ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

TV White Spaces in the UK, and a Major Trial within the Ofcom TV White Spaces Pilot

Oliver Holland, *King's College London*

On behalf of our trial – see acknowledgement slides at end for range of contributors

Please refer to back-up slides at the end of this presentation for more detailed content—these slides will be uploaded and available after the event

WInnComm-Europe 2014
Rome, Italy, 6 November 2014

Overview

- TV White Spaces in the UK
- Our Trial
- Some (Still Relatively Early) Results
- Conclusion

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

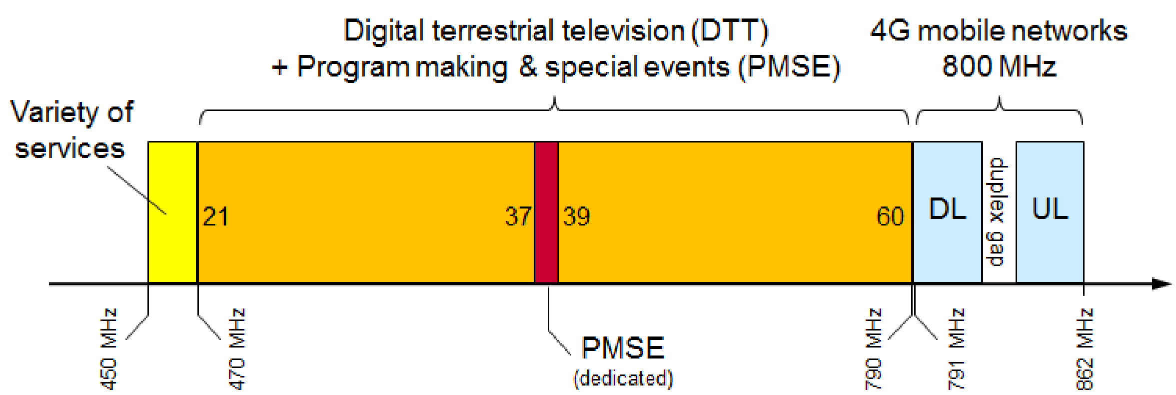
TV White Spaces in the UK

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 North America

- 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 North America
  - Current UK trials limited to channels 22 to 59 (of course excluding channel 38) to help protect services that are next to TV frequencies; unclear as yet whether the final TV White Spaces rules will also have that limitation

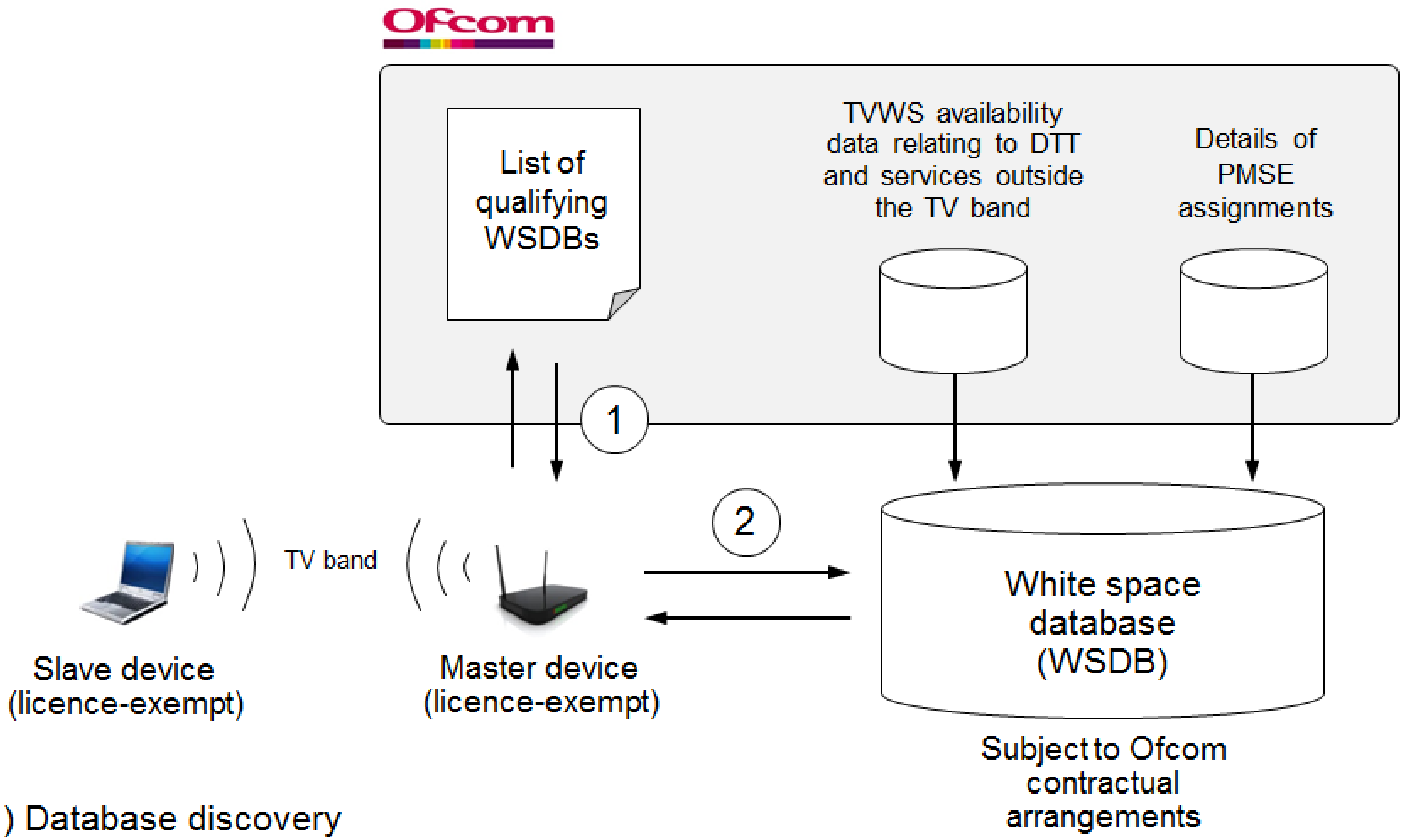
- Channel 38 (606-614 MHz) reserved exclusively for shared PMSE usage. Cannot be used by white space devices



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 and Device-Database Communications



1) Database discovery
2) Device-database communications.

Database Discovery

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

- Response

https://tvws-databases.ofcom.org.uk/weblist.xml

This XML file does not appear to have any style information associated with it. The document tree is shown below.


```
▼<ws_databases xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="https://TVWS-Databases.ofcom.org.uk/wsdbList.xsd">
  <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

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

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

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

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

So What is Happening with all of this? –Ofcom Pilot and Next Steps

- Ofcom initiated a large pilot of this technology in the UK, with currently 7 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 is ongoing, at least continuing until early 2015 and likely a lot later than that. Seems to be ramping-up well
  - Currently testing white space devices from Adaptrum, Carlson Wireless, Eurecom, 6Harmonics, KTS Wireless/Sinecom, Mediatek, MELD, Neul and NICT
    - Others seem very likely to join, specifically within our trial
  - 8 Geolocation databases now qualified: Spectrum Bridge, Fairspectrum, NICT, Nominet, Google, Sony, iconectiv and Microsoft

So What is Happening with all of this? –Ofcom Pilot and Next Steps

- Ofcom are also doing their own investigations, e.g., coexistence testing of white space devices with DVB-T and PMSE, protection ratio analysis, coupling ratio studies, intermodulation studies, etc.
  - Concentrating on interesting scenarios, e.g., areas with challenging DVB-T coverage characteristics, PMSE deployment locations/scenarios, e.g., London theatres, etc.

- Ofcom will release a report on the pilot, and its coexistence testing, towards the end of this year

- Ofcom hopes that the white space devices will move to commercial usage in the UK. In most recent communications, they state that this will “possibly” be achieved as early as early 2015

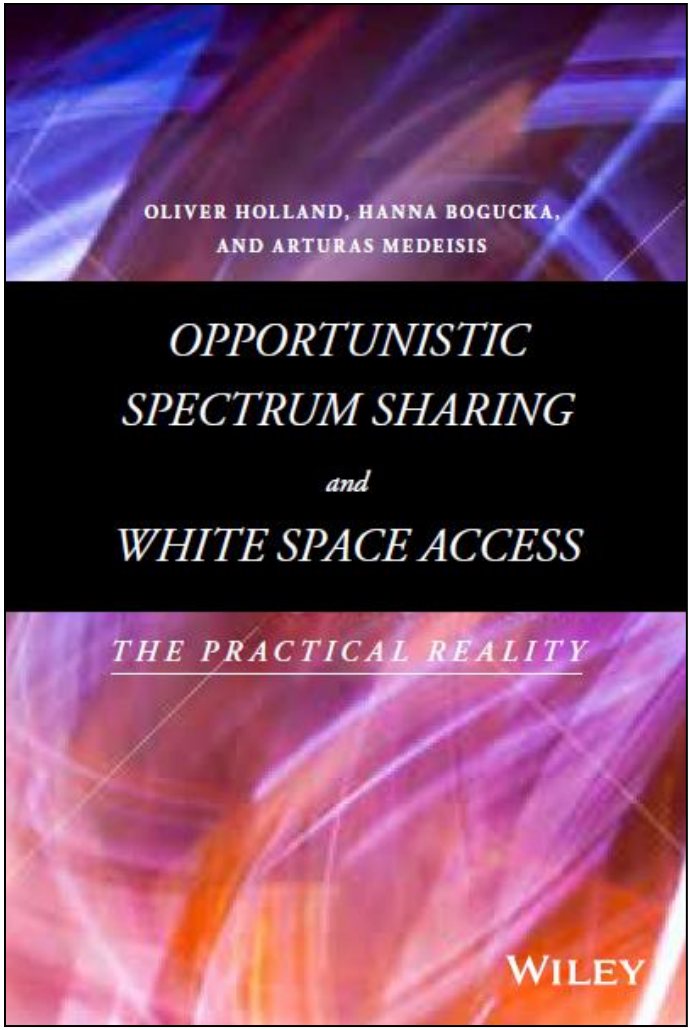
ETSI 301598, Key Ofcom Consultations and other Publications

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- 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
- H. R. Karimi, "UK framework for access to TV white spaces," book chapter in O. Holland, H. Bogucka, A. Medeisis, *Opportunistic Spectrum Sharing and White Spaces Access: The Practical Reality*, Wiley, February 2015
- J. Schmidt, P. Stanforth, "Spectrum Sharing using Geo-location Databases," book chapter in O. Holland, H. Bogucka, A. Medeisis, *Opportunistic Spectrum Sharing and White Spaces Access: The Practical Reality*, Wiley, February 2015

Book

- Please buy it if you want to find out what is in the aforementioned Chapters, among other interesting content prepared by key experts working in associated areas
- O. Holland, H. Bogucka, A. Medeisis (Ed.), *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality*, Wiley
- Available approx Jan-Feb 2015



ACROPOLIS
European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Our Trial

Objectives (Including Longer-Term Aspirations)

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- To test communications systems and scenarios that may be implemented in TV White Space
  - LTE multicast/broadcast (eMBMS)
  - Broadband for public protection and disaster relief
  - TD-LTE and other TDD systems for more general applications in TV White Space (e.g., general broadband provisioning, and small cells in TV White Space)
  - WiFi in TV White Space (802.11af draft)
  - Wireless backhaul links in TV White Space
  - M2M implementations (possible future work)
- To support the development/assessment of the ETSI 301598 standard, and assessment of white space devices

Objectives (Including Longer-Term Aspirations)

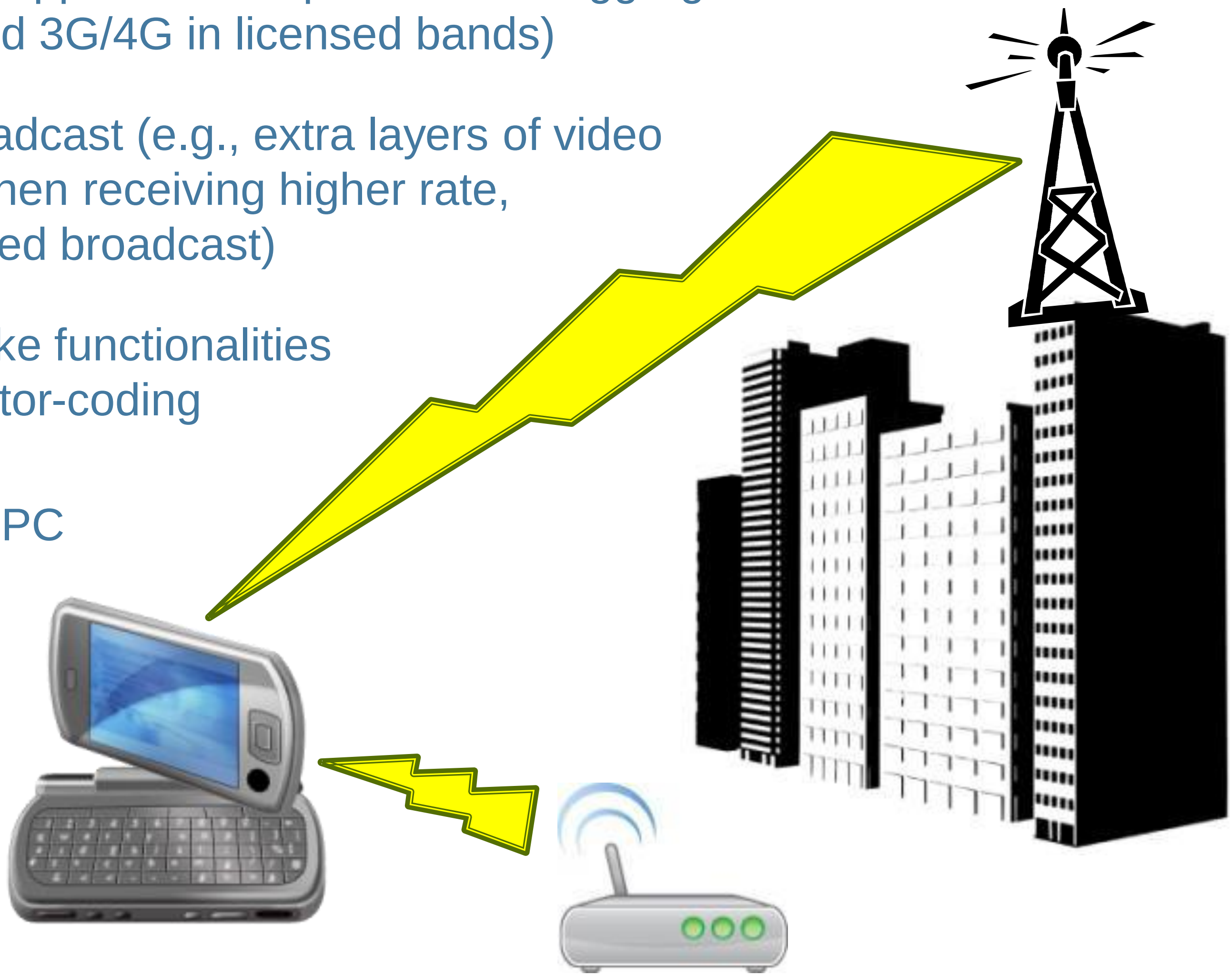
- To test the correct performance of the UK's TV White Spaces framework in general
- To carry out research studies using TV White Space implementations
  - Aggregation of resources/links (e.g., TV White Space with licensed and other unlicensed such as ISM, and links within TV White Space)
    - Development of methods to assist aggregation, e.g., MAC solutions, intelligent database-assisted solutions
    - Qualitative and quantitative performance surveys
  - Secondary coexistence (e.g., LTE coexisting and 802.11af in TV White Space, and multiple instances of different standards/devices coexisting)
  - To undertake studies and surveys on the performances that are achieved, e.g., in terms of interference to primary (!), secondary user performance through objective user opinion polling
  - Spectrum monitoring and assessment (e.g., spatial and temporal effects on the spectrum—correlation)

LTE MBMS and Spectrum/Link Aggregation Scenario

ACROPOLIS
European NoE on Cognitive Communications

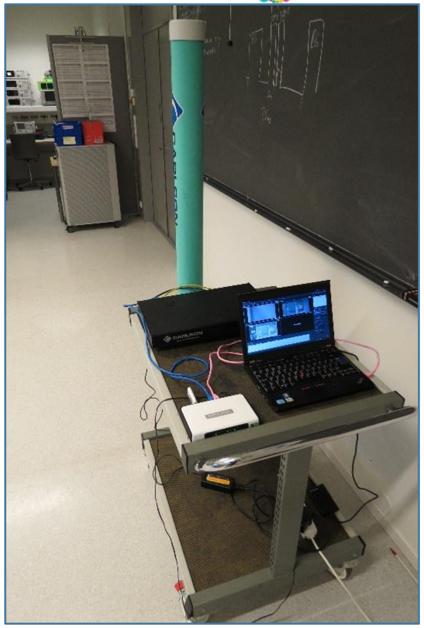
SOLDER

- LTE MBMS and opportunistic spectrum/link aggregation with other services (WiFi in ISM, and 3G/4G in licensed bands)
- Augmented broadcast (e.g., extra layers of video subscribed to when receiving higher rate, locally customised broadcast)
- Data carousel-like functionalities achieved by raptor-coding the data set
  - Augmented CPC
  - Software upgrades



Public Protection and Disaster Relief Scenarios

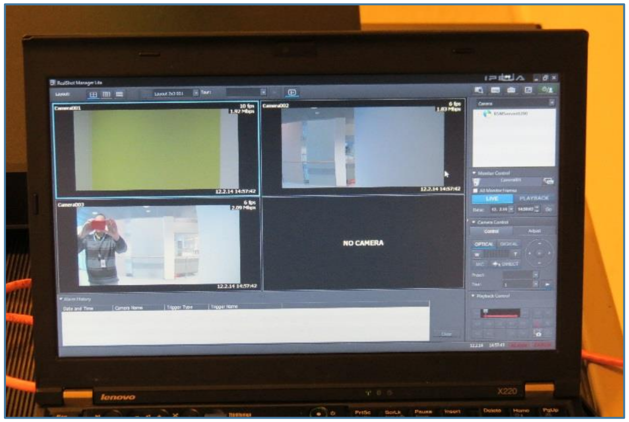
- Video surveillance system in TV White Space



Carlson Basestation

2 Sony SNC-CH220
+ 1 Carlson Terminal

1 Sony SNC-ER550
+ 1 Carlson Terminal



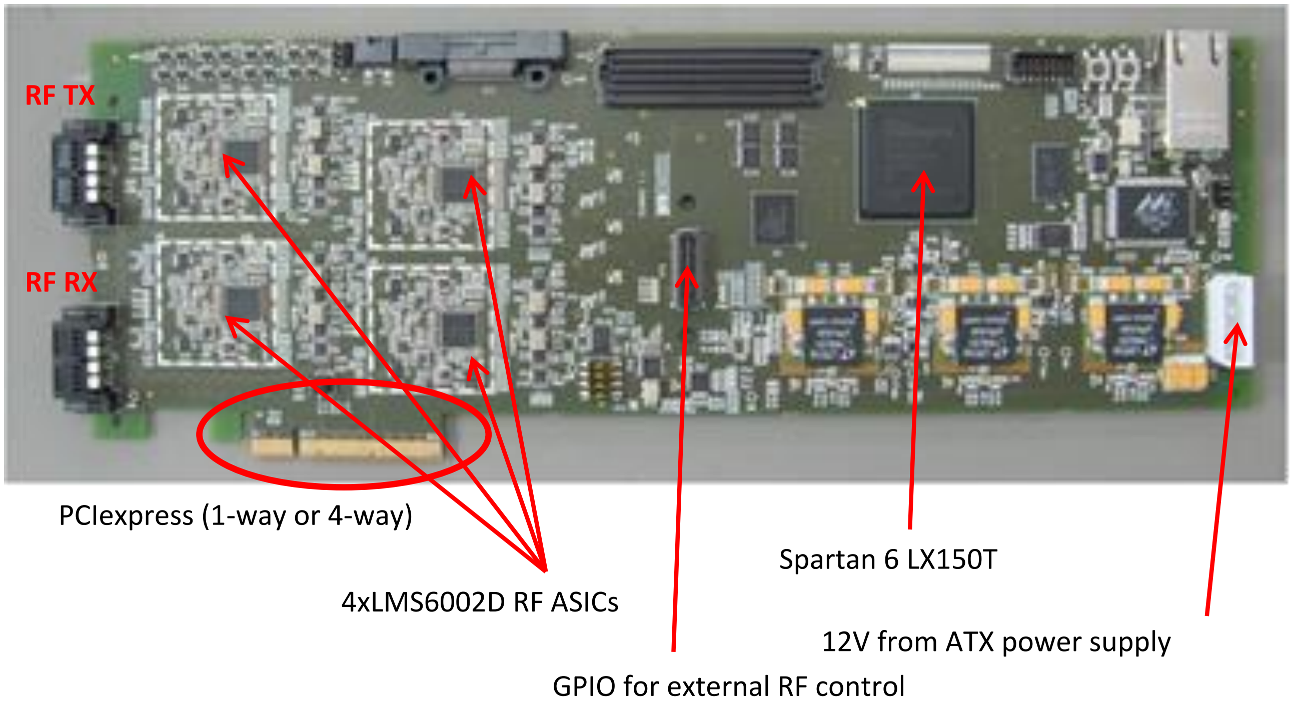
Sony Real Shot manager software

Other Scenarios

- Point-to-point links for backhaul provisioning, between different university campuses of participants in our trials (two challenging examples we will attempt to achieve are to the right)
- General broadband provisioning using a range of devices and systems
- LTE small cell implementations, likely indoor
- Wireless local area networking in TV White Space
- Machine-to-Machine communications in TV White Space (possible at later stage)

White Space Devices: Eurecom ExpressMIMO2

- ExpressMIMO2 is the basis for the LTE MBMS case initially, and likely other LTE cases later—perhaps also 802.11af at a very late stage
- No DSP on board, FPGA primarily used just for routing data; host PC must be powerful and running in a real-time operating system!!! 4 RF chains achievable on the card (all Tx+Rx)
- Have set up 3 devices based on this so far (1 base station and two terminals), each hosted in a PC with (in the case of base station) a separate box handling RF



White Space Devices: Carlson Wireless RuralConnect

- http://www.carlsonwireless.com/ruralconnect
- Built for US market, but adapted to operate under Ofcom/ETSI rules in terms of database (and database of databases) communication, channelization, etc. Variable powers and (complete) UK frequency range currently not adapted
- Our trial will use at least 2 base stations and 4 terminals (perhaps different sets at different times)
- Deployment scenarios include the public protection and disaster relief cases
- Also broadband provisioning cases, and to test longer-distance point-to-point links

White Space Devices: Sinecom/KTS Agility White Space Radio

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- http://sinecom.net/product.html
- There are geolocation database interaction challenges with these devices, although it is hoped that they can be solved and the devices used
- In the shorter term, to be used for low-rate broadband provisioning
- In the longer term, likely to also be used for M2M cases
- Likely to be used for the point-to-point long-distance links at a later stage
- Our trials will have at least 6 of these devices

White Space Devices: NICT and Others

- NICT devices deployed for a short duration, in collaboration with NICT
  - TD-LTE in TV White Space
    - Base stations and terminals - 3 of each
    - Used for general testing of LTE scenarios (small/femto cells, and larger cellular provisioning cases)
  - Low-power IEEE 802.11af (WiFi in TV White Space)
    - Wireless local area networking is prime use case
    - 5 of these devices
  - High-power IEEE 802.11af
    - Long-distance backhaul link provisioning
    - 2 of these devices
- Too early to declare the companies involved, but a manufacturer implementing WiFi in TVWS (with channel aggregation), and another implementing WiMAX in TVWS (with channel aggregation), will be joining our Trial in January 2015

Geolocation Databases

- Noted that the interfaces between TV White Space devices and geolocation databases are not standardised. It is therefore typically the case that particular TV White Space device manufacturers are working with particular databases
- We are using a range of databases in our trials
  - Fairspectrum → Carlson Wireless and Eurecom devices
  - NICT → NICT and Eurecom devices
  - Spectrum Bridge → KTS/Sinecom devices, and other new device additions
  - Joint Research Centre of the European Commission → for comparison using a range of devices, not deployed in UK
- Haven't pursued the implementation details yet simply due to time constraints, but also have been in discussion and have verbal agreement with following
  - Nominet (although looks likely to be mostly in the scope of a dedicated additional trial that Nominet has specifically set up with us)
  - Sony (perhaps at a later stage)
  - BT (there have been discussions, current status is unknown on whether they will move to qualification for participation in Ofcom Pilot)

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

Locations

- Extensive range of locations, covering almost all imaginable environments, tested (mostly) sequentially
  - Cluttered vs. non-cluttered
  - High incumbent systems TV bands usage vs. relatively low usage
  - A range of propagation characteristics

- Almost exclusively campuses/buildings among the range of universities that are collaborating in our trials

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Some (Still Relatively Early) Results

Long-Distance Links

- Long distance (7km) Queen Mary to Denmark Hill link has been extremely challenging due to interference from distant TV transmitters, even on channels in which the devices are allowed to use maximum power. Also Fresnel effects, despite almost certain to be direct line of sight between the two sites

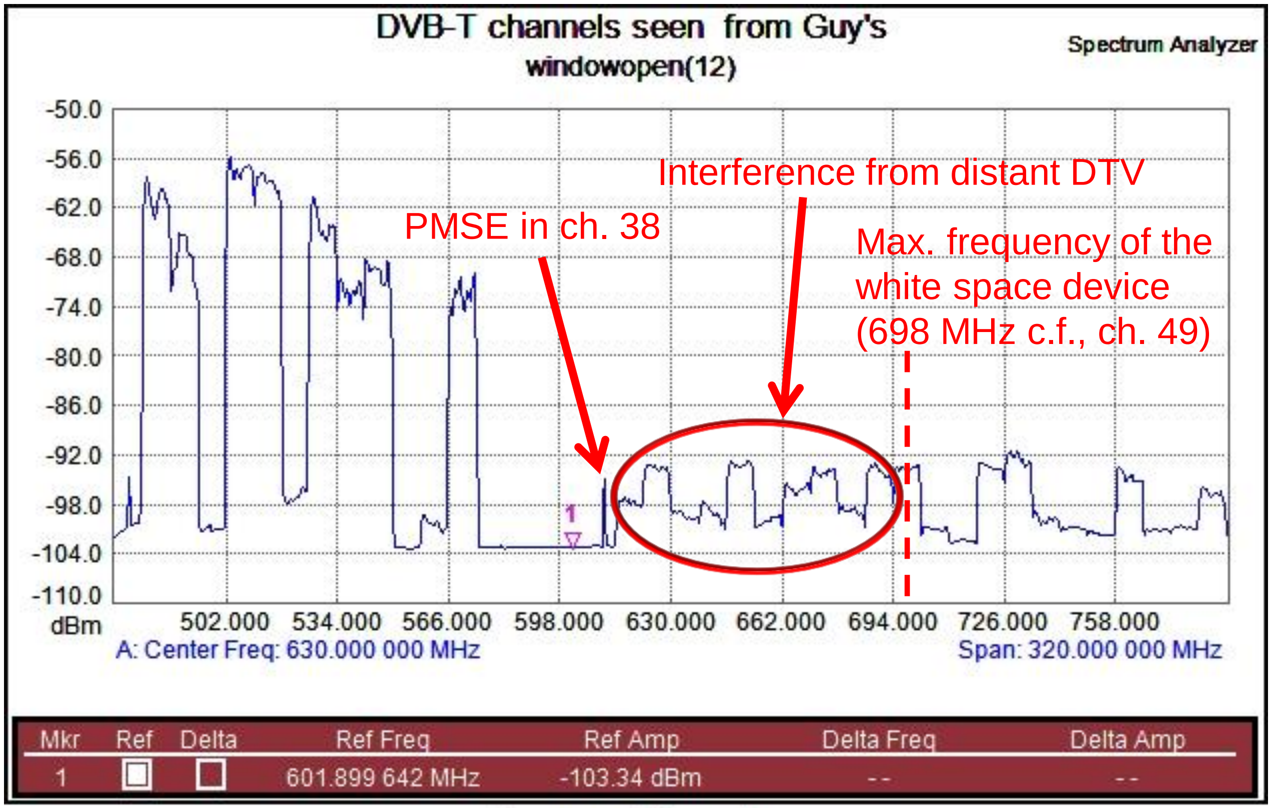
- E.g., channel 48 allowed to use maximum power (36 dBm EIRP) at both ends
  - Achievable SINR significantly less than zero, although unreliable measurements from the device due very low numbers

- *Far better* to use, e.g., channel 37, on which 5dB less than maximum power is allowed (31 dBm EIRP), however, interference is extremely low—likely linked to 600MHz clearout and spectrum award in the UK
  - *Far better* performance can be achieved: data rate only in the range of 20 to 60 kb/s in initial exploratory investigations, although this is *very far from optimised* currently and we expect that at least a magnitude improvement is possible; observed SINR 8-10 dB *in best case*

Long-Distance Links

- Approx. 3.7 km link between Denmark Hill and Guys also tested, and this is better. In the channel 37 case, up to 20 dB SINR achieved → BER ~ 10^{-6} with 16QAM modulation and coding rate 1/2 → 6.4 Mbps downlink and 5.1 Mbps uplink
- Interference (even with our vertically-polarised antennas vs. the horizontally-polarised DTV transmissions) implies that device should carefully sense channel quality/interference first before selecting channel to use. Also has implications for scenarios in which TV White Space will be most successful, and for secondary-secondary coordination and tragedy of the (spectrum) commons
- Interestingly, have found the propagation environment for these rooftop long-distance direct line-of-sight links to match closely to Hata Open path loss model

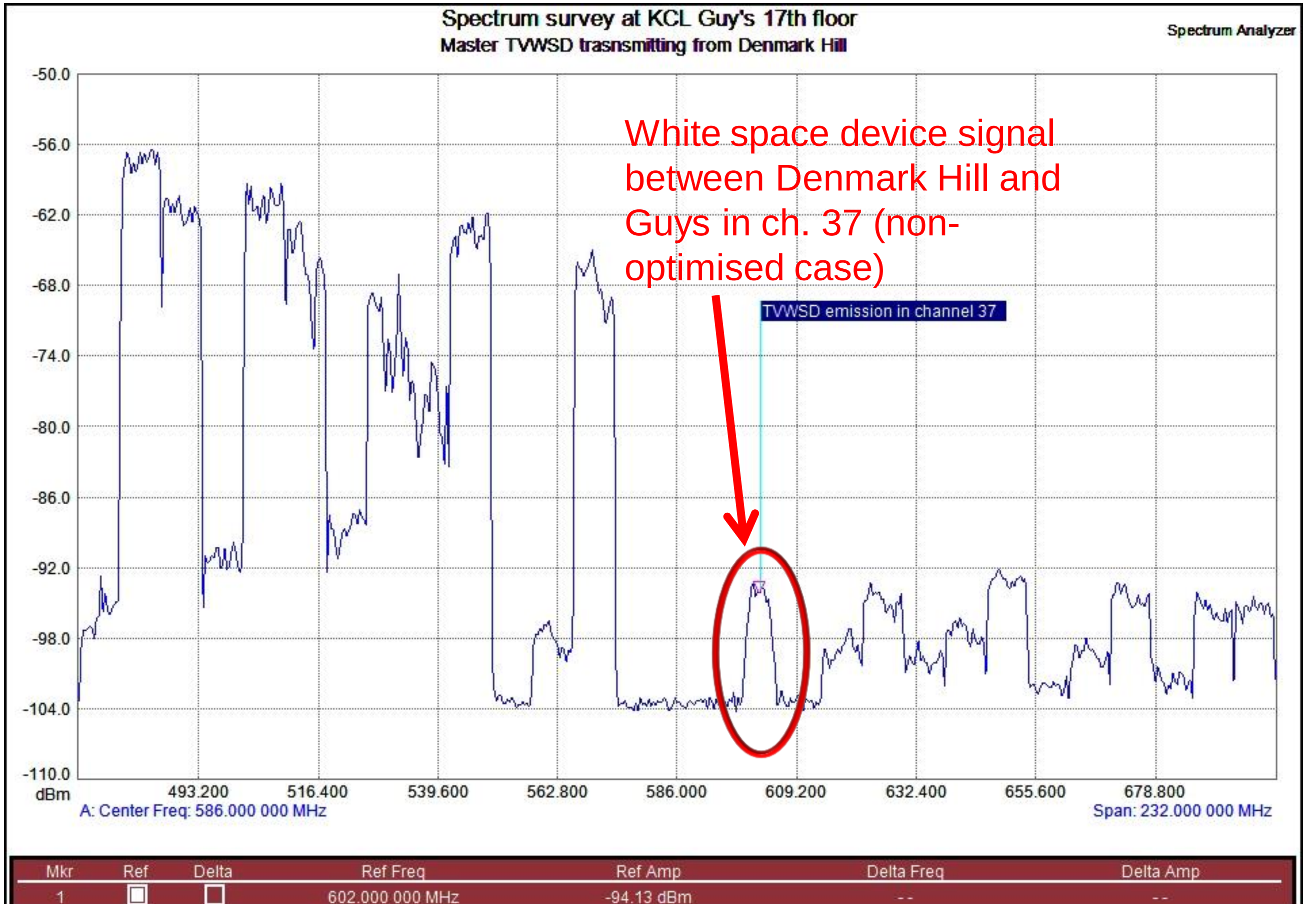
Long-Distance Links



Measurement Parameters

Trace A data:Trace Average	10	Start Frequency	470.000 000 MHz
Trace Mode	Average	Stop Frequency	790.000 000 MHz
Preamp	OFF	Frequency Span	320.000 000 MHz
Min Sweep Time	5E-05 S	Reference Level	-20.000 dBm
Reference Level Offset	0 dB	Scale	10.0 dB/div
Input Attenuation	0.0 dB	Serial Number	942140
RBW	30.0 kHz	Base Ver.	V3.08
VBW	30.0 kHz	App Ver.	V4.15
Detection	RMS	Date	8/6/2014 9:31:35 AM
Center Frequency	630.000 000 MHz	Device Name	ms2721b_01ri20090352874

Long-Distance Links

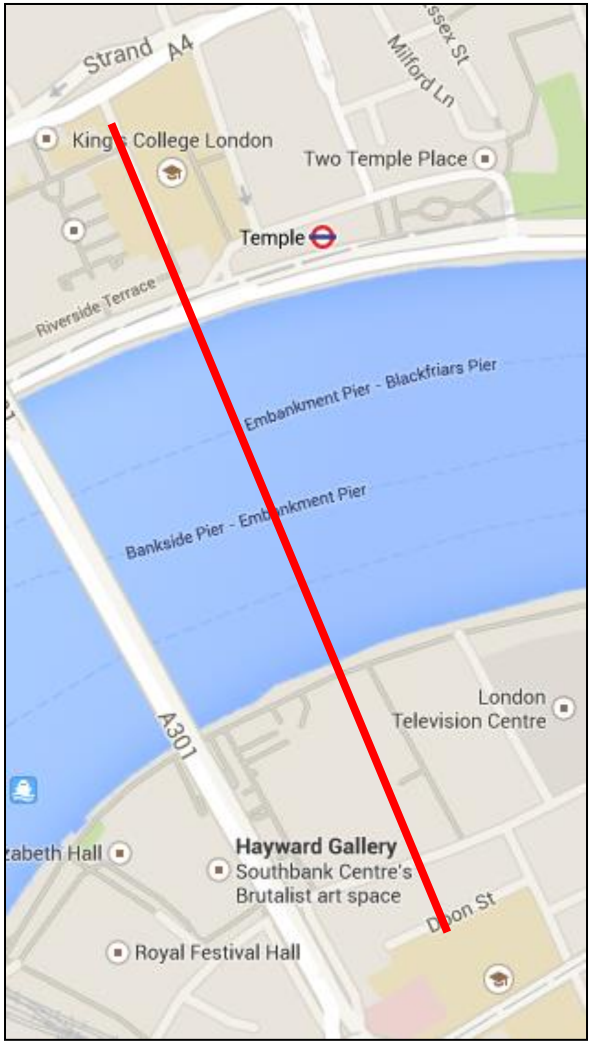


Measurement Parameters

		Start Frequency	470.000 000 MHz
Trace Mode	Normal	Stop Frequency	702.000 000 MHz
Preamp	OFF	Frequency Span	232.000 000 MHz
Min Sweep Time	5E-05 S	Reference Level	-50.000 dBm
Reference Level Offset	0 dB	Scale	6.0 dB/div
Input Attenuation	0.0 dB	Serial Number	942140
RBW	30.0 kHz	Base Ver.	V3.08
VBW	30.0 kHz	App Ver.	V4.15
Detection	RMS	Date	8/6/2014 8:40:39 AM
Center Frequency	586.000 000 MHz	Device Name	ms2721b_01ri20090352874

Long-Distance Links—Strand to Waterloo

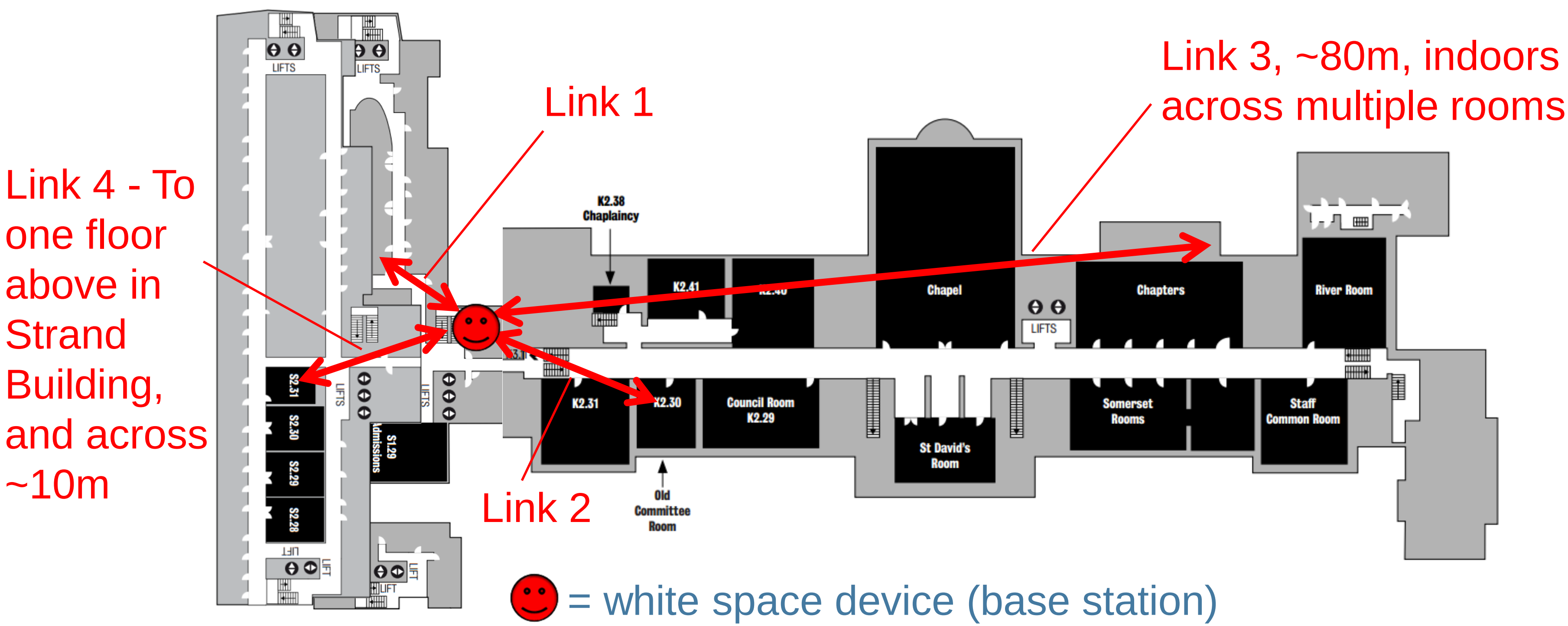
- 700m across River Thames, direct line of sight, although indoor at each end through challenging windows—not measured yet but loss through windows combined is at the *very least* 10 dB
- Only allowed to transmit at 31 dBm EIRP max at each end, using either channel 27 or 37 (the common channels at each end)
- Various speed tests using a range of tools/means: 0.1-1.7 Mbps d/l, 0.1-0.2 Mbps u/l
- Noted that there was quite a big variance with even small moves of the antennas
- Noted that Strand and Waterloo are perhaps some of the most challenging locations in the whole of UK for TV white space due to local PMSE usage (theatres, TV production, etc.)



ACROPOLIS
European NoE on Cognitive Communications
SOLDER

Indoor Strand

- Early tests at the Strand Campus of King's College London
- There is no channel at which maximum power can be used, although two channels in which 31 dBm (5 dB below maximum) can be used



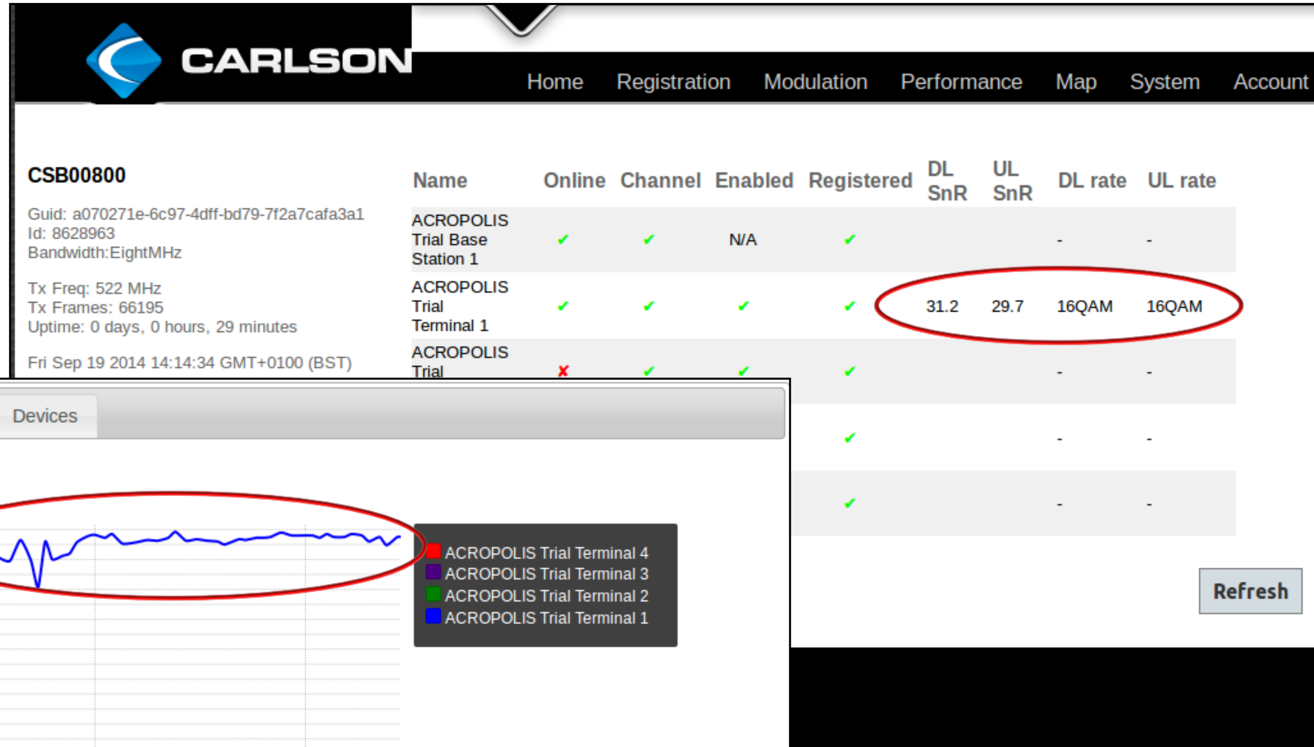
Indoor Strand

- Some very early analyses of a vast wealth of statistics! –Far more work to be done in the near future…!
- Link 1 (to Oliver's Office)
  - 16QAM with no coding - bit error rate typically 10^{-4}
- Rate performance
  - E.g., speedtest, 6.5-8.3Mbps downlink, and 2.6-3.2 Mbps uplink
  - Single 100Mbps file download, 92 seconds → 8.7Mbps average downlink
  - Noted that RuralConnect firmware has been updated and since then we are getting improved downlink of 10-11.5 Mbps; little noticeable improvement on uplink

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

Indoor Strand

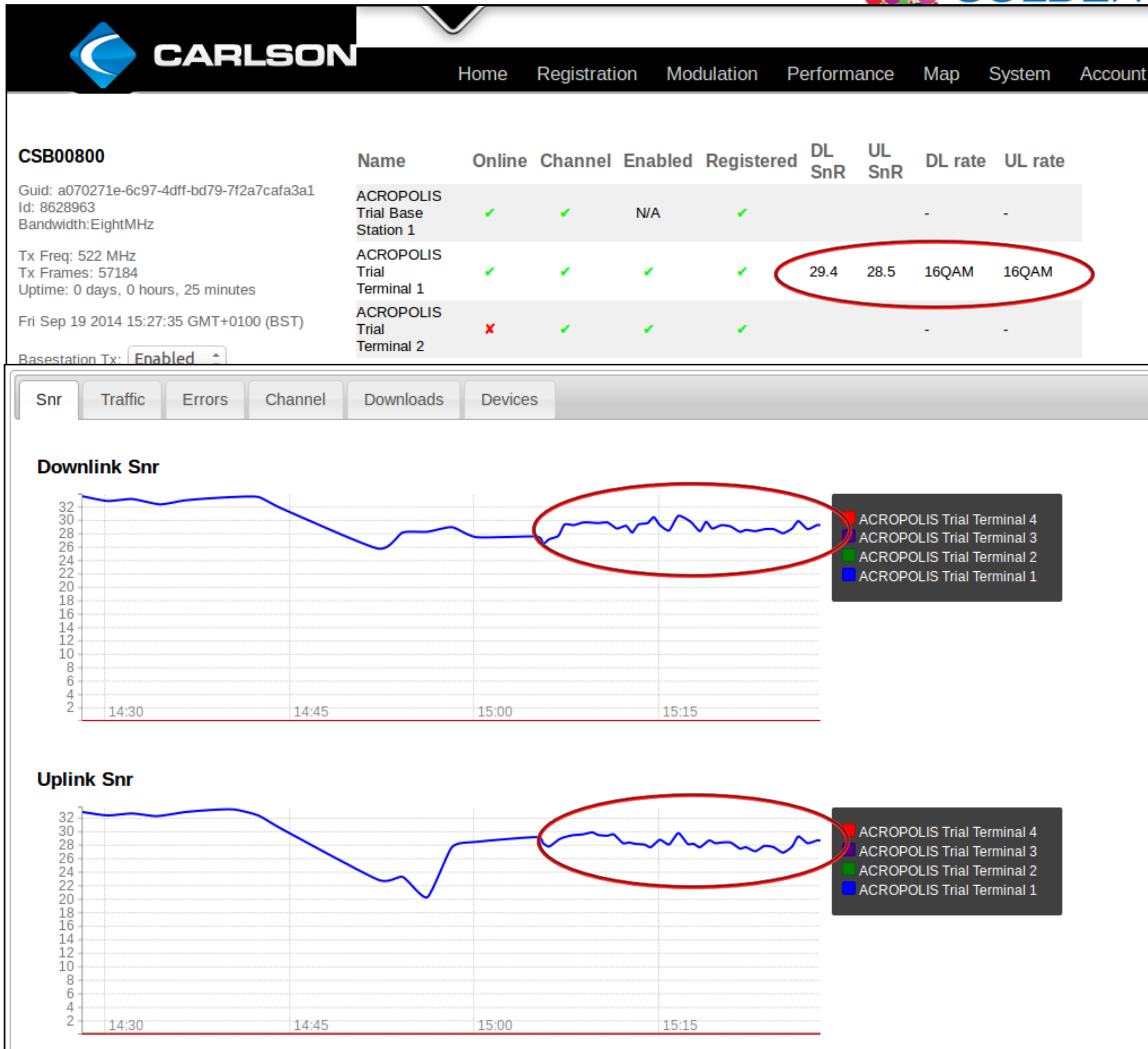
- Link 1 (to Oliver's Office)



ACROPOLIS
European NoE on Cognitive Communications
SOLDER

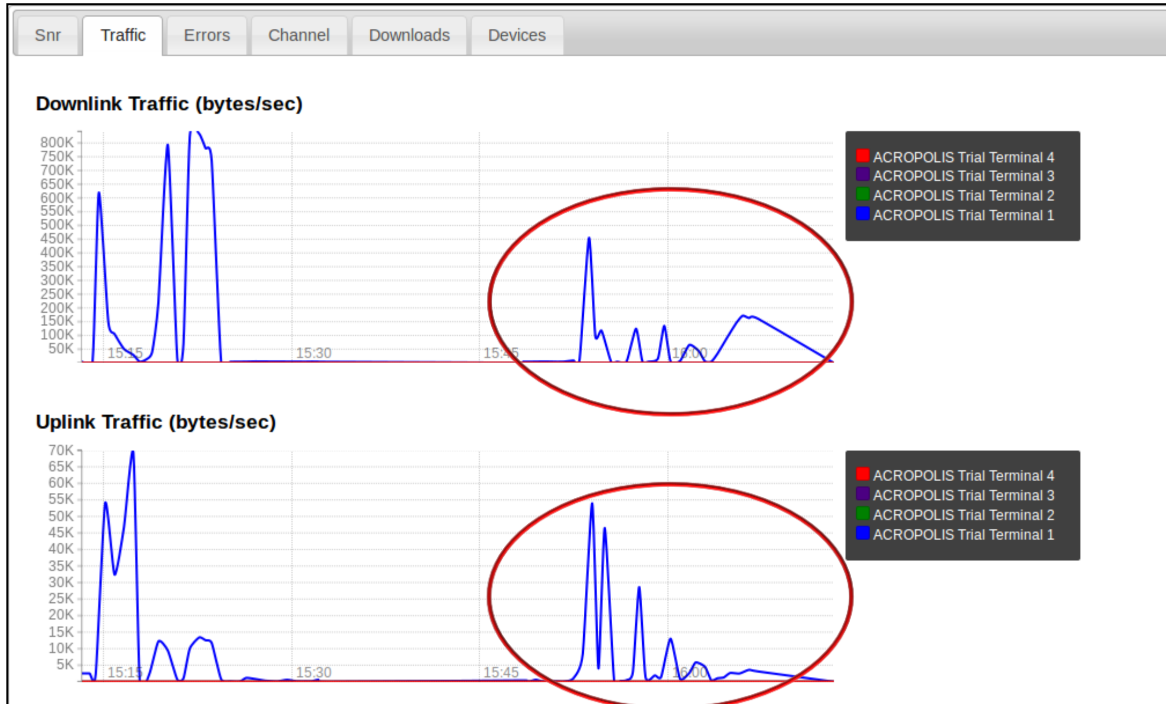
Indoor Strand

- Link 2 (to Old Committee Room)
- 5.7-9.9 Mbps d/l; 1.0-2.2 Mbps u/l
- 100MB download test, 138 seconds → 5.8 Mbps average
- Note, latter was after the link dropped to a lower modulation/coding rate



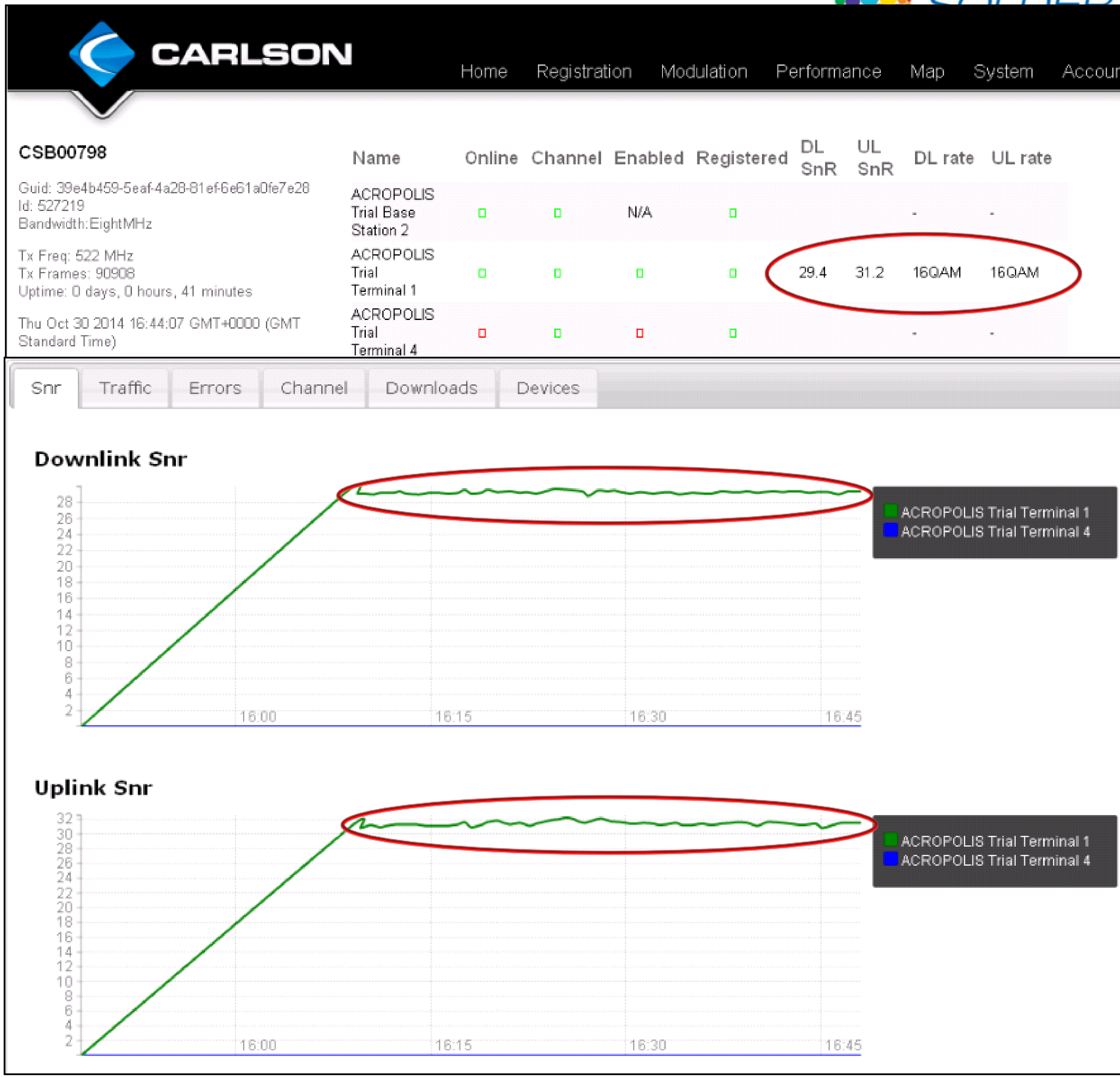
Indoor Strand

- Link 3 (to Refectory)
- 1.1-9.8 Mbps d/l; 0.1-1.2 Mbps u/l
- 20MB download test, 131 seconds → 1.2 Mbps
- Variance is due to testing extremely good as well as more average antenna positions; lower achieved rates are for average antenna position



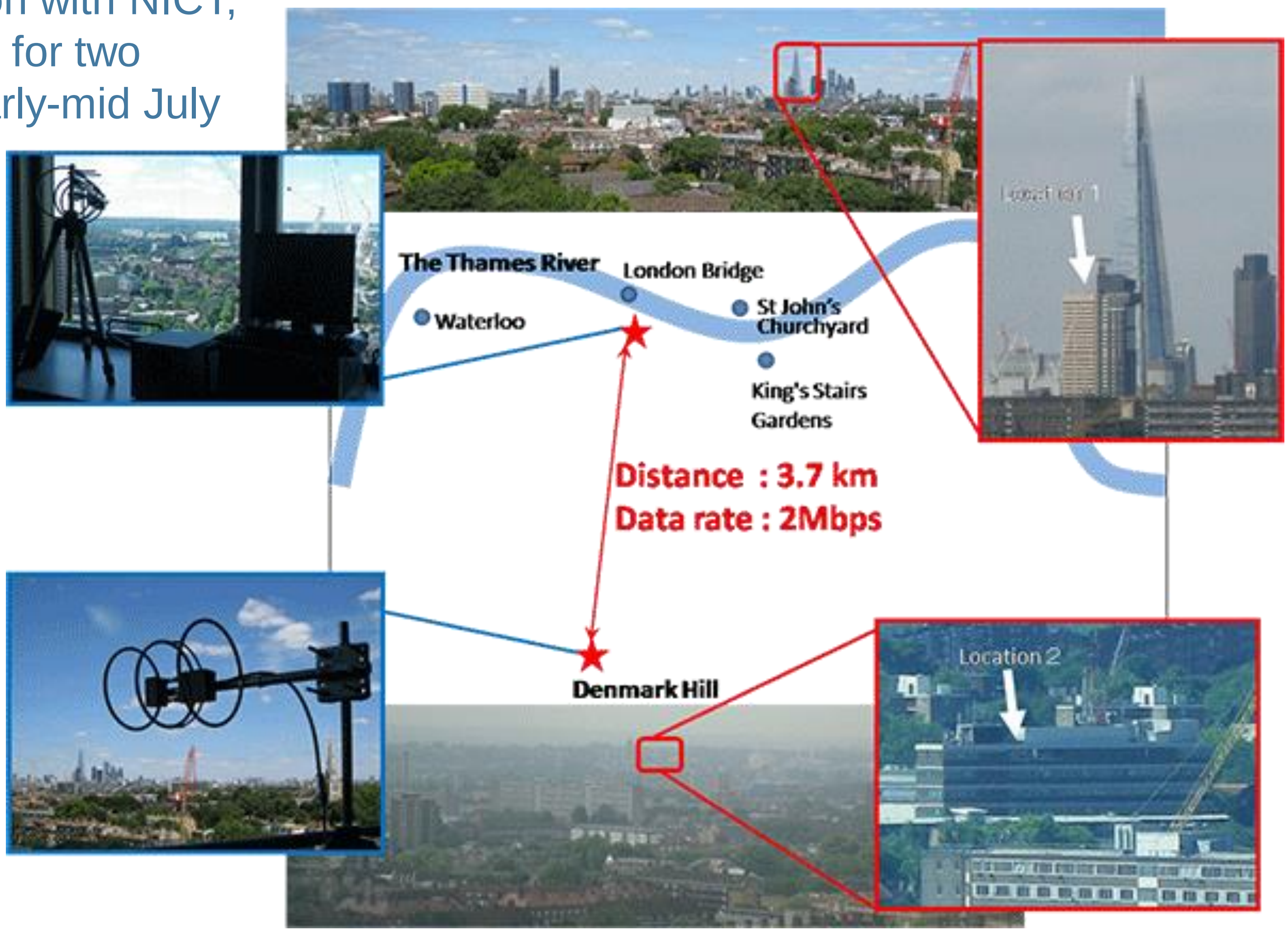
Indoor Strand

- Link 4 (to floor above and ~15m to the side in Strand, across several rooms)
- This time using the new firmware; also tested using a range of tools
- 10.9-11.6 Mbps d/l; 1.7-2.3 Mbps u/l
- 50MB download test, 40 seconds → 10 Mbps



NICT 802.11af (high/low power) and LTE in TVWS

- Collaboration with NICT, visiting KCL for two weeks in early-mid July



DVB-T Coexistence

- Created challenging scenarios for interfering with DVB-T
- DVB-T monitored by Wavecom Wavesys system
  - Also allows the recording of “transport streams” to see the effects on actual stream, as well as obtaining some various statistics
- Wavesys listening to DVB-T on Channel 25 or Channel 23
- White space device transmitting on adjacent Channel 24, at maximum allowed power of 33 dBm EIRP for that adjacent channel
- DTV reception antenna and white space transmission antenna mounted on the same pole, some 15cm apart from each other

ACROPOLIS
European NoE on Cognitive Communications

SOLDER

DVB-T Coexistence

- No noticeable effect on the DVB-T transport stream

  Without white space device transmitting DVB-T on channel 25:

  ts 0 33 20.vlan

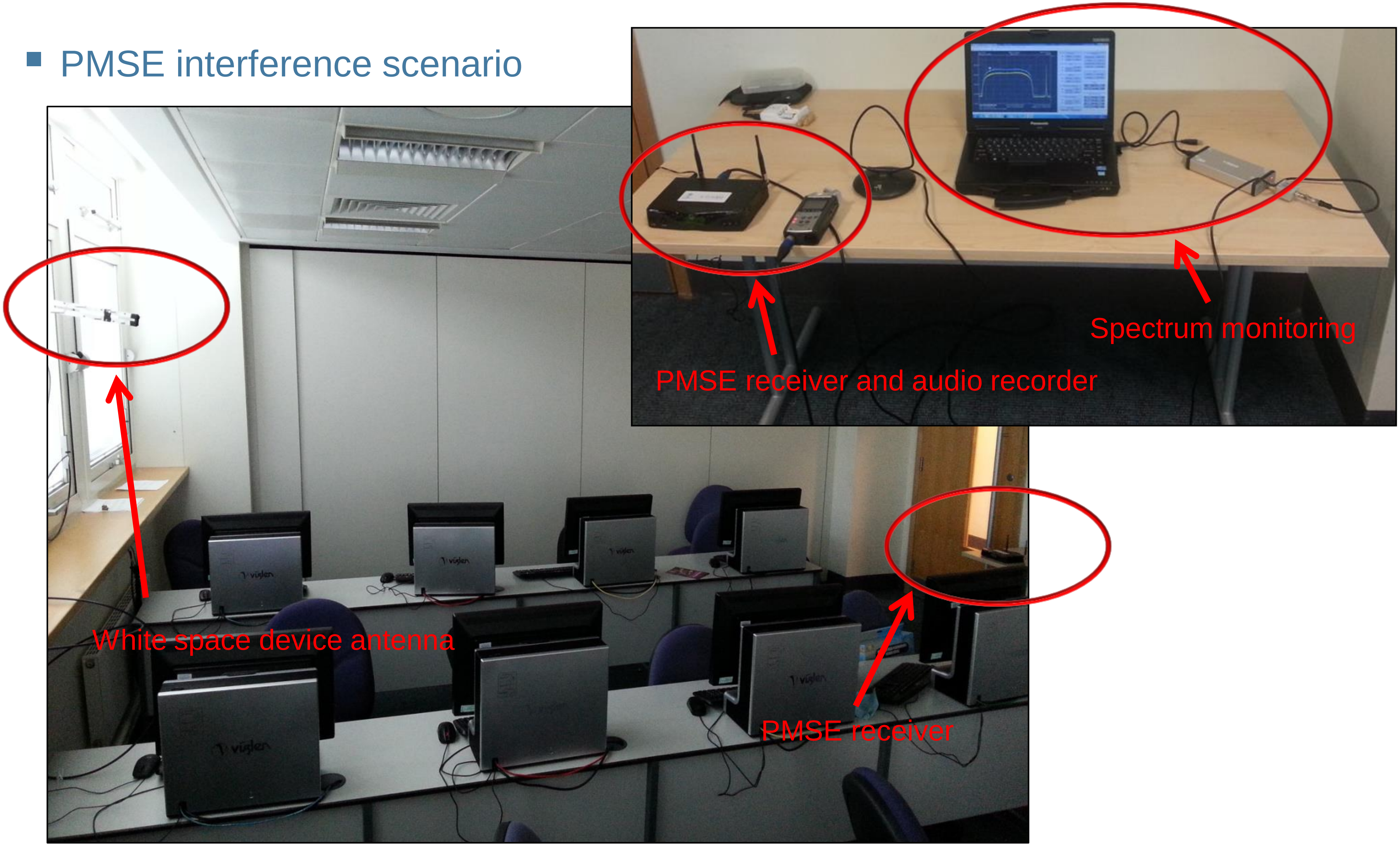
  With white space device also transmitting on channel 24:

  ts 0 39 26.vlan

- Also various statistics are available and being investigated for these cases

PMSE Coexistence

- PMSE interference scenario



ACROPOLIS
European NoE on Cognitive Communications
SOLDER

PMSE Coexistence

- No noticeable interference effects based on PMSE listening tests
- Will be expanded to large scale blind listenings and multiple choice questions of the recordings among a large number of students ,and statistical analysis of the blind listening tests
- An example (note, limiting factor in this presentation is likely the audio on my laptop and/or the audio system in the conference room…!)

  Without white space device transmitting: MONO-019.wav

  With white space device transmitting: MONO-027.wav

  For comparison, what interference (white space device on same channel as PMSE) sounds like: STE-037.wav
- Note, a video that is not in the public domain has been made explaining what was done – please ask me if you want access to it

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Conclusion

Conclusion

- Given high-level overview of TV white spaces in the UK
- Overviewed some aspects of our extensive series of trials within the Ofcom Pilot
  - Testing of many TV White Space devices and deployment scenarios
    - Interoperability and verification of/with a large number of geolocation databases
    - Testing of framework and certification for TV White Space in the UK/EU
  - Testing of many deployment locations
  - A number of research aspects being investigated and some early results obtained
  - Already some early interesting observations based on these scenarios

Acknowledgements – Key People (participants or collaborators)

- Led by
  - Oliver Holland – King's College London, UK
  - Pravir Chawdhry – Joint Research Centre of the European Commission, EU
  - Raymond Knopp – Eurecom, France

- Some other key people (may not be exhaustive)
  - Nishanth Sastry, Shuyu Ping, Reza Akhavan, Hong Xing – King's College London, UK
  - Florian Kaltenberger, Dominique Nussbaum – Eurecom, France
  - Jean-Marc Chareau, James Bishop, Michele Bavaro, Tiziano Pinato, Philippe Viaud, Emanuele Anguili – Joint Research Centre of the European Commission, EU
  - Juhani Hallio, Mikko Jakobsson, Jani Auranen, Reijo Ekman, Jarkko Paavola, Arto Kivinen – Turku University of Applied Sciences, Finland
  - Yue Gao, Zhijin Qin, Qianyun Zhang – Queen Mary University of London, UK
  - Ha-Nguyen Tran, Kentaro Ishizu, Keiichi Mizutani, Hiroshi Harada – NICT, Japan
  - Rogerio Dionisio, Paulo Marques – Institute of Telecommunications, Portugal
  - Heikki Kokkinen, Olli Luukkonen – Fairspectrum, Finland
  - David Grace – University of York, UK
  - Klaus Moessner – University of Surrey, UK
  - David Crawford – University of Strathclyde, UK
  - Andrew Stirling – Larkhill Consulting, UK

Key People Who have Participated in Getting Early Results So Far

- Oliver Holland, Nishanth Sastry, Shuyu Ping, Reza Akhavan – King's College London, UK
- Pravir Chawdhry, Jean-Marc Chareau, James Bishop, Michele Bavaro, Tiziano Pinato, Philippe Viaud – Joint Research Centre of the European Commission, EU
- Paulo Marques, Rogerio Dionisio, Jose Carlos Ribeiro – Institute of Telecommunications, Portugal
- Frank Gao, Zhijin Qin, Qianyun Zhang – Queen Mary University of London, UK

Acknowledgements – Key Projects

This work is supported by the ICT-ACROPOLIS Network of Excellence, FP7 project number 257626, www.ict-acropolis.eu, and ICT-SOLDER, FP7 project number 619687, www.ict-solder.eu. Some of the PMSE and DVB-T coexistence assessment aspects have been assisted by the ICT-CRS-i project, FP7 project number 318563, http://www.ict-crsi.eu

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Thank you!
Questions/discussion?

Oliver Holland
oliver.holland@kcl.ac.uk

Rome, Italy, 6 November 2014

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Back-up Slides

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

ACROPOLIS
SOLDER

Device-Database Communications

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

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

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

ACROPOLIS

European NoE on Cognitive Communications

SOLDER

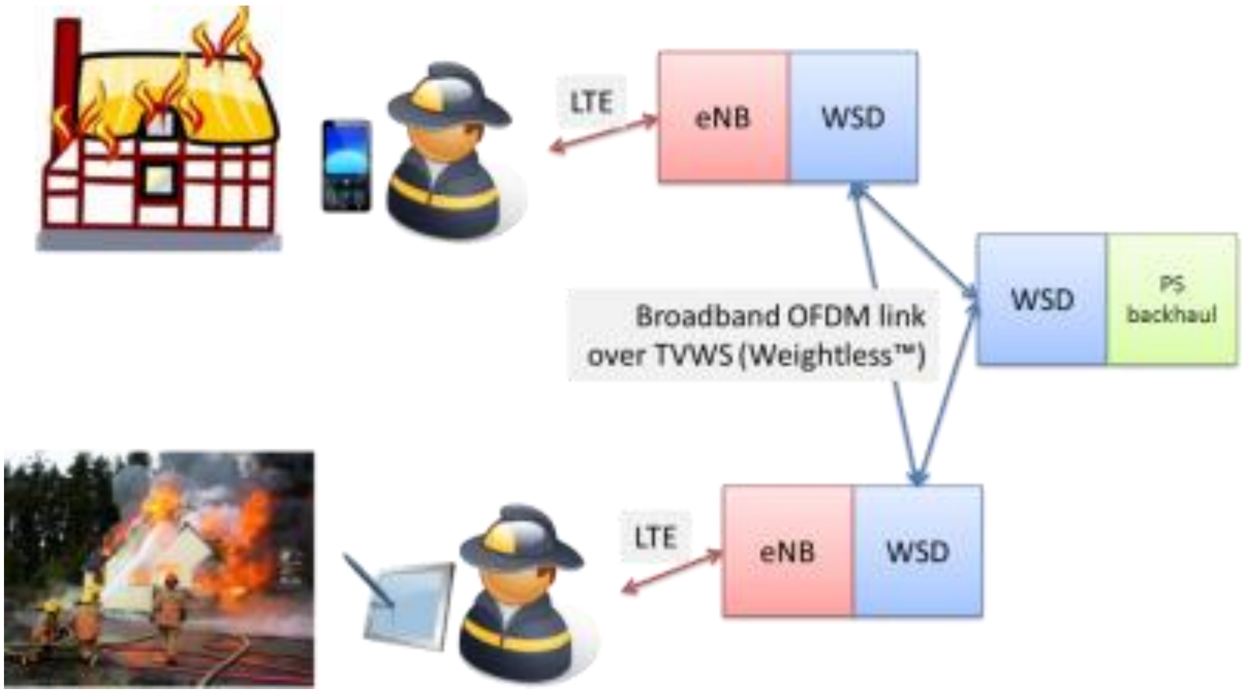
ACROPOLIS
SOLDER

Our Trial

Public Protection and Disaster Relief Scenarios

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- LTE femtocells + intercellular links in TV White Space
  - Quickly-deployable field solutions for emergency situations (e.g., enhanced provisioning or coverage extension to emergency workers)
  - Ad-hoc repair of communications links (e.g., backhaul) in disaster scenarios (e.g., earthquakes)



NICT Devices (collaboration with NICT—available for short durations)

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- Wireless mesh network deployment example at NICT, Yokosuka, Japan (*very* low Tx power in this case), also with graphical representation of the NICT database implementation


Locations

- London
  - King’s College London Strand
  - King’s College London Waterloo
  - King’s College London Denmark Hill
  - King’s College London Guys (London Bridge)
  - King’s College London St. Thomas’ (opposite Westminster)
  - King’s College London Hampstead
  - Queen Mary University of London
- Outside London
  - University of Surrey (Guildford)
  - University of York
  - Strathclyde University (Glasgow—under discussion)
  - Cambridge University
  - University of Bath
  - Leeds University (back-up)

The Trials Team

- ACROPOLIS Project
  - Led by
    - King’s College London, UK
    - The Joint Research Centre of the European Commission, EU
    - Eurecom, France
  - Also involving
    - RWTH Aachen University, Germany
    - Saints’ Cyril and Methodius University in Skopje, FYRoM
    - Poznan University of Technology, Poland
    - University of Rome “La Sapienza”, Italy
    - University of Piraeus Research Centre, Greece
    - Institute of Accelerating Systems and Applications, Greece
    - University of Surrey, UK
    - University of Leeds, UK

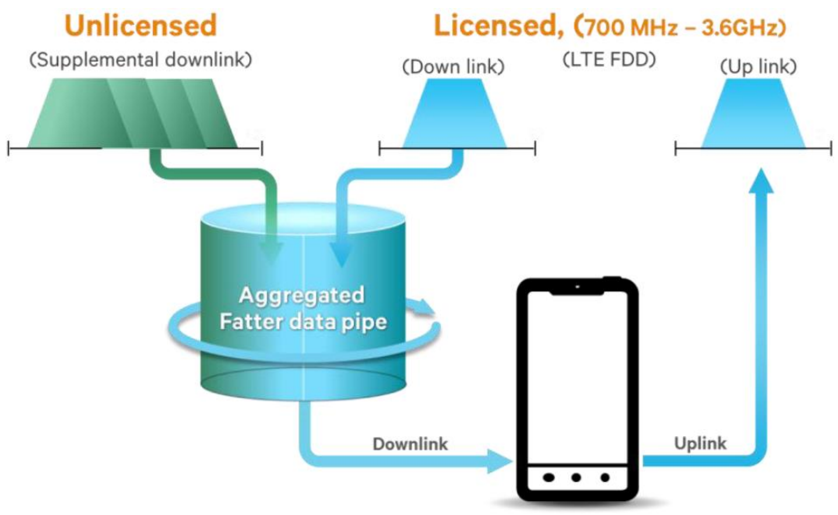
The Trials Team

- Extensive involvement of other projects, notably ICT-SOLDER (www.ict-solder.eu), ICT-CREW (www.crew-project.eu), Newcom# Network of Excellence (www.newcom-project.eu), ICT-CRS-i (http://www.ict-crsi.eu). Also numerous high-profile individual groups participating

- Following reflects both the above projects participants, and individual groups participating (not exhaustive)
  - Belgium: iMinds, IMEC
  - Finland: Fairspectrum, Turku University of Applied Sciences
  - Germany: Technical University of Dresden
  - Greece: Industrial Sciences Institute
  - Ireland: Trinity College Dublin
  - Italy: CNIT/Politecnic of Torino, Fondazione Ugo Bordoni, Create-Net
  - Japan: NICT, Sony
  - Portugal: IT/University of Aveiro, IT/University of Beira Interior
  - Slovenia: Jozef Stefan Institute
  - UK: Queen Mary University of London, University of York, University of Cambridge, University of Bath, University of Strathclyde/Larkhill, British Telecom, Nominet

Research Examples - Aggregation

- Solutions for Aggregation of resources/links (TVWS resources aggregated with licensed and unlicensed ISM, and channels aggregated in TVWS)
  - As well as assessing performances, to look at technical means of achieving aggregation compatible with ETSI/Ofcom rules (e.g., cross-band scheduling decisions, intelligent database assistance, etc.)
  - LTE in unlicensed spectrum (LTE-U) one among many interesting cases
  - Why not such a LTE-U supplemental downlink in TV White Space license-exempt spectrum opportunities?

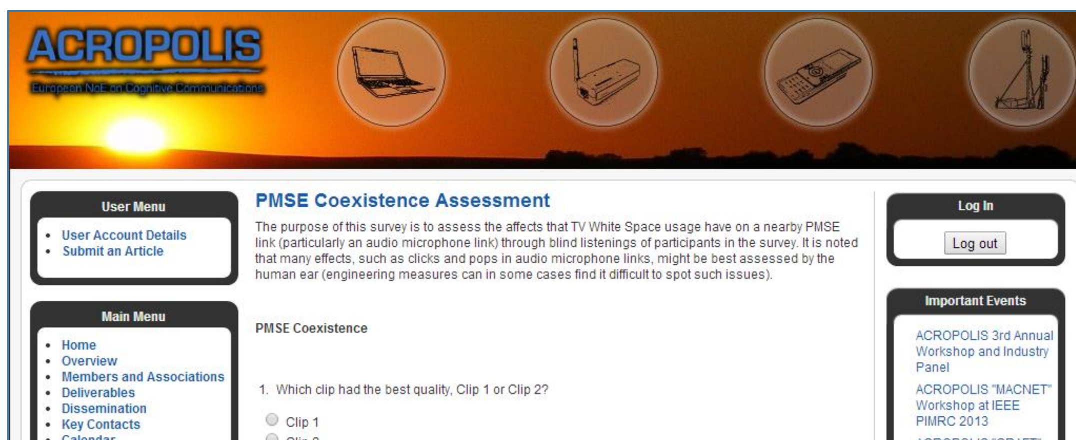


Qualcomm White Paper, "Extending LTE Advanced to Unlicensed Spectrum," December 2013

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

Research Examples – Primary Service Coexistence Assessment

- Dedicated equipment to look at effect on DTT, e.g., Wavecom devices
  - Signal Power, Modulation Error Rate, SINR, CINR, BER before Viterbi, BER after Viterbi, BER after Reed-Solomon, etc.
- Will devise challenging scenarios to interfere with DTT, within the scope of ETSI/Ofcom rules (e.g., indoor TV antennas in same room as white space device, saturating TV antenna amplifiers, etc.)
- Also plan to test interference with PMSE through our own PMSE equipment, again within Ofcom/ETSI rules. E.g., blind online surveys



Research Examples – Spectrum Monitoring and Statistical Inferences

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

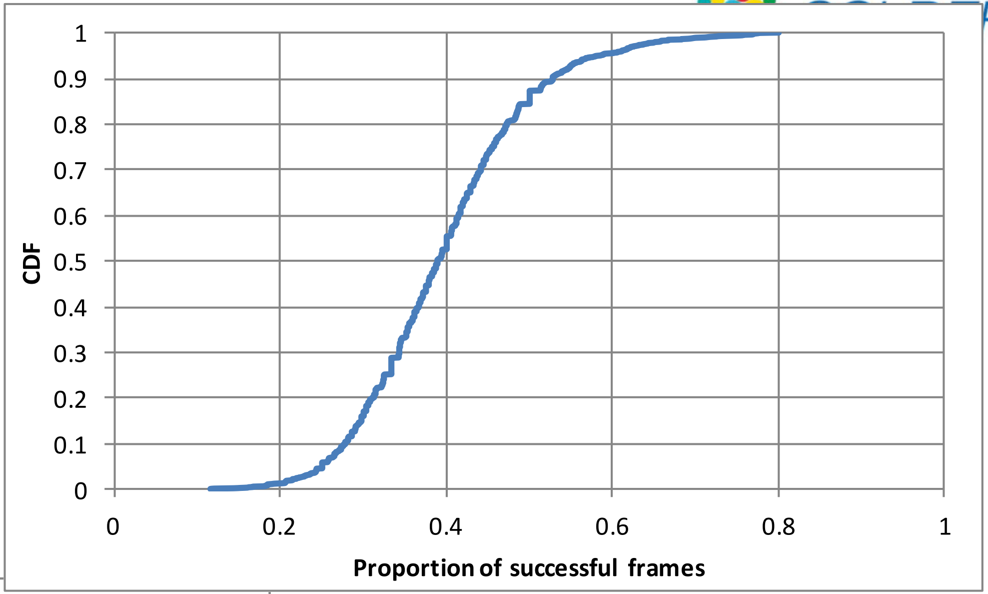
- Long-term fixed measurements or spatially distributed measurements, to assess the effects on the spectrum of TV White Space devices
  - Assessment of correlation aspects of spectrum usage both with and without white space devices present (useful for, e.g., assessing the spatial uncertainty in the effects on the spectrum) that white space devices may have
  - One monitoring location on roof of King’s College London Strand Campus

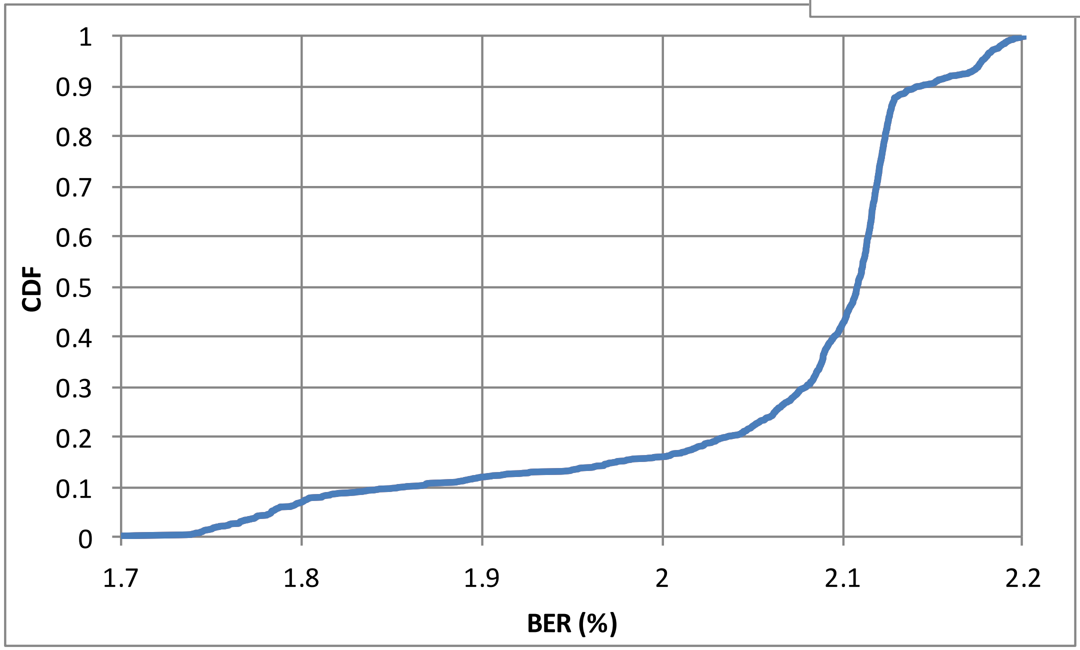
ACROPOLIS
SOLDER

Some (Still Relatively Early) Results: Long-Distance Links

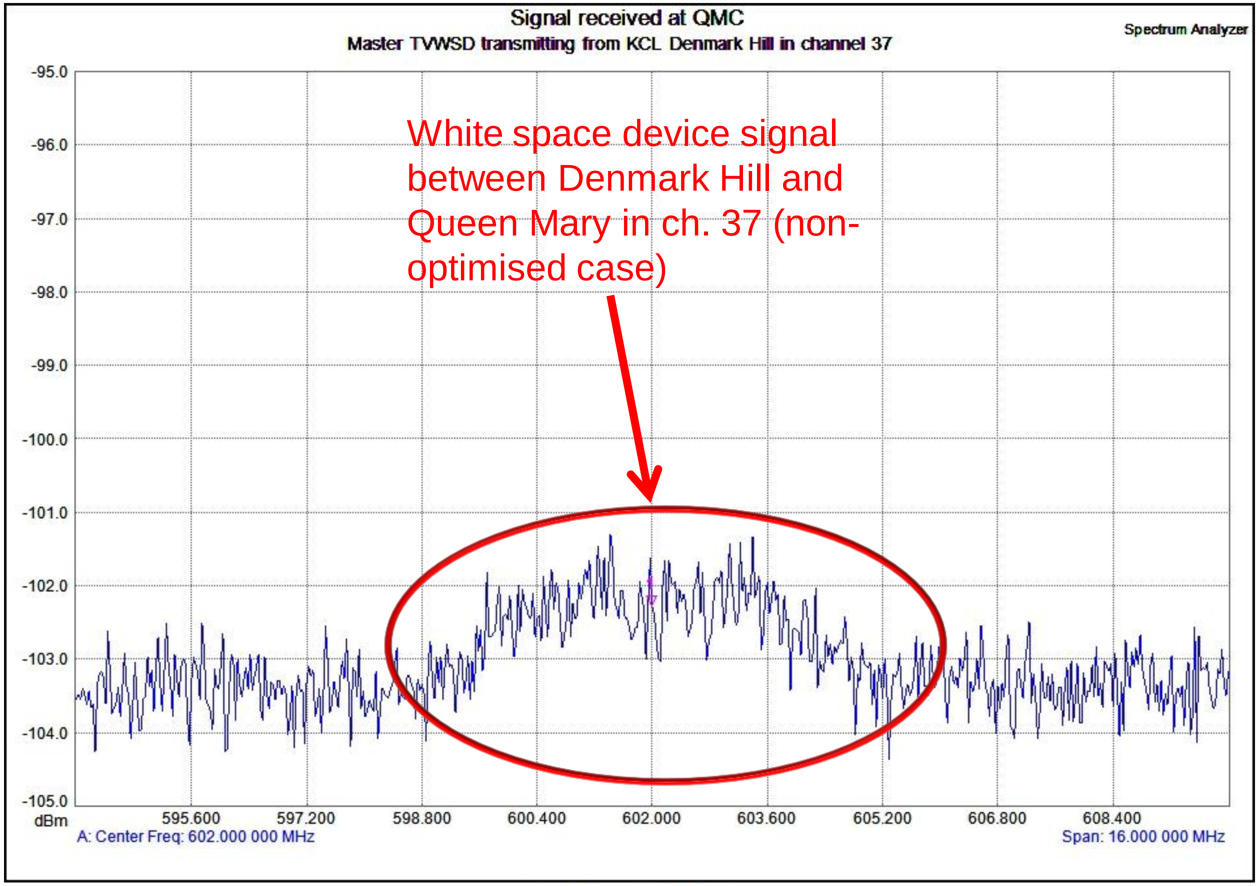
Long-Distance Links

- Denmark Hill to Queen Mary, BPSK ½
- One example





Long-Distance Links



Measurement Parameters

Trace A data:Trace Average	10	Frequency Span	16.000 000 MHz
Trace Mode	Average	Reference Level	-95.000 dBm
Preamp	OFF	Scale	1.0 dB/div
Min Sweep Time	5E-05 S	GPS Longitude	W 0 2 29
Reference Level Offset	0 dB	GPS Latitude	N 51 31 22
Input Attenuation	0.0 dB	GPS Fix Time	08 07 2014 11 02 58
RBW	30.0 kHz	Serial Number	942140
VBW	30.0 kHz	Base Ver.	V3.08
Detection	RMS	App Ver.	V4.15
Center Frequency	602.000 000 MHz	Date	8/7/2014 3:39:04 AM
Start Frequency	594.000 000 MHz	Device Name	ms2721b_01ri20090352874
Stop Frequency	610.000 000 MHz		

Long-Distance Links—Strand to Waterloo

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- Examples
- 31dBm EIRP each side

3.4	-0.4	BPSK ¾	BPSK ½

0.0	0.9	BPSK ¾	BPSK ½

d/l SINR u/l SINR d/l rate u/l rate

0.5	3.2	BPSK ¾	BPSK ¾

3.6	-0.5	BPSK ½	BPSK ½

0.7	1.0	BPSK ¾	BPSK ½

Channels 27 and 37 are common

Strand, BS

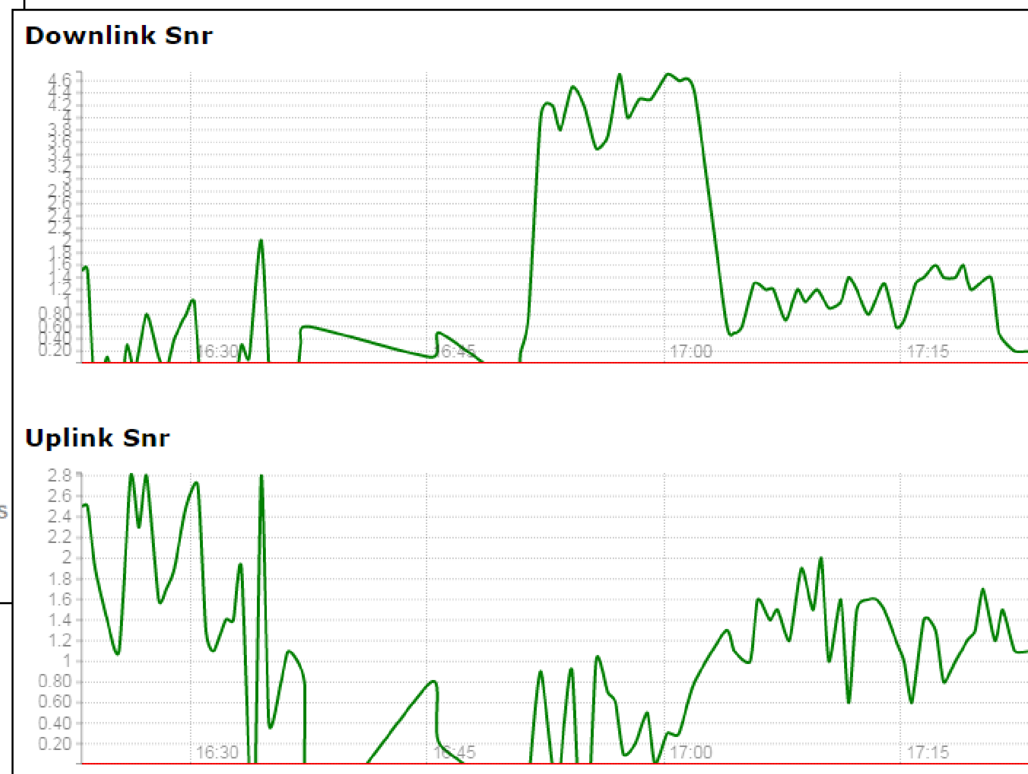
Name
ACROPOLIS Trial Base Station 1
Role
BaseStation
FccId
OPA-RC2-BS
Latitude
51.511911
Longitude
-0.116629
Antenna Height (m)
25
Notes

WSDB Access
Registration state
Registered
Status of last database access
Channels successfully retrieved
Time of last registration attempt
10/13/2014 1:38:00 PM
Channels returned on last database access
522,578,602
Time of last channel fetch
10/13/2014 5:28:00 PM

Waterloo, CPE

Name
ACROPOLIS Trial Terminal 2
Role
Client
FccId
OPA-RC2-CPE
Latitude
51.505905
Longitude
-0.112516
Antenna Height (m)
20
Enabled
✓
Notes
CST00801

WSDB Access
Registration state
Registered
Status of last database access
Channels successfully retrieved
Time of last registration attempt
10/13/2014 1:39:00 PM
Channels returned on last database access
498,522,602,674,682
Time of last channel fetch
10/13/2014 5:29:00 PM



ACROPOLIS
European NoE on Cognitive Communications
SOLDER

ACROPOLIS
SOLDER

Some (Still Relatively Early) Results: NICT Devices

NICT 802.11af (high/low power) and LTE in TVWS

ACROPOLIS
European NoE on Cognitive Communications
SOLDER

- Collaboration with NICT, visiting KCL for two weeks in early-mid July
- Over 2Mbps achieved across our link from KCL Denmark Hill to KCL Guys (exactly the same scenario as mentioned on previous slides)
  - High-power 802.11af device
- Over 40 Mbps local provisioning using LTE system over three contiguous TV White Space channels in Central London (KCL Guys, London Bridge)

ACROPOLIS
SOLDER

Some (Still Relatively Early) Results: PMSE Coexistence

PMSE Coexistence

- Transmitting white space device at maximum allowed power (31 dBm in this case), with PMSE in the main lobe on the adjacent channel at 5m distance from the white space device antenna, PMSE tuned as close as possible to the channel of the white space device on the adjacent channel
- Using analogue FM PMSE, which would be directly (audibly) affected by interference
- PMSE transmitter approximately 6m away from receiver – also tested for highly attenuated / low receive power PMSE scenario (>20dB additional attenuation) by placing PMSE transmitter behind a metal box
- Recorded audio over the PMSE link using audio test files, with and without white space devices transmitting, for blind listening tests
- A video has been made explaining exactly what was done, although not in public domain – please inform if you wish to have access to it