



2010-2025MHz

2290-2302MHz

2500-2690MHz

Spectrum Awards

Technical Study
Adjacent and In-Band Compatibility Assessment for
2500-2690MHz

Research Document

Publication date: 11 December 2006

Disclaimer

This technical study ("Technical Study") has been prepared by Ofcom, in connection with the award of wireless telegraphy licences to use the three spectrum bands at 2500-2690 MHz, 2010MHz -2025MHz and 2290-2300MHz (the "Spectrum Bands"). It is referred to in the Consultation Document on Ofcom's proposals for the grant of wireless telegraphy licences to use the Spectrum Bands and the method for their allocation

This Technical Study is intended for information purposes only. This Technical Study is not intended to form any part of the basis of any investment decision or other evaluation or any decision to participate in the award process for the Spectrum Bands, and should not be considered as a recommendation by Ofcom or its advisers to any recipient of this Technical Study to participate in the award process for the Spectrum Bands. Each recipient of this Technical Study must make its own independent assessment of the potential value of a licence after making such investigation as it may deem necessary in order to determine whether to participate in the award process for the Spectrum Bands. All information contained in this Technical Study is subject to updating and amendment.

The content of the Technical Study, or any other communication by or on behalf of Ofcom or any of its advisers, should not be construed as technical, financial, legal, tax or any other advice or recommendation. Accordingly, any person considering participating in the award process for the Spectrum Bands (either directly or by investing in another enterprise) should consult its own advisers as to these and other matters or in respect of any other assignment of any radio spectrum.

Contents

Section	Page
1 Introduction	1
2 Potential interference into 2500 – 2690 MHz	2
2.1 Civil radars 2700-3100 MHz into UMTS	2
3 Potential interference from the award bands into adjacent band services	18
3.1 UK UMTS into European radio astronomy	18
3.2 UK UMTS into EESS (passive) systems	23
4 In-band interference issues	28
4.1 TDD mobile to UMTS mobile, localised in-band blocking	28
4.2 Cross border interference issues.	31
Annex	Page
1 Glossary/Acronyms	41
2 Parameters used in ICS Telecom modelling	42
3 Radio Astronomy Observatories in Europe	44
4 Parameters used in Visualyse modelling	46
5 MMDS transmitter locations in the Republic of Ireland	47

Section 1

Introduction

This report is divided into three sections:

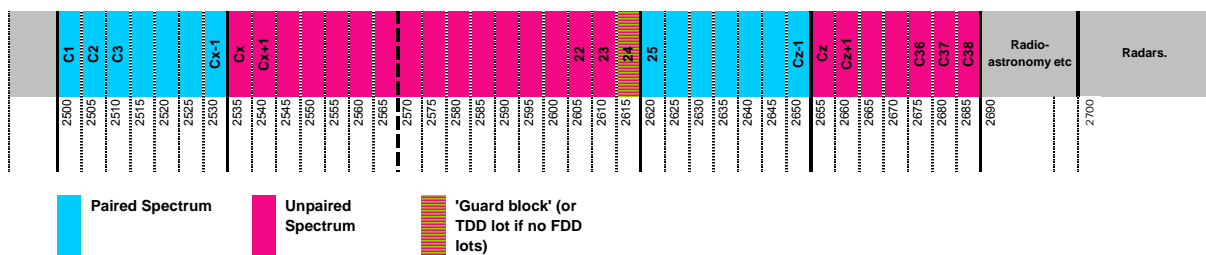
- Compatibility concerning interference from services in other bands into the award band
- Compatibility issues for interference generated in the award band that may affect services in other bands.
- In-band compatibility issues.

For each section Ofcom has modelled a range of scenarios that we believe represent realistic deployments of the systems concerned, using simulation parameters agreed by industry for such purposes.

We have assumed that deployments in the 2500 – 2690 MHz award band will be UMTS FDD, UMTS TDD or mobile WiMAX (802.16e), because we think these are the most likely technologies that would be deployed, but recognise that other technology types could be used.

Our results do not attempt to analyse in detail the impacts on each technology, instead we have looked at where agreed interference limits could be breached by interfering systems in neighbouring bands or neighbouring countries.

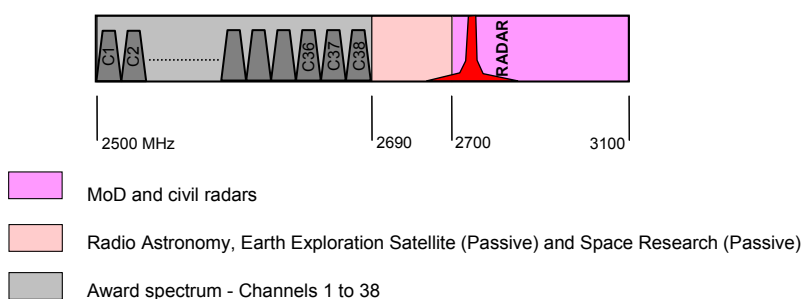
The following diagram shows the channel numbering used for the 2500 – 2690 MHz band. Our analysis focuses on channels 30 and 38, 2645-2650MHz and 2685-2690MHz respectively. (The TDD/FDD split is for illustrative purposes only.)



Channel numbering for the 2500 – 2690 MHz band

Section 2

Potential interference into 2500 – 2690 MHz



The 2500 – 2690 MHz band in relation to services in other bands

2.1 Civil radars 2700-3100 MHz into UMTS

Civil radars above 2.7GHz

The ITU-R Radio Regulations allocates the band 2700-3100 MHz to the Radiolocation Service and in the UK there are approximately 38 civil radars operating there. These are pulsed radars used to support air-traffic management and are sited mainly at or near airports. There are three main amplifier technologies used to generate radar transmissions: magnetron, travelling wave tube (TWT) and solid state, all of which have different spectral properties and other emission characteristics.

Some radars, particularly older magnetron or TWT types, may have significant out of band (OOB) or spurious emissions that can extend for 10's of MHz beyond their operating frequencies. If these operate on frequencies close to the 2700 MHz band edge, their emissions may extend into the top channels of the award band (2500-2690MHz). We have identified 22 civil radars that operate within 100MHz of the expansion band's topmost channel 38 (C38, 2685-2690MHz). Of those:

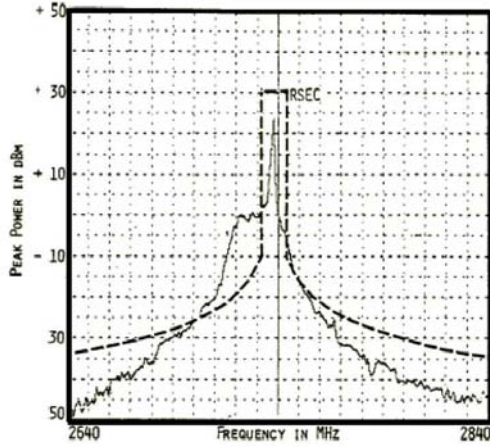
- Eleven are magnetron radars operating at peak EIRP power levels up to 92dBW
- Six are TWT radars operating at peak EIRP power levels up to 82dBW
- Five are solid state radars operating at peak EIRP power levels up to 80dBW

Methodology

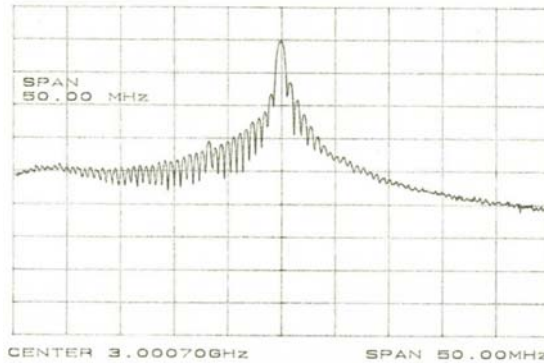
This study seeks to assess the impact of these radars on potential systems using the upper channels of the award band. The out of band power generated by radars into C38 and C30 is estimated and the coverage range of those emissions is plotted based upon UMTS receiver sensitivity levels.

Civil radar emissions into channel 38 and channel 30

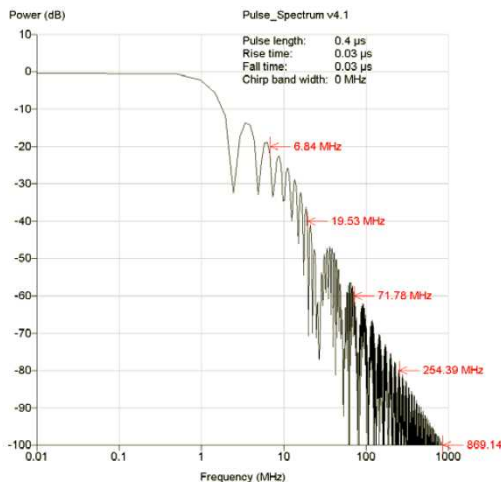
Out of band emissions are estimated based on radar powers, frequency and location, coupled with published spectral plots (shown below) for the three main radars types (generic plots were used for the varied older magnetron types).



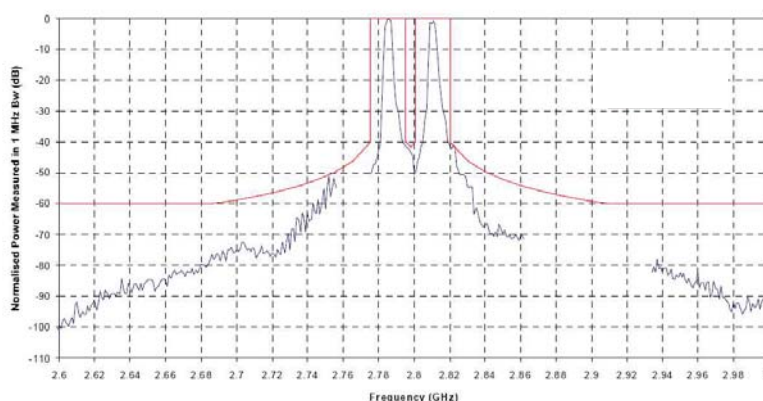
Generic spectrum plot for s-band magnetron radar



Expanded spectrum plot for s-band magnetron radar (vert: 10dB/div)



Spectrum characteristics for s-band Watchman TWT radar



Example spectrum plot for s-band ASR-10 solid state radar

Using the appropriate envelope of the above plots, and each radar’s specified peak EIRPs, we graphically estimated the individual radar emissions into C38 and C30. (Some of above diagrams show predefined spectrum masks, but our envelopes followed the radars’ actual spectrum plots.) Pre-calculating the emissions into individual award band channels allows co-frequency interference models to be developed, which are much simpler to simulate. Peak powers were chosen as these would demonstrate how far radar emissions might reach.

Victim receiver characteristics

A variety of technologies could theoretically be deployed in the award band, one of which is FDD UMTS, and at the top of the band this would be in mobile receive mode. We have used this as a representative technology because the specification is relatively mature and based on technology deployed in other bands.

An alternative implementation could be TDD UMTS, where both base stations and mobiles would be in receive mode. The interference potential to base stations would be greater because their antennas are typically mounted on towers or buildings and have higher antenna gain (we assume a 15dBi antenna at 15m) than mobiles which are at ground level or inside buildings (we used a 0dBi antenna at 1.5m).

Calculating the interference zones

Using the derived C38 radar peak power figures we used ATDI ICS Telecom to plot the areas in the UK where radar emissions theoretically exceed the established -6dB I/N interference threshold levels (defined above) into a reference UMTS receiver, these are taken from ITU-R Report M.2039.

Receiver noise floor kTB + 8dB noise factor)	-100dBm
Maximum interference level into receiver	-106dBm
Antenna gain	0dBi

UMTS mobile receive parameters

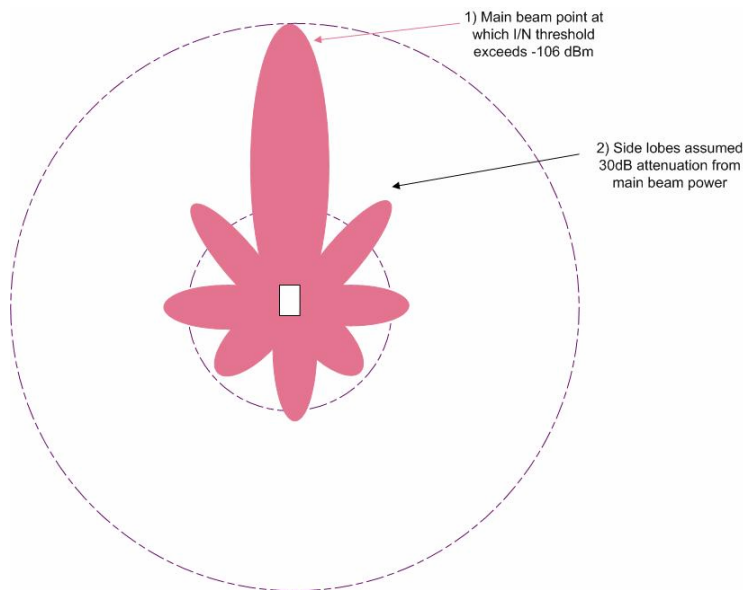
Receiver noise floor (kTB + 4dB noise factor)	-104dBm
Maximum interference level into receiver	-110dBm
Antenna gain	15dBi

UMTS base station parameters

The propagation parameters factored into the ICS Telecom model in are detailed in Annex 2.

There are effectively three zones where interference may occur:

- i) Swept beam zone – an area where pulsed emissions from the radar main beam are calculated to exceed the maximum interference levels into a UMTS receiver (-106 dBm for a mobile, and -110 dBm for a base station, taking the respective UMTS receiver antenna gains into account) each time the rotating radar beam sweeps in that direction (approximately every four seconds). This ‘swept’ zone is largest because the main beam contains the highest power and is therefore seen at longer ranges (a key radar design aim).
- ii) Side lobe zone – an area where pulsed emissions from radar side lobes are calculated to exceed the same interference levels as above. This zone is smaller than the swept beam zone because side lobe emissions are designed to be as low as possible (we use an averaged figure of -30dB relative to the main beam). Because the side lobes extend all around the antenna, this interference would be visible nearly continuously.

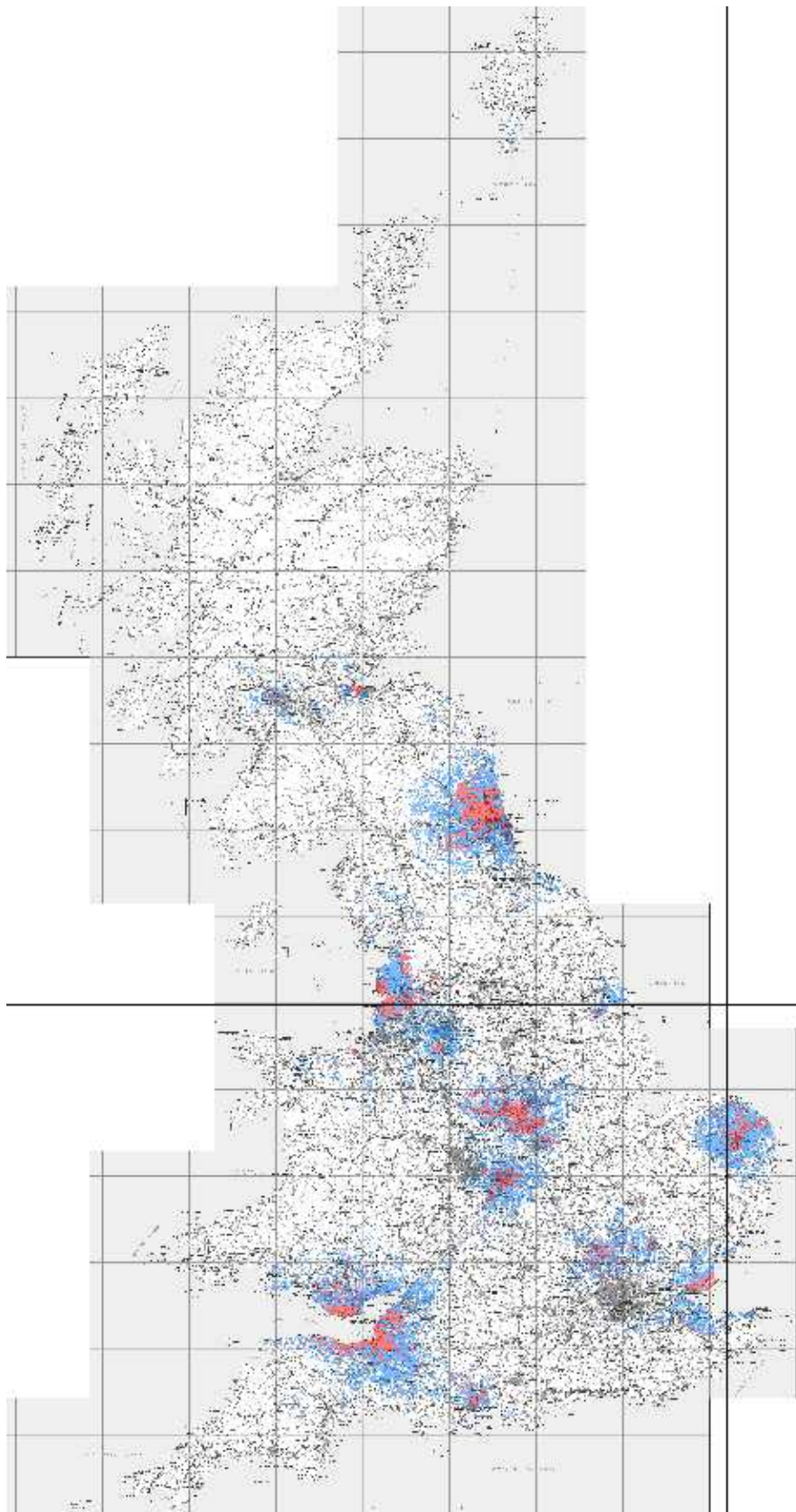


Radar interference zones

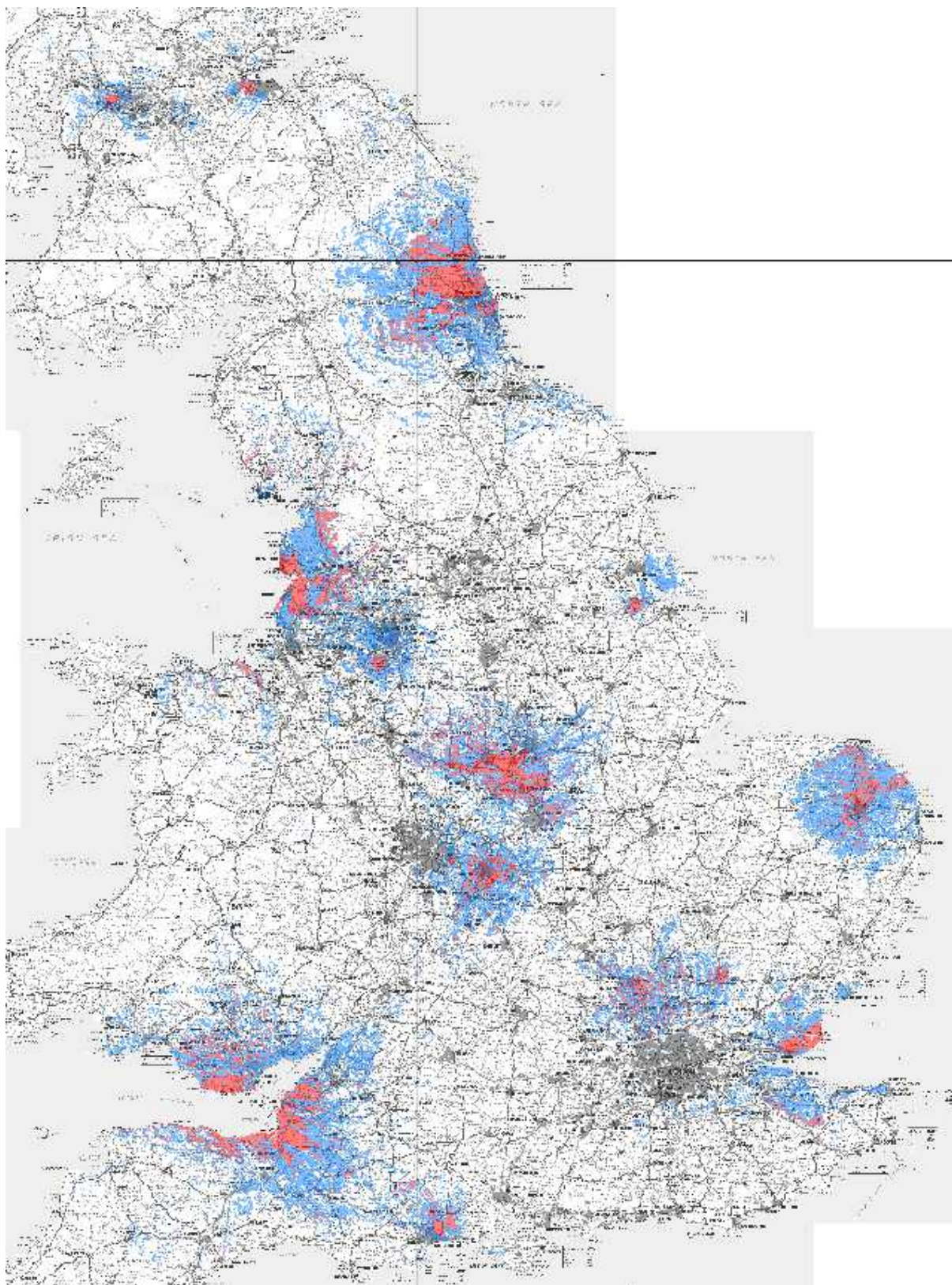
Results for C38

The coverage plots below show the areas where radar signals will exceed the agreed I/N interference threshold of a UMTS receiver operating in C38 and. The term “visibility” is used because interference may not always occur. Typically magnetron and TWT radars use pulse lengths of about 1µs and solid state about 70µs. The differing pulse lengths may cause different effects on award band systems and for this reason solid state radars are plotted separately from magnetron and TWT. (Plots should be viewed in colour)

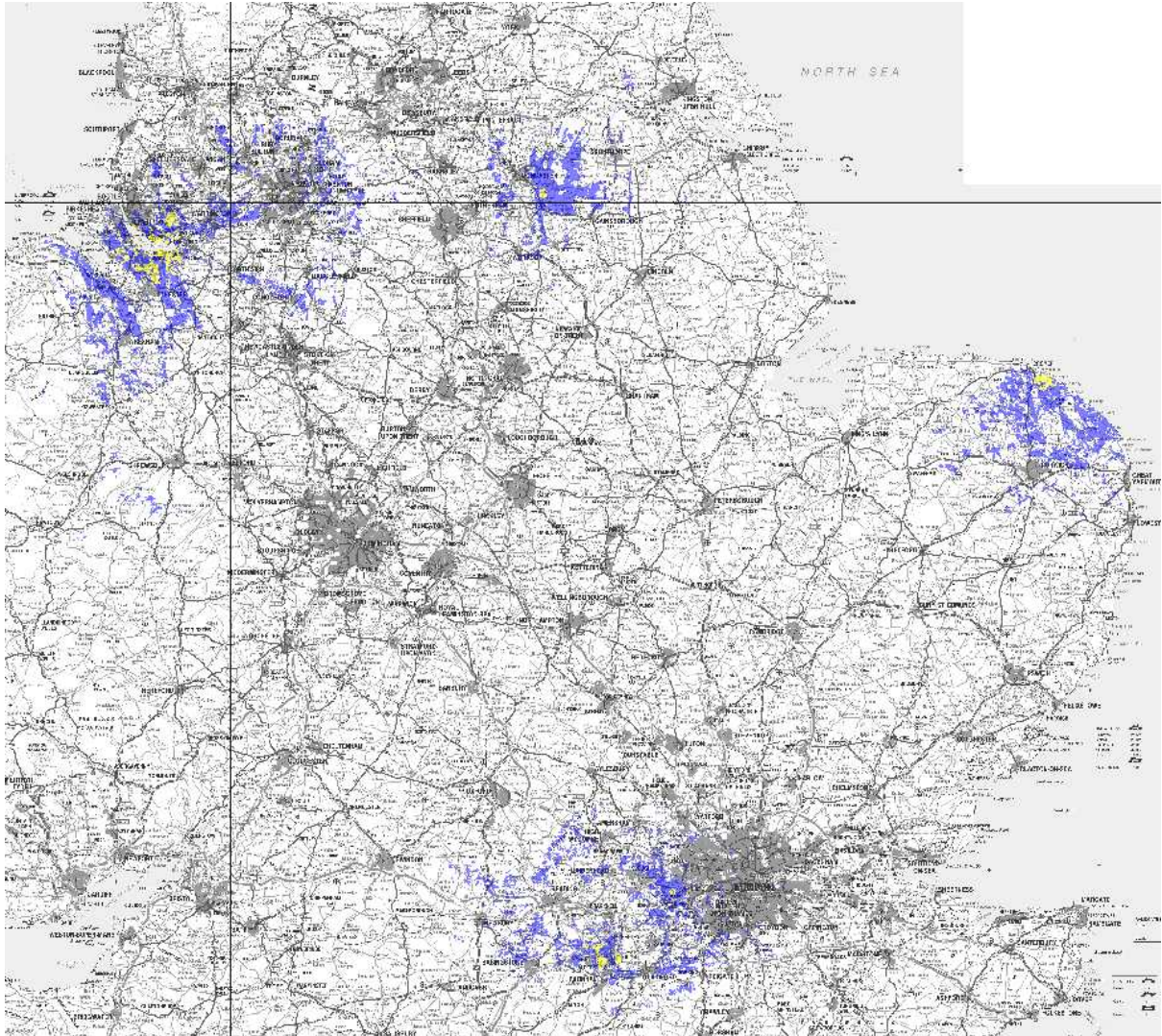
C38 mobile reception



Visibility zones for TWT and magnetron radars into UMTS mobiles in C38 (red: side lobe, blue: swept)

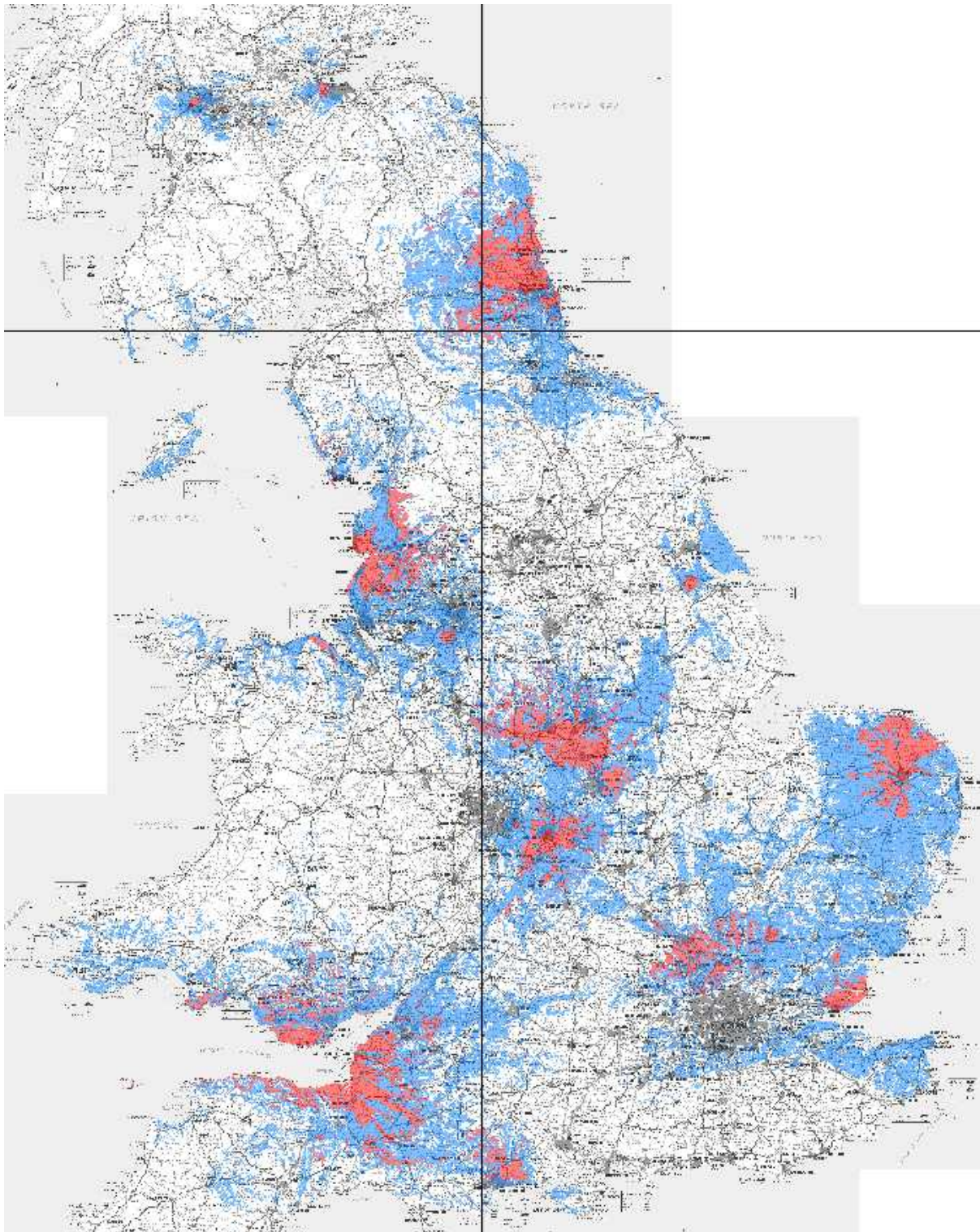


Magnified visibility zones for TWT and magnetron radars into UMTS mobiles in C38 (red: side lobe, blue: swept)

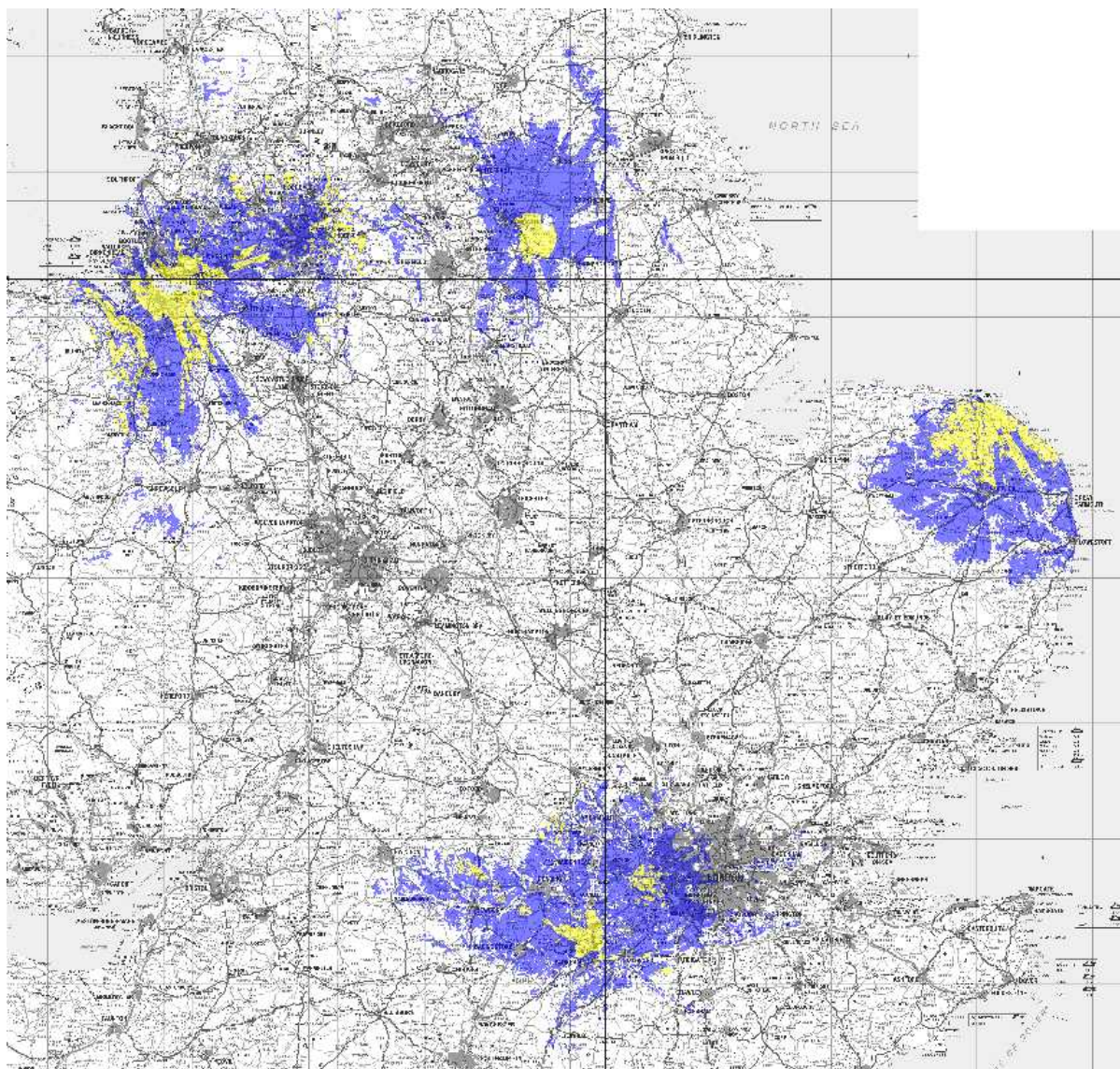


Visibility zones for solid state radars into UMTS mobiles in C38 (yellow: side lobe, blue: swept)

C38 base station (TDD only) reception



Visibility zones for TWT and magnetron radars into TDD UMTS base stations in C38 (red: side lobe, blue: swept)

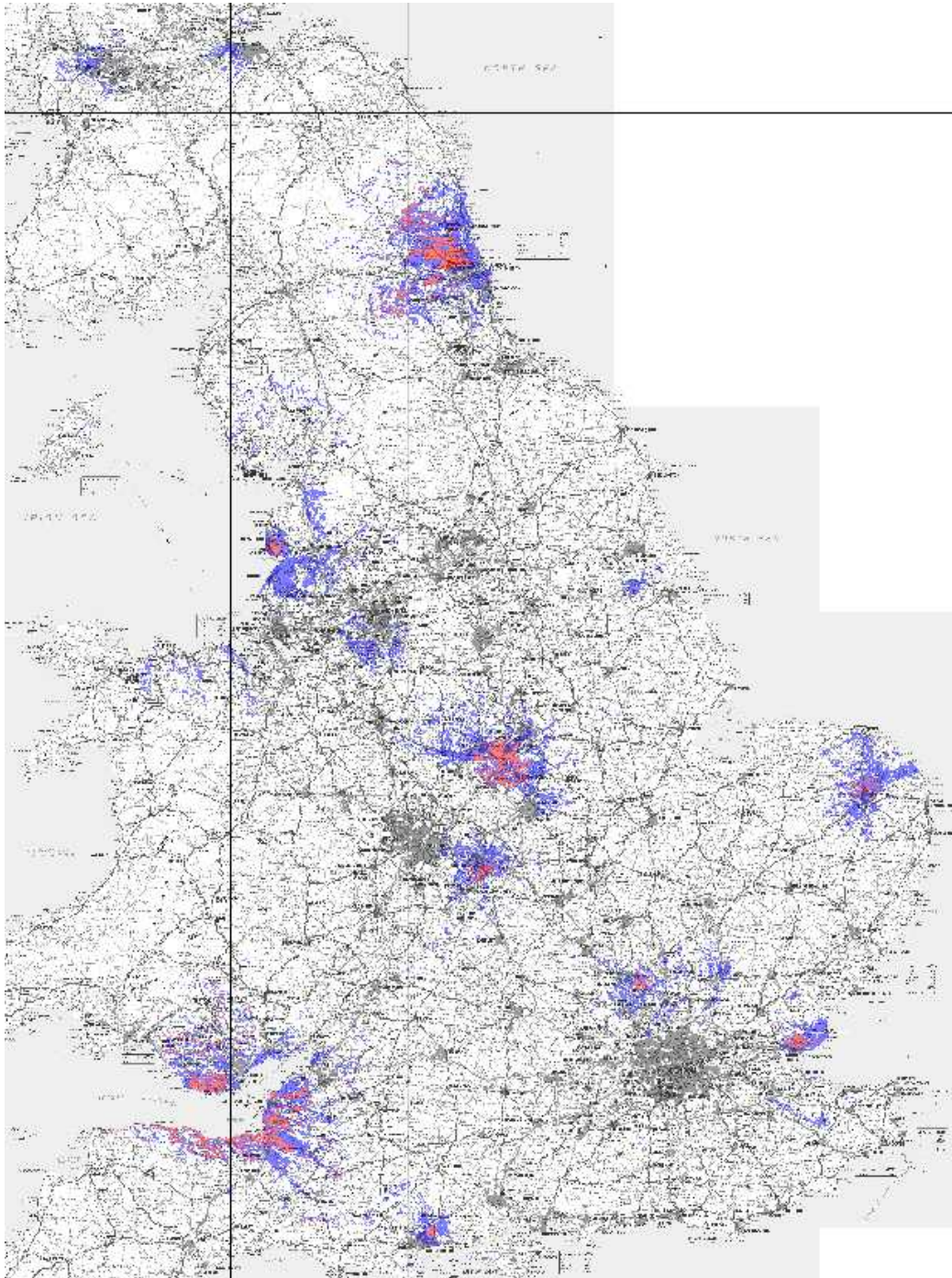


Visibility zones for solid state radars into TDD UMTS base stations in C38 (yellow: side lobe, blue: swept)

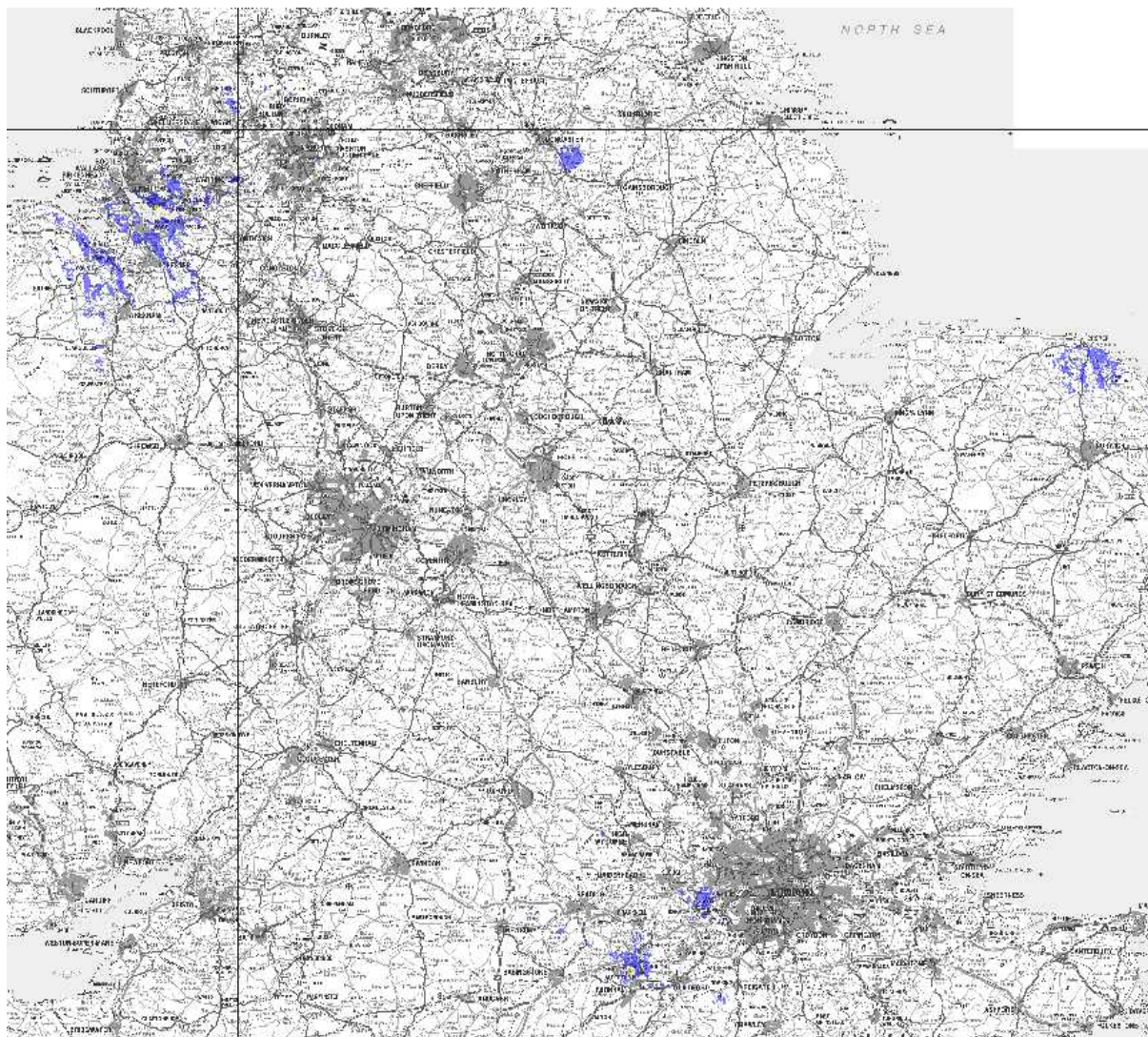
Results for C30

To gauge how the OOB emissions from radar tail off, the following plots show the zones where interference levels are predicted to exceed the same threshold levels within UMTS receivers in C30.

C30 mobile reception

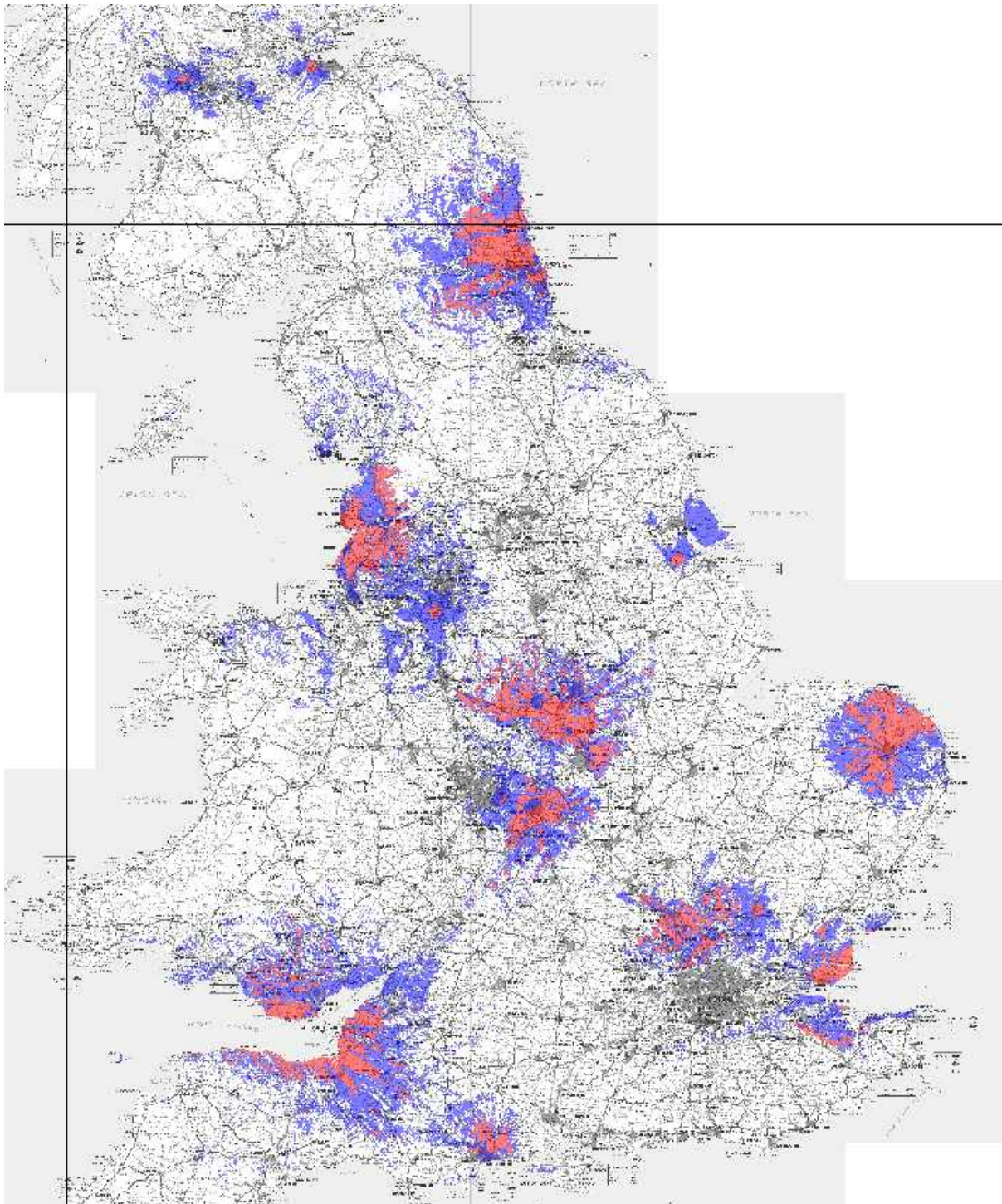


Visibility zones for TWT and magnetron radars into UMTS mobiles in C30 (red: side lobe, blue: swept)

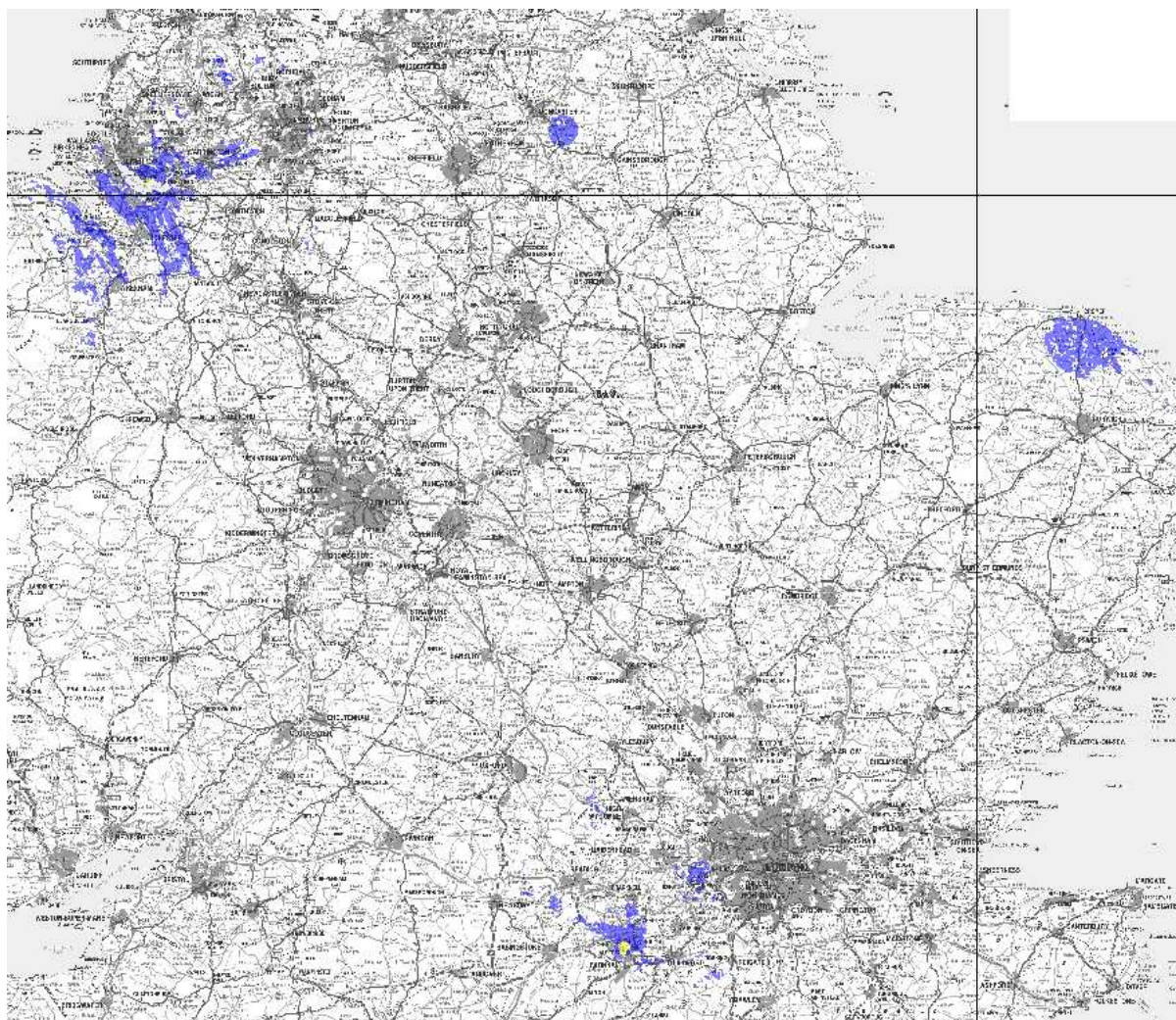


Visibility zones for solid state radars into UMTS mobiles in C30 (blue: swept)

C30 base station (TDD only) reception



Visibility zones for TWT and magnetron radars into TDD UMTS base stations in C30 (red: side lobe, blue: swept)



Visibility zones for solid state radars into TDD UMTS base stations in C30 (blue: swept)

Interference impact

Although within these zones radar signals theoretically exceed the UMTS interference threshold, it does not mean that UMTS receivers will suffer harmful interference. In the follow section, using a simplified analysis, we seek to demonstrate why this is the case, but we do not attempt to analyse detailed effects on each system.

Radar emissions are not continuous; they are pulsed with large gaps between each pulse. Because of this any interference seen by the UMTS receiver will be transitory: brief but with predictable timing.

Magnetron and TWT amplified radars produce short high powered pulses of around $1\mu\text{s}$ duration separated by about 1ms (1:1000 duty cycle). Radar solid state amplifiers are not able to produce the same peak powers as either magnetron or TWT types but compensate by using longer duration pulses of around $70\mu\text{s}$ in order to 'illuminate' targets with equivalent energy. Their emission characteristics are likely to have different affects on victim UMTS receivers and we consider this and antenna rotation and side lobe effects below.

Radar Technical parameters

Air traffic control radars use pulsed emissions and we assume the following typical characteristics for the different radar types, based on those used by UK civil radars in this band

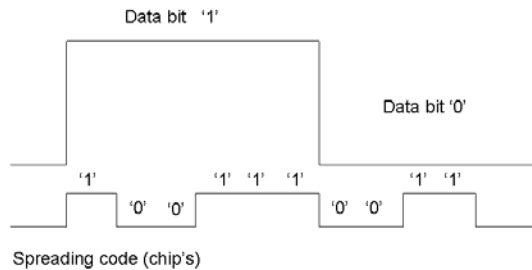
Type	Pulse length	PRF	Duty cycle	Beamwidth	rotation duration
Magnetron	1.7µs	1kHz	0.17%	1.5°	4s
TWT	0.4µs	1kHz	0.07%	1.5°	4s
Solid state	70µs	1kHz	7%	1.5°	4s

Radar parameters

Impact on UMTS

UMTS spreading codes

Pseudo random binary spreading codes (or scrambling codes) are used to modulate the UMTS data stream to enable differentiation between different UMTS users, this is known as Code Division Multiple Access or CDMA. This spreads the data signal across a wider bandwidth, improving fade performance and also makes the signal more resistant to interference.

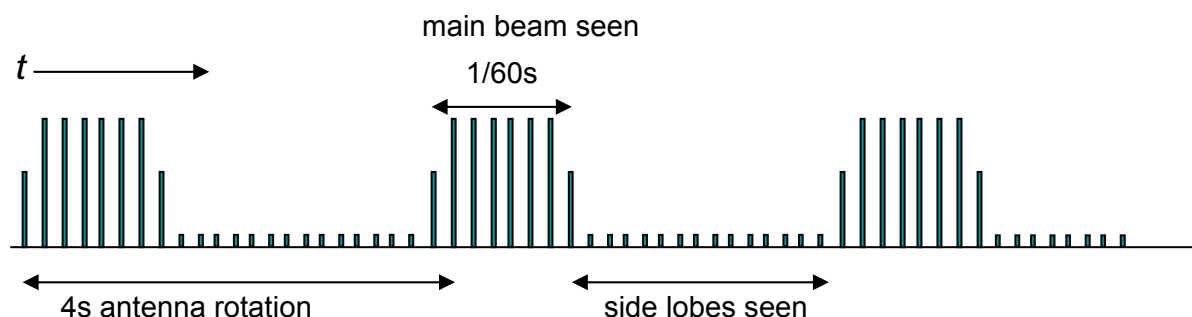


UMTS chips

The modulating spreading codes are composed of a pattern of code 'chips' and UMTS modulates the signal at 3.84 million chips per second (3.84Mcps) so each chip has a 0.26 µs duration.

Calculating chip loss

During a 4 second rotation of the 1.5° beamwidth radar antenna, the main beam will 'sweep by' the receiver for 1/60s. In this time, at a 1 kHz pulse repetition rate (PRF), the receiver will see about 17 radar pulses.



Illustrative radar pulse train as seen by a stationary receiver (not to scale)

In the swept zone only the main beam is seen, and then only for 1/60s. In this time, the number of chips potentially lost as a result of radar interference is:

$$= (\text{radar pulse length} / \text{chip length}) \times \text{number of pulses seen per rotation}$$

eg, for magnetron radars:

$$(1.7\mu\text{s} / 0.26\mu\text{s}) \times 17 = 111 \text{ chips are potentially lost per rotation}$$

In the side lobe zone, a receiver would see all the pulses produced by the radar, so the potential number of chips lost per rotation is:

$$= (\text{radar pulse length} / \text{chip length}) \times \text{number of pulse seen in one rotation}$$

eg, for magnetron radars:

$$(1.7\mu\text{s} / 0.26\mu\text{s}) \times 4 \times 1000 = 26,154 \text{ chips are potentially lost per rotation}$$

This compares with the number of chips sent by the UMTS transmitter during the four second rotation, which is:

$$4 \times 3.84 \times 10^6 = 15,360,000$$

So the percentage of potential lost chips can be determined and these are tabulated below for the various radar types.

radar type	Swept zones		Side lobe zone	
	chips lost in 1/60s	% lost overall	chips lost per rotation	% lost overall
magnetron	111	0.0007	26,154	0.17
TWT	26	0.00017	6154	0.04
solid state	4576	0.03	1,076,924	7

Potential chip lost

Compared with the code error rates designed to be routinely handled UMTS, this potential number of lost chips is not considered significant and should be easily managed by the UMTS built in forward error correction system.

Impacts on WiMAX

WiMAX deployments are expected to be at similar maximum power levels with comparable receiver performance figures to UMTS.

WiMAX (802.16e) uses OFDM with a symbol length of 102.9 μ s within a 5ms frame¹. With 1 to 2 μ s pulse lengths, magnetron and TWT radars could theoretically corrupt a single WiMAX symbol with every pulse. But in practice short impulse-like noise such as radar pulses may not be noticed². Longer pulses deployed by solid state radars maybe more likely to corrupt a WiMAX symbol, particularly if the automatic gain control at the receiver's front end is lowered because of overload by the radar energy, but it is unlikely that two consecutive symbols will be lost. Even so, interleaving and forward error correction techniques would mitigate the impact, but a bit error rate increase could be expected. In addition, the 802.16e mobile WiMAX standard supports provision of active beam forming antennas, which could provide further mitigation against radar emissions if there was sufficient angular separation between the WiMAX base station and the radar installation.

Conclusions

TWT and magnetron radars are not expected to cause significant degradation to UMTS or WiMAX services if they are deployed in the award band.

The longer solid state pulse lengths may cause service degradation in channels towards the top of the award band but only within the visibility zones. The higher chip loss (up to 7%) associated with proximity to these radars means there may be an increase in bit error rates for both UMTS and WiMAX systems. However, because there are fewer solid state radars, which typically operate at lower peak powers, their potential impact will be over a smaller geographic area compared with TWT and magnetron radars.

Although there are relatively few solid state radars in operation within 100MHz of the award band at the moment, as older magnetron and TWT radars are replaced, solid state technology will become more common. Despite this, the relatively well controlled solid state radar spectrum means the impact of their longer pulses could be largely offset by better out of band emission characteristics, but this will depend on the particular radar deployment.

What the results also show is that TDD base stations in the top channels of the award band would be more susceptible to interference, and over a far wider area, than FDD mobile receive services. The radio signal received by FDD mobiles (and TDD mobiles) at ground level or in buildings is greatly attenuated by clutter. TDD base stations typically mounted above most clutter do not have this 'advantage' and also utilise more sensitive receiver systems.

The plots for C30 also demonstrate that the OOB emissions from radars extend some way into the award band, but their impact is lessened. Potential interference will be worse for channels closest to the radar bands.

¹ http://www.wimaxforum.org/news/downloads/Mobile_WiMAX_Part1_Overview_and_Performance.pdf

² Understanding WiMAX and 3G for Portable/Mobile Broadband Wireless – Intel December 2004

Section 3

Potential interference from the award bands into adjacent band services

3.1 UK UMTS into European radio astronomy

The ITU-R Radio Regulations allocate the band 2690-2700MHz exclusively to passive services including radio astronomy and ITU-R Recommendation RA 769-2 defines threshold interference levels for in-band emissions detrimental to radio astronomy observations. For the 2690-2700 MHz band that level is -207dBW (-177dBm) across the whole 10MHz bandwidth.

Study methodology

We developed a model using ATDI ICS Telecom software to simulate the effects of a reference UK network of UMTS transmitters. We pre-calculated what the actual theoretical UMTS base station emissions into the RAS band in order to develop a simple co-frequency UMTS/RAS model. Then ICS Telecom was used to calculate the aggregate network effect of these emissions.

European radio astronomy sites are listed in Annex 3, these sites were taken from the European radio astronomy organisation, CRAF, website. Initially only those RAS sites closest to the UK were considered. These are:

Country	Place	Latitude	Longitude	Altitude (m)
Belgium	Humain	05° 15' 19"	50° 11' 31"	293
Netherlands	Borger-Odoorn	05° 52' 00"	52° 55' 00"	15
	Dwingeloo	06° 23' 48"	52° 48' 48"	25
	Westerbork	06° 36' 15"	52° 55' 01"	16

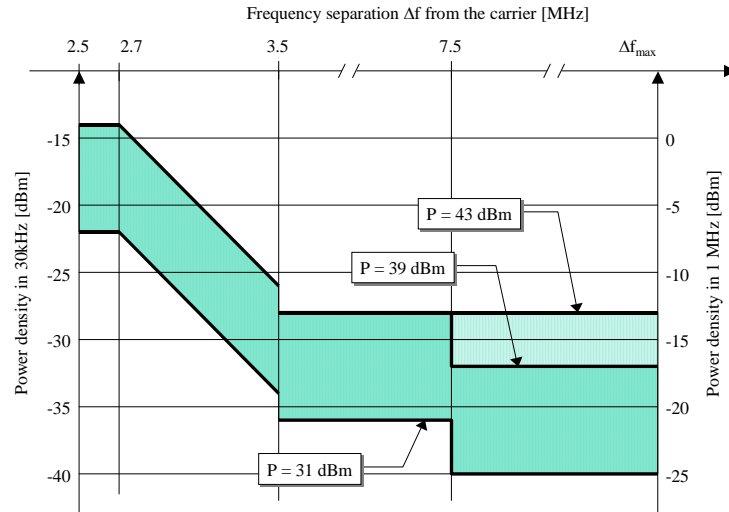
Selected European radio astronomy sites

If significant interference effects are seen at these four radio astronomy sites further analysis would be carried out to assess the potential impact at other sites.

Calculating UMTS emissions from C38 into the radio astronomy band

UMTS emissions from C38 are expected to be either TDD or FDD base transmit. We used UMTS FDD base transmit mode because the potential for interference from continuous base station emissions at 15m height is greater than that for TDD emissions from mobile devices at 1.5m.

C38 UMTS base station emission powers into the RAS band were calculated from the standard ETSI/3GPP UMTS emission mask shown below to make the simulation a co-frequency scenario and reduce the required computation time.



Illustrative diagram of spectrum emission mask

The table below shows how the OOB emissions from a 5MHz WCDMA signal in C38 that fall within the 10MHz radio astronomy band are calculated using the high power UMTS mask ($P > 43\text{dBm}$), ref ETSI TS125104. This consists of three sections; two flat and one sloped and for each, the maximum permitted total power is determined by considering the mask limit, the specified measurement bandwidth for that limit and the bandwidth for each section.

Section beyond edge of C38 (kHz)	section bandwidth (kHz)	measurement bandwidth (kHz)	maximum power in measured bandwidth (dBm)	(mW)	total power within section bandwidth (mW)	total power (dBm)
2.690 – 2.6902	200	30	-14	0.0398	0.265	
2.6902 – 2.691	800	30	-19.8	0.0105	0.279	
2.691 – 2.7	9000	1000	-13	0.0501	0.451	
					0.996	-0.02

Out of band emissions from Channel 38 falling within the RA band

Note: In practice, actual equipment may have better out of band characteristics than the maximum limit set in the ETSI mask. There would be a consequential reduction in emissions into the radio astronomy band, but we have not assumed this.

The other parameters used in the model are listed below.

UMTS	
base station height	15m
OOB emissions	- 0.02 dBm
Antenna gain	15dBi
EIRP	14.98dBm
radio astronomy	
antenna height	50m
interference limit	-177dBm

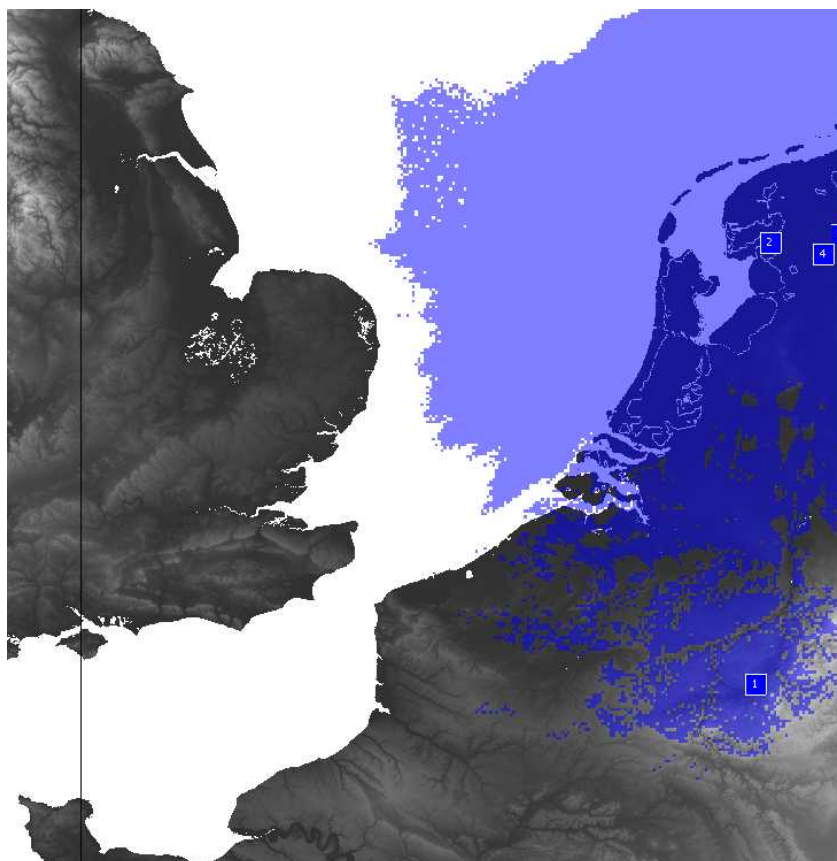
Other model parameters

The accepted standard height for UK RAS antennas is 50m in our analysis and uses an agreed standard side lobe gain antenna gain of 0dBi to calculate terrestrial interference. With a C38 UMTS base station peak power of 43dBm, the effective emissions from that

base station into the RAS band is calculated to be 14.98 dBm EIRP. Propagation model ITU-R P 452 was used as before (but with a more stringent 5% probability of interference setting, rather than the 10% used for our other studies) with parameters as listed in Annex 2.

Single UMTS base station emissions

As a first check, the potential impact from a single transmitter located anywhere in the UK was determined using a “reverse coverage” plot. This shows zones of interference power around European RAS sites, ie “if a single transmitter is located here the interference power seen by the RAS site is this”. This gave a useful feel for the range of UMTS emissions and whether further analysis would be required.



Reverse coverage plot from a single UMTS base station (the blue area indicates where the interference threshold would be exceeded) – RAS sites shown in blue squares.

The plot shows that emissions from a single full power UMTS base station transmitter would not breach the European radio astronomy protection levels. However, this is not a realistic deployment scenario for any operator in the award band, which will be a network of base station transmitters; the single transmitter propagation distances suggest that further analysis is required.

Aggregate UMTS reference network emissions

To simulate this scenario, a reference network of 5000 base stations was modelled, spread throughout the UK, with concentrations in urban areas. Rural macro-cell base stations use the same UMTS parameters as above, but urban transmitters are likely to utilise micro/pico-cells and we have used a transmission figure some 10dB lower than the full power figure.

Again the model was set up as a C38 (co-frequency) simulation and used the same ATDI parameters as before.

The aim was to calculate the aggregate interference effects from all base stations at each RAS site. Theoretically it would be possible to produce a plot similar to that for a single base station but in practice the number of required calculations means exceptionally long simulation times per plot would be required. Therefore for each RAS site considered a single aggregate interference figure is calculated and these are shown in the table below.

Country	Station	Receiver kTBF [dBm]	Aggregate power sum [dBm]	I/N margin [dB]
Belgium	Humain	-177	-183.69	-6.69
Netherlands	Borger-Odoorn	-177	-177.24	-0.24
Netherlands	Westerbork	-177	-185.63	-8.63
Netherlands	Dwingeloo	-177	-182.98	-5.98

Aggregate power sum calculation results for UMTS

The table shows that the interfering aggregate power sum of UMTS emissions into Europe is predicted not to exceed the low levels recommended to protect RA observations in the adjacent RAS band. Although it is close to the limit, it should be noted that the reference UMTS network was modelled using omni-directional antennas. Realistically, an operator would also use down-tilted and sectored antennas, and could also plan to point peak emissions away from RAS sites if required.

We estimate that these additional mitigation factors would significantly reduce potential interference so that it is well below the recommended protection levels for RA observations in Europe.

WiMAX

WiMAX (802.16e) emissions, spectrally quite different to UMTS, will typically operate at fixed power levels unlike UMTS base stations (WiMAX power control is optional). This means there maybe a greater potential of interference. For the same reference network as above we modelled full power transmissions at the same level as UMTS. The aggregate power sum results are shown below.

Country	Station	Receiver kTBF [dBm]	Aggregate power sum [dBm]	I/N margin [dB]
Belgium	Humain	-177	-177.73	-0.73
Netherlands	Borger-Odoorn	-177	-170.89	6.11
Netherlands	Westerbork	-177	-181.27	-4.27
Netherlands	Dwingeloo	-177	-178.79	-1.79

Aggregate power sum calculation results for WiMAX 802.16e

Conclusion

Ofcom concludes that there will be no impact on current European radio astronomy observations from a UK network of UMTS base stations operating in C38 of the award band. However, this conclusion is based on existing radio astronomy sites and if RAS sites were located closer to the UK interference to observations at those new sites could not be entirely ruled out. In reality, given the current difficulties identifying new 'quiet' sites for RAS operations the likelihood of new RAS sites in Western Europe is small.

Emissions from a WiMAX network in C38 may breach European RAS protection levels. However, if WiMAX network antennas are pointed away from RAS sites and use downtilt, which cellular operators normally do, there should be little or no impact to radio astronomy observations at the sites mentioned above.

3.2 UK UMTS into EESS (passive) systems

The band 2690-2700MHz is also allocated to the Earth exploration satellite service (passive) on a primary basis. Like the radio astronomy service EESS (passive) does not employ transmitters and relies on receive-only systems. Although no EESS (passive) systems using this band were identified, it should not be assumed that this will always be the case.

Therefore interference effects were modelled using parameters based on existing EESS systems in other bands. The band is also allocated to the Space Research Service (passive) which operates in a similar manner to EESS (passive), and, for the purpose of this study, we assume its systems to have similar characteristics.

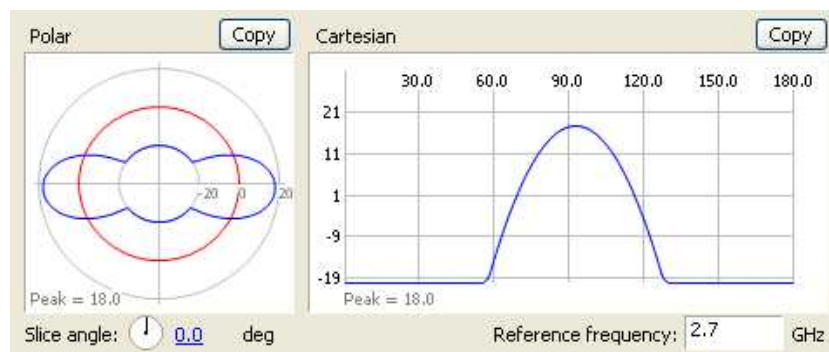
Methodology

Transfinite Visualyse software (version 2.5.1) was used to simulate the effect of a reference UK UMTS network on EESS (passive) operations over the UK and over continental Europe (no UK coverage assumed).

Whereas other studies in this report only consider (two-dimensional) terrestrial interference scenarios, for this situation involving a non-GSO satellite it was important to model the three-dimensional emission characteristics. Because of this, the simulation model had to more accurately represent the antenna systems used to better define the interference coupling mechanisms. The antenna characteristics were defined in Visualyse, which allowed base station antenna down tilt, and satellite beam shape and coverage to be easily modelled.

UMTS parameters

The UMTS base station parameters for the reference network are the same as those used in the UMTS/radio astronomy study, but in this case Visualyse determines the effective OOB EIRP based on the previously determined OOB power (-0.02dBm , see OOB emissions calculations table in radio astronomy study) and the radiation pattern for the base station antenna which is defined below.



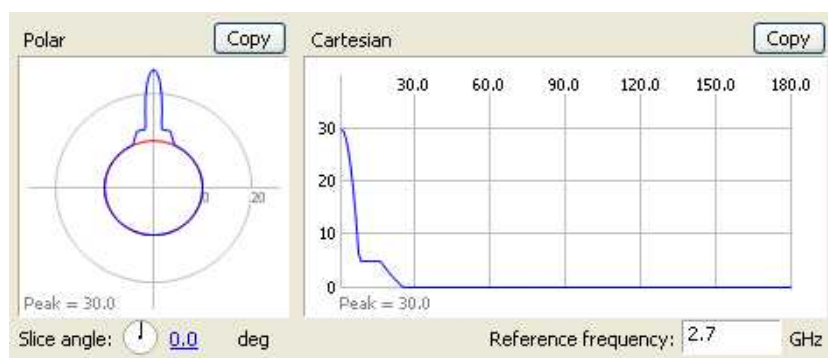
UMTS base station antenna emissions profile

EESS parameters

Orbit parameters from a NOAA satellite were used as a representative EESS satellite system and adapted for application around 2.7GHz, these were used to model a reference EESS (passive) satellite system operating in the 2690-2700MHz band.

Receiver interference threshold	-176 dBW/10 MHz (from Rec SA 1029-2)
Semi-major axis	7728 km
height above sea level	1343.8 km (taken from Visualyse)
Inclination	99 deg
Antenna	Rec S.672-3 In = -25 (diameter = 2m, efficiency = 0.6, temp = 300k)

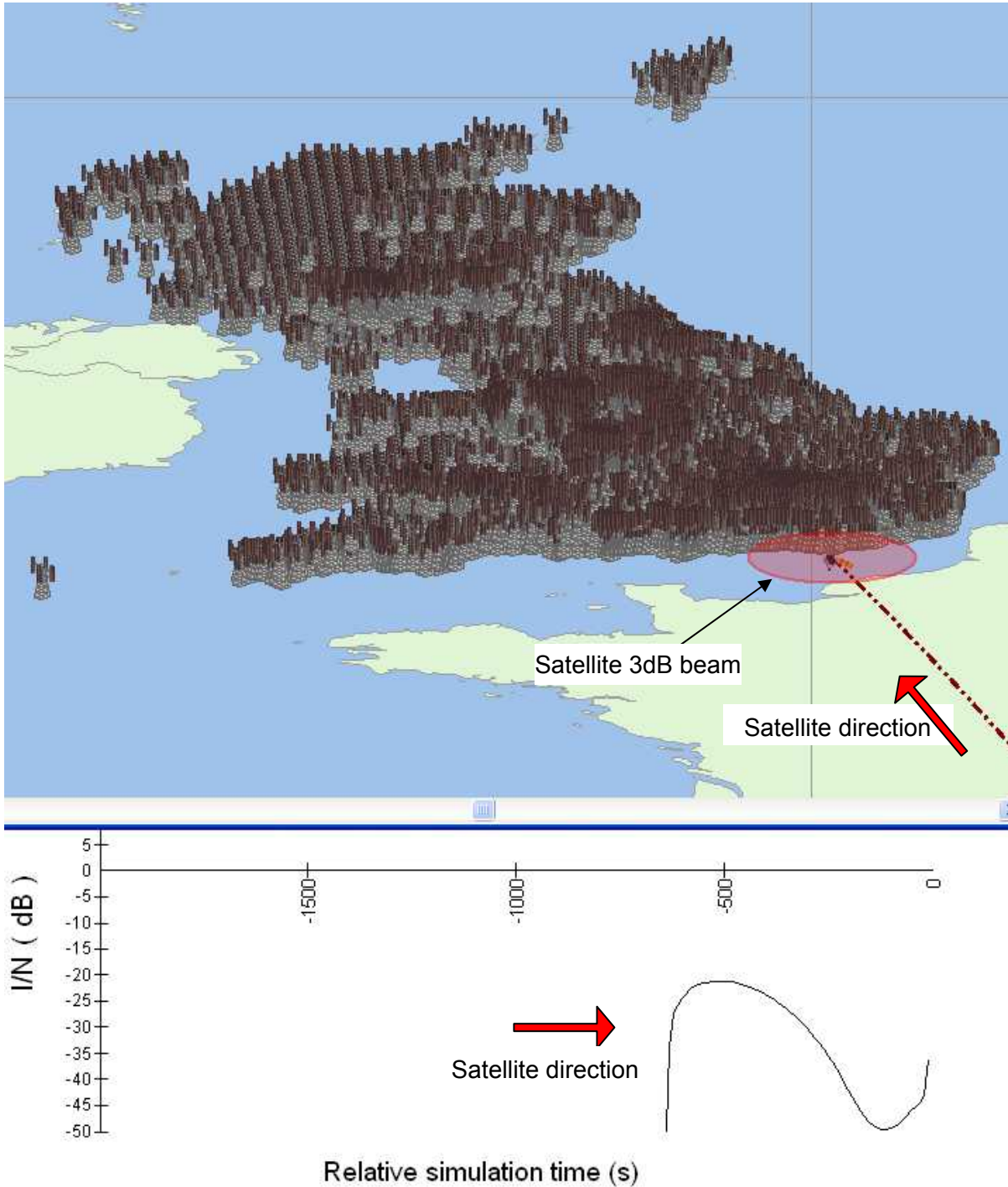
EESS Satellite Receiver Parameters



EESS satellite antenna emission profile

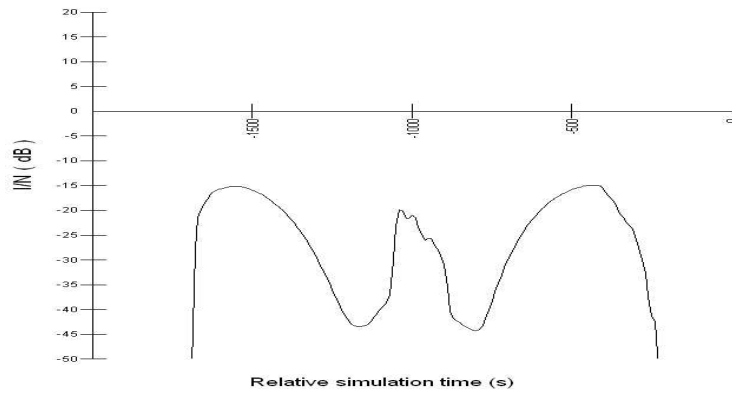
The model

A model was developed in Visualyse that simulated an EESS satellite in polar orbit as it passes over the UK. The satellite beam covers the UK as the satellite is over head and many UMTS base stations fall within the beam. The I/N ratio as seen by the EESS satellite receiver is calculated based upon the in-band emissions from all the UMTS base stations within the beam. The parameters included in the Visualyse model are shown in Annex 4.



Results

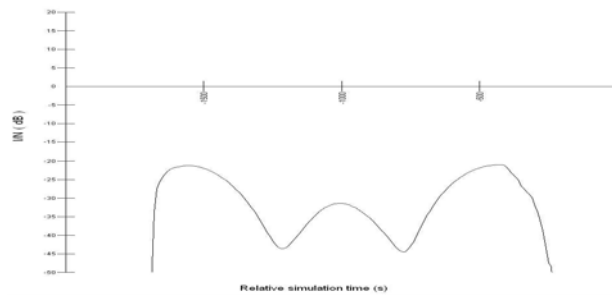
Stepping through the Visualyse simulation shows where the interactions between the reference UMTS network and the EESS satellite occur. The plot above shows the Visualyse simulation in progress as the EESS satellite approaches the UK south coast and indicates that the satellite receiver's I/N interference ratio rises as its (3dB) beam begins to pass over the reference network. The peak interaction over the UK occurs when the satellite beam covers dense urban areas, but the EESS I/N protection margin (at the 0dB axis) is never exceeded and UMTS emissions always remain at least 15dB below the protection level.



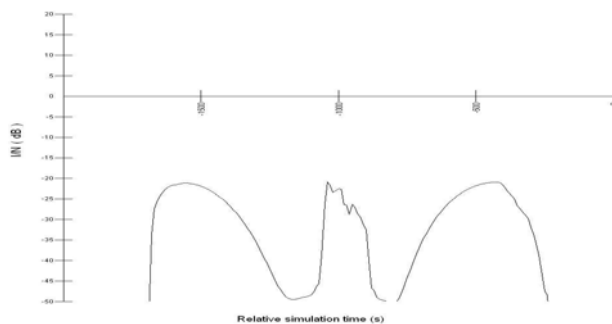
C38 UMTS reference network interference into the EESS (passive) satellite

The simulation also shows that the peak interaction between the satellite and the reference terrestrial network occurs when the satellite is rising above the horizon, when several thousand base station main beam emissions (sideward) are seen by the EESS antenna side lobes. However, once again, the EESS protection margin is never exceeded.

But this does demonstrate that the satellite antenna (particularly side lobe) performance will be crucial in making sure interference to the EESS system never exceeds the protection requirements. The EESS antenna we used in this simulation has a fairly basic emission pattern, so as a check we tried two other common EESS antenna types based on proposed systems (SMOS and Aquarius in the 1.4GHz band³).



Using antenna based on SMOS parameters (wide beam, 9dB gain)



Using antenna based on Aquarius parameters (elliptical beam, 35dB gain)

³ provisional new annex to ITU-R Rec SM 1633

All the EESS antennas modelled had conservative 0dBi side lobe gain but despite this, the reference UMTS network emissions never came close to exceeding the EESS interference protection margin. EESS systems typically have much better antenna side lobe performance than those we modelled and several antenna patterns planned for future EESS satellites (operating at lower frequencies where side lobe suppression is more difficult) already demonstrate this.

Conclusions

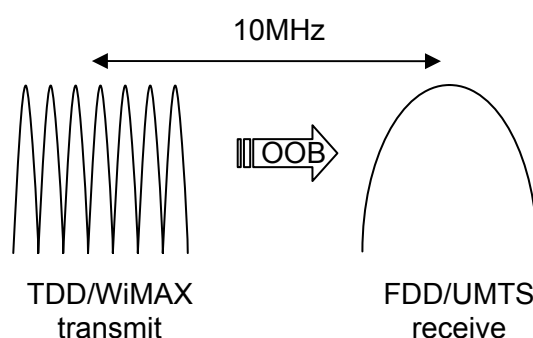
Based upon parameters for existing and planned EESS systems, the results show that emissions from a reference UMTS network in C38 are expected to be at least 15dB below the recommended protection levels for EESS (passive) operations over the UK. As the OOB emissions from award band channels below C38 will be far lower, Ofcom concludes that the aggregate emissions from all award band transmissions will not exceed the EESS protection limit, particularly given the 15dB margin. This assumes that the EESS main beam is not operated at extreme slant angles where coupling with UK base station horizontal emission peaks may begin to occur.

Section 4

In-band interference issues

4.1 TDD mobile to UMTS mobile, localised in-band blocking

This study aimed to determine if transmissions from a TDD mobile might impact the downlink to an FDD mobile if both are located within an office and are each served by different macrocells using different radio channels. The two mobiles use carriers 10MHz apart (minimum separation between full power FDD/TDD channels). This scenario represents a typical high density handset deployment at medium power levels.



TDD out of band (channel) emissions into FDD UMTS

Methodology

A model was developed as a bespoke Java program to simulate a UMTS cell within a cluster of other UMTS cells. The model included between 150 and 1000 mobiles within the cluster, their distribution and UMTS power control processes. The scenario was modelled with all parameters randomly distributed for 500 iterations. For each iteration, the model was permitted to converge to a power level for each terminal as would be expected if no external interference was present. A TDD WiMAX mobile device (802.16e) operating 10MHz away (carrier to carrier) connected to a separate WiMAX network is then added to the model at a predetermined distance from one of the UMTS mobiles and its effect on the UMTS mobile's required downlink power is determined.

Power control for transmissions to a mobile (downlink) is crucial for correct operation of CDMA technology underpinning UMTS. The proportion of the downlink power which is dedicated to a terminal is controlled by the required carrier to interference ratio. If there is more interference then more power is dedicated to that terminal until the maximum downlink power per terminal is achieved. If, at the maximum downlink power, the required C/I ratio cannot be achieved then the service is not available and the terminal is disconnected.

The power control loop is affected by many factors including how many handsets are within the cell and in neighbouring cells, all of which affect the downlink power from each base station in the cluster. For this study we modelled a central cell with two surrounding co-frequency rings of interfering cells (a 19 cell structure). The UMTS mobile is modelled as it goes through its power control loop, with Monte Carlo varied location distribution within that cell and 6-12dB of random slow fading variation.

The UMTS cell parameters used in the modelling are defined in the table below:

Cell structure	Reference cell + two rings of interferers (a cluster of 19 cells, 3 sectors/base station)
Path Loss model	BS to MS: 3GPP for UMTS MS to BS: 3GPP for UMTS mobile to mobile: free space
standard deviation of path loss	set for indoor reception (10dB)
Base station antenna height	15 metres above roof
Base station antenna gain	15 dBi
Mobile height	1.5 m
Mobile gain	0 dBi
Bandwidth assumed	3.84 MHz
MS Noise Factor	8 dB
Max CPICH Power	30 dBm
Voice channel bit rate	12.2 kbps
Antenna azimuth	120 degrees to 95 degrees (105 degrees used for the studies)
Maximum BS power	40 to 44 dBm

Table of UMTS parameters used. Note - Link parameters were obtained from SEAMCAT for 1900 MHz UMTS downlink but they would equally apply to this band.

The model then adds a TDD WiMAX (802.16e) mobile at fixed power, which is connected to a completely different cell (not in the 19-cell UMTS structure) using another frequency channel, 10MHz away. The WiMAX parameters used are shown in the table below.

EIRP	23 dBm
ACIR	-45 dB

Table of mobile WiMAX (802.16e) parameters used

The results of the power control loop operation with and without the TDD WiMAX mobile were then compared, to determine the potential service outage to the UMTS mobile, ie an inability to achieve service without exceeding the maximum downlink power.

Results

We found that for a 2m UMTS/WiMAX separation there was between 5 and 25% probability of outage for the UMTS base station to mobile connection. For a 10m separation the outage varied from 0 to 7.5%.

The model was run with a cell size of 2 kilometres and varying cell pitches from 1.5 to 3.5 kilometres in order to ensure that the optimum cell size was selected. The valid range of cell pitches for this model was found to be 1.8 to 2.5 kilometres.

The cell load was also varied and it was found that the overall cell outage increases for lightly loaded cells; even though individually, the mobile's own outage probability declines (this is because, with relatively few terminals in each cell, there is lower inter-cell

interference and hence a greater power control margin). However, if any mobile (not always adjacent to the TDD mobile) loses its connection with the base station it represents a higher proportion of the total number of mobiles in that cell.

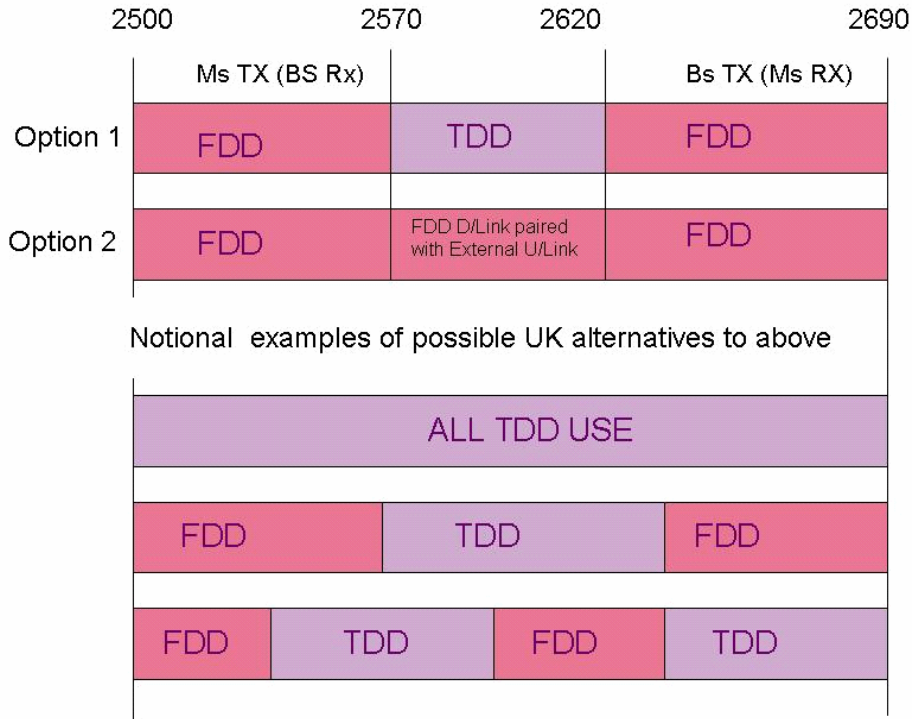
It is worth noting that power control is only optional for WiMAX devices and they will typically transmit at full power, unlike UMTS, whose mobiles transmit with an 80dB dynamic range. For this reason UMTS TDD (rather than WiMAX) interference into UMTS FDD is expected to cause less outage probabilities because UMTS TDD mobile power levels (max EIRP 21dBm) will be typically 10dB lower than WiMAX so the probability of interference will be small even at 2 metres separation.

Conclusions

At separations up to a few metres indoors in a typical network deployment, there will be significant potential for WiMAX TDD mobiles to interfere with UMTS FDD mobile reception - enough to cause noticeable service degradation to the UMTS user. For separations beyond 10m, UMTS service disruption reduces to a level that may not be noticed. In the same environment, TDD UMTS mobiles, at 10MHz or greater separation, are not expected to cause significant service degradation to FDD UMTS mobile reception.

4.2 Cross border interference issues.

ECC Decision (05)05 designates the 2500 – 2690MHz band for terrestrial IMT2000/UMTS systems with the provision that its use will be ‘subject to ‘market demand and national licensing schemes’. This means that the awarded spectrum in the UK may differ from the CEPT agreed channel plan, both in channelling and the deployed technologies. The CEPT plan and possible UK alternatives are shown below:



Possible channel arrangements for the 2500 – 2690MHz band

Cross border scenarios

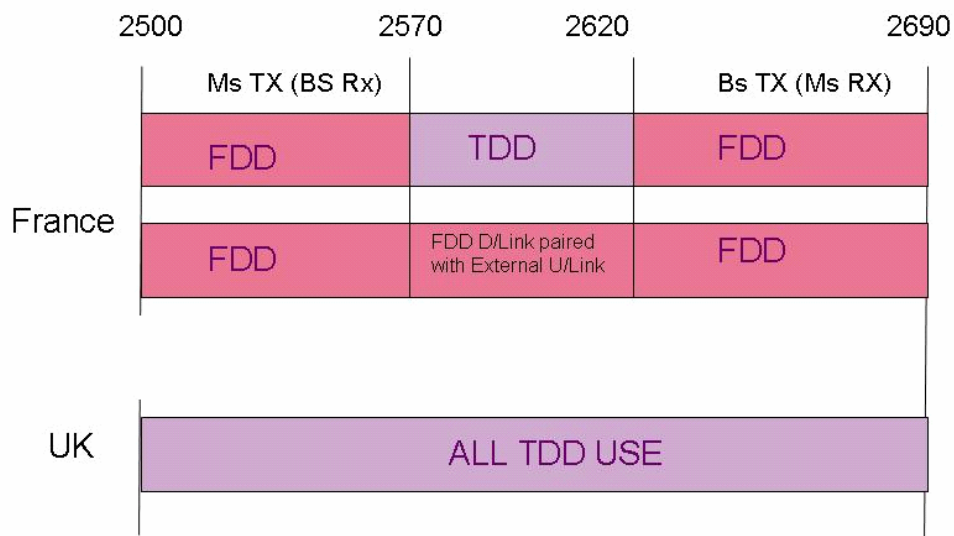
The cross border scenarios modelled in this section assume that the UK deploys TDD in the whole 190MHz award spectrum and that France deploys in accordance with the CEPT band plan. The Republic of Ireland (RoI) currently uses a system called Multi-channel Multipoint Distribution Service (MMDS) across a portion of the 2500-2690MHz band and the potential impact of this on UK networks is determined based upon the limited system data available at the time this study was carried out.

Analysis method

This analysis is based on an I/N ratio of -6dB. As in this report’s previous studies, that is an agreed figure for use in sharing studies between UMTS and other systems⁴. For a base station in receive mode this figure equates to an interference power level of -110dBm in the UMTS receiver. We used ‘ICS Telecom’ to determine the areas where cross border interference is predicted to exceed this level.

⁴ Report ITU-R M.2039

4.2.1 Interference: France → UK



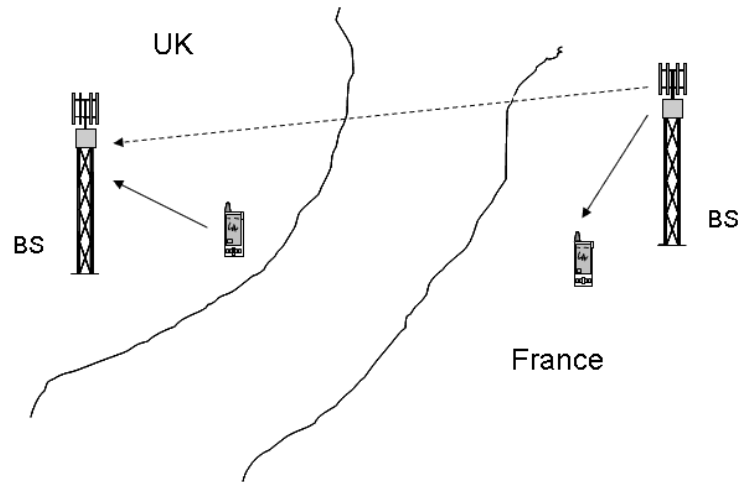
French and UK channelling arrangements

Scenario 1 – French base station interfering into UK TDD base station

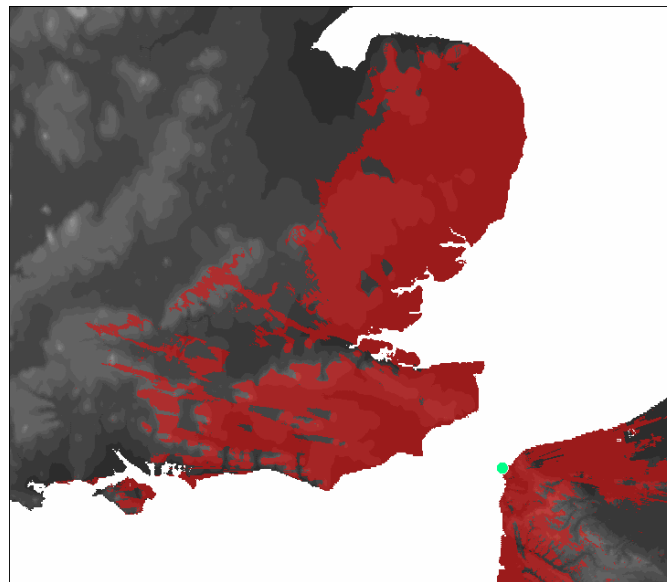
This illustrates the interference scenario between two base stations at 20 m height. The French base station is modelled located 1.2 km inland from the coast.

	Tx (France)	Rx (UK)
EIRP (dBm)	43	-
Antenna Gain	-	18dBi
Antenna height (m)	20	20
Propagation model	Rec P. 452-12 @ 1% of time	

Parameters used for modelling



French base stations interfering into UK UMTS base stations



Areas (red) where the interference from French base stations into UK UMTS base stations will exceed -110dBm

Results

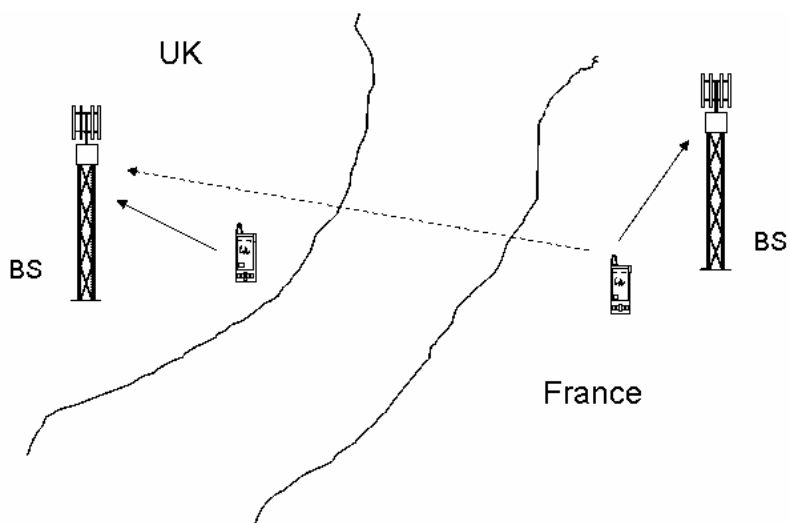
This worst case scenario depicts base station to base station interference and demonstrates that a UK operator deploying a TDD system in the award band upper channels (where the CEPT plan defines FDD base transmit) would experience a service degradation in the areas shown. In reality, base stations are unlikely to be pointed towards each other, so actual interference would probably be at lower levels.

Scenario 2 - French mobiles interfering into UK TDD base station

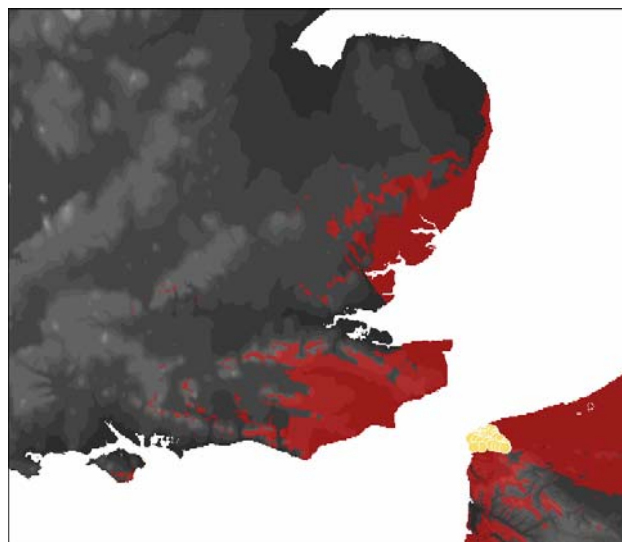
This scenario modelled the aggregate emissions from 35 mobile terminals, located 1.2 km inland from the French coast.

	Tx (France)	Rx (UK)
EIRP (dBm)	23	-
Antenna Gain	-	18dBi
Antenna height (m)	1.5	20
Propagation model	Rec P. 452-12 @ 1% of time	

Parameters used for modelling



French mobiles interfering into UK base stations



Areas (red) where the interference from French mobiles into a UK UMTS base station will exceed -110dBm

Results

The red areas in the above map show where the interference power from French mobiles into a UK UMTS base station is predicted to exceed -110 dBm and the UK system would most likely suffer service degradation. The area is less than that for the base station to base station case as mobile antennas are omni direction with 0dBi gain and are at 1.5m heights, compared to 18dBi antennas used by base stations which are also higher (20m in this study).

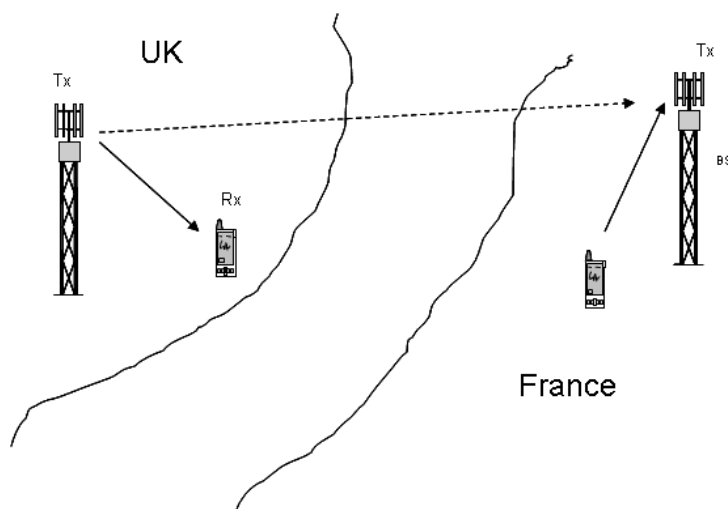
Conclusion

Interference from French mobile terminals is expected to be considerably less than that from French base stations. If the UK used the whole band for TDD, operators in higher channels (FDD base transmit in the CEPT plan) could expect higher interference levels from the continent than UK operators using the lower channels (CEPT FDD mobile transmit).

4.2.2 Interference: UK → France

Scenario – UK base stations interfering into a French TDD base station

This scenario modelled the emissions from a UK base station into a base station on the French coast.

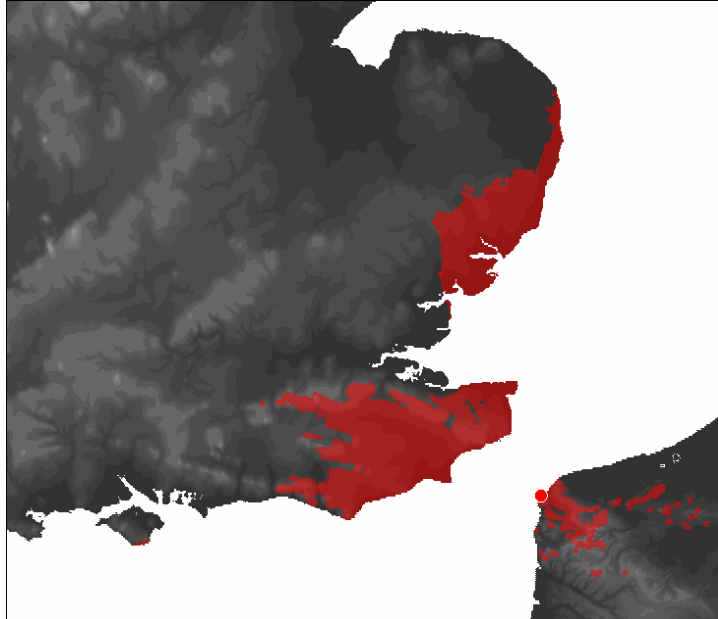


UK TDD base station interfering into French base station

	Tx (UK)	Rx (France)
EIRP (dBm)	54	-
Antenna Type	-	18dBi
Antenna height (m)	20	20
Propagation model	Rec P. 452-12 @ 1% of time	

Parameters used for modelling

The plot below depicts a reverse coverage plot for a single UK base station. Reverse coverage shows zones of interference power around the base station, ie “if a single transmitter is located here the interference power seen at French base station site is this”.



Reverse coverage plot of UK TDD base station interfering into a French base station

Results

The plot shows areas in the UK where if a TDD base station was sited it would exceed the interference threshold limit of -110 dBm into a French base station.

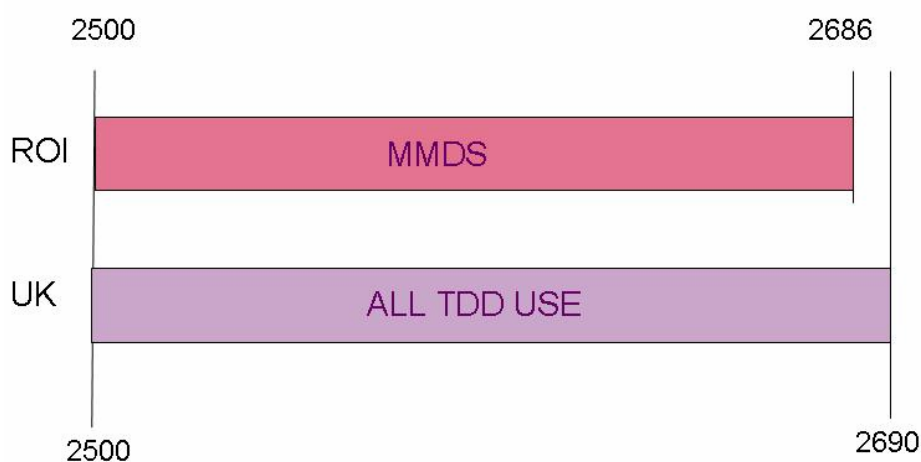
Conclusion:

This interference scenario is for a single transmitter, but for the worse case base station to base station situation (in reality base stations are unlikely to point directly at each other). In order to protect the French base station shown, an operator within the UK would need to reduce the EIRP of all base stations within the red areas. The area would be far larger for a realistic UK network deployment. We conclude that UK/French operators will need to co-ordinate their networks

4.2.3 UK/Republic of Ireland

Interference: RoI → UK

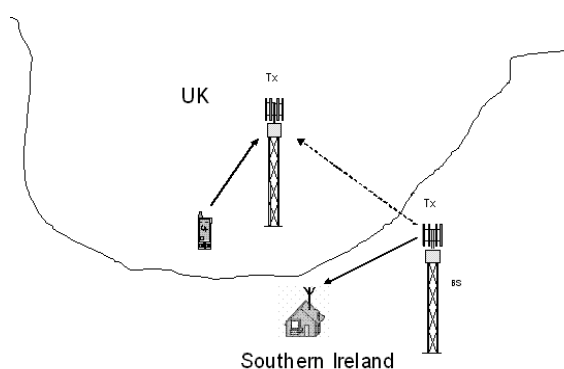
The Microwave Multimedia Distribution service (MMDS) is a broadcast system operating across the whole of the frequency range 2500 – 2686 MHz, utilising tall antennas and high power transmissions to provide TV services to subscribers in the Irish Republic.



Different channelling arrangements between countries

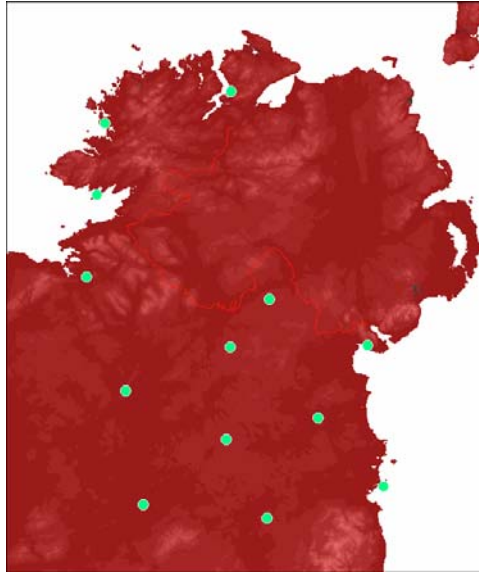
The antenna heights and associated EIRPs used in the modelling were derived from field strength curves contained within the technical document for digital program services⁵, these are tabulated in Annex 5. Actual MMDS network deployment parameters may differ from those defined in the reference Comreg document, but these details were not available at the time of this modelling. It is therefore possible that the actual MMDS system as deployed would cause more or less interference.

Scenario 1 - MMDS transmit interference into a UK (Northern Ireland) TDD base station



Irish MMDS stations interfering into UK (Northern Ireland) TDD base stations

⁵ Irish, Commission for Communications Regulation (Comreg) 98/67 - Technical conditions for the operation of digital programme services distribution systems, published 9th June 2004.

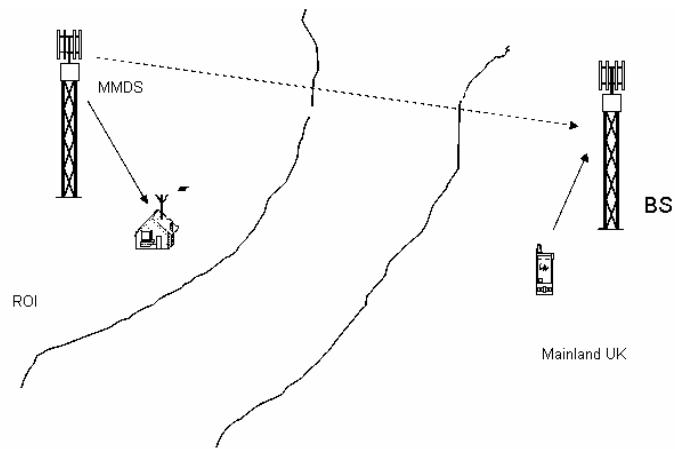


Predicted interference areas (red) due to MMDS stations located close to the border

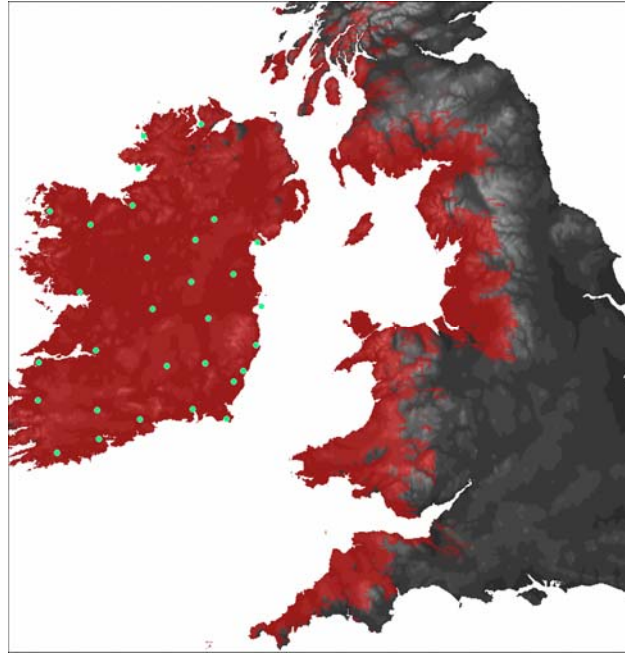
Results

The red areas shown above indicate that UMTS base station reception will suffer interference across Northern Ireland.

Scenario 2 - MMDS broadcasts into mainland UK TDD base station



Irish MMDS transmitters interfering into a mainland UK TDD base station



Areas (red) where interference from MMDS is predicted to exceed -110dBm into a UMTS TDD base station

Results

The red areas shown above indicate that MMDS transmissions extend beyond their intended service area and will cause degradation to networks on the west coast of mainland UK.

Conclusion

Based upon data for the example Comreg MMDS network modelled, Ofcom concludes that there will be significant interference to UK networks deployed in the award bands in western mainland UK, and particularly in Northern Ireland where under the current scenario it would be very difficult to deploy a network because of severe interference caused by the Irish MMDS. Negotiation with the Irish Administration will be required to determine mitigation measures and/or co-ordination procedures to reduce the interference effects.

Annex 1

Glossary/Acronyms

C30 / C38	channel 30 or 38 of the award band (2645-2650MHz and 2685-2690MHz respectively)
CRAF	Committee on Radio Astronomy Frequencies
dBm or dBW	power level in decibels relative to 1mW or 1W
dBi	antenna gain in decibels relative to an isotropic antenna
EESS	Earth Exploration Satellite Service (an ITU-R definition)
EIRP	equivalent isotropic radiated power
ETSI	European Telecommunication Standards Institute
FDD	Frequency division duplex
I/N	interference to noise (power ratio)
ICS Telecom	Radio system modelling software by ATDI Ltd
ITU-R	International Telecommunications Union - Radio sector
MMDS	Multi-channel Multipoint Distribution Service
n-GSO	Non-Geostationary orbit
OOB	out of band (emissions)
PRF	Pulse repetition frequency
RA/RAS	Radio Astronomy (Service)
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool (radio system modelling software commissioned by CEPT)
SMOS	Surface Meteorological Observation System (a satellite system)
TDD	Time division duplex
TWT	Travelling wave tube (a type of amplifier used by radar)
UMTS	Universal Mobile Telephone System
Visualyse	Radio system modelling software by Transfinite Systems Ltd
W-CDMA	Wideband Code Division Multiple Access (multiple access scheme used by UMTS)
WIMAX	Worldwide Interoperability for Microwave Access

Annex 2

Parameters used in ICS Telecom modelling

Software: ICS Telecom - version 8.2.3 with 50m resolution digital terrain.

Propagation model: ITU-R Rec P 452 @ 10% probability, with terrain and clutter enabled.

Unless otherwise specified, default ICS Telecom settings were used.

Propagation models

Models

- Fresnel method+
- Woinar method
- Wien method...
- ITU-R 370...
- ITU-R 525
- ITU-R 525/526
- ITU-R 1225
- ITU-R 1546...
- ITU-R 368...
- ITU-R 533...
- ITU-1147...
- Medium frequency****
- Okumura - Hata
- Hata - Cost 231
- Cost 231 open...
- rural c:0,5,6,8,>11
- sub.c:1,9,10,11
- urban c:2,3,4,7
- SUI method...
- > prop452
- Usermod.dll

Diffraction geometry

- Bullington method
- Deygout 94 method
- ITU-R 526, round mask
- ITU-R 526, cylinders
- ITU-R 526, deygout
- ITU-R 1225
- Visibility / Indoor
- No diffraction loss
- ITU-R 452 * (0=rand)

Time (0 to 50%)

Subpath attenuations

- Standard (1)
- Coarse integration (2)
- Fine integration (3)
- Area (4)
- ITU-R 526
- Free ellipsoid (5)
- No subpath loss (6)

FZ fraction

Spherical wave

Anomalous propagation

- Ducting

Climate

Earth radius km (land)

Earth radius km (sea)

ITU-R 676 gaz ITU-R 840 fog

Vapour Water g/m3

hPa T* C*

Rain att. ITU-R 838/530(!)

Rain att. Crane global

Rain rate (mm/h)(!!)

Time (0.001 to 1) %

Slope model coefficient (A*E+B)

A factor B (dB)

Attenuation (dB/km)

Reflections

Reflectance (if no clutter)

3D coverage only

Reflection dist. limit (m)

Altitude filter > (m)

- Ground reflections (minima/maxima)
- Ground reflections (mn/mx flat earth)
- Ground reflections (reflection point)

ERP/EIRP

- 1/2 wave antenna
- isotropic antenna
- short vertical ant.

Options

Rx gain (dBi)

impedance 75 50

Offset (dB)

Field strength=E-offset

- Use Tx/Rx effective heights
- Flat earth profile sent to DLL

+ Rx: 50 or 75 ohms, dBd
(!) default for path reliability
(!!) Use 0.01% for ITU

(1) this option calculates the max h/r (h<0) and adds the weighted attenuation: 20.log(75000.D/PI/h1/h2/F)
 (2) this option calculates the mean elevation (h) compared with the max r (h>0). Used for coverage only (fastest).
 (3) this option calculates the max h/r (h>0)
 (4) this option compares the overlapped area (H=sum of altitudes in ellipsoid) with the total area (R) to obtain H/R
 (5) if the ellipsoid*FZ fraction is not free, then the calculation returns 0. Used for site searching.
 (6) no attenuation calculated if the ellipsoid is not free. Used for site searching.
 **** Empirical model: F0=80.2-10log(D)-0.00176*pow(f,0.26)*D with f(KHz) and D(km) - 1Kw ERP - F0(dBu)
 Diurnal propagation assumed (-10 dB).
 * only used for point to point interference calculation

Propagation options

Clutter parameters

Clutter code	Name	Attenuation (dB)	Clutter height	Reflection factor (0-1)	Erlang/km2	Surface factor	Diffraction factor	Station/km2	Stddev (dB)	Tip...
0	none	9.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
1	open land	18.0	0	0.300	1.0000	1.000	1.00	30.000	1.00	<input checked="" type="checkbox"/> rx ground
2	agricultural	28.0	0	0.300	1.0000	1.000	1.00	30.000	1.00	<input checked="" type="checkbox"/> rx ground
3	rangeland	31.0	0	0.300	1.0000	1.000	1.00	30.000	1.00	<input checked="" type="checkbox"/> rx ground
4	water	34.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
5	forest land	27.0	10	0.300	1.0000	1.000	0.60	0.000	1.00	<input checked="" type="checkbox"/> rx ground
6	wetland	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
7	residential	38.0	10	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
8	urban/building	9.0	20	0.300	1.0000	1.000	0.40	0.000	1.00	<input checked="" type="checkbox"/> rx ground
9*	commercial	0.0	40	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
10	snow/ice	0.0	0	0.300	1.0000	1.000	1.00	5.000	1.00	<input checked="" type="checkbox"/> rx ground
11	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	<input checked="" type="checkbox"/> rx ground
12**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
13**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
14**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
15**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
16**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
17**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
18**	none	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	
19*	Border*	0.0	0	0.300	1.0000	1.000	1.00	0.000	1.00	

Default name: CCIR UER dB/km Flat User Tuning none TSB-8E Indoor

Reference frequency (MHz): 2695.0000

pre-defined Height factor: 1.0

Path/Sub/Rx cov (R): T/R over clutter T/R over ground spot Rx over ground relaxed

Tx/Jam/MW (T): T/R over clutter T/R over ground

load save OK Cancel

Clutter parameters

Annex 3

Radio Astronomy Observatories in Europe

Country	Place	East Longitude	Latitude	Height above sea level (m)
Austria	Lustbühel	15o 29'34"	47o 04'03"	483
Belgium	Humain	05o 15'19"	50o 11'31"	293
Czech Republic	Ondrejov	14o 47'01"	49o 54'38"	533
Finland	Metsähovi	24o 23'37"	60o 13'04"	61
	Sodankylä	26o 37'48"	67o 21'36"	197
France	Bordeaux	-00o 31'37"	44o 50'10"	73
	Nançay	02o 12'00"	47o 23'00"	150
	Plateau de Bure	05o 54'26"	44o 38'01"	2552
Germany	Effelsberg	06o 53'00"	50o 31'32"	369
	Tremsdorf	13o 08'12"	52o 17'06"	35
	Wettzell	12o 52'39"	49o 08'43"	648
Greece	Pentetele	23o 51'48"	38o 02'54"	509
	Thermopyles	22o 41'12"	38o 49'27"	
Hungary	Penc	19o 16'53"	47o 47'22"	283
Italy	Medicina	11o 38'49"	44o 31'14"	28
	Noto	14o 59'21"	36o 52'34"	30
	Sardinia	09o 14'40"	39o 29'50"	650
	Trieste	13o 52'30"	45o 38'30"	400
Latvia	Ventspils	21o 51'17"	57o 33'12"	15
Netherlands	Borger-Odoorn	05o 52'	52o 55'	15
	Dwingeloo	06o 23'48"	52o 48'48"	25
	Westerbork	06o 36'15"	52o 55'01"	16
Norway	Longyearbyen	16o 03'	78o 09'	
	Tromsø	19o 13'48"	68o 34'12"	85
Poland	Kraków	19o 49'36"	50o 03'18"	314
	Torun	18o 33'30"	52o 54'48"	100
Portugal	Espiuunca	-08o 13'52"	40o 59'57"	205
Russia	Badari	102o 13'16"	51o 45'27"	832
	Dmitrov	37o 27'00"	56o 26'00"	200
	Kalyazin	37o 54'01"	57o 13'22"	195
	Medvezij Ozera	37o 57'06"	55o 52'06"	239
	Pushchino	37o 40'00"	54o 49'00"	200
	Svetloe	29o 46'54"	61o 05'	80
	Zelenchukskaya	41o 35'32"	43o 49'53"	1000
	Zimenki	43o 57'00"	56o 18'00"	200
Spain	Pico Veleta	-03o 23'34"	37o 03'58"	2870
	Robledo	-04o 14'57"	40o 25'38"	761
	Yebes	-03o 05'22"	40o 31'27"	981
Sweden	Kiruna	20o 26'24"	67o 52'12"	418
	Onsala	11o 55'35"	57o 23'45"	10
Switzerland	Bleien (Zürich)	08o 06'44"	47o 20'26"	469
Turkey	Kayseri	36o 17'58"	38o 59'45"	1045
Ukraine	Evpatoriya	33o	45o	
	Kharkov	36o 56'30"	49o 38'40"	150
	Lvov	23o 49'33"	51o 28'32"	
	Odessa	30o 16'24"	46o 23'51"	
	Poltava	34o 49'36"	49o 37'57"	
	Simeiz	34o 01'00"	44o 32'06"	676
	Zmiev	36o 21'20"	49o 39'50"	
United Kingdom	Cambridge	00o 02'20"	52o 09'59"	24
	Darnhall	-02o 32'03"	53o 09'22"	47
	Defford	-02o 08'35"	52o 06'01"	25
	Jodrell Bank	-02o 18'26"	53o 14'10"	78
	Knockin	-02o 59'45"	52o 47'24"	66
	Pickmere	-02o 26'38"	53o 17'18"	35

Annex 4

Parameters used in Visualyse modelling

Software: Visualyse 2.51, no terrain or clutter

Propagation model: ITU-R Rec P 525

Gaseous attenuation for elevation angles >10 degrees	none
rain, cloud or scintillation effects considered	no
Polarisation	no

Propagation options

Annex 5

MMDS transmitter locations in the Republic of Ireland

Location	Antenna height (m)	ERP (dBW)	EIRP (Watts)
Buncrana	81	28	631
Dungloe	45	25	316
Dunkineeley	45	25	316
Sligo	45	25	316
Curraghoe	182	31	1,259
Stadone	45	25	316
Cavanagarvan	20	22	158
Dundalk	81	28	631
Cork Airport	81	28	631
Drinagh	45	25	316
Cheekpoint	81	28	631
Villierstown	45	25	316
Mallow	81	28	631
Farranfore	45	25	316
Ballycanew	81	28	631
Kilcotty	45	25	316
Gorey	20	22	158
Boggan	182	31	1,259
Limerick	182	31	1,259
Ballybunnion	81	28	631
Wicklow	45	25	316