Spectrum issues affecting EU/US ICT development collaboration

Policy Briefing 4

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Foreword

On January 1st, 2016, the project PICASSO was launched with two aims: (1) to reinforce EU-US collaboration in ICT research and innovation focusing on pre-competitive research in key enabling technologies related to societal challenges - 5G Networks, Big Data and the Internet of Things/Cyber Physical Systems; and (2) to support EU-US ICT policy dialogue related to these domains with contributions related to e.g. privacy, security, internet governance, interoperability and ethics.

PICASSO is aligned with industrial perspectives and provides a forum for ICT communities. It is built around a group of 24 EU and US specialists, organised into the three technology-oriented ICT Expert Groups and an ICT Policy Expert Group, working closely together to identify policy gaps in, or related, to the technology domains and to recommend measures to stimulate policy dialogue. This synergy among experts in ICT policies and in the three ICT technology areas is a unique feature of PICASSO. The Policy Expert Group we chair also includes Jonathan Cave, Avri Doria, Ilkka Lakaniemi and Dan Caprio and develops its insights in consultation with other specific experts in the field (depending on the topic).

This policy paper focuses on Spectrum policy considerations in the EU and the US that affect and are affected by, in particular ICT, development collaboration related to 5G Networks, Big Data and Internet of Things/Cyber Physical Systems. The content reflects the results of desk study and subsequent discussion and will be subject to further discussion during a PICASSO webinar on April 28th, 2018 and the PICASSO Conference in Washington DC in June 2018, together with written comments by experts collected via email.

Spectrum is the fourth of five thematic Policy Papers and accompanying Webinars scheduled during 2017 and 2018. A Policy Paper on *Privacy & Data Protection* one on *Cybersecurity,* and one on *ICT Standards* have already been published. A fifth Policy paper, on *Smart Communities*, is in preparation: a subject in which all the other policy issues come together within a wider context. The intent is to provide a clear overview of the most pressing and/or challenging policy issues that confront technological, business and policy collaborations and to develop well-formed and practical insights into how they can be addressed from a transatlantic multistakeholder perspective operating in a global context.

Important inspiration for this paper came from all those who contributed to our understanding of the issues related to ICT standards, ICT security and Data protection policies in the EU and the US and of the specific policy issues related to the three PICASSO domains by their active participation in our meetings. We could not have done this without them.

Please feel free to share your thoughts via email to maarten@gnksconsult.com.
Looking forward to engaging with you all,

Best regards

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PICASSO project	PICASSO project

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Introduction

One objective of the PICASSO project is to bring forward policy recommendations designed to improve EU/US ICT-orientated collaborations, specifically in the domains associated with 5G networks, Big Data and the Internet of Things/Cyber Physical Systems (IoT/CPS)[1].

The aim of this paper is to establish a framework for the consideration of Spectrum issues as they affect the development of future EU/US ICT-orientated research collaborations, specifically in the technological domains associated with 5G networks, Big Data and IoT/CPS.

The PICASSO technological domains rely on connectivity. Radio is an important part of this connectivity. Increasingly, users can obtain similar services on the move and in fixed environments (ubiquitous connectivity). We are also seeing more of today's 'fixed-line' connectivity via physical infrastructures (e.g. copper, cable) replaced by radio connections that do not require the same level of fixed capital investments (for both new settings and retrofitting) – and which, in consequence may be both often easier and cheaper to maintain, extend and update. PICASSO-relevant developments (including the core areas of 5G, Big Data, Internet of Things/CPS and derived areas such as Machine to Machine (M2M) communications, Broadcasting, Cloud Computing, Internet access and Smart Cities) all rely on connectivity that depends on various forms of radio and fixed communications based on new and innovative forms of wireless communication.

The resulting increased demand for spectrum will be partially met by using higher frequencies. But much of the demand will have to be accommodated by making better use of current spectral bands, many of which are idle most of the time. TV white space[2] is one spectral domain that can be more efficiently exploited by means of Dynamic Spectrum Access (DSA) techniques, which facilitate flexible and controlled use of radio spectrum by giving individual users, uses, items of equipment, etc. just the connectivity required at a particular time and place. This gives users the impression of an almost infinitely wide channel; as soon as one use ends, the spectrum is available for something else. Particular frequencies may thus move from IoT to M2M to telephony etc. over a short space of time.

Until now, most areas have relied on systems for providing exclusive spectrum access rights, obtaining flexibility by allowing these to be traded or recontracted. But it seems fairly clear that exclusive spectrum ownership in a given region or jurisdiction will no longer be the dominant model. While DSA use is expected to grow steadily over the next few years, it is unrealistic to expect all spectrum to convert to DSA in a single step – or for DSA to provide the best long-term solution in all cases. DSA and conventional spectrum allocation methods will coexist for the foreseeable future, and DSA itself may have several modes of operation. In some domains, it may be more efficient to provide entirely

[1] The IoT and CPS are distinct entities from the spectrum policy point of view: the IoT is a network of physical objects containing embedded technology to communicate, sense or interact with their internal states or the external environment; CPS are embedded intelligent ICT systems, which are interconnected, interdependent, collaborative and autonomous and which provide computing and communication to enable monitoring and control of physical components and processes in various applications. A more extended discussion of this distinction from the spectrum perspective is included as Annex A.

[2] This is discussed separately in Annex B.

unregulated access to portions of the spectrum, in order to facilitate experimentation, uses for which the costs of DSA are disproportionate to the efficiency advantages, etc. The range of DSA approaches is indicated in the following Figure, adapted from Zhao and Sadler 2006.

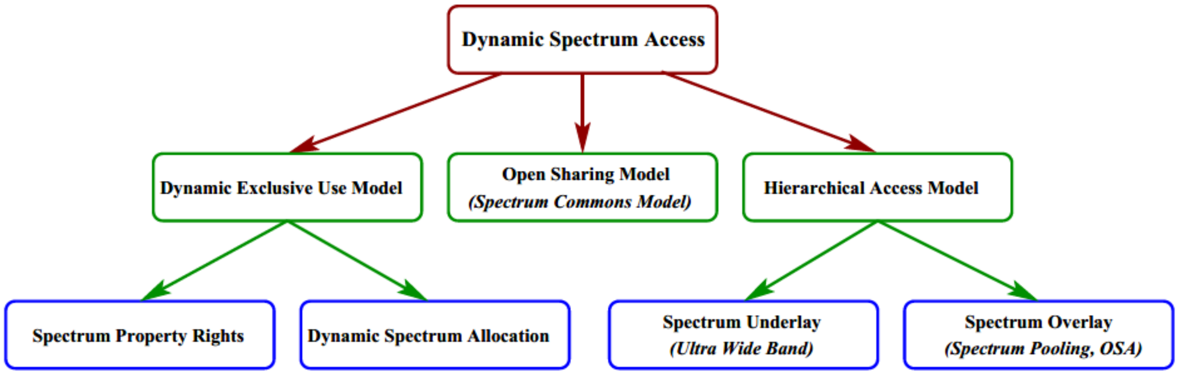

Figure 1: varieties of DSA approaches

As a result, we can foresee three main areas of overlap between spectrum policy and research with a transatlantic footprint:

- The need to adapt and adjust spectrum allocation and management polices to cope with the implications of technological development. Many of these policies are internationally coordinated to harmonise spectral bands and their usage conditions, to foster the creation of global markets for hardware and to make interoperability smoother and more efficient.
- The need to anticipate and coordinate changes to research programs and outputs arising from spectrum policy. Spectrum policy determines the socio-economic role and profitability of different technological and service approaches and thus implicitly influences the eventual 'winners' and 'losers'. These outcomes are of national and international importance; it is important that nationally-based policies do not unduly inhibit or distort technology development.
- The need to ensure, through policy and other means, the availability of suitable spectral resources for scientific purposes. This is both a general objective, and one that is specific to the use of PICASSO domain approaches for collaborative research and innovation.

We briefly discuss each of these in turn before considering specific elements relating to the three PICASSO domains.

Challenges to existing spectrum policies

The interactions among spectrum policy, technology development and research raise technological, economic, operational and cultural issues that challenge existing spectrum management rules (esp. on licensing and access) and create a need for research to establish the possibilities and the impossibilities that determine the balance among different 'styles' of spectrum access control:

- *Prohibition* – banning or excluding[3] access to or use of specific spectral resources by designated users, uses or technologies, with the default being to allow access or use under common framework conditions[4];

- *Permission* – allowing access or use by designated users, uses or technologies, with the default being not to permit such access;

- *Trade* – creating a system of tradeable spectrum access or use rights[5]; and

- *Negotiation* among those who create, administer or own spectral resources and those who might need access to them or usage rights.

Such arrangements have both immediate and dynamic effects. The immediate effects are to enable (or inhibit) the identification and implementation of efficient use of spectral resources (and thus to improve or impair the production and distribution of services over existing spectrum). In the longer term, they create incentives for the development and deployment of new technologies, services and business models all along any value chain that runs in part over the electromagnetic spectrum.

Implications for research into wireless technologies and services

In simple terms, the potential availability and price of suitable spectrum access will determine whether technologies are developed, deployed, licensed, etc.

The technologies considered by PICASSO require adjustments to conventional spectrum allocation and management policies to cope with a range of new features, each of which poses its own research challenges.

- *Different user demands* – users of capabilities and services associated with PICASSO technologies will have different requirements for e.g. service continuity, quality, privacy and security. These are likely also to vary among e.g. mobile users, Autonomous Vehicles and IoT devices, smart systems.

- *Different uses* – the use of spectrum across these domains will involve: different access and management technologies; varying time-patterns[6]; different needs for (fixed or varying) frequencies; high, low or variable bandwidth; exclusive, negotiated or pre-emptive access; fixed or agile location (including frequency); etc.

- *Different property rights and (re)assignment mechanisms* – the system of rights must conform not only to the contending needs of different spectrum users and uses but also to their own business models with implications on the Quality of Service and organisational structures. Variations

[3] By legal, contractual or technological means.
[4] ‘Resources’ range from spectral space (defined by location, time, frequencies and power limits) to access to necessary hardware (e.g. masts).
[5] E.g. Spectrum Utilisation Licences
[6] Ranging over the necessity for real-time/linear access vs. bursty transmission to connection frequencies ranging from continuous to occasional and from static to scheduled to on-demand.

include: licensed, unlicensed and overlay/underlay spectrum; requirements to monitor and make available unused spectrum within a licensed block; and white space issues.

- *Different physical infrastructure* – users associated with different technologies may require (or already have) different dedicated physical infrastructures and links to wireline/fibre networks. Associated issues include e.g. femtocell planning, permissions, ownership and operation; train/road/subway/plane provision; and creating, operating and maintaining networks of 4G/5G repeaters.

Example: 2.6 GHz spectrum auction

The 2.6 GHz spectral band(s) are available in the European Union for wireless broadband based on technology neutral use. They are suitable for use by both symmetric/paired (e.g. LTE) and asymmetric/single-band (e.g. WiMAX) technologies. It was not obvious a priori how much of the available spectrum should be used for each technology, but it was clear that the allocation would determine the amount of bandwidth available, because adjacent licenses using the same technology would not create interference, while adjacent licenses using different technologies would require 5MHz 'guard bands[7].' Moreover, the likely bidders interesting in deploying the two technologies were not drawn from the same population; LTE bidders were typically MNOs (mobile network operators), while those intending to deploy WiMAX were almost exclusively fixed-line broadband providers or ISPs. The 3-stage auction mechanism used to allocate this spectrum in the UK was designed to determine the optimal division of the licenses between the two classes of technology; the impact assessments recognised that the allocation and pricing of the spectrum would directly influence the development of each of the technologies. It was further recognised that secondary trading (resale) of licenses would further change the technological and commercial landscape and the nature of regulatory requirements[8].

Availability of spectrum for research purposes

A closely related issue is the need for policy commitment to the availability of spectrum for research and innovation purposes. Coordinated 'scientific spectrum' policy can facilitate transatlantic research cooperation and the development of interoperable and globally-compatible technologies. The

[7] Strictly, the amount of guard band technically required varies with the adjacent technologies (some pairs have particularly severe interference problems) and can be mitigated to some extent by sharp filtering and careful network planning. But as a matter of policy, a 5MHz guard band was recommended by CENELEC and baked into e.g. the UK's 2.6 GHz auction design. Note also that, according to GSMA "Studies performed and discussed in technical international fora show that a minimum guard band of 5 MHz is necessary to address potential interference between TDD and FDD systems operating in adjacent bands in the same geographical area." (GSMA "The 2.6GHz Spectrum Band: An Opportunity for Global Mobile Broadband" at: https://www.gsma.com/spectrum/wp-content/uploads/2012/07/Spectrum-The-2-6GHz-band-Opportunity-for-global-mobile-broadband-English.pdf).

[8] See e.g. Marsden, R., Sexton, E., & Siong, A. (2010). Fixed or flexible? A survey of 2.6 GHz spectrum awards. DotEcon Discussion Paper or Ofcom (2008) "Award of available spectrum: 2500-2690 MHz, 2010-2025 MHz" at: https://www.ofcom.org.uk/__data/assets/pdf_file/0013/43006/statement.pdf.

associated issues range from the direct availability of 'research spectrum' and its integration into spectral policy more generally to the mobilisation of spectral policies to extend the reach and utility of shared scientific infrastructures such as the European Open Science Cloud.

Spectrum in PICASSO focus

Within PICASSO, the focus is on 5G networks; Big Data; and the Internet of Things, specifically Cyber Physical Systems. From the background reflected above, we focus on these three domains, below.

5G networks

5G will probably provide the first major use of DSA approaches, either exclusively or via a mixture of DSA and other spectrum allocation techniques. Although 5G is a single system concept, it will combine many different elements, each of which will be equivalent to a single service[9]. This will involve the convergence of engineering concepts in the construction of 5G and converging current business models to allow them to interoperate harmoniously. The glue that holds this together is the allocation of spectrum for 5G use. Spectrum must be allocated in ways that serve current and forthcoming technological possibilities while at the same time allowing currently quite diverse business models to evolve into a new 5G way of working. It must also serve a wide range of needs; from M2M services that only need a few kilobytes of data on an occasional basis to real-time video experiences enhanced by demanding graphics. The resulting spectrum needs are profoundly diverse - but DSA in principle can deal with them and provide the best use of the spectrum for each. Implementation requires a 5G infrastructure; this in turn needs an evolution of ideas, then design, finance and building from now until rollout.

Issues identified in the GSMA position paper:

1. Significant new widely harmonised mobile spectrum is needed to ensure 5G services meet future expectations and deliver the full range of potential capabilities.
2. 5G needs spectrum within three key frequency ranges to deliver widespread coverage and support all use cases. The three ranges are: Sub-1 GHz, 1-6 GHz and above 6 GHz.
3. WRC-19 will be vital to realise the ultra-high-speed vision for 5G with low cost devices.
4. Licensed spectrum should remain the core 5G spectrum management model. Unlicensed bands can play a complementary role.
5. There is significant potential for the coexistence of 5G and other wireless services in higher frequency bands above 24 GHz.
6. Technology neutral spectrum licences are essential. They allow bands used for existing mobile technologies to be easily refarmed for 5G thus ensuring spectrum is used most efficiently.
7. It is important that governments and regulators successfully support the needs of 5G at international spectrum discussions including WRC-19 and its preparatory meetings. This is essential due to the lengthy timeframes involved in making new mobile spectrum available.
8. Governments and regulators need to adopt national policy measures to encourage long-term heavy investments in 5G networks.

[9] E.g. providing the equivalent of mobile telephony facilities as well as Wi-Fi.

Specific issues (tentative)

The following list collects some potential areas for EU-US R&I collaboration relating to spectrum policy as it affects 5G technologies.

- Access methods – what access methods are specifically needed for 5G and how can they be reconciled with other uses of dedicated, shared or adjacent spectrum? Are there any promising hybrid or general-purpose access methods or arrangements? What is relevant for the connectivity for 'vertical' sectors such as connected cars or healthcare or industrial automation?

- What are the major technical components as well as potential research challenges and opportunities for enabling innovative agile spectrum access and management? How should these limitations and possibilities be reflected in the spectrum policy-making to ensure effective 5G deployment that will work seamlessly over different frequency ranges/bands, with different use cases, e.g., mobile broadband and IoT, and among different actors, e.g., MNOs, new entrants and vertical industries?

- Licensing mechanisms, in particular for high frequency bands – e.g. for the 26 GHz band and also 40 GHz and 60-70 GHz[10].

- What are the particular requirements of 5G?
- What complications for co-existence / sharing are created by existing uses (e.g. fixed links and satellite services) and how can they be overcome?
- What is the scope for licensed vs rule-based spectrum use controls? Possibilities include:
    - Exclusive licences;
    - Licensed shared use;
    - Tiered authorisation (by priority, Quality of Experience, etc.) – like CBRS[11];
    - Light-touch licensing[12];
    - Dynamic Spectrum Allocation[13] to facilitate inter-tier coordination;

[10] More specifically, for the World Radiocommunication Conference 2019 (WRC-19), the CEPT has prioritised the following bands for potential 5G use: i) 24.25-27.5 GHz (adjacent to the US 28 GHz band); ii) 40.5-43.5 GHz (adjacent to the US 29 GHz band); and iii) 66-71 GHz (considered in the frame of 57-71 GHz for licence-exempt use). For more details of the current situation, see e.g. Tomimura, D. (2018) "New spectrum: bands under study for WRC-19" ITU presentation at: https://www.itu.int/en/ITU-R/seminars/rrs/RRS-17-Americas/Documents/Forum/9_ITU%20Diana%20Tomimura.pdf.

[11] This is "Citizens Broadband Radio Service", which is an FCC-authorised wireless shared access arrangement for 3.5 GHz spectrum previously reserved for US military uses. It uses the same radio interface as licensed LTE and unlicensed 5 GHz spectrum, but with assignment requires users to request and be assigned bands by an automated Spectrum Allocation Server (SAS), which checks RF density and channel availability using terrain and radio propagation data. The assignment is automatically freed when no longer needed.

[12] This only obliges users to register on a database and meet specified operational conditions.

[13] E.g. via geolocation databases.

  - Splitting bands into different exclusive, light/concurrent use blocks; and
  - Awarding different priority licence in same blocks
- Changes arising from 5G development with spectrum implications

- Transition to denser networks, targeted small cells;
- Virtualisation; and
- Equipment considerations – scalability, cost, ease of deployment.
- Assessment of the amount of spectrum available, esp. in the 26 GHz band:

- Setting and negotiating band boundaries and locations;
- Defining spectrum blocks - contiguous/non-contiguous, sizes, configuration; and
- Safeguarding EESS and FSS earth station use, evaluating options for fixed stations and inter-satellite links, protecting passive use (e.g. below 24 GHz)[14].
- Analysis and policy for spectrum use conditions and pricing – in the 5G context, this is complicated by lack of precedent benchmarks and the wide range of demand and deployment options. There are also visible tensions in setting conditions that must be resolved. For example, incumbent MNOs favour longer licences than other (entrant) players. It is not obvious whether licenses should be issued and conditions set at national or subnational level, or whether the conditions should mandate levels of coverage, sharing mechanisms, etc.

These issues can be seen in the context of a range of different use cases, which might form a fruitful basis for R&I collaboration. These include mobile broadband, 5G FWA[15], ultra-reliable networks, IoT and, media uses. This wide range of use cases covers a corresponding range of motives for seeking spectrum, which in turn can be served by different approaches.

- 5G mm-wave awards should attract players seeking to provide converged fixed + mobile services (the mobile services possibly needing agile/cognitive capability).

- Verticals[16] seeking to exploit 5G in specific contexts such as smart towns, cars, trains, airports, universities, industrial plants or parks, etc. or those developing intra-vertical combined or converged services, will seek localised licences or local shared access.

- Neutral host small cell providers, need reliable access to serve a wide range of localised uses.

- mm-wave small cells that are privately owned and/or deployed by their users will require a degree of exclusivity and/or negotiation or real-time access sharing.

[14] At the moment, use drops off steeply with frequency.
[15] This denotes Fixed Wireless Access, which entails providing Internet access to homes using mobile network technology rather than fixed lines; it works best where existing fixed-line coverage is poor or inadequate.
[16] E.g. manufacturing (Industry 4.0/Factories of The Future), automotive, health, energy, media & entertainment. See https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf.

- Dual use (access services + backhaul) spectrum may be needed by integrated service providers or their affiliates.

It should be noted that not all of the resulting allocation issues will involve '0-based' or blank sheet definition and implementation of efficient access rights; moreover, mechanisms (e.g. auction designs) that assume symmetry among specific classes of user. However, some users, e.g. MNOs already have 'high spectrum' licenses, and may start with an advantage or only need 'complementary' access[17].

The following figure shows some of the issues that must be resolved in respect of the different access models before a choice among them can usefully be made.

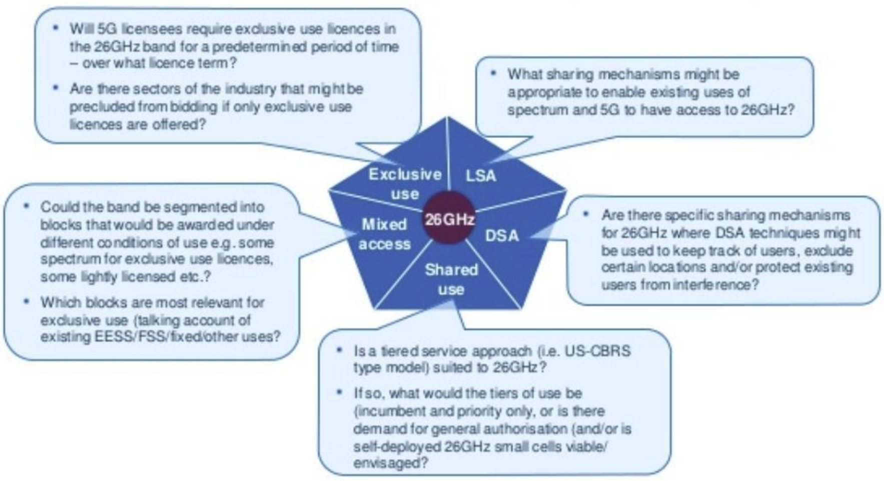

Figure 2: issues for various (5G) spectrum access arrangements.

This diagram merely outlines the main questions. It does not fully resolve them; for example, exclusive use conditions can only be evaluated once the amount of spectrum available for 5G use is specified, or once the mechanisms for determining this allocation or managing an adaptable or 'technology neutral' allocation scheme are modelled. But the kind of questions specified do provide a useful framework for a more general consideration of the main items on the agenda of any coherent programme of EU-US collaboration (once extended beyond the purely 5G focus indicated here).

[17] In the 2.6 GHz allocations, such 'legacy spectrum' delayed the auctions by up to 4 years (due to lawsuits by bidders without pre-existing licences on the boundary of the allocated blocks).

Internet of Things/Cyber Physical Systems

A vast number[18] of devices will be wirelessly connected to the internet by the end of the decade. This evolution will depend critically on Machine-to-Machine (M2M) communication, which allows complex 'things' such as utility meters, vending machines and cars to connect and interact with others, even when the primary purpose of the device does not require connectivity.

From the perspective of spectrum policy, the distinction between IoT and CPS

Data transfer among machines usually does not require (or even permit) human intervention (or control). M2M is thus a fundamental enabler for the Internet of Things (IoT), at least in the initial phases that involve adding connectivity to passive objects[19], deploying connected sensors[20] and transmitting instructions to dependent or (semi-)autonomous actuators. To function properly, the IoT requires these data to be readily accessible by many different (human and otherwise) users[21]. As the CPS-enabled society gains in complexity, objects that are able to sense their environment and communicate with each other become increasingly necessary tools for understanding this complexity and responding to it swiftly and effectively[22]. This decentralisation of communication and control has huge potential for enhancing efficiency – and equity - in all areas of the economy. For instance, information from many parts of the environment can be used to alter other parts dynamically to produce collective benefits as implied by e.g. the Smart City concept.

Such physical information systems are already in widespread use. Pill-shaped micro cameras and bio-sensors can be implanted in the human body (or swallowed) and send back images or other data in order to locate sources of illness; soon they will also be able to deal with localised problems by

[18] Estimates range from 8.4 billion (see: https://www.gartner.com/newsroom/id/3598917) to much larger numbers quoted by Ericsson (initially set at 50 Billion (https://www.ericsson.com/thecompany/press/releases/2010/04/1403231) but now considerably scaled back (see e.g. https://spectrum.ieee.org/tech-talk/telecom/internet/popular-internet-of-things-forecast-of-50-billion-devices-by-2020-is-outdated).

[19] E.g. sensors in streetlights or fire alarms that notify responsible organisations when they need servicing.

[20] E.g. remote temperature, traffic or pollution sensors.

[21] This access will come in particular – though not exclusively – over the Internet. Here, we must use the term Internet broadly; there is no reason to suppose that these communications will employ the Internet protocol. For instance, information-centric networking (ICN) or Constrained Application Protocol (CoAP) have been proposed as wholesale replacement for the IP protocol or as extensions to its capabilities to enable the Internet (in a classical sense) better to serve the needs of IoT/CPS. See Trossen, D., Reed, M. J., Riihijärvi, J., Georgiades, M., Fotiou, N., & Xylomenos, G. (2015) "IP over ICN-the better IP? an unusual take on information-centric networking" *arXiv preprint arXiv:1507.04221* or Fotiou, N., Xylomenos, G., Polyzos, G. C., Islam, H., Lagutin, D., Hakala, T., & Hakala, E. (2017, September). ICN enabling CoAP Extensions for IP based IoT devices. In *Proceedings of the 4th ACM Conference on Information-Centric Networking*: 218-219.

[22] The complexity dimension is important; it may not be possible to detect evolving situations and emergent challenges at a systemic level, or to respond in a timely fashion. Moreover, the decentralisation of sensing and response may help in giving critical CPS the necessary level of 'robust-yet-fragile' adaptiveness.

administering localised drug or radiation therapies or conducting micro-surgical interventions. For practical reasons, such communications must use spectral resources.

Remote satellites and ground sensors collect data and send them wirelessly back to precision irrigation, agrichemical etc. equipment to improve farming efficiency. The remoteness of these areas combined with low population and signal densities argue strongly for use of wireless communications, especially those not requiring extensive local hardware.

Billboards and ‘smart devices’ in the home instantly assess consumer behavioural profiles and adapt advertisements – or alert helpers - accordingly. The costs of retrofitting the built environment to support wired communications would make many such implementations prohibitively costly; on the other hand, the WLAN communications employed by most existing Smart Home Hub devices may not adequately support the security, privacy and Quality of Service requirements of the full range of potential uses.

Some IoT/CPS devices will be physically mobile while others will be stationary. Although both mobile and fixed devices could place demands on mobile data service networks, fixed devices could also use wired or fixed wireless communications (including short range devices), depending on practicability, performance and cost. This suggests that the best spectrum policy for realising this potential will need to reflect the technological and organisational specifics of communications infrastructures.

From the spectrum management perspective, projected per-connection IoT data volumes are likely to be low compared to other forms of mobile broadband consumption. The devices involved may be further from the locations covered by conventional mobile networks. Therefore, such applications would particularly benefit from a low capacity but ubiquitous coverage layer – and are more likely to be developed and supported where such a layer exists. In addition, they may have different service requirements, such as the absolute need to prioritise robustness of the communications link for safety critical uses[23].

Widespread adoption will take time, but the underlying technologies are already improving rapidly. The intention of existing IoT/CPS R&I is to connect the widest possible range of devices anytime, anywhere and for (almost) any purpose. There remain questions over the extent to which R&I for policy and policy itself should continue this ‘agnostic’ approach and when it should become more specific. Overall, however, the diversity of IoT/CPS uses and their inevitable criticality will force spectrum policy to adapt in order to ensure that priority uses, devices, functions and users are identified and connected in appropriate ways.

Furthermore, because any IoT object can be a data source, conventional concepts of ownership are becoming blurred. This obviously applies to the functional plane - who owns the devices, the data they exchange and the functions that they (collectively) perform. It also extends to the use of public goods like the electromagnetic spectrum. In this regard it seems inevitable that neither exclusive licences nor an unregulated commons model will prove sustainable.

[23] This does not require high-bandwidth communications; indeed, highly redundant *ad hoc* networks may prove a superior substitute or valuable complement to ‘conventional’ (and congested) fixed and wireless connections.

The resulting rich research agenda must be tackled in ways that cross all kinds of boundaries, including oceans. Specific elements include:

- The general range of requirements applying to IoT/CPS traffic;
- Device-specific needs of Machine-to-Machine communications such as smart metering[24];
- Use case specific needs such as Smart Cities or intelligent/additive manufacturing.

Beyond this, the main policy concern is less about how much (or which) spectrum is allocated to IoT/CPS uses than about the nature and stability of allocation mechanisms (including shared access). This is further discussed in Annex A.

Big Data

Data analytics interacts with spectrum policy in less direct ways that 5G or IoT/CPS, but does give rise to two distinct sets of considerations that might influence spectrum policy; the use of spectrum as an infrastructure to support Big Data applications and data analytics-intensive systems, and the application of Big Data to spectrum management, especially as affected by 5G and IoT/CPS uses of spectrum.

Big Data traffic flows over the electromagnetic spectrum

The communications demand associated with Big Data use are likely to grow in both size and complexity as the range, distribution and criticality of Big Data-enabled services expands. Inevitably, much of this traffic will be wireless. This gives rise to a set of related policy and research issues:

- Scaling;
- Handling the 3+ Vs;
- Data latency spectrum; and
- Mobile data access restrictions (privacy and security).

For instance, as sensor nets spread and deepen, there may well be a wireless exaflood involving many different degrees of sensitivity and required Quality of Experience or Quality of Service. Conventional ways of establishing (or refusing to establish, in the name of net neutrality) priorities and access may not scale well to this environment, and research[25] as well as policy experimentation[26] will be needed

[24] This might entail some combination of dynamic spectrum access, unlicensed spectrum or approval- or rule-based approaches as indicated in the previous section.
[25] E.g. on machine learning and predictive analytics to reduce the volume and increase the utility of collected and processed data.
[26] The reason for experimentation is that a ‘predict and provide’ approach is neither technologically feasible nor sensible in view of the adaptiveness of Big data/Machine Learning approaches, which balance new data acquisition against the reuse of models estimated from existing or prior data.

to handle the challenge. Dealing with this increase in scale and intensity will also require new techniques for e.g. using bursty transmission to move data in and out of cloud or fog environments without the need for 'big data moves'.

At a more systemic level, different 'real-time' data analytics approaches are sensitive to communication performance (which is in turn affected by spectrum policy). Big data approaches increasingly need to adapt to data volume, velocity, variety and complexity of information[27].

Part of this involves the stratification of data flows according to the time-scales on which they are collected and must be processed and acted on. Within a single organisation, this so-called "data latency spectrum" should optimally give rise to a natural protocol for prioritising data flows (i.e. dealing quickly with the most urgent flows) even if it is likely to be complex and highly dynamic in practice. Between organisations using the same network and/or spectral resources, the problem becomes much harder; it is constrained by spectrum policy, and also affects global operations and hardware markets, but it needs to be much better understood if it is to be reflected in spectrum policy, standards, etc.

A final and related issue concerns the question of mobile privacy, especially in relation to deploying Big Data approaches to addressing societal aims such as the UN Sustainable Development Goals, delivering: more effective health outcomes; better environmental management; increased opportunities for learning; and improved goods and services for consumers. The same considerations apply to commercial uses of Big Data in mobile environments esp. under GDPR. On a commercial level, access restrictions are of particular importance in e.g. automated data exchange among firms.

Use of data analytics to allocate rights and manage spectrum use

The final set of issues concerns the potential of Big Data approaches to handle spectrum management in more agile and efficient ways. This is similar to the potential contributions of data analytics in other network contexts, such as electricity or transport, where it is associated with Smart Grid or Smart network approaches, or to the more fine-grained approaches associated with active supply management and active demand management.

These applications range from existing uses of data visualisation, technical calculations and control monitoring systems and devices (generally tied to specific entities and devices) to more flexible, adaptive and 'open' forms of sensing and control, including the use of Machine Learning (ML) techniques to detect new patterns in unstructured data and to conduct interventions and experiments in order to manage a system where both the management and the users are responding to each other[28].

[27] These terms mean: volume - data volumes approaching multiple petabytes; velocity - data generated and ingested for analysis in real-time; variety - tabular, documents, e-mail, metering, network, video, image, audio, etc.; and complexity - different standards, domain rules, and storage formats for each data type, increasingly including unstructured data flows whose characteristics are endogenous.

[28] See Thelen-Bartholomew, R. (2017) "Bringing the worlds of Spectrum Management, Policy, and Monitoring together through Big Data analysis" at the ITU-D Spectrum management Conference:

Such systems are already under active development in contexts as far-flung as Shanghai and Canada. In particular, it is worth noting in this regard that the Canadian Research Council has developed a prototype system for advanced spectrum monitoring that relies on, among other things, a sensor network and big data visualization to create comprehensive insights about the spectrum environment so that spectrum managers can make queries about the RF environment and get answers in near real-time[29].

Perspectives towards the future

A number of new developments will co-determine how spectrum will be used towards the future. The following developments are expected to be key in this:

- Technologies become invisible – require seamless connectivity, with wires as part of the mix but more so through use of licensed and unlicensed spectrum. Ambient intelligence is an emerging discipline that brings intelligence to our everyday environments and makes those environments sensitive to people. Ambient intelligence (AmI) research builds upon advances in connected sensors and sensor networks, pervasive computing and artificial intelligence. Because these contributing fields have experienced tremendous growth in the last few years, AmI research has strengthened and expanded. Because AmI research is maturing, the resulting technologies promise to revolutionize daily human life by making people's surroundings flexible and adaptive. When intelligence gets embedded in our environments, moving around and interacting, this will require high levels of connectivity;
- Artificial intelligence: will eventually be part of how our systems will help us manage the complexity and interactions. AI eventually will find its way in interacting with data, connected systems and other intelligence on the Internet. It is also helping systems to be better able to deal with complexity, as in how to manage connectivity making best use of wired and wireless connections. This allows other ways of using spectrum than were available before.

These and other developments firmly indicate what we can learn from the past: the future, 10 years from now, will contain elements and characteristics that are currently beyond most imaginations.

Conclusions

Spectrum use has changed dramatically over the last decades, and is bound to change even more. Primarily, these changes will bring activity in from the extremes towards a more varied and dynamic centre ground:

https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2017/Spectrum%20Management/Robert_LS%20telcom%20Thelen_Bartholomew.pdf.

[29] See SAS TDWI Best Practices Report "Operationalizing and Embedding Analytics for Action" available from https://www.sas.com.

- The modalities of spectrum management will shift away from static, long-term licensing to a mixture with dynamic and uncontrolled regimes, within broad limits on interference;
- Spectrum allocation will become less likely to be restricted to specific uses or to all uses by specific single 'owners' of a particular band;
- Spectrum use will become far more agile in time, with today's long-term exclusive licences superseded by short-term, local, transferrable and 'recombinant' alternatives; and
- The inception of spectrum policy and the regulation will no longer be the exclusive domain of telecommunications regulators, but will increasingly involve other public entities (e.g. competition, privacy, financial, health etc. regulators) and a mix of industry and civil society stakeholders, in order to reflect the increasing diversity of uses and impacts of spectrum choices. Therefore, spectrum policy will be part of a more integrated set of digital policies.

It has become clear that 5G development requires increased availability of specific types of spectral resource, not only to traditional users but to an increasingly varied population of new players. Therefore it puts into sharp relief almost all the spectrum policy issues considered in this paper and those being fought over in policy and legal circles today. However, 5G, despite its close and obvious dependence on wireless communications, is not the only use or set of users. Therefore, its specific needs should be balanced against those of other technologies and stakeholders (e.g. those coming from the IoT/CPS and Big Data communities of interest) if spectrum policy is to be fit for the future.

IoT/CPS requires spectrum availability in both very local and more regional contexts, and thus may require a layered structure of negotiable rights. Moreover, its requirements for bandwidth, latency, reliability and other characteristics may be more flexible, or at least may become more flexible if the incentives for technology development provided by spectrum policy dictate. This includes, in particular, the very different timescales and data volumes associated with e.g. sensor nets, M2M communications and autonomous mobile devices. These requirements may also be context-dependent, meaning that special spectral management regimes may evolve for use in e.g. Smart Cities, Smart factories, etc. The resulting tensions between potentially incompatible access and utilisation regimes can be dealt with 'by design' in both the physical architecture of the various devices and through the standards that govern their communications and interactions.

Finally, the flows of data through the wireless networks of the future are bound to increase in scope and volume, even if not necessarily to the exaflood levels that some have foreseen. Volumes can be reduced by analytics and modelling, and data can be used to manage data (e.g. by analysing traffic to adjust spectrum access). This self-reflexive quality can open the door to new forms of 'smart spectrum regulation' in which many of the competing policy considerations (from efficient use of scarce resources to reconciling competing use priorities or protecting communication privacy and security) can be dealt with endogenously, automatically and in ways that are transparent but hard to manipulate.

At this point our conclusion is that EU/US research collaboration should mainly focus on understanding our common challenges and the ways in which those aspects of these technologies that span our two legal, commercial and societal environments can be equipped both to robustly work around the world and to support joint research that exploits these technologies to resolve common problems ranging from food security and environmental damage to financial trading and privacy. Among the various aspects, the possibilities and implications of agility in spectrum allocation and management constitute perhaps the most promising research area.

Towards the Summer of 2018, we intend to deliver a White Paper on policy issues such as privacy and data protection, security, standardisation and spectrum that are most relevant to technological and commercial development in the PICASSO domains and conversely to identify the aspects of such policies that are most likely to be affected by 5G, Big Data and IOT/CPS development. This PICASSO Policy Paper and the ones that follow will feed in to this White Paper, therefore we invite you to share any comments and suggestions relating to these policy papers with the PICASSO Policy Expert Group either in person during one of our meetings (workshops or webinars) or via email to the Chairman of the Policy Expert Group at maarten@gnksconsult.com.

Annex A: Some comments on IoT and CPS from the spectrum perspective

This annex is provided to 'drill down' into the above discussion of spectrum policy issues as they relate to IoT/CPS in order to differentiate the two.

Internet of Things

The **Internet of Things** is a network of physical objects containing embedded technology that enables them to communicate, sense or interact with their internal states or the external environment. Depending on what aspect is to be discussed, this definition in terms of 'thing layer' can be extended to include related layers e.g.:

- (tech layer) efficient wireless protocols, improved sensors and cheaper processors; and
- (user layer) consumer, business and industrial Internets.

The 'vertical' linkages among these layers enable a *potentially* open, global network connecting people, data, and things. However, it is not obvious that all such connections will or should be made:

- The openness, geographic reach, range of connected entities and possible or permitted uses will fall some way short of what is technically feasible;
- These limits may be efficient or inefficient from the perspective of multiple stakeholders; and
- The realisation or inhibition of these possibilities will in turn affect the evolution of the Internet.

The IoT often uses the platforms to connect 'intelligent' things that collect, process and transmit a broad array of data. These platforms allow entities from the 'thing', 'tech' and 'user' layers to 'find' each other and interact; to do this, the platforms may host people, organisations, applications and functionalities. This platform capability helps to create services that would not be obvious without this connectivity and analytical intelligence. Therefore the development of the IoT is linked (at present) to the characteristics, economics, operation and governance of platforms and in turn to transformative technologies such as cloud, things, and mobile.

Cyber-Physical Systems

Cyber-Physical Systems (CPS) represent 'next generation' embedded intelligent ICT systems that are interconnected, interdependent, collaborative and (to an extent) autonomous. They provide computing and communication, enabling monitoring and control of physical components and processes in various applications, creating "one logical system of objects and services". Their development can be described in stages.

1. Creation and interconnection of virtual 'models' of physical systems (often as computer simulations) to facilitate operation and control – a 'twinning' of the cyber and the physical;
2. Allowing each of the cyber and physical planes to go beyond their counterparts;
3. Enabling and exploiting joint capabilities (including emergent functionalities) that could not be implemented in either a purely physical or a purely cybernetic system; and
4. Restoring the understanding of the cybernetic plane to its original definition (Weiner, 1948) as "the scientific study of control and communication in the animal and the machine."

From this perspective, we can delineate some requirements of future CPS. They will need to be:

- *Appropriately* scalable, distributed and decentralised;
- Capable of interaction with interaction with humans, physical and societal environments and machines while being connected to Internet or to other networks; and therefore
- Endowed with a range of features or functions such as adaptability[30], reactivity, optimality, resilience and security – and possibly even pro-active or first-mover' versions of these.

These features may be embedded, designed or simply emergent, because CPS are already forming an invisible 'neural network' of our society and will do so even more in future.

Link to spectrum

The way the IoT and CPS will develop and the effects of that development will inevitably be shaped by the communication and interaction possibilities – hence the link to spectrum policy. In particular, the demands of the thing and user layers of the IoT, filtered through the tech layer (esp. wireless protocols) will determine their demands for spectral resources and the coexistence possibilities with other uses. This topic requires careful investigation due to its feedback loops; the availability/scarcity and 'cost' of spectrum will drive both the design and the competitive evolution of IoT devices, which will in turn impose constraints on other uses and on the form of spectrum rights and allocations. This is particularly pressing because 'things' are likely to be so many, so small and so complex in terms of ownership and control that treating them as 'rights-holders' in the standard spectrum management sense will be unworkable.

This challenge is, if anything even sharper for the second and third stages of CPS development, because the 'cyber' aspect can be implemented in a distributed way via wireless connections that can go well beyond what may be physically possible. This transcendence is specifically linked to wireless connections, which are less tightly coupled to a physical plane of wired or fibre infrastructure and its far more limited possibilities for sharing and changing 'rights of way'.

[30] including the ability to be updated or to update themselves.

Annex B: TV White Space (TVWS)

About a decade ago, TVWS seemed a promising and revolutionary resource that had the potential to take the success of Wi-Fi to a whole new level, using radio bands that could travel farther and better penetrate walls, buildings, and other obstructions. This proved technically challenging due to the 'coexistence problem':

- If white space devices (WSD) assess channel availability when there is a very weak signal from a TV station (esp. DTT – digital terrestrial television) very far away, they may create interference;
- High-power TV broadcasts can interfere with or even saturate WSD receivers operating properly on adjacent vacant channels; and
- WSDs properly operating on vacant channels can interfere with nearby TV receivers tuned to an adjacent TV channel.

Technical 'fixes' (devices that looked for and used unoccupied space) proved ineffective, so most countries (including the US and the UK) opted for a database (WSDB) approach.

These databases identify channels that can safely be used at a given location and time without interfering with incumbent users (TV, low-power wireless microphones, etc.). WSD certification requires compliance with radio emission standards and WSDB interfacing requirements.

Regulatory approaches being used or developed range from requiring licence holders to maintain WSDBs and make them available to requiring them to provide the information to regulatory authorities, who will in turn make them available.

The database approach is being used to some (limited) extent in at least 18 countries in US, Europe, Asia, and Africa, but has not yet 'taken off' – in part due to the lack of a suitable international standard.

There are some standards, such as IEEE 802.22 for the rural market and 802.11af for the Super-Wi-Fi market, but they have not been adopted by industry and no dedicated low-cost Application-Specific Integrated Circuits (ASICs) are currently available, though several have been developed. TVWS vendors have therefore tended to rely on general-purpose processors, which offer the flexibility required for this emerging market.

There are also some interesting clashes between different sectors; Microsoft has put a lot of effort into encouraging the use of TVWS for rural broadband delivery, but major telcos are less keen – perhaps because the frequencies are inconveniently low and because there are limited opportunities for 'ownership'[31].

Beyond this, it is worth noting that various countries are developing regulations (US, Canada, UK, EU, Singapore), but regulatory initiatives are far less visible in the developing world. The UK provides a good example of the approach being taken in many developed countries. Its regulator, Ofcom has built TVWS explicitly into their plans by:

[31] See e.g. https://steepsteel.com/microsoft-registers-trademark-for-airband-tvws-initiative-report/

- Committing to unlicensed access;
- Implementing regulatory requirements to disclose and publicise available TVWS spectrum via public databases; and
- Studying and making arrangements for 'coexistence' between digital terrestrial television and TVWS devices.

o Other initiatives underway for using this 'digital dividend include:

- Anatel in Brazil and SRFC in Russia adoption of the 450 MHz band for 3GPP as LTE band 31, which will compete with other bands for rural markets; and
- The FCC is considering the 600 MHz band (providing almost 100 MHz of TVWS spectrum) and other countries are expected to follow suit.