A Series of Trials in the UK as part of the Ofcom TV White Spaces Pilot

Oliver Holland, Nishanth Sastry, Shuyu Ping
Centre for Telecommunications Research
King's College London
London, UK
{oliver.holland, nishanth.sastry, shuyu.ping}@kcl.ac.uk

Raymond Knopp, Florian Kaltenberger, Dominique Nussbaum
Eurecom
Sophia Antipolis, France
{raymond.knopp, florian.kaltenberger, dominique.nussbaum}@eurecom.fr

Juhani Hallio, Mikko Jakobsson, Jani Auranen, Reijo Ekman, Jarkko Paavola, Arto Kivinen
Turku University of Applied Sciences
Turku, Finland
{juhani.hallio, mikko.jakobsson, jani.auranen, reijo.ekman, jarkko.paavola, arto.kivinen}@turkuamk.fi

Ha-Nguyen Tran, Kentaro Ishizu, Hiroshi Harada
Smart Wireless Laboratory
National Institute of Information and Communications Technology (NICT)
Yokosuka, Kanagawa prefecture, Japan
{haguen, ishidu, harada}@nict.go.jp

Pravir Chawdhry, Jean-Marc Chareau, James Bishop, Michele Bavaro, Emanuele Anguili
Institute for the Protection and Security of the Citizen
Joint Research Centre of the European Commission
Ispra, Italy
{pravir.chawdhry, jean-marc.chareau, james.bishop, michele.bavaro, emanuele.anguili}@jrc.ec.europa.eu

Yue Gao
School of Electronic Engineering and Computer Science
Queen Mary, University of London
London, UK
yue.gao@qmul.ac.uk

Rogerio Dionisio, Paulo Marques
Institute of Telecommunications
Aveiro, Portugal
{rdionisio, pmarques}@av.it.pt

Heikki Kokkinen, Olli Luukkonen
Fairspectrum Oy
Helsinki, Finland
{heikki.kokkinen, olli.luukkonen}@fairspectrum.com

***Abstract*—TV White Spaces technology is a means of allowing wireless devices to opportunistically use locally-available TV channels (TV White Spaces), enabled by a geolocation database. The geolocation database informs the device of which channels can be used at a given location, and in the UK/EU case, which transmission powers (EIRPs) can be used on each channel based on the technical characteristics of the device, given an assumed interference limit and protection margin at the edge of the primary service coverage area(s). The UK regulator, Ofcom, has initiated a large-scale Pilot of TV White Spaces technology and devices. The ICT-ACROPOLIS Network of Excellence, teaming up with the ICT-SOLDER project and others, is running an extensive series of trials under this effort. The purpose of these trials is to test a number of aspects of white space technology, including the white space device and geolocation database interactions, the validity of the channel availability/powers calculations by the database and associated interference effects on primary services, and the performances of the white spaces devices, among others. An additional key purpose is to undertake a number of research investigations such as into aggregation of TV White Space resources with conventional (licensed/unlicensed) resources, secondary coexistence issues and means to mitigate such issues, and primary coexistence issues under challenging deployment geometries, among others. This paper describes our trials, their intentions and characteristics, objectives, and some early observations.**

Keywords—TV white spaces, geolocation databases, field trials, experimentation

I. INTRODUCTION

Originating from regulatory soundings in the early 2000's, TV White Spaces (TVWS) technology has been a hot research topic ever since the FCC produced its initial opinion on rules for TVWS Devices (WSDs) in November 2008. After much regulatory tweaking [1], [2], and the initial deployments of such devices taking place in the US, Europe is now following with the finalization of rules and the testing of TVWS technology and WSDs on a large scale [3], [4], [5], [6]. This is particularly driven through the UK regulator Ofcom's instantiation of a large pilot of the devices and the underlying enabling technology [6]. Of course, all trials within this pilot must be based on Ofcom's prospective rules for WSDs, which are reflected in the ETSI 301 598 harmonized standard for WSD requirements at the European level [5].

The rules for TVWS in the UK/EU are very different from those in the US. In the US, a fixed maximum power (EIRP) is assumed for all WSDs, as authorised to transmit by a geolocation database (GDB). This fixed power has the benefit of providing more certainty on the performance that will be achieved by the WSDs as experienced by the end-user, however, its high (fixed) value vastly increases the number of locations for which unacceptable interference would be caused to the primary service in a given channel. This constrains the locations in which WSDs are allowed to operate for a given channel, or conversely, the number of channels that can be used at a given location.

The UK/EU rules, on the other hand, allow the GDB to decide on the maximum power (EIRP) that a WSD can use in a given channel and location. The UK/EU rules do this based on information that is inferred about the WSD in its request to operate at the given location, such as on its spectrum mask class of performance (this is inferred by the GDB based on its conveyed model number), elevation, and other characteristics. The GDB calculates the power that can be used in each channel based on its implied interference to the edge of the primary service area, under the assumption of a given interference limit plus a protection margin for the primary service at that edge of coverage. Under the UK/EU rules, it is therefore likely that WSD will be allowed to operate in far more locations for a given TV channel than would be the case for the US rules, albeit likely at far lower allowed transmission EIRPs in those locations for which devices would otherwise not be allowed to transmit under the US rules. Further, lower quality hence cheaper WSDs with less challenging RF spectrum masks can be used under the UK/EU model, through their allowed transmission power being reduced to take into account adjacent channel interference implications of their lower-quality spectrum mask Class specifications.

Under the UK/EU rules, embodied in the device requirements of ETSI 301 598 [5], the Ofcom Pilot aims to serve a number of purposes:

- Provision a proof of concept of the TVWS framework.
- Provision of a step of verification before full-scale TVWS operations start.
- Involvement of the regulator, industry, and end users in the process, such that the interactions between the relevant stakeholders can be verified.

The Ofcom Pilot also aims to test several aspects, such as:

- Device operations.
- Database contract qualification.
- Database operation and calculations.
- Ofcom's provision of the qualifying database listing.
- Ofcom's DTT calculation results and provision of Programme Making and Special Events (PMSE) data.
- Interference management.
- Coexistence.

In practice, this further includes verification of a number of aspects, such as the methodology for testing of the WSDs RF performances, the methodology for testing of their interactions with Ofcom's "database of GDBs" and selection of the appropriate GDB to use, the methodology for testing of WSD interactions with the GDB (including aspects such as security of interactions), the methodology for testing the correct operation of WSDs (e.g., RF channel/power settings based on information from the GDB, ceasing to transmit when communication with the Ofcom "database of GDBs" or the GDB itself is not successfully carried out, changing of RF channels and powers if necessary, in response to changed information from the GDB, etc.), the methodology for monitoring interference levels and the correctness of interference levels around deployments of WSDs under the Ofcom Pilot, the assessment of any possible effects on primary services, and verification of security precautions, among other aspects. The correct performance of all of these elements is essential to the assurance of the viability of the wider picture of TVWS technology and the confidence that the regulator is able to authorize a move of such a technology to commercial use within its domain.

Our trials within the Ofcom Pilot are the subject of this paper. Some of our conformance testing work is described in Section II, and our range of WSDs is described in Section III. The locations that are being investigated are in Section IV. Section V discusses the deployment and performance testing scenarios, and research topics that we are investigating. Section VI concludes.

II. CONFORMANCE TESTING

Ofcom, as a key purpose of the trials, is perhaps most interested in testing the validity of the underlying TVWS technology (e.g., the GDBs and interactions thereof) and the conformance of WSDs with certification requirements. This serves the key interest of the regulator in ensuring that the spectrum of primary services is adequately protected.

It is a requirement for all triallists participating in the Ofcom TVWS pilot to certify their devices are performing according to ETSI 301 598, both in terms of RF aspects and in terms of logical aspects such as communication with the GDB and appropriate setting of parameters in accordance with responses from the GDB. Reaching even beyond such requirements, our trials have very strong capabilities and are undertaking a range of work for such conformance testing.

A wide range of equipment is available for conformance testing as a part of the ICT-ACROPOLIS led trials. Some of the equipment, in particular the Rohde and Schwarz FSV series of spectrum analysers, for example, available at King's College London and at the Joint Research Centre of the European Commission, is able to perform measurements such on Adjacent channel Frequency Leakage Ratios (AFLR) directly, as configured by the user. This is a useful option to confirm performance in terms of the spectrum mask ("Class" of device, as specified by Ofcom/ETSI) and compare with the ETSI 301 598 specified procedure, noting that ETSI 301 598 specifies that the spectrum analyser should merely be set to sweep the spectrum and output the observed values at a

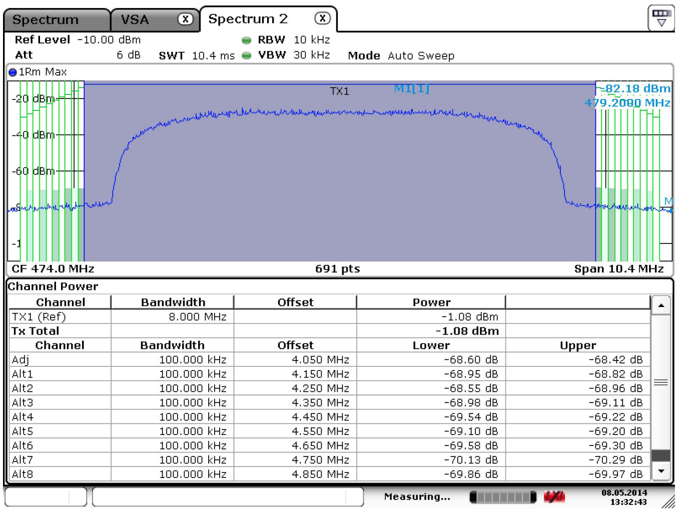

Fig. 1. Example of adjacent channel emissions measurements performed by a spectrum analyser (AFLR per each 100 kHz compared with the intended channel power in 8 MHz).

resolution bandwidth (i.e., in chunks) of 10 kHz, which must then be manually processed to assess the RF performance of the WSD using a more complicated procedure. This procedure means that, for the purpose of conformance assessment of WSDs, the key parameter of interest is the sensitivity of the spectrum analyser (aside from other more obvious important parameters, such as accuracy and distortion performance, and ability to set the resolution bandwidth (RBW) correctly to 10kHz, among others). In practice, maximum input levels to most spectrum analysers, in conjunction with RF output levels of WSDs of typically much less than 30 dBm, mean that only minimal attenuation, or in some cases zero attenuation, is necessary—implying that the dynamic range that the device is capable of is usually less of a consideration. It should be noted, however, that increasing attention on the input also increases the noise floor in equal measure, so the dynamic range is sometimes of a limited consideration, dependent on the sensitivity of the analyzer. Further, it is noted that the ACLR measurements for performance Classes 1 and 3 are very challenging, typically requiring a high sensitivity spectrum analyser to measure down to -84 dB from the power in the intended channel.

In terms of RF performance, Ofcom/ETSI specify 5 performance classes (Table 1, see p. 15 of [5] for more detail). These performance classes compare power in the intended channel of width 8 MHz with power outside of the intended channel in 100 kHz chunks, and specify requirements in terms of the intended channel emissions ±1, ±2, and ±3 channels, with limits further out from ±3 channels being equal to those for the ±3 channel. The measurement example in Figure 1, performing the ACLR measurement directly on the spectrum analyzer for a limited subset of the 100 kHz bandwidths in the adjacent channel as opposed to the procedure specified in [5], shows one clear example of one of our WSD achieving Class 3 performance for the adjacent channels (i.e., ±1 from the intended channel). This same device was ascertained to easily meet Class 1 requirement in terms of ACLR for channels ±2 and ±3.

TABLE I. OFCOM/ETSI AFLR REQUIREMENTS IN TERMS OF THE MINIMUM POWER REDUCTION RATIO IN EACH 100 KHZ COMPARED WITH THE POWER IN THE 8 MHZ INTENDED CHANNEL [5].

Where P_{OOB} falls within the nth adjacent DTT channel (based on 8 MHz wide channels)	AFLR (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

It is noted that Ofcom also specifies stringent requirements for assessment of emissions outside of the TV bands, i.e., outside of the 470 MHz to 790 MHz for the range from 30 MHz up to 4 GHz. Importantly, these are fixed for all devices and not dependent on different classes of performance. Our trials have assessed such emissions and found devices to be generally compliant, however, there can sometimes be issues with conformance close to the edges of the TV bands if the WSDs are transmitting on the TV channels closest to those edges. Practically however, all of the WSDs we consider have their upper frequency limit some distance away from the 790 MHz upper end of the TV spectrum in the UK—this is most commonly because they were originally developed for operation in other countries such as the US and Japan with different ranges for TV spectrum.

III. TV White Space Devices

Our trials have amassed a wide range of devices for use. These include:

- Three different forms of WSDs created by collaborators at NICT, Japan, namely:
    - 2 IEEE 802.11af high-power variant WSDs (see, e.g., [7]).
    - 3 IEEE 802.11af low-power variant WSDs [7].
    - 3 TD-LTE base station and 3 TD-LTE terminal WSDs (see, e.g., [8]).
- At least 3 WSDs that are based on Eurecom ExpressMIMO2 software radios [9], driven by OpenAirInterface LTE-MBMS waveforms (and perhaps, at a later stage, IEEE 802.11af and other waveforms) [10].
- Carlson RuralConnect devices [11], comprising at least 2 base stations and 5 consumer premises equipment, which use a proprietary waveform.
- A number of KTS/Sinecom Agility White Space Radio [12] WSDs, which use a proprietary waveform.

Figure 2 depicts some of the devices that are used in our trials. Particularly discussing the ExpressMIMO2/OpenAirInterface solution in Figure 2(a), this is notable for achieving Class 1 characteristics, the only WSD participating in the Ofcom Pilot that we are aware of that achieves Class 1 (all other WSDs achieve somewhere between Class 3 and Class 5, with the achievement of Class 3 by some of them being debateable). Eurecom with KCL have set out from the start to achieve a Class 1 LTE base station, where a number of challenges have been realised in that process, highlighting the difficulty that manufacturers will face towards

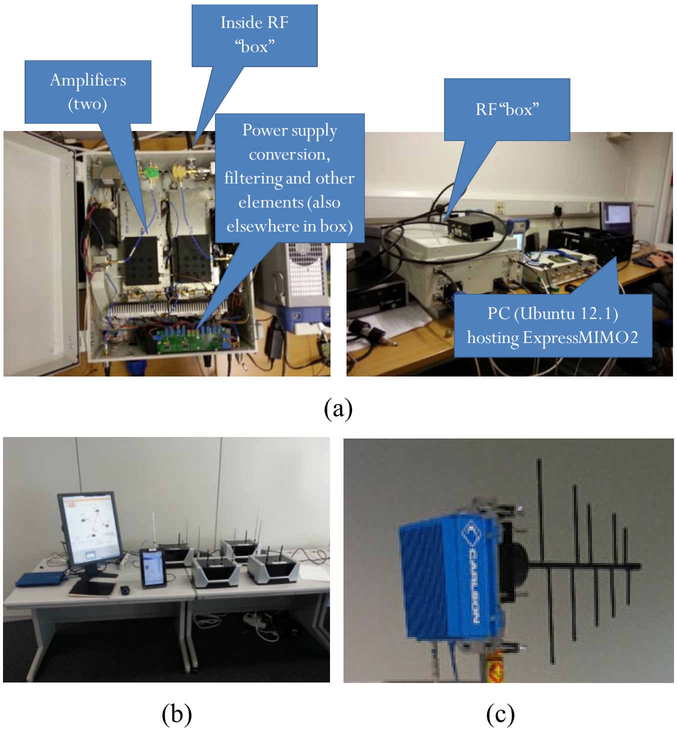

Fig. 2. Some of the devices being used in our trials: (a) Eurecom ExpressMIMO2-based solution, incorporating a PC with an ExpressMIMO2 software radio card incorporated and a separate custom-built RF, (b) NICT low-power 802.11af devices operating in a mesh network configuration, and (c) a Carlson RuralConnect consumer premises equipment.

such ends. As a first issue, achieving the required linearity of amplification over a high peak-to-average power signal such as LTE is challenging, in our case requiring a custom-made amplifier to be developed that has an extremely large back off which can hence can remain linear enough at the required signal levels to achieve amplification without degrading to Class 3. As a next challenge, minor spurious emissions were witnessed from the ExpressMIMO2 card, in approximately the range of 400-600 MHz, immediately reducing the solution once again to Class 3. To overcome this, it was decided to produce the pre-amplification signal at a higher frequency, then filter it with a very precise band-pass filter, then down-convert the resulting signal to the intended TV channel using an additional RF chain on the ExpressMIMO2 card as a Local Oscillator (LO), noting that the ExpressMIMO2 has 4 RF chains each of which are both transmit and receive. This was still found to not achieve Class 1, due to the characteristics of the LO. Hence, finally, it was decided to use dedicated hardware for the LO, controlled by the PC hosting ExpressMIMO2 and running the OpenAirInterface LTE waveform. This solution just achieves Class 1. It is noted that the down-conversion process produces an image of the signal at the frequency of the difference and the sum of the LO and generated signal frequency, however, the sum image is filtered out by dedicated filters within the custom-made amplifier.

A further observation that has become apparent in developing the ExpressMIMO2-based Class 1 solution, and in testing the other equipment, is that the devices typically will easily achieve Class 1 performance at ±2 and ±3 or more from the intended transmission channel, even if they only achieve Class 3 performance at ±1 from the intended channel. In fact, our trials have discussed the value of Ofcom maintaining the Class 2 specification, which seems to not easily match to any typical WSDs that are currently being developed. One recommendation that our trials therefore have is that the Class 2 specification be adapted to better suit some WSDs and therefore allow the WSDs to take advantage of more spectrum opportunities and/or higher powers through achieving operation at Class 2 instead of Class 3.

IV. Deployment Locations

A key consideration in the TVWS Pilot is to investigate performance at a wide range of locations. Given that our ICT-ACROPOLIS led trials are driven by academics and research-institutes, a very large number of University campuses are being taken advantage of for usage as a part of the trials. These include:

- Numerous locations at King's College London campuses, including the Strand, Waterloo, Guys (London Bridge), St. Thomas (opposite Westminster), Denmark Hill, and Hampstead Campuses, possibly in addition to others available to King's College London.
- Further, sites at:
    - Queen Mary University of London (East London).
    - University of York.
    - University of Surrey (Guildford).
    - Strathclyde University (Glasgow).
    - Cambridge University.
    - University of Bath.

Importantly, these locations range from some of the most challenging that it is possible to envisage for operation of WSDs in the UK, such as at the Strand, close to perhaps the most extensive licensed PMSE usage in the world through West-End theatres, concert halls, television studios, etc. (indeed, due to the challenges it is aimed for such locations to be a longer-term objective, to avoid PMSE interference risk as Ofcom finalizes its rules), to far less busy cases such as at the University of York with a large coverage of a mainly rural, low population-density area—particular in the South-East direction from the campus. Moreover, rooftop sites at numerous locations, including the Strand, Waterloo, Denmark Hill, Queen Mary University of London, and others such as the aforementioned University of York, allow for both the investigation of relatively large-area provisioning in TVWS, and the option of point-to-point links, for example, to provide enhanced backhaul. One such example of a direct line-of-sight point-to-point link that our trials are investigating is between a rooftop site at the King's College London Denmark Hill Campus in South-East London, and a rooftop site at Queen Mary University of London in East London, covering a distance of approximately 7 km.

In addition to the wide-area coverage and point-to-point scenarios involving rooftop transmissions or installations, it is noted that numerous other likely scenarios for WSD deployment are covered by our trials and the range of locations available, including indoor coverage and indoor-to-outdoor coverage with a range of building characteristics, and of course a range of building characteristics and geometries with which to study outdoor-to-indoor coverage provision.

V. Deployment and Performance Testing Scenarios, and Research Topics

Our trials are investigating a large number of deployment and performance testing scenarios, attempting to both play to the strengths of the wide range of WSDs that we have available, and to test a diversity of challenging cases for WSDs deployment. The following scenarios are anticipated:

- LTE Multicast/broadcast (eMBMS), using the Eurecom ExpressMIMO2/OpenAirInterface SDR equipment/software, and extensions to that. A range of transmission coverage scenarios will be investigated, from wide-area rooftop to relatively limited area (indoors or ground level), dependent on the deployment locations and associated characteristics.
- TD-LTE in TVWS, using NICT LTE WSDs. Moderate coverage ranges are anticipated to be investigated.
- Broadband for Public Protection and Disaster Relief (PPDR), LTE+TVWS, using Carlson Wireless WSDs.
    - This case also involves the investigation of point-to-point links in TVWS, as might provide emergency backhaul in PPDR scenarios.
    - A further case, video surveillance using Carlson WSDs, is also being investigated.
- WiFi in TVWS (802.11af draft), using NICT devices. It is an aspiration of the Eurecom OpenAirInterface software to also be enhanced to support this, although uncertain whether that will be achieved.
    - Conventional wireless local-area coverage using low-power WiFi, based on NICT devices.
    - High-power WiFi for direct point-to-point links, again serving PPDR among other scenarios, based on NICT devices.
- M2M implementations, using KTS/SineCom devices. More specifically, smart city-wide networking based on those devices.
- Broadband provisioning using KTS/SineCom devices and Carlson Wireless devices.

Being driven by academics and research institutes, a very strong emphasis is put on the research elements of our trials. The research studies that are being undertaken include:

- Solutions for Aggregation of resources/links (TVWS with licensed and unlicensed ISM, and within TVWS).
    - Qualitative and quantitative performance surveys.
- Secondary coexistence (e.g., LTE with 802.11af in TVWS).
- To undertake studies and surveys on the performances achieved, e.g., in terms of interference to primary TV services and PMSE services, and secondary performance through objective user opinion polling.

VI. Conclusion

The Ofcom TV White Spaces (TVWS) Pilot represents an important milestone in the realisation of TVWS technology. This paper has described a range of trials that are being undertaken in this pilot by a consortium led by the ICT-ACROPOLIS Network of Excellence. Numerous aspects have been described, such as conformance assessment, the white space devices that will be used, locations, deployment scenarios, and research investigations to be undertaken, among others.

Acknowledgment

This work has been supported by the "ICT-ACROPOLIS Network of Excellence", www.ict-acropolis.eu, and the "Spectrum Overlay through Aggregation of Heterogeneous Dispersed Bands" project, ICT-SOLDER, www.ict-solder.eu. The authors would like to thank Andrew Stirling of Larkhill Consultancy Ltd for his extensive advice and assistance, and David Grace of the University York, Klaus Moessner of the University of Surrey, Jon Crowcroft of the University of Cambridge, and Robert Watson of the University of Bath, for their kind assistance.

References

[1] FCC, "In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band, Second Memorandum Opinion and Order," Sept. 2010.

[2] FCC, "In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band, Third Memorandum, Opinion and Order," April 2012.

[3] Ofcom, "TV white spaces - A consultation on white space device requirements," consultation, November 2012.

[4] Ofcom, "TV white spaces - approach to coexistence," consultation, September 2013 (an addendum to this from November 2013 also exists).

[5] ETSI, "White Space Devices (WSD); Wireless Access Systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive," v1.1.1, April 2014.

[6] Ofcom TV White Spaces Pilot, http://stakeholders.ofcom.org.uk/spectrum/tv-white-spaces/white-spaces-pilot, accessed May 2014.

[7] NICT Press Release, "World's First TV White Space WiFi Prototype Based on IEEE 802.11af Draft Standard Developed," October 2012, accessible at http://www.nict.go.jp/en/press/2012/10/17-1.html, accessed May 2014.

[8] NICT Press Release, "Alleviating Overcapacity, Specially Developed Smartphone Utilizing TV Whitespace with LTE Technology," March 2014, accessible at http://www.nict.go.jp/en/press/2014/03/19-1.html, accessed May 2014.

[9] Eurecom ExpressMIMO2, http://www.openairinterface.org/expressmimo2, accessed May 2014.

[10] OpenAirInterface Twiki, https://twiki.eurecom.fr/twiki/bin/view/OpenAirInterface/WebHome, accessed May 2014.

[11] Carlson Wireless RuralConnect, http://www.carlsonwireless.com/ruralconnect, accessed May 2014.

[12] KTS Agility White Space Radio, http://www.ktswireless.com/agility-white-space-radio-awr, accessed May 2014.