} %ile	95^{th} %ile
2 Antennas	– 0.73 dB	– 1.01dB
4 Antennas	– 1.39 dB	– 1.89 dB

6 Representations on the impact assessment

The whole of this response constitutes representations on the impact assessment in the consultation document. In this section we highlight matters relating to the adequacy of this impact assessment.

The impact of applying "Case A" emissions limits to all frequencies and geographic on the cost of deployment of networks (especially those using the bottom blocks of 800 MHz spectrum) has not been considered. This impact will be far greater than simply the cost of filters.

This consultation does not include any analysis of the impact of the proposed base station in-block powers for the 800MHz, 900 MHz and 1800 MHz bands.

This consultation does not include any analysis of the impact of using spectrum for low power shared access instead of for a 'standard power' mobile network, and neither has any previous consultation. In the absence of any evidence that low power shared access will make effective use of this spectrum, making an explicit reservation of spectrum for this purpose would be incompatible with Ofcom's duty to promote efficient use of spectrum. There is no evidence from the experience of the DECT guardband to support the assertion by Ofcom in the March 2011 consultation[2] (para. 5.18, first bullet) that sub-national RAN operators in mobile spectrum have increased competition in the ***retail*** market[18].

Ofcom has not considered the potential of alternatives to its proposal for low power shared access to achieve the benefits that it perceives from sub-national RAN operators:

- Use of unpaired 2.6GHz spectrum, where there is already a power limit for the restricted channels that is comparable to the proposed power limit for shared access base stations.
- Increased use of GSM in the DECT guard band
- Deployment of a 3MHz LTE channel[19] in the 2 X 3.3 MHz of the DECT guard band[20].
- Use of WiFi in the 2.4 GHz and/or 5 GHz bands.

[18] As far as we are aware, only one DECT guard band licence holder has attempted to provide a retail service to consumers, which was not a commercial success.

[19] A 3MHz LTE channel has been standardised by 3GPP for the 1800 MHz band. See Table 5.6.1-1 of ETSI TS 136.101.

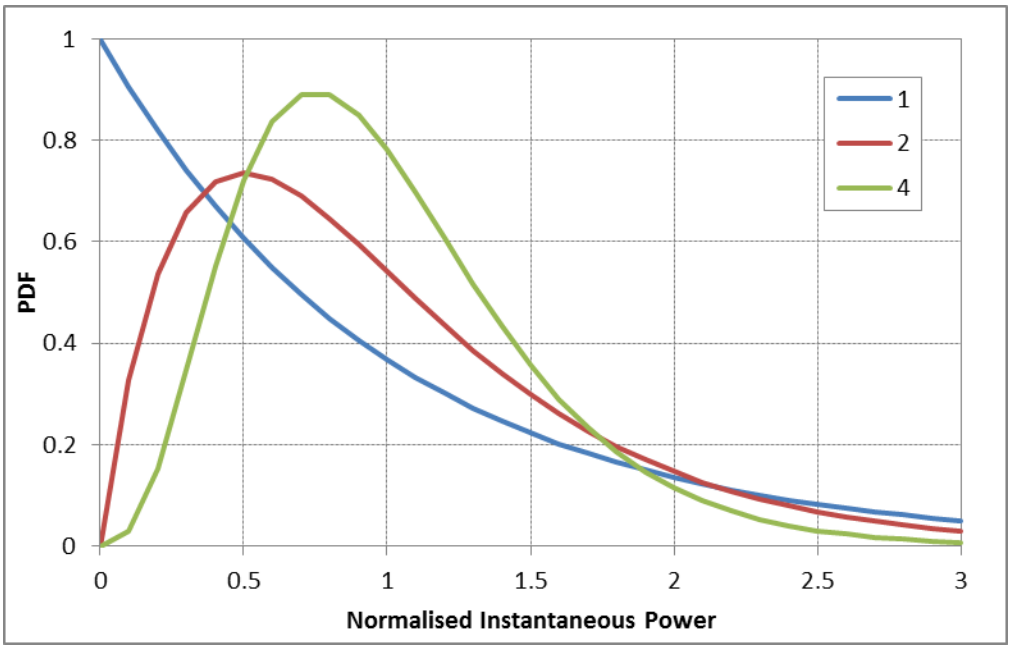
[20] We note that the FCS and Cable and Wireless Worldwide have previously raised concerns that "it is not possible to deploy UMTS in that spectrum as UMTS requires a 5 MHz carrier" (see Ofcom's Statement on variation of 900 MHz and 1800 MHz Wireless Telegraphy Act licences, 6 January 2011, paras. 3.12 and 3.13). However, these concerns have been addressed by the availability of the 3 MHz LTE channel.

Annex Analysis of blocking of terminals with MIMO base stations

The instantaneous power of a normalised (unit mean power) Rayleigh process has a Gamma distribution with both the shape parameter, k, and scale parameter, θ, being equal to unity. Equivalently, the distribution is a Chi-squared distribution with 2 degrees of freedom.

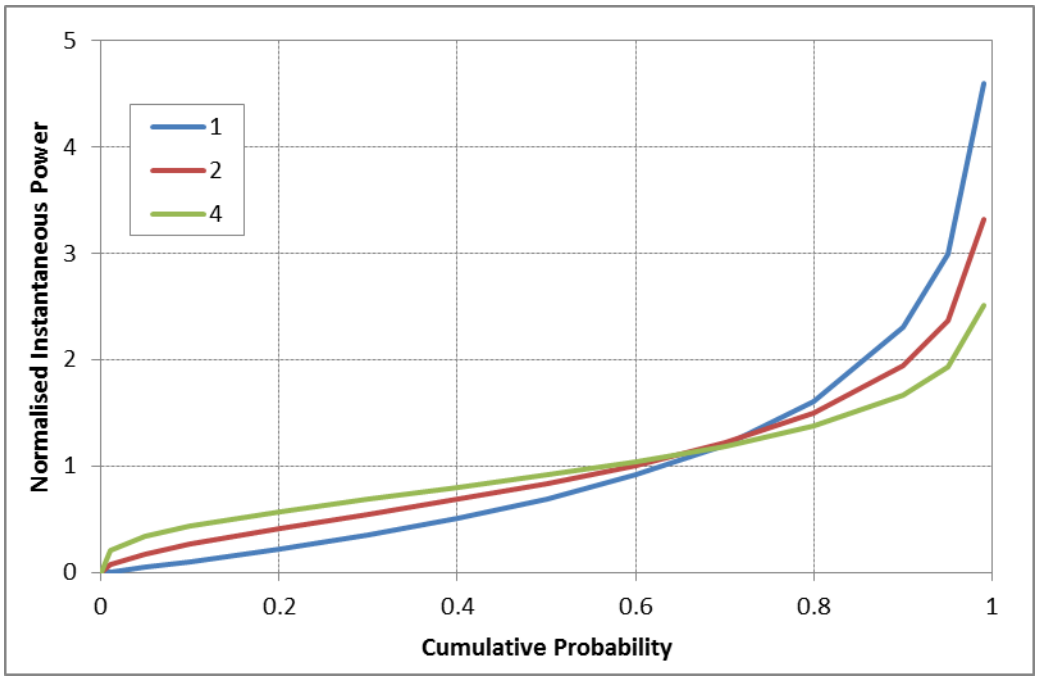
If N random variables following a normalised Rayleigh process are added together, the power of the resulting random variable will also have a Gamma distribution, in this case with a shape parameter equal to N. This resulting random process can be re-normalised to have unity mean power by setting the scale parameter equal to 1/N, as the mean of the Gamma distribution is given by kθ. Equivalently, the power of the Rayleigh sum can be said to be a Chi-squared distribution with 2N degrees of freedom.

The Gamma distribution can be evaluated using the statistical functions of Excel. If we restrict our attention to the sum of 1, 2 and 4 processes (equivalent to interference from a transmitter with 1, 2 and 4 antennas), the PDF (probability density function) of the instantaneous power of the resulting sum is shown in the figure below.



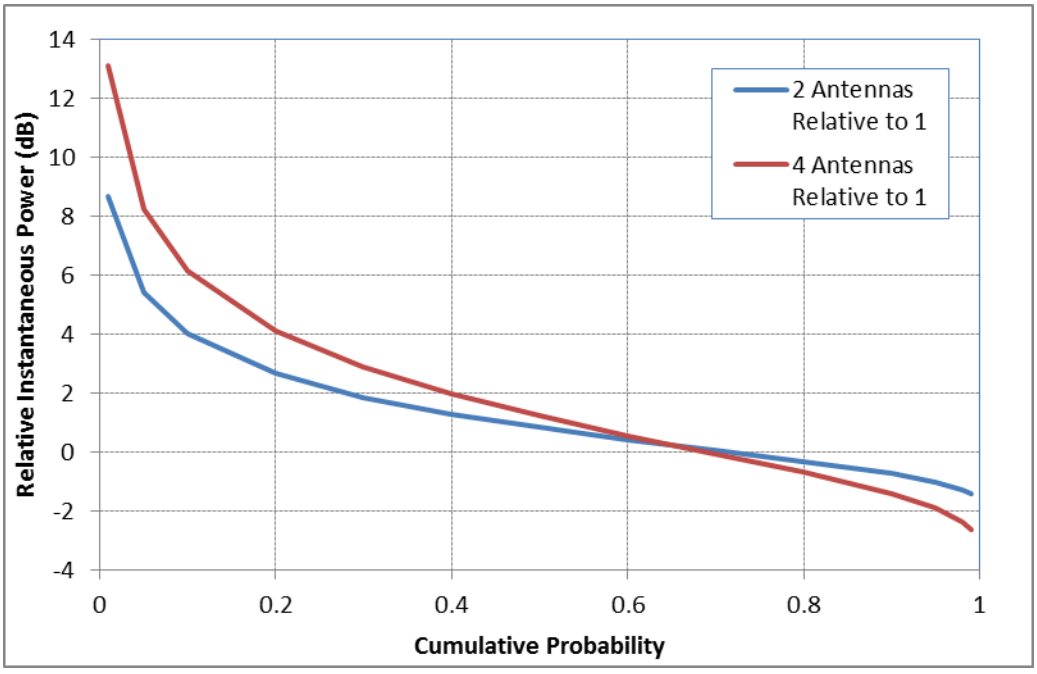
Note that all 3 processes have been normalised to have unit mean power. This reflects the fact that a MIMO transmitter does not transmit additional power, but has to share the available power amongst the available antennas. It can be seen that increasing the number of transmit antennas reduces the variance of the resulting process, meaning that extreme values of instantaneous power (both high and low) are less likely.

If we consider the cumulative probability function, and plot this along the x-axis, we get the following figure:



Of interest to us here are the higher levels of instantaneous power, which largely determine the effect of the interference on a victim receiver. It can be seen that the highest levels of instantaneous interference power reduce as the number of transmit antennas increases. An instantaneous power reduction can be observed in about 30% of all instances.

If we compare the instantaneous power for the 2 and 4 antenna case relative to the single antenna case, we get the following figure:



It can be seen there is an instantaneous power reduction for percentiles greater than about 70% for both the 2 and 4 antenna cases. In other words, for the 30% of cases when the highest levels

of instantaneous received power are experienced, increasing the number of transmit antennas will reduce the total power received. Of particular interest for receiver blocking are the 90%ile and 95%ile cases, which will roughly correspond to the interference level at which bit errors start to be experienced at the victim receiver if a total raw BER of 5% is experienced by that receiver (obviously this ignores the temporal characteristics of the fading processes, but this effect becomes less important as the raw bit period decreases). For these cases, the following instantaneous power reductions are observed:

Number of MIMO Transmit Antennas	Reduction in Instantaneous Power	
	90^{th} %ile	95^{th} %ile
2 Antennas	– 0.73 dB	– 1.01dB
4 Antennas	– 1.39 dB	– 1.89 dB