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European NoE on Cognitive Communications

TV White Spaces in the UK: Update, and Focus on Aggregation of Resources

Oliver Holland, *King's College London*

WInnComm 2015
San Diego, CA, USA, 24-26 March 2015

Overview

- Quick Overview of Ofcom/ETSI Framework: White Spaces in the UK
- Update: Latest Developments and Changes
- So, What is Achievable in TV White Space?
  - Focus on Aggregation of Resources
- Conclusion

Ofcom/ETSI Framework: White Spaces in the UK

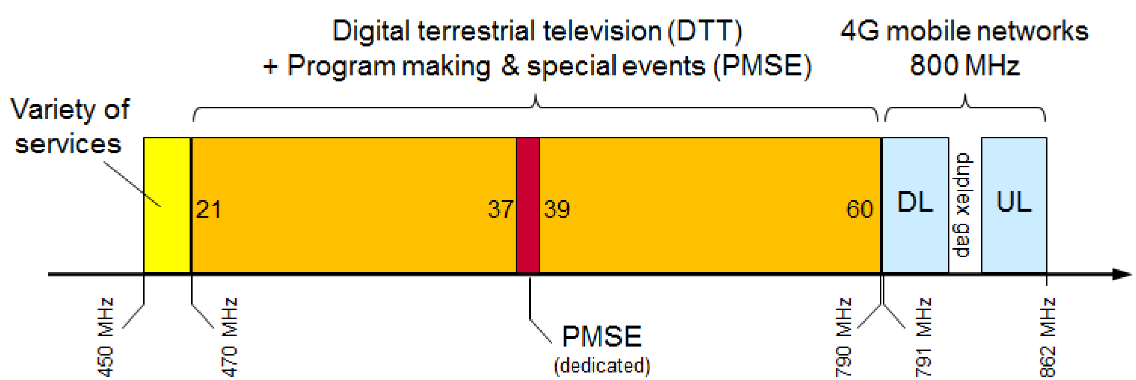
(far more detail in back-up slides at end of presentation)

Which Frequencies? –Bandwidth?

- 470-790 MHz
  - 320 MHz total; **312 MHz** excluding shared PMSE channel 38
  - 694(exact value TBD)-790 MHz approved for co-primary mobile broadband in ITU Region 1 (includes UK) with rules to be decided in WRC 2015; if all this spectrum were removed would leave us with **216 MHz** in the UK
  - Compares with a sum of **300 MHz** in the 54-72, 76-88, 174-216, and 470-698 MHz VHF/UHF bands in US (Region 2—Region 3 similar)

- 8 MHz channel raster – channel numbers 21 (474 MHz centre frequency) to 60 (786 MHz centre frequency); compares with 6 MHz channel raster and channel numberings 2-51 in US (Region 2—Region 3 similar)
  - Current UK trials limited to channels 22 to 59 (of course excluding channel 38) to help protect services that are next to TV frequencies

- Channel 38 (606-614 MHz) reserved exclusively for shared PMSE usage. Cannot be used by white space devices



Database Discovery and Device-Database Communications

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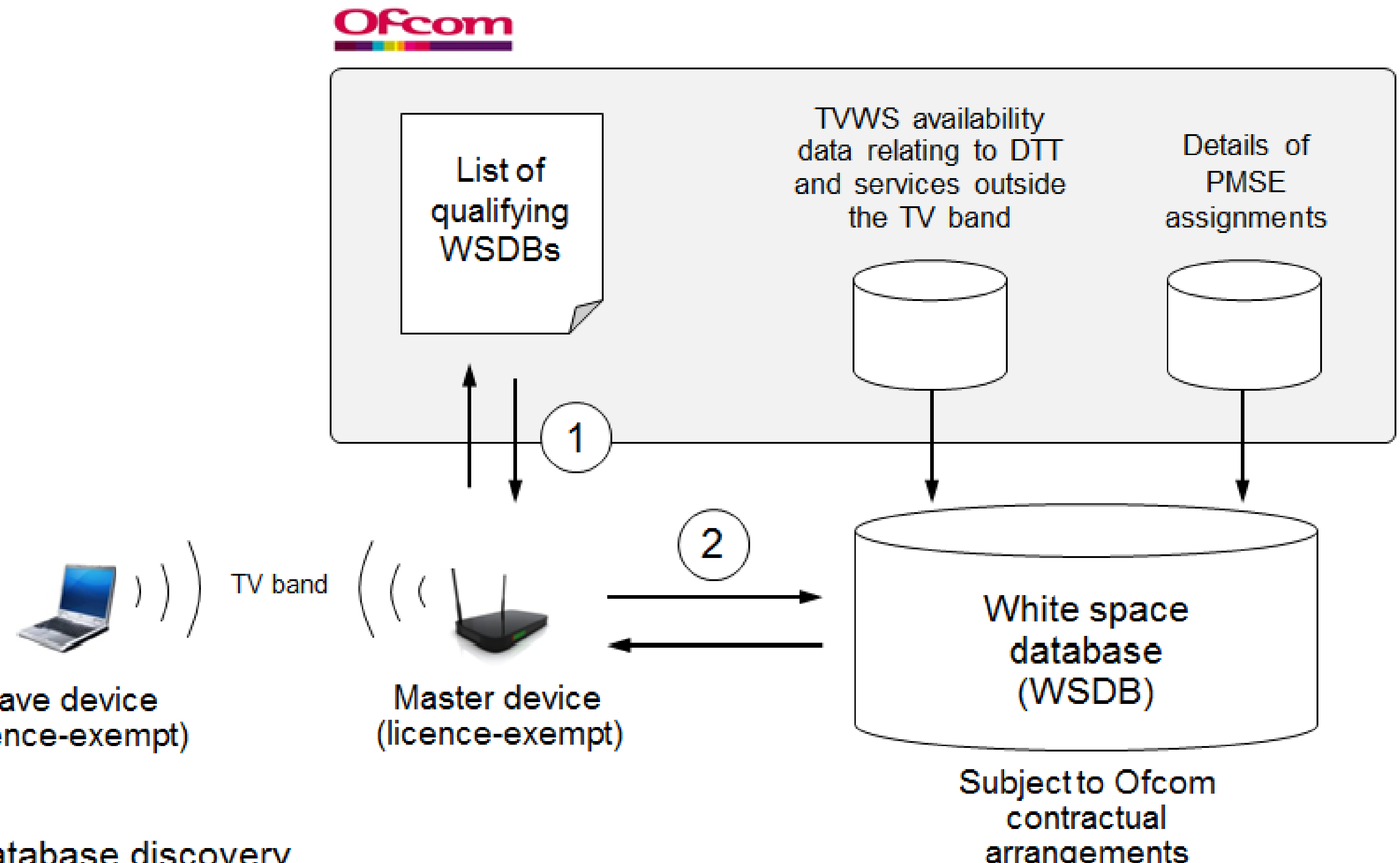


1) Database discovery
2) Device-database communications.

Emissions Requirements—In TV Bands (and *key* differences from US)

- Ofcom/ETSI define 5 classes of devices' ACLR performance
  - Better ACLR performance means less interference in adjacent channels hence typically the ability to transmit at higher EIRP without violating adjacent channels interference limits
- Variable maximum EIRPs are given to devices, thereby allowing them to transmit (at reduced EIRP) in many locations that they wouldn't be able to under the US rules
- **These are key differences from US case, giving a lot of flexibility**, with devices of even relatively poor ACLR performance and in poor locations being able to use white space with appropriate powers
- Noted that power in 100kHz chunks in adjacent channels is compared with power in 8 MHz intended channel. Already 80x (approx. 19dB) lower. I.e., -74 dB here is equivalent to -55 dB in terms of power spectral density

$$P_{OOB}\ (\text{dBm} / (100\ \text{kHz})) \leq \max\{\ P_{IB}\ (\text{dBm} / (8\ \text{MHz}))\ -\ \text{ACLR (dB)},\ -84\ (\text{dBm} / (100\ \text{kHz}))\ \}$$

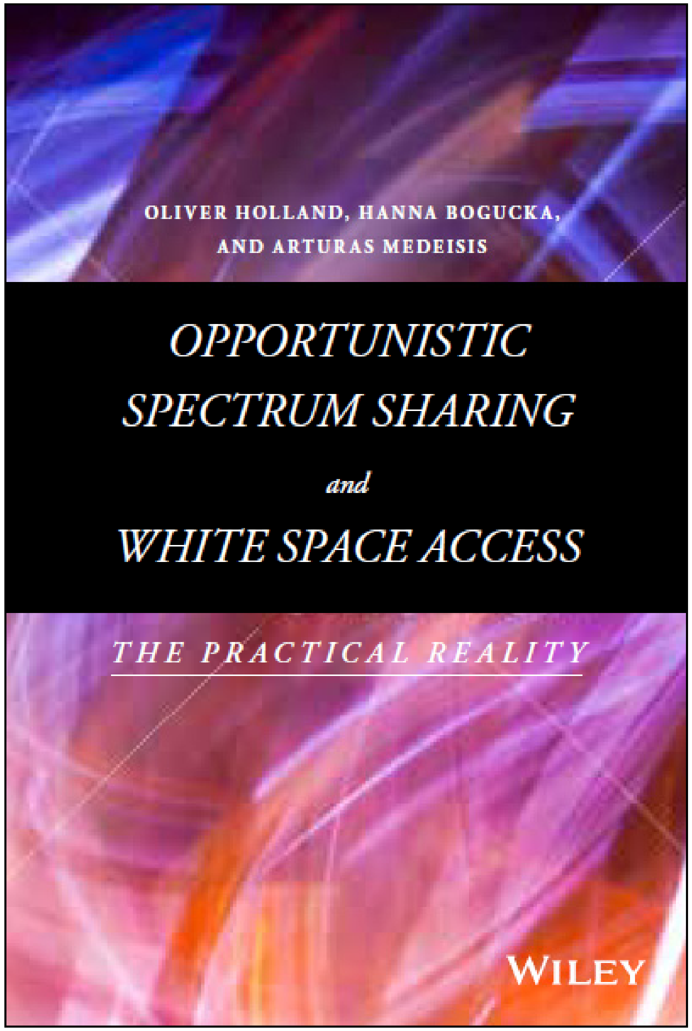
Where P_{OOB} falls within the nth adjacent DTT channel (based on 8 MHz wide channels)	ACLR (dB)				
	Class 1	Class 2	Class 3	Class 4	Class 5
n = ±1	74	74	64	54	43
n = ±2	79	74	74	64	53
n ≥ +3 or n ≤ -3	84	74	84	74	64

ETSI EN 301 598, Key Ofcom Consultations and other Publications

- White Space Device white space device conformance requirements defined in ETSI EN 301 598; heavy input of Ofcom in creating that standard
  - http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.01.01_60/en_301598v010101p.pdf
- Key Ofcom consultations (see http://stakeholders.ofcom.org.uk/spectrum/tv-white-spaces)
  - “TV white spaces: approach to coexistence”, September 2013 (also note addendum from October 2013)
    - http://stakeholders.ofcom.org.uk/consultations/white-space-coexistence
  - “TV white spaces - A consultation on white space device requirements”, November 2012
    - http://stakeholders.ofcom.org.uk/consultations/whitespaces
  - “Implementing Geolocation”, November 2010
    - http://stakeholders.ofcom.org.uk/consultations/geolocation
  - “Manually configurable white space devices”, February 2015
    - http://stakeholders.ofcom.org.uk/consultations/manually-configurable-wsds
- Ofcom coexistence studies
  - “TV White Spaces: PMSE coexistence tests – technical report”, November 2014
    - http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/2014/tvws-pmse-coexistence
  - “TV White Spaces: DTT coexistence tests – technical report”, December 2014
    - http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/2014/tvws-coexistence-tests
- Ofcom statement on allowance of license-exempt white space devices
  - “Implementing TV White Spaces”, February 2015
    - http://stakeholders.ofcom.org.uk/consultations/white-space-coexistence/statement

Book

- A detailed coverage of aspects of TV white spaces and other solutions for opportunistic spectrum sharing
- O. Holland, H. Bogucka, A. Medeisis (Eds.), *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality*, Wiley
- Available imminently
- Chapters include (among many other high quality contributions)
  - H. R. Karimi, "UK framework for access to TV white spaces"
  - J. Schmidt, P. Stanforth, "Spectrum Sharing using Geo-location Databases"



Update: Latest Developments and Changes

(more detail in back-up slides at end of presentation)

Update: Latest Developments and Changes

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- Ofcom initiated a large pilot of this technology in the UK, with 9 triallists participating
- Initial schedule was hoped to be from October 2013 for approx 6 months
- In practice, real work on the pilot started with the qualification of the first databases in May/June 2014
- Pilot remains ongoing, at least continuing until early 2015 and likely a lot later than that
  - Currently testing white space devices from Adaptrum, Carlson Wireless, InterDigital, Runcom, Eurecom, 6Harmonics, KTS Wireless/Sinecom, Mediatek, MELD, Neul and NICT
  - 8 Geolocation databases now qualified: Spectrum Bridge, Fairspectrum, NICT, Nominet, Google, Sony, iconectiv and Microsoft

Update: Latest Developments and Changes

- Ofcom have done their own investigations and published studies on, e.g., coexistence testing of white space devices with DTT and PMSE, protection ratio analysis, coupling ratio studies, intermodulation studies, etc., in November and December 2014 (see slide 7)
- Ofcom released a statement on the pilot on 12 February, confirming that it is approving of white spaces on a license-exempt basis, providing some background (e.g., testing) information and comment on the progress of the pilot, and outlining some tweaks to the framework
- Published consultation on manually configurable white space devices, requiring licensing of those whereby their operation will be according to exactly the same TV white space framework (fully-automated devices, e.g., those with integrated GPS, are license-exempt) (see slide 7)
- Current estimate (Ofcom have changed this from estimates late last year) is that Ofcom expect the system to go live towards the end of this year. The pilots are continuing at least throughout 2015

Ofcom Statement (12 February)

- “Implementing TV White Spaces”, February 2015
  - http://stakeholders.ofcom.org.uk/consultations/white-space-coexistence/statement

- Ofcom have approved license-exempt TV white space devices
  - “This document sets out Ofcom's decision to allow a new wireless technology access to the unused parts of the radio spectrum in the 470 to 790 MHz frequency band. Our decision follows extensive consultation with stakeholders and a pilot.”

- Covers numerous aspects, including
  - An overview of aspects of the UK TV white spaces framework
  - The TV White Spaces Pilot including details and observations from that
  - Detail on white space device assumptions/capabilities necessary to authorise devices to operate on license-exempt basis in TV white spaces
  - Ofcom’s approach to coexistence with DTT and PMSE
  - Assessment of white space availability in some particular areas
  - Next steps to the commercial realisation of the technology

Ofcom Statement (12 February)

- Appendices covering numerous interesting aspects
  - Detail on the Ofcom white space device emissions limits calculation process for aspects of the framework
    - Protection of PMSE (including location-agnostic shared PMSE channel 38)
    - Protection of DTT
    - Protection of mobile services above TV bands
    - Protection of services below TV bands
    - Cross-border protection
  - Work on protection ratios analysis for DTT and PMSE
  - Summary of responses to Ofcom’s consultations, and Ofcom’s comments
- Linked to provided drafts of the Ofcom “Statutory Instruments” (regulations) and interface requirements documents to realise license-exempt TV white space devices in the UK

Ofcom Statement—Key Changes to the Ofcom Framework

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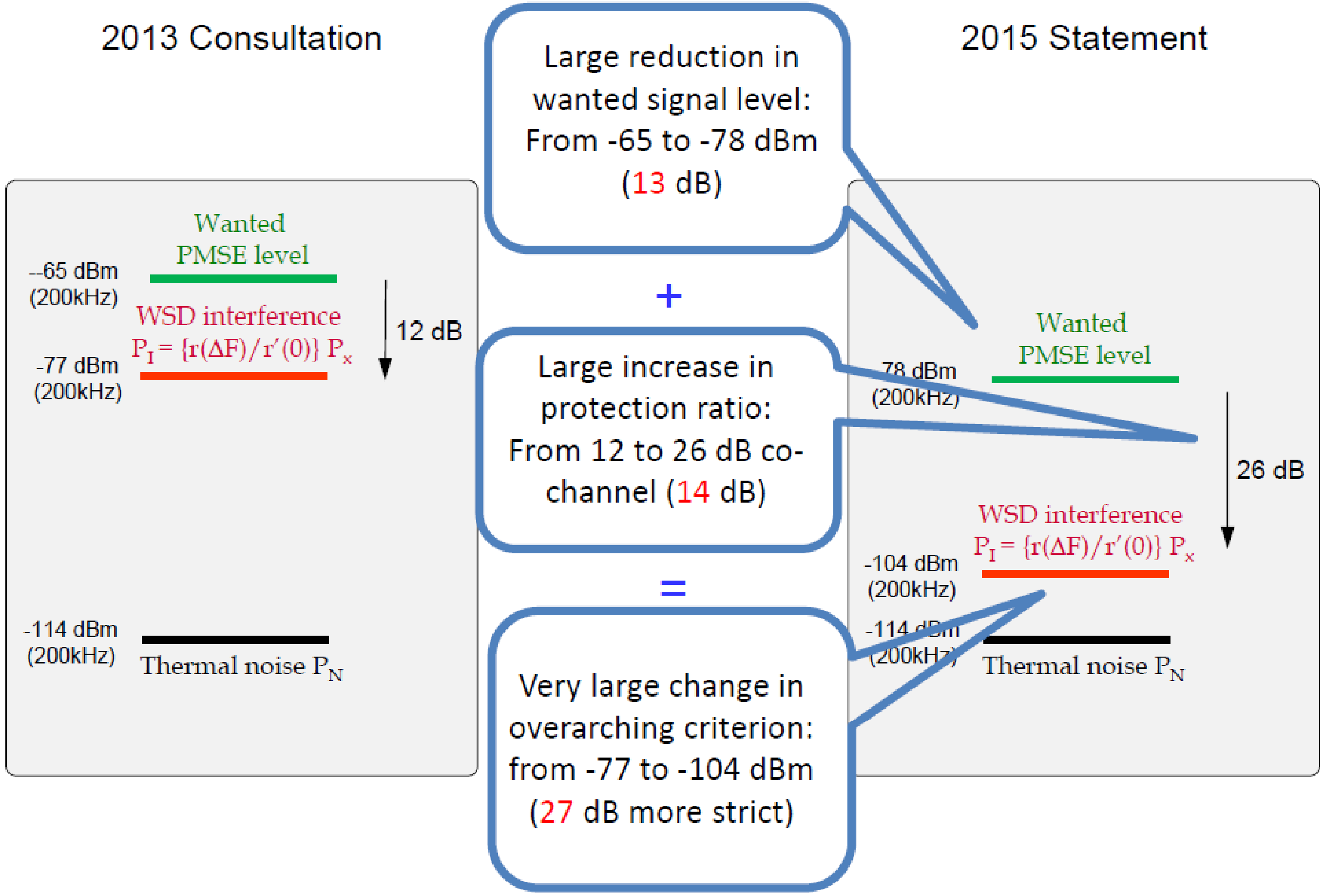
- PMSE protection (Ofcom PMSE Technical Working Group Meeting, 26 February—Copyright Ofcom)



Ofcom Statement—Key Changes to the Ofcom Framework

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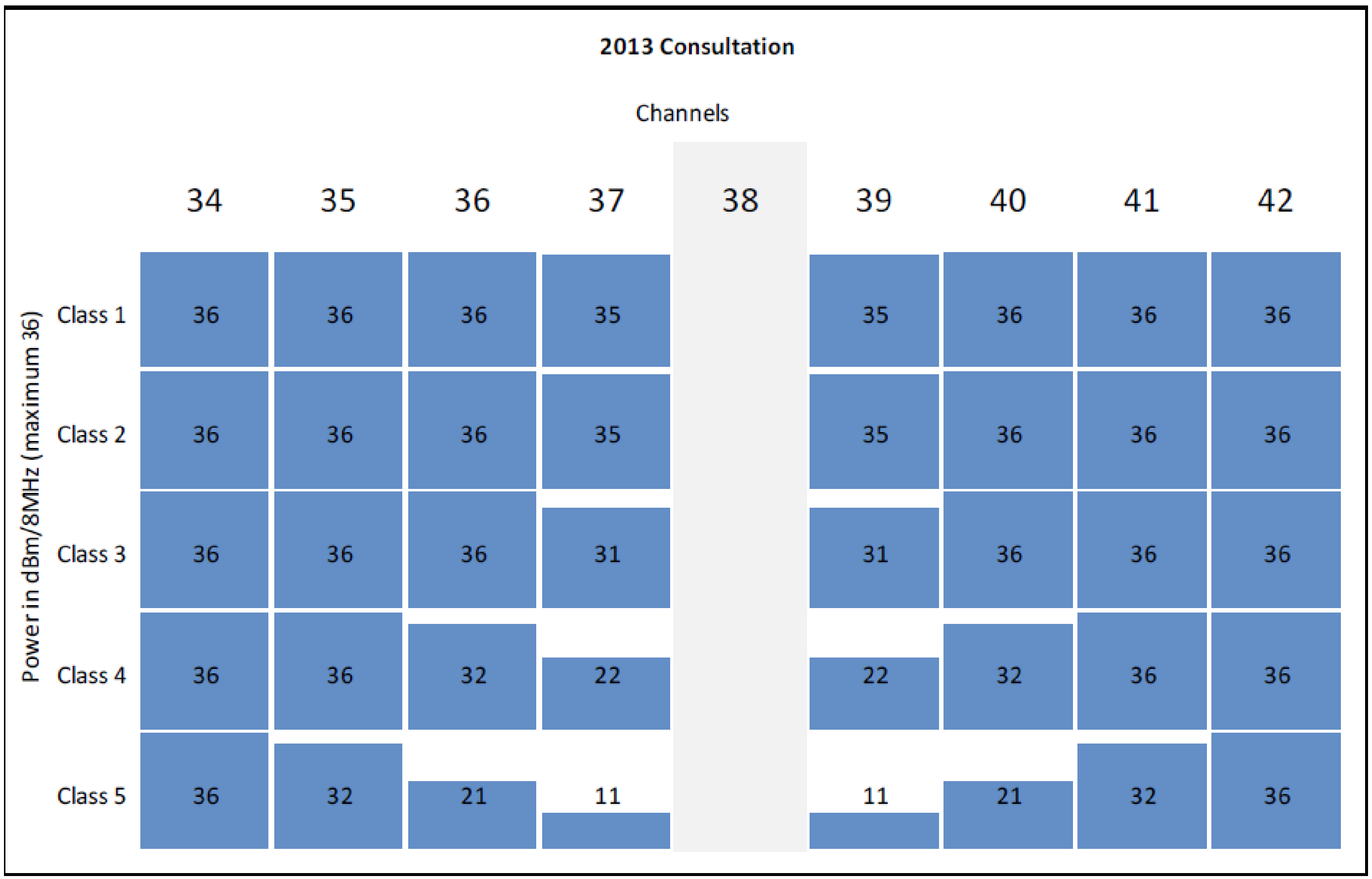
- PMSE protection, Channel 38, Situation **before** statement (Ofcom PMSE Technical Working Group Meeting, 26 February—Copyright Ofcom)



Ofcom Statement—Key Changes to the Ofcom Framework

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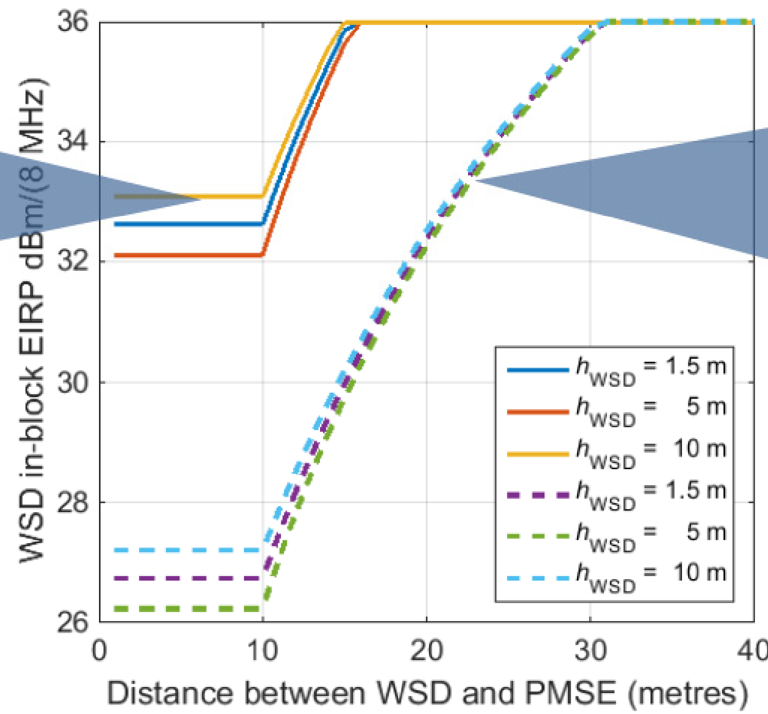
- PMSE protection, Channel 38, situation **after** statement (Ofcom PMSE Technical Working Group Meeting, 26 February—Copyright Ofcom)

Ofcom Statement—Key Changes to the Ofcom Framework

- PMSE protection, Intermodulation (Ofcom PMSE Technical Working Group Meeting, 26 February—Copyright Ofcom)
  - Detail in Annex 4
  - Dashed lines show example intermodulation restrictions for various heights
  - Solid lines show the restrictions due to adjacent channel leakage and selectivity. The dominant restriction will depend on frequency separation

Type A WSD (class 1): EIRP restrictions – **5th adjacent channel** for outdoor mic

Absent intermod restrictions, ACS/ACLR would dominate and the maximum power would be set here…



… but at short distances, the intermodulation restrictions are dominant.

The dashed lines, therefore, determine the actual allowed EIRP (leaving aside constraints relating to other services)

Ofcom Statement—Key Changes to the Ofcom Framework

- DTT protection
  - Changed coupling gains for tier 0/1/2 pixels from 70th percentile values to 90th percentile values. For tier 3 pixels and beyond no change
  - Used same tier 0/1 coupling gains for rural, suburban and urban pixels and not the previous lower bounds to separation distances for the different clutter classes
  - No change to approach to modelling coupling gains over longer distances based on the extended Hata model, although will keep under review
  - Recalculated protection ratio tables based on laboratory measurements with a WSD and 50 DTT receivers
  - Moved from high/medium/low classification to a high/low classification based on real time discontinuous behaviours of different WSDs
    - Proposed that further work should be undertaken to address how devices would be classified as high or low in category
  - Introduced additional margin of 9 dB to allow for DTT field strength prediction uncertainty and other real world effects for co-channel operation
  - Localised additional protection for some areas that have unusual propagation performance
  - Various other minor changes

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So, What is Achievable in TV White Space?

(far more detail in back-up slides at end of presentation)

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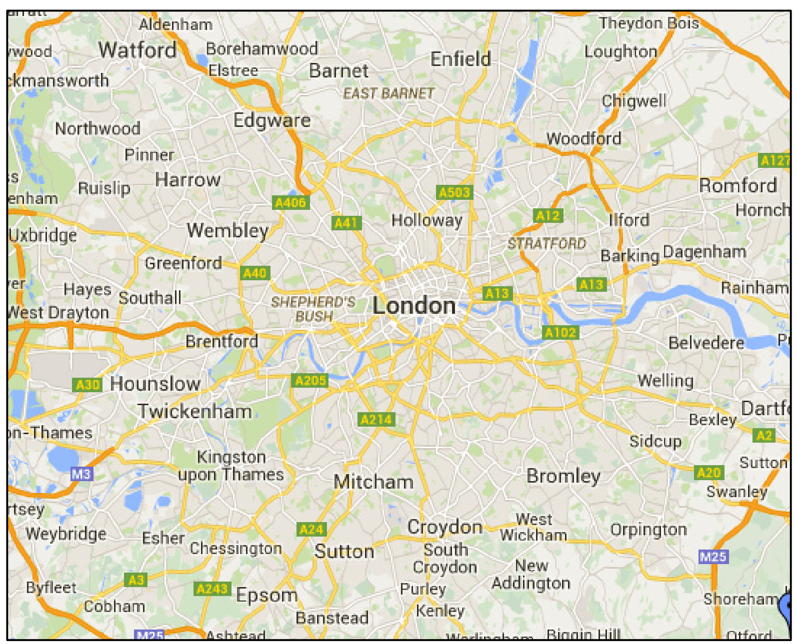
Availability and Capacity

- Have adapted one of our implementations of white space device side to methodically query Fairspectrum to obtain information on available white space, and do capacity analyses with particular emphasis on aggregation. Of course, not taking into account Ofcom framework changes, which are not yet implemented
  - London M25 area, top-left corner (lat, lon) 51.678064, -0.506744, bottom-right corner 51.312133, 0.22934, sampling “spatial frequency” 0.01 degrees equally in latitude and longitude. 2,775 samples total for each of the assessments on a London-area basis



Availability and Capacity

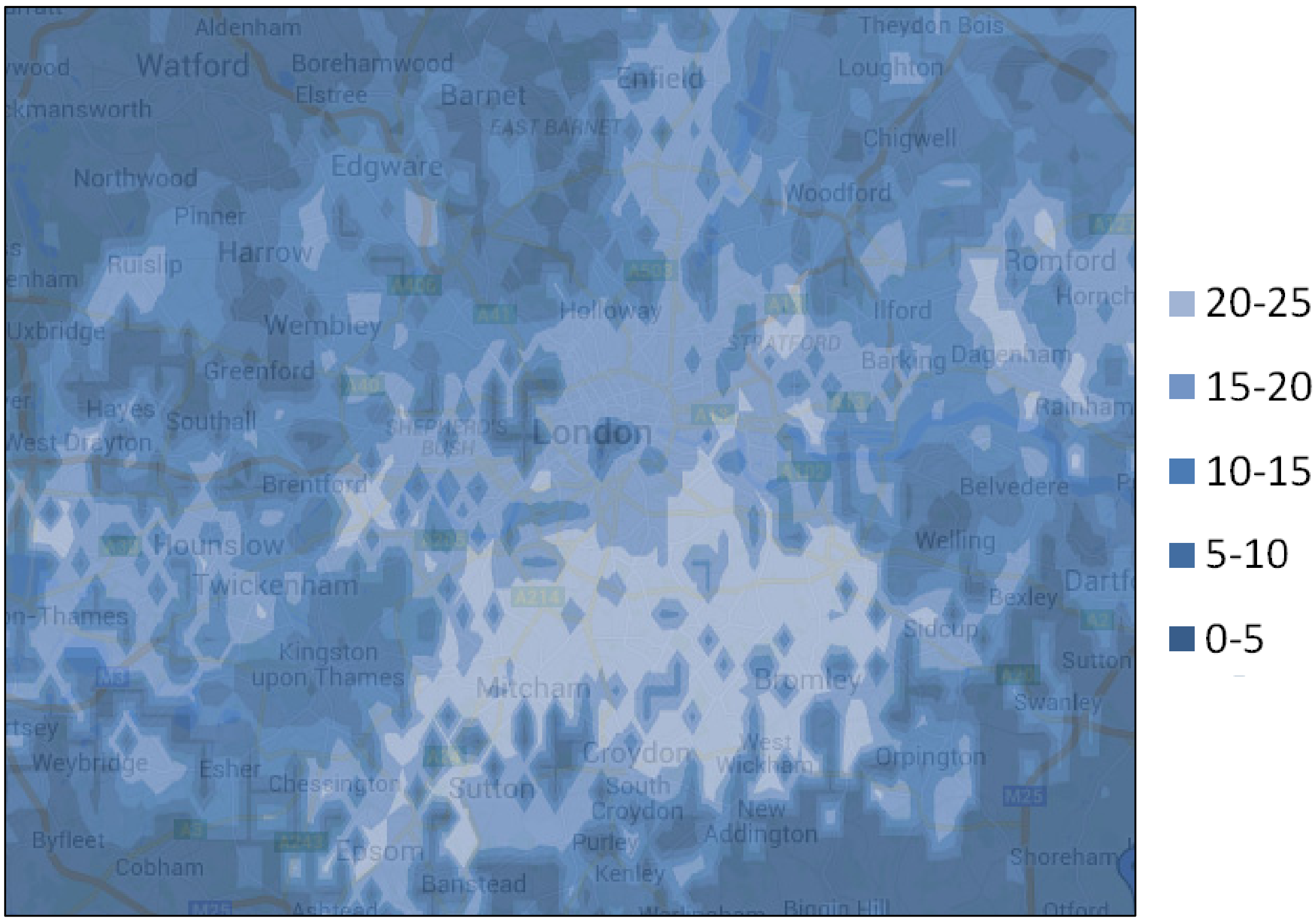
- Scenario configurations

Scenario	Transmitter Height (m)	Receiver Height (m)	Transmission Distance (m)	Path loss	Shannon Efficiency
Mobile Broadband Downlink	30	1.5	2,000	Hata Urban, large city	0.5
Indoor Wireless Local Area Networking	1	1	80	Yamada model, 8 walls, same floor, King's College Strand parameters [1]	0.5

[1] W. Yamada, …, O. Holland, et al., "Indoor Propagation Model for TV White Space," CROWNCOM 2014, Oulu, Finland, June 2014.

Availability—Number of Channels

- At least 30 dBm allowed EIRP – “Mobile Broadband Downlink” scenario, Class 5, London M25 area



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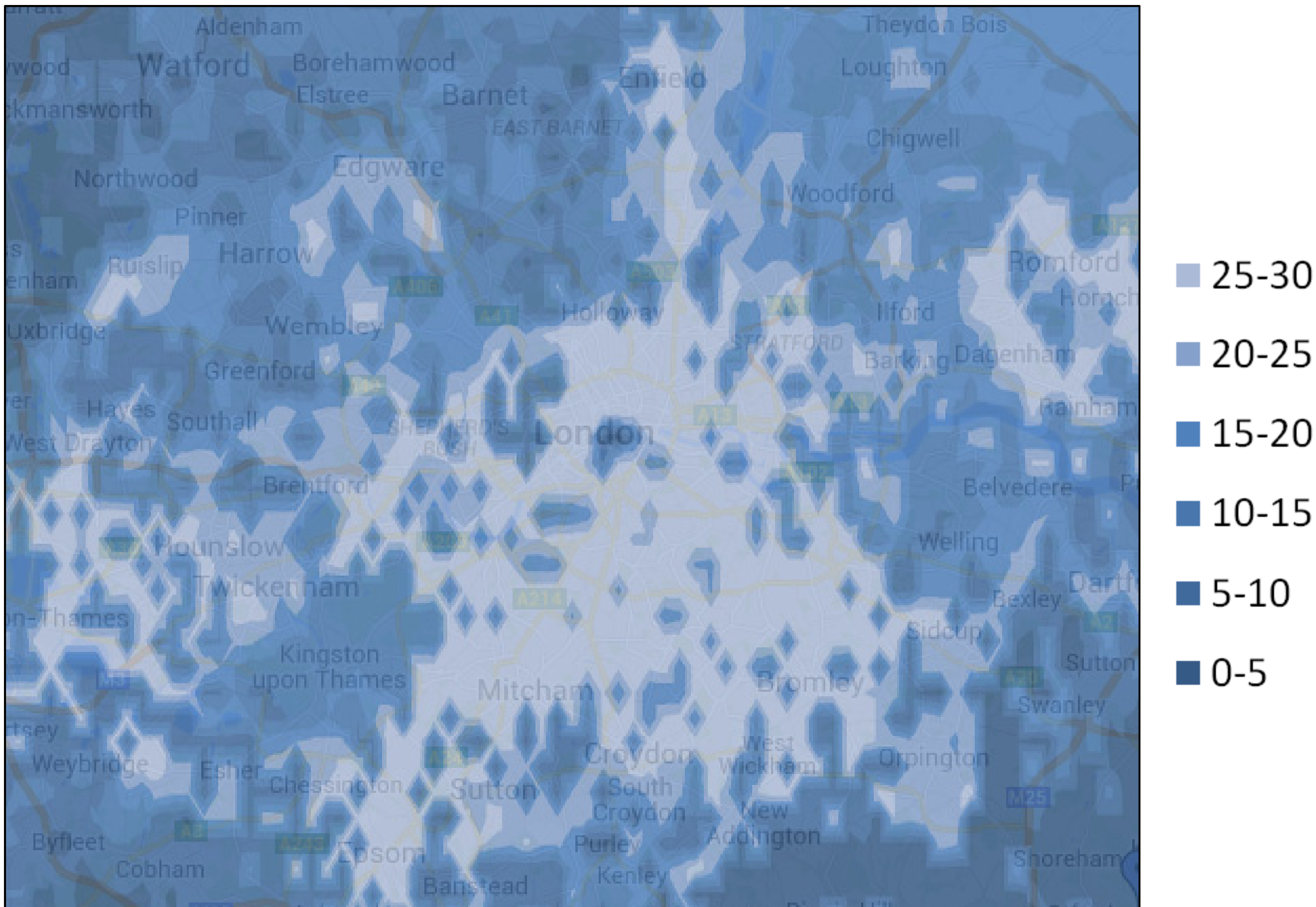
Availability—Number of Channels

- At least 30 dBm allowed EIRP – “Mobile Broadband Downlink” scenario, Class 1, London M25 area



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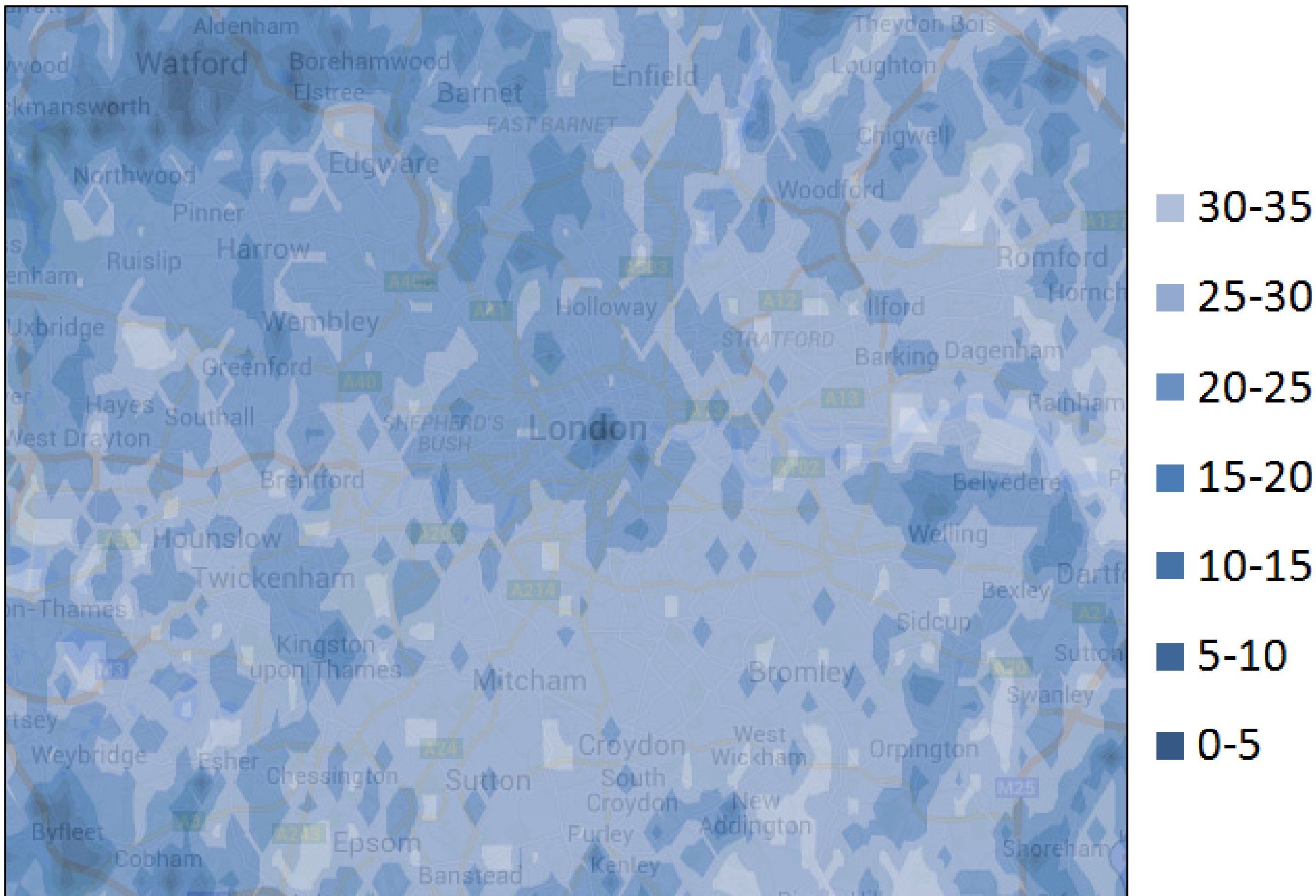
Availability—Number of Channels

- For comparison: at least 20 dBm allowed EIRP – “indoor Wireless Local Area Networking” scenario, Class 5, London M25 area



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Availability—Number of Channels

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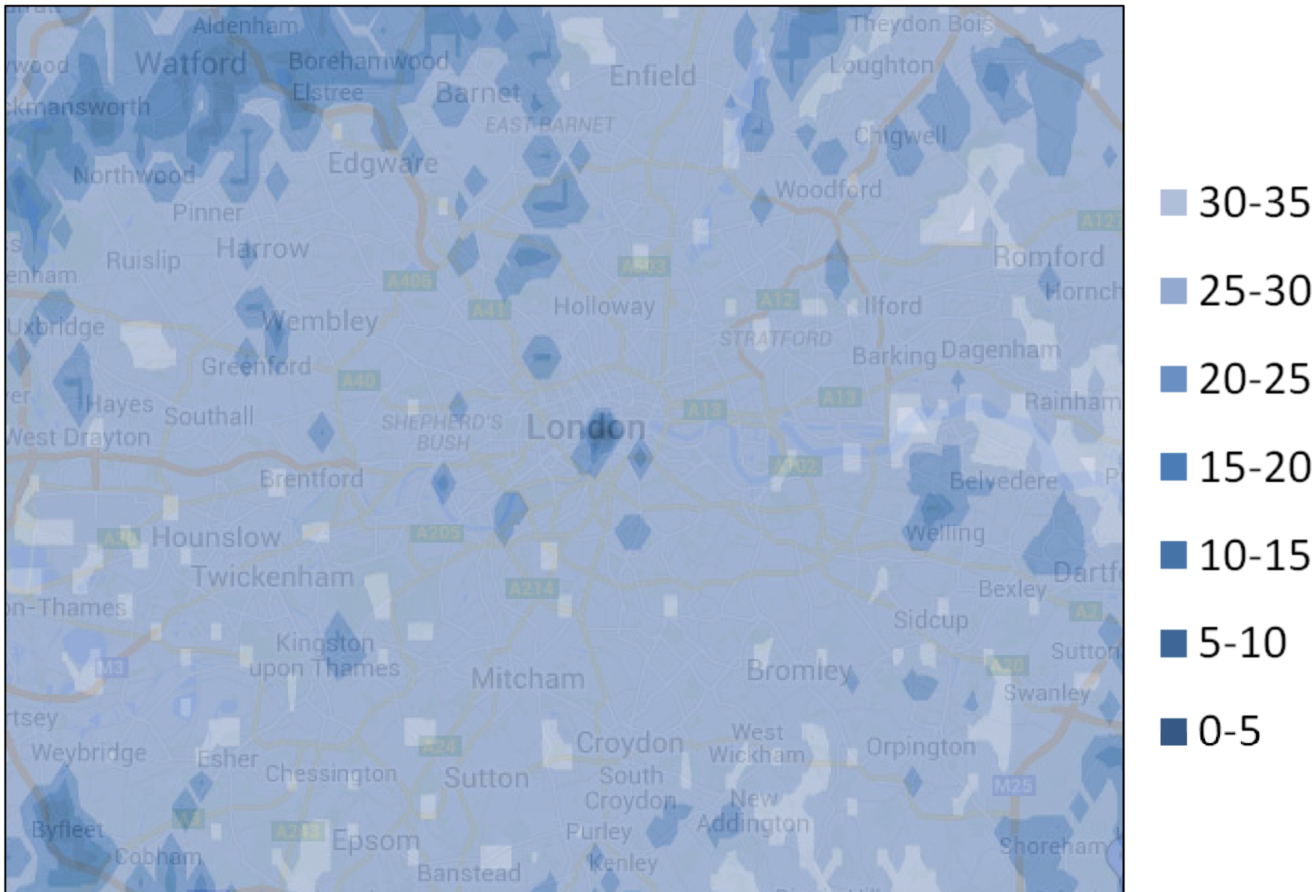

Availability—Number of Channels

- At least 30 dBm allowed EIRP – "Mobile Broadband Downlink" scenario, London M25

Number of channels

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	15.6	15.4	15.2	12.6	10.2
STD	8.4	8.4	8.5	8.1	7.1
CoV	0.54	0.55	0.56	0.64	0.70

- At least 20 dBm allowed EIRP – "Indoor Wireless Local Area Networking" scenario, London M25

Number of channels

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	25.7	25.6	25.5	24.9	23.4
STD	3.4	3.4	3.6	4.2	5.2
CoV	0.13	0.13	0.14	0.17	0.22

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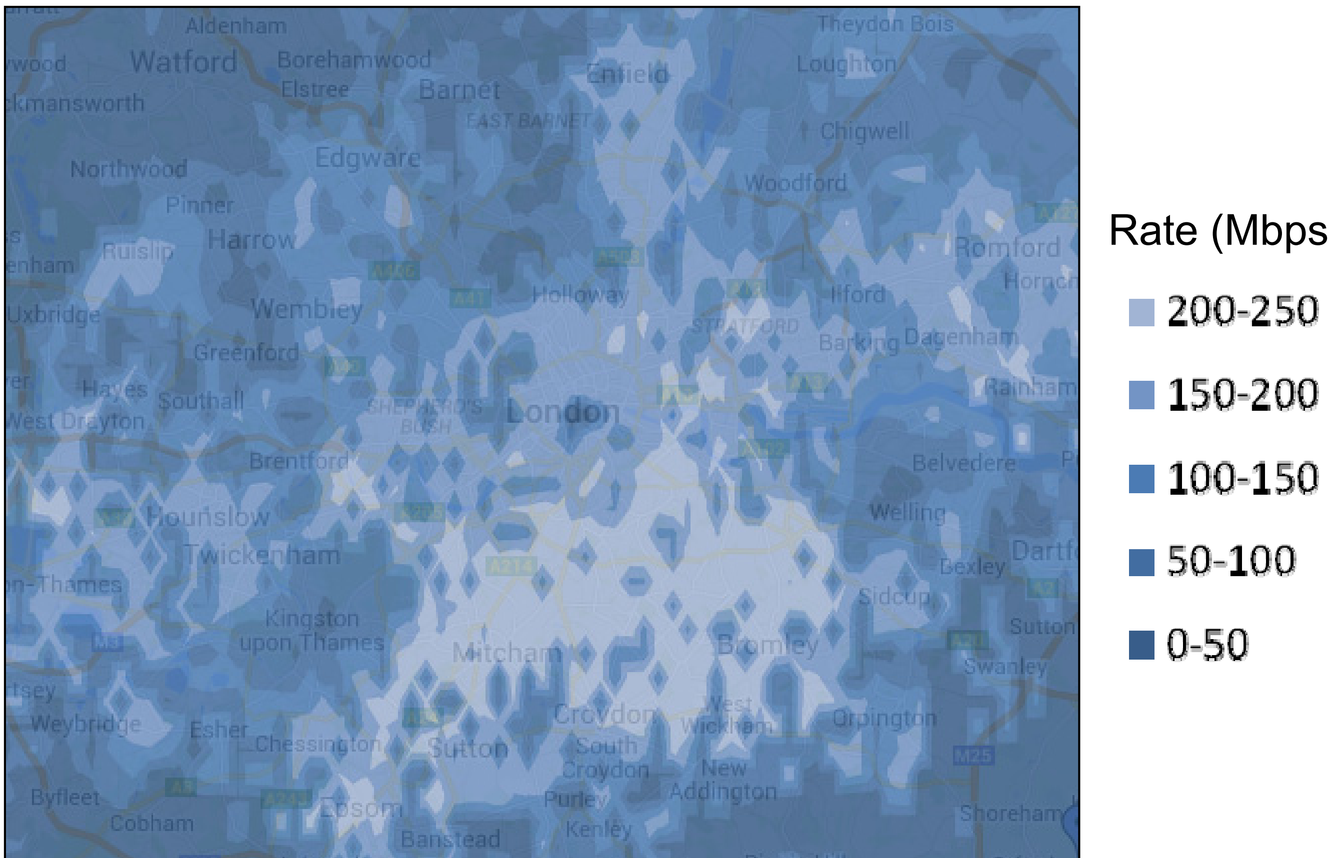
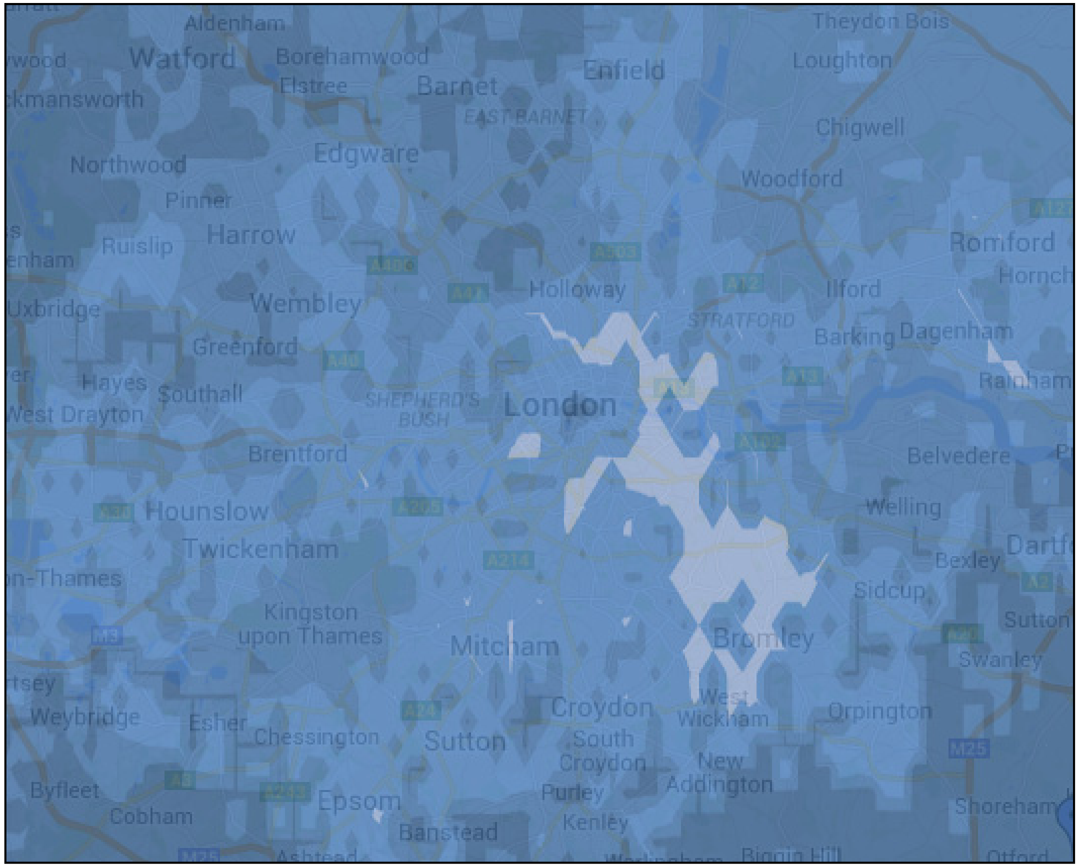
Capacity Through Aggregation

- Optimally aggregating all available channels at maximum allowed EIRP on a per-channel basis, London M25 area, Class 5, Mobile broadband downlink scenario



Capacity Through Aggregation

- Optimally aggregating all available channels at maximum allowed EIRP on a per-channel basis, London M25 area, Class 1, Mobile broadband downlink scenario



Rate (Mbps)

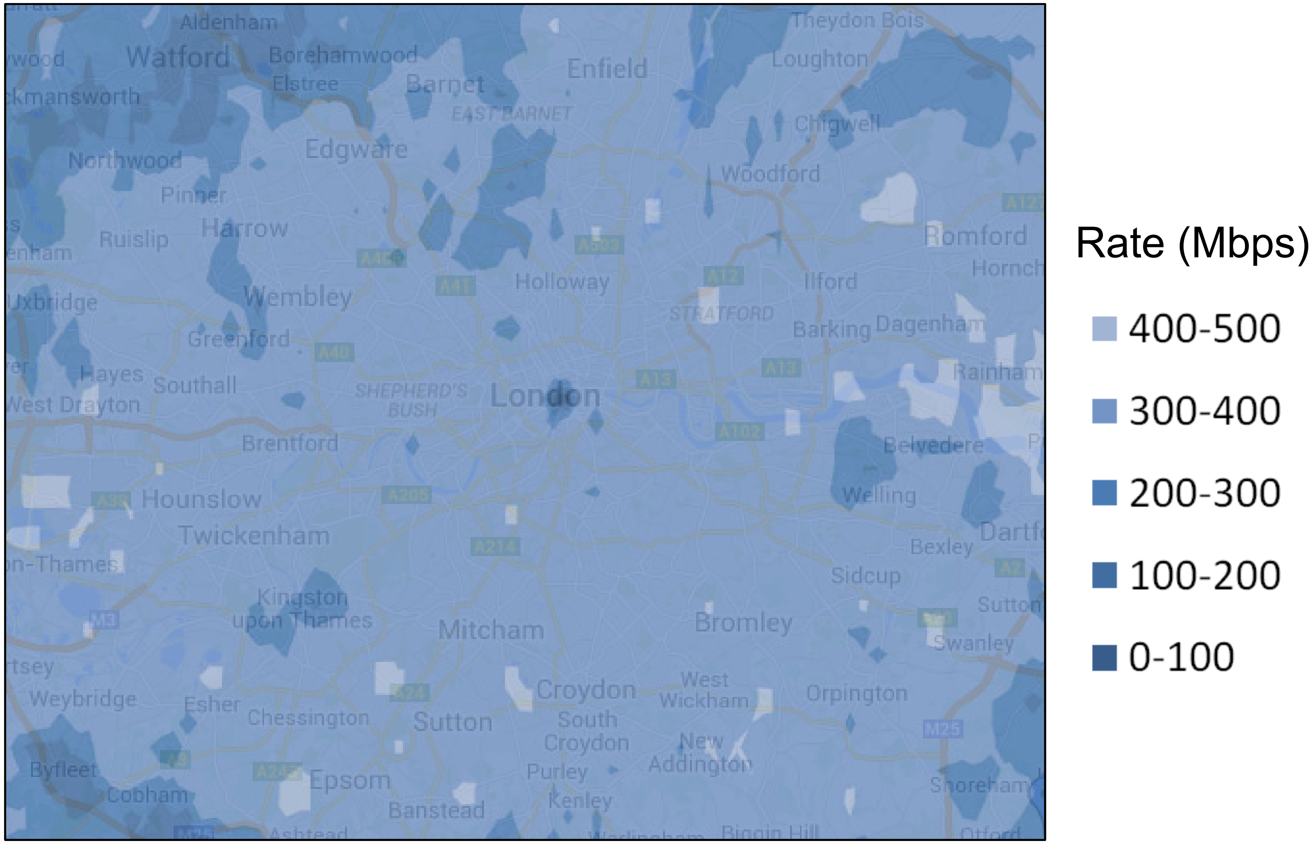
- 300-400
- 200-300
- 100-200
- 0-100

Capacity Through Aggregation

- Optimally aggregating all available channels at maximum allowed EIRP on a per-channel basis, London M25 area, Class 5, Indoor Wireless Area Networking scenario

Capacity Through Aggregation

- Optimally aggregating all available channels at maximum allowed EIRP on a per-channel basis, London M25 area, Class 1, Indoor Wireless Area Networking scenario



Capacity Through Aggregation

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- “Mobile Broadband Downlink” scenario, London M25 area

Achieved Rate (Mbps)

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	167.0	165.1	155.4	130.9	104.7
STD	84.2	84.4	82.5	77.4	66.8
CoV	0.50	0.51	0.53	0.59	0.64

- “Indoor Wireless Local Area Networking” scenario, London M25 area

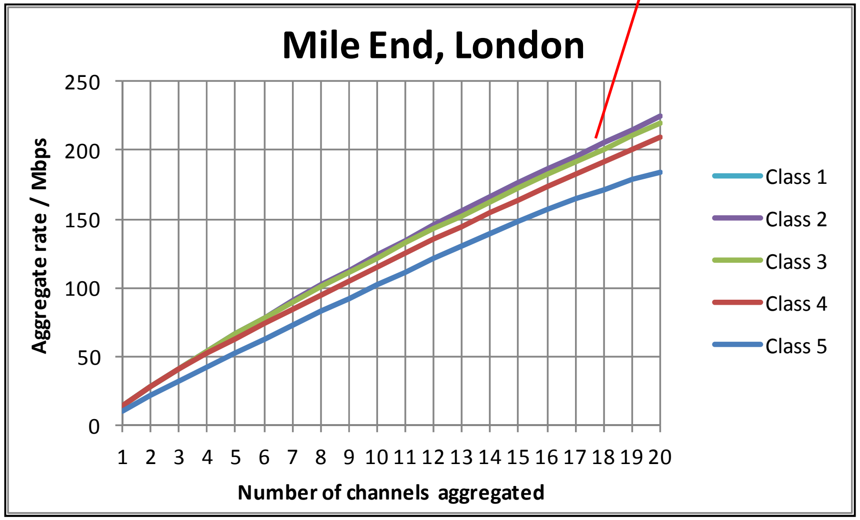
Achieved Rate (Mbps)

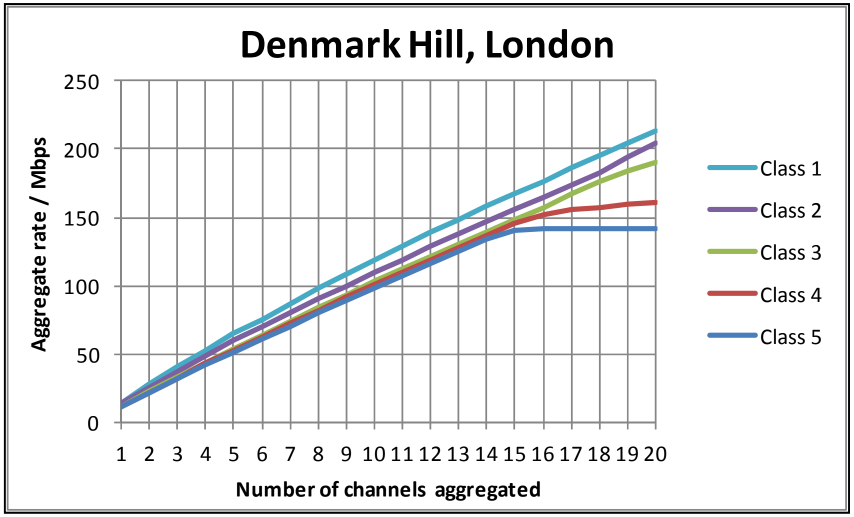
	Class 1	Class 2	Class 3	Class 4	Class 5
Average	333.5	330.9	327.5	312.5	285.6
STD	54.9	55.6	58.8	65.4	67.9
CoV	0.16	0.17	0.18	0.21	0.24

Capacity Through Aggregation

- "Mobile Broadband Downlink" scenario
  - Channel selection rule: Max power, and if power is equal then lowest frequency. Contiguous or non-contiguous (unlimited radios/filtering)

Classes 1 and 2 identical





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Capacity Through Aggregation

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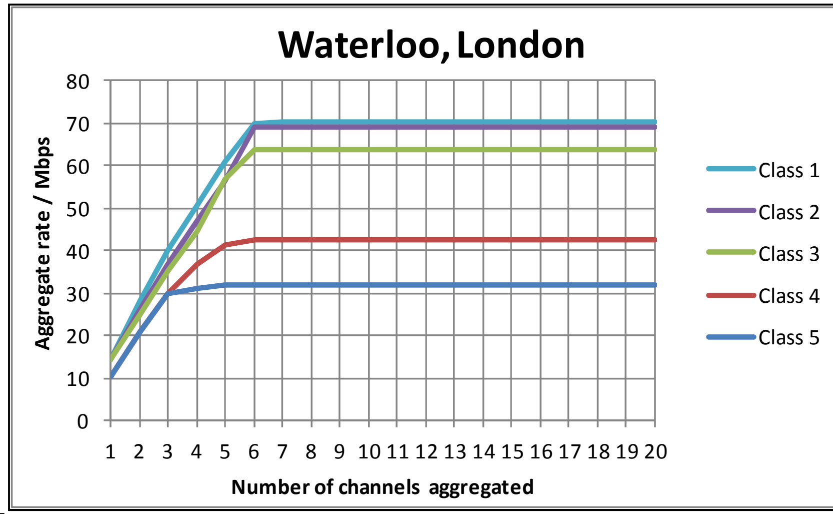
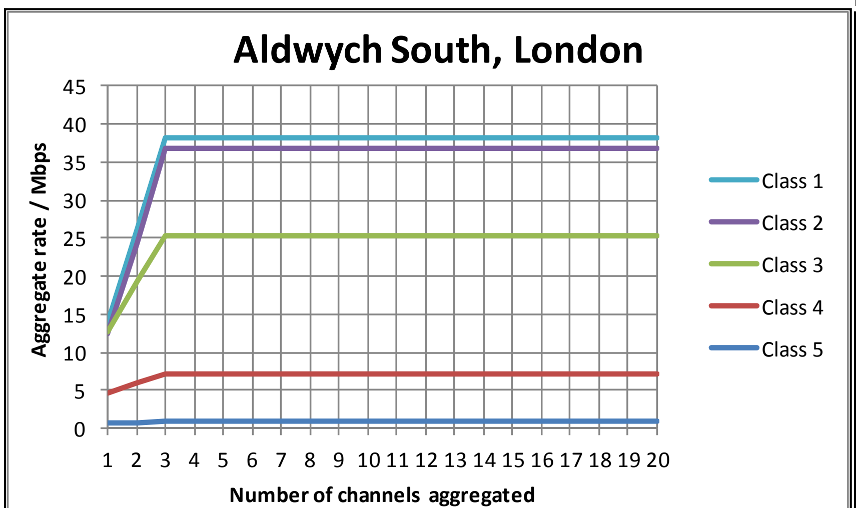
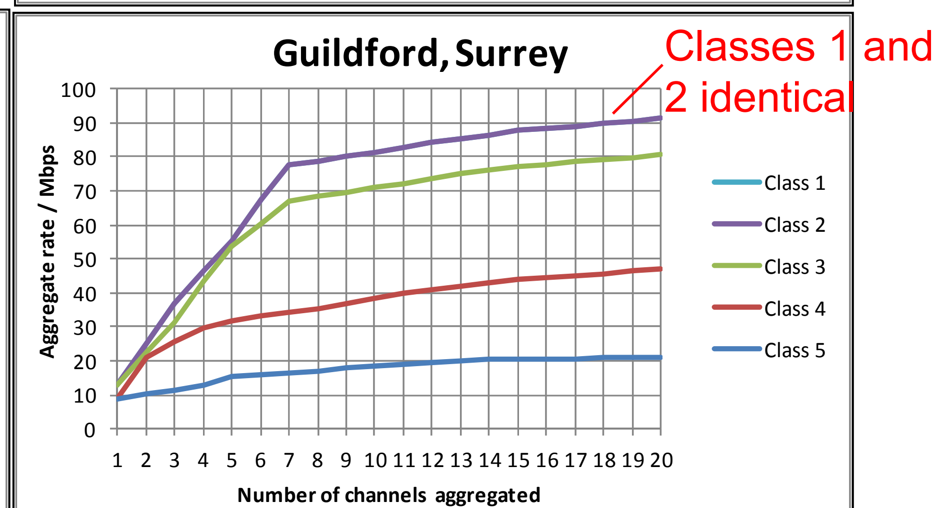
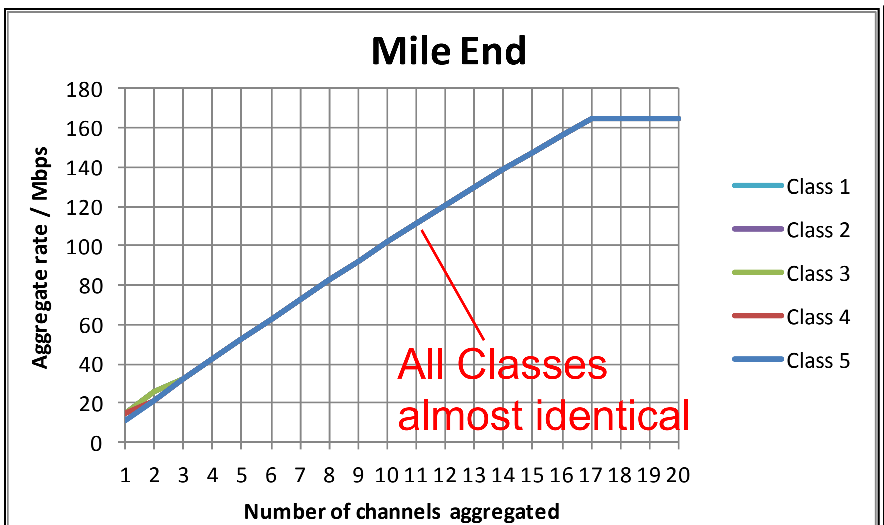


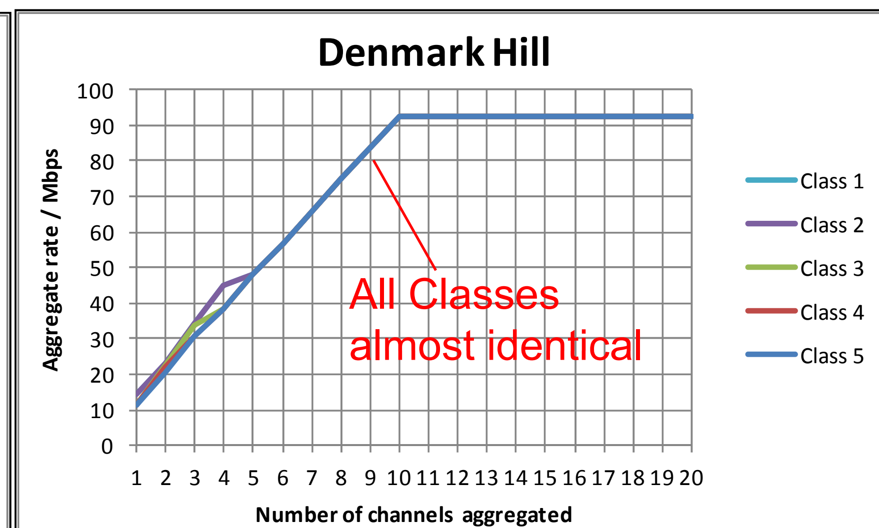




Capacity Through Aggregation

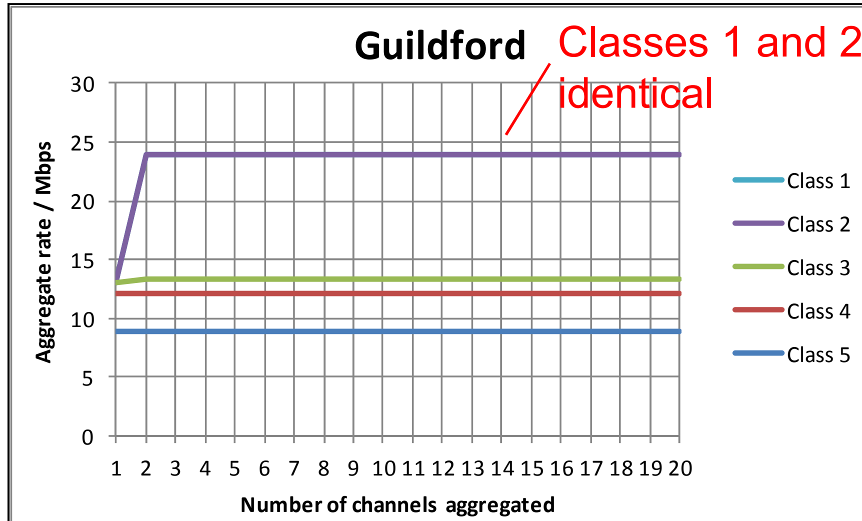
- "Mobile Broadband Downlink" scenario
  - Contiguous aggregation only (single radio covering multiple channels)
    - Rule: for all possible sets of *n* contiguous channels set power (per channel) to the lowest of those allowed for the contiguous channels, then take the result for the highest rate among the possible sets of contiguous channels with this power limitation
  - Except for rare examples (e.g., Guildford, below), Class doesn't have major effect on capacity achievable

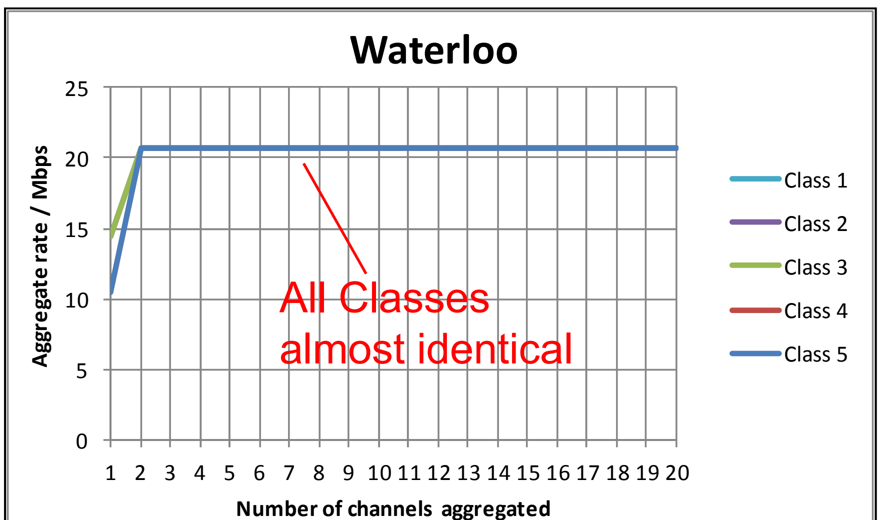


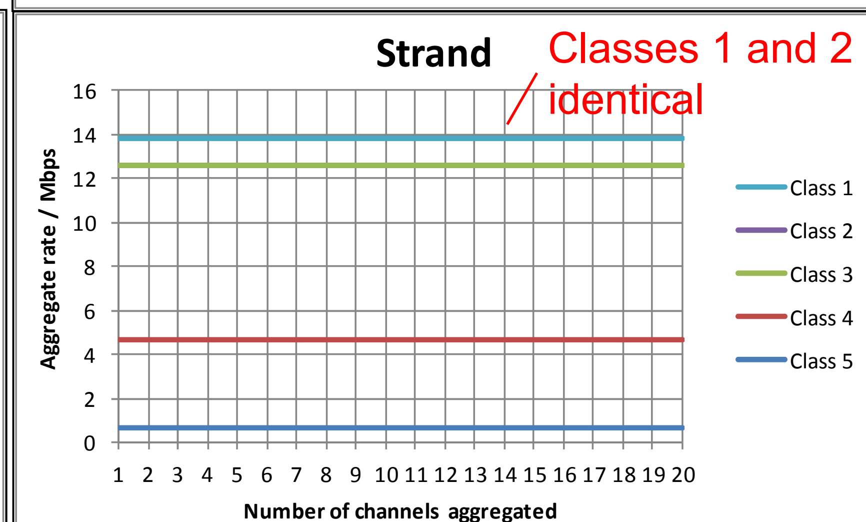


Capacity Through Aggregation

- "Mobile Broadband Downlink" scenario
  - Contiguous aggregation only (single radio covering multiple channels)
    - Same rule/observations







WRC 2015: How Much of a Problem for TV White Space?

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- ~694-790 MHz to be assigned to mobile broadband on co-primary basis – precise rules and lower bound to be decided at WRC 2015 (November 2015)
  - What happens if all goes to mobile broadband, no white space access allowed (worst case scenario)?
  - Rule out all channels above 48 (upper edge 694 MHz)
- "Mobile Broadband Downlink" scenario (>= 30 dBm for num chan)

Number of channels

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	8.5	8.4	8.1	5.6	3.6
STD	5.0	5.0	5.1	4.6	3.5
CoV	0.58	0.60	0.62	0.82	0.96

Achieved Rate (Mbps)

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	102.2	100.4	90.8	67.4	43.7
STD	53.0	53.4	51.5	46.3	34.0
CoV	0.52	0.53	0.57	0.69	0.78

- "Indoor Wireless Local Area Networking" scenario (>= 20 dBm for num chan)

Number of channels

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	14.1	14.1	14.0	13.3	12.0
STD	2.6	2.7	2.8	3.4	4.2
CoV	0.19	0.19	0.20	0.26	0.35

Achieved Rate (Mbps)

	Class 1	Class 2	Class 3	Class 4	Class 5
Average	165.4	163.0	160.0	146.2	121.5
STD	36.8	37.6	40.3	45.2	43.4
CoV	0.22	0.23	0.25	0.31	0.36

Conclusion

Conclusion

- Given high-level overview of TV white spaces in the UK
- Presented some key updates that Ofcom are applying as a result of their work, and observations from participants in the Pilot
- Overviewed performances that are possible in TV white spaces in terms of availability (number of channels) and capacity (aggregation of channels)
  - Mobile broadband downlink
  - Indoor wireless local area networking
  - Non-contiguous aggregation
  - Contiguous aggregation
  - Worst case effects of WRC 2015 on availability and performance of TV white spaces

Acknowledgement

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Thank you!
Questions/discussion?

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Maynooth, Ireland, 18 November 2014

Back-up Slides

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Ofcom/ETSI Framework: White Spaces in the UK

Device Types

- Master
  - Geolocated; able to communicate directly with a geolocation database
- Slave
  - Only able to communicate with other white space devices; under the control of a master device; not necessarily geolocated
- Type A
  - Fixed use only. Integral, dedicated or external antennas
- Type B
  - Not intended for fixed use. Integral or dedicated antenna

Database Discovery

- Send the following to Ofcom: https://TVWS-Databases.ofcom.org.uk/weblist.xml?UniqueID=myDeviceSerialNumber

- Response


```
▼<ws_databases xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="https://TVWS-Dat
   <last_update>2014-10-20T13:34:00</last_update>
   <refresh_rate>1440</refresh_rate>
  ▼<db>
     <url>https://tvwsdb.broadbandappstestbed.com/json.rpc</url>
     <db_provider_name>Spectrum Bridge Incorporated</db_provider_name>
     <ws_db_id>1</ws_db_id>
   </db>
  ▼<db>
     <url>https://tvwsdb-ofcom.nict.go.jp:4433/</url>
     <db_provider_name>NICT</db_provider_name>
     <ws_db_id>2</ws_db_id>
   </db>
  ▼<db>
     <url>https://www.fswsdb.com/wsd/index.php</url>
     <db_provider_name>Fairspectrum</db_provider_name>
     <ws_db_id>3</ws_db_id>
   </db>
```


…

- Check again every refresh_rate minutes—currently 1,440 mins, 24 hours. If can't be accessed then check again every 1-2 hours, and continue using the last received information

Device-Database Communications

- Typically close to IETF Protocol for White Space Access (PAWS), https://datatracker.ietf.org/doc/draft-ietf-paws-protocol, **although this is not a requirement so there are (sometimes considerable) differences in device-database communication implementations for the UK case**
  - Leads to pairings of manufacturers/databases; firmware and/or other updates typically necessary if device wishes to change to a different database→databases are typically **not** interchangeable

- Typically (in fact, for all the implementations we have seen) JSON messages

- Devices must check with database at start-up before transmitting and every 15 minutes; if any check fails then they must immediately stop transmitting

- Following order – note, I use my own terminology to describe the phases
  - Master specific messages
  - Master usage messages
  - Slave generic messages
  - Slave specific messages
  - Slave usage messages

Master Specific Messages

- Process can start only after the master has checked and selected a database from the Ofcom list of gelocation databases
- Master obtains specific parameters from one of those databases for itself
  - Sends its information to the database, including its description (manufacturer, model, serial number, type (A or B), master or slave, spectrum mask class of performance (although this is sometimes substituted simply for the serial number, under the assumption that the database knows the device characteristics based on the serial number), technology identifier), location (including height AGL—optionally with other information antenna orientation), among other information
  - Database calculates the powers that can be used in which channels at which times based on this information
  - Database responds with information on allowed maximum powers in which channels (database implementations vary: can be per 8MHz and power spectral density (per 100 kHz); some databases report only the density) along with other information such as a time stamp and echoed device information. Channels powers are typically in the form of a schedule, stating the start and finish times for which the information is valid

Master Usage Messages

- Master must confirm with the database which channels/powers it has chosen to use before it uses them
  - Master device responds to the database confirming again its description, location, and its chosen channels and powers. It is noted that various combinations of channels and powers can be used through the format of the associated JSON messages. Further, aggregation of channels is possible trough the information structures supported
  - Database then responds with a confirmation, or otherwise error message – if there is an error then the master must not transmit

Slave Generic Messages

- Slave generic operational parameters reflect the worst case slave power allowed in any location that is in the master's coverage, thereby applying to a slave for which its position (among other characteristics) is not known

- Purpose is generally only to allow initial slave transmissions in link formation, although can be used on a longer-term basis if desired
  - The master requests information for a generic slave device from the database
  - The database then uses its knowledge of the master obtained in previous phases (e.g., its chosen channels/powers), among other characteristics, and also other knowledge, e.g., on location characteristics, to calculate the master's coverage. In each channel, it will take the most conservative (lowest) value of allowed slave power for any possible slave location in the master's coverage area
  - The resulting list of channels and allowed maximum powers will be returned back to the master much as for the master specific messages
  - The master can then transmit these parameters to the slave in the channel it has chosen, and the slave can start transmitting with these parameters in order to form the link and report its precise information to the master

Slave Specific Messages (Includes Master Association)

- Using the generic parameters, the slave can now transmit to the master its detail, e.g., location
- It is a requirement that the slave must anyway associate with the master, and that association must be informed to the database, whether it not the slave chooses to use the generic or specific operational parameters
  - Master sends description for itself and the slave in a message (thereby informing of the association) to the database, including now the slave’s location if specific operational parameters are required
  - The database then calculates and returns the specific allowed channels/powers for the slave’s characteristics and location
  - The master can then transmit those specific parameters to the slave on its chosen channel

Slave Usage Messages

- Slave must confirm with the database which specific channels/powers it has chosen to use before it uses them
  - Slave device responds (transmitting via the master with its generic parameters, noting that the master is the only gateway to the Internet it has) to the database confirming again its description, location, and its chosen channels and powers. It is noted that various combinations of channels and powers can be used through the structure of the associated JSON messages. Further, aggregation of channels is possible trough the information structures supported
  - Database then responds with a confirmation, or otherwise error message – if there is an error then the slave must not transmit. These messages are again relayed by the master to the slave
  - After it receives a successful confirmation, the slave can then transmit with its chosen specific parameters

Emissions Requirements—Out of TV Bands

- Quite strict requirements for out of TV band emissions by TV white space devices. However, of course can be relatively easily dealt with by fixed filters
- E.g., -54 dBm is equivalent to a class 1 white space device transmitting at no more than 20 dBm in adjacent channel – biggest challenge seems likely to therefore be satisfying the limit for LTE 800 (790-862 MHz) just above the TV band

Frequency Range	Maximum power	Measurement Bandwidth
30 MHz to 47 MHz	-36 dBm	100 kHz
47 MHz to 74 MHz	-54 dBm	100 kHz
74 MHz to 87,5 MHz	-36 dBm	100 kHz
87,5 MHz to 118 MHz	-54 dBm	100 kHz
118 MHz to 174 MHz	-36 dBm	100 kHz
174 MHz to 230 MHz	-54 dBm	100 kHz
230 MHz to 470 MHz	-36 dBm	100 kHz
790 MHz to 862 MHz	-54 dBm	100 kHz
862 MHz to 1 GHz	-36 dBm	100 kHz
1 GHz to 4 GHz	-30 dBm	1 MHz

Ofcom Statement—Further Work Potentially Resulting in Changes

- Identified due to the Pilot and Ofcom's Coexistence testing (text directly from Ofcom Statement)
  - a) Choice of propagation model in calculations to define coexistence parameters with DTT. This would include a review of the use of the extended Hata model, the assumption of 0 dB standard deviation for longer path distances, the use of Infoterra clutter data and potentially other more sophisticated terrain-based prediction models. It could also include a review of current modelling of household installation gains
  - b) Choice of propagation model in calculations to define a master WSD coverage area and coexistence parameters with PMSE. This would include a review of the use of the extended Hata model, our approach to clutter data and consideration of the use of more sophisticated terrain-based prediction models
  - c) UK DTT Planning Model data that is used in the DTT coexistence calculations – ensuring that the underlying data in the model better reflects the actual position regarding DTT viewers' reception in any particular pixel for example in terms of the transmitters that provide TV services to the viewer and the DTT field strength. This could also include a review of whether the definition of the threshold of coverage (99% time, 70% locations) reflects actual transmitter usage in weak signal areas

Ofcom Statement—Further Work Potentially Resulting in Changes

- Identified due to the Pilot and Ofcom's Coexistence testing (text directly from Ofcom Statement)
  - d) Categories of protection ratios for DTT – consideration of whether different device technologies or use cases may be more likely to disrupt DTT receivers and whether and how the framework should take account of this
  - e) Pixel resolution in the calculation limits to protect DTT services in neighbouring countries
  - f) Whether narrowband WSDs, when not in the vicinity of PMSE users, may be allowed additional power to recognise the fact that they do not use the entire 8 MHz channel and therefore their total power in the channel is lower than a comparable wideband device
  - g) Further consideration of whether there are genuine likely worst case scenarios for PMSE use that are not foreseen by the framework and where further information would help us to better understand and take account of the issues
  - h) WSD to WSD transmit intermodulation – consideration of whether this is an issue that we should seek to raise during a further ETSI review process in the future
  - i) Default WSD sensitivity level used in master WSD coverage area calculation – a value of -114 dBm/100 kHz will be used at the beginning but further consideration will be given to whether a higher level would be more realistic

Ofcom Statement—Further Work Potentially Resulting in Changes

- Identified due to the Pilot and Ofcom's Coexistence testing (text directly from Ofcom Statement)
  - j) Transmissions within PMSE venues – following implementation of venue boundaries, consideration of how to minimise WSD transmission within venues, taking account of the need for slave WSDs to be able to make initial contact with masters
  - k) Determination of generic operational parameters and master-slave association – we plan to review, following the implementation of the approach set out in this Statement, the extent to which master-slave association imposes a constraint on the deployment of WSDs, and if so what changes may be possible and how to address any related risks to PMSE
  - l) Consideration of the ETSI Harmonised Standard – a review of how the current standard could be developed, for example whether new emission classes, or a refinement to the class system for WSDs in relation to their propensity to cause interference to DTT receivers, would be beneficial, so that this can be fed into a future ETSI review process
  - m) Planned consultation on whether to introduce a licensing regime to authorise manually configured devices (i.e. that require the user to determine and specify the device parameters) that will not meet the requirements of the licence exemption