



University of
Salford
MANCHESTER

The struggle for co-existence : communication policy by private technical standards making and its limits in unlicensed spectrum

Rashid, I and Simpson, S

<http://dx.doi.org/10.1080/1369118X.2019.1662072>

| | |
|--------------------------|---|
| Title | The struggle for co-existence : communication policy by private technical standards making and its limits in unlicensed spectrum |
| Authors | Rashid, I and Simpson, S |
| Publication title | Information, Communication and Society |
| Publisher | Taylor & Francis |
| Type | Article |
| USIR URL | This version is available at: http://usir.salford.ac.uk/id/eprint/52321/ |
| Published Date | 2021 |

USIR is a digital collection of the research output of the University of Salford. Where copyright permits, full text material held in the repository is made freely available online and can be read, downloaded and copied for non-commercial private study or research purposes. Please check the manuscript for any further copyright restrictions.

For more information, including our policy and submission procedure, please contact the Repository Team at: library-research@salford.ac.uk.

The Struggle for Co-existence: Communication Policy by Private Technical Standards Making and its Limits in Unlicensed Spectrum

Pre-Publication Version:

This article was accepted for publication in *Information, Communication and Society* on 26 August 2019

Imir Rashid,
Department of Politics,
University of Exeter,
Amory Building,
Rennes Drive,
Exeter EX4 4RJ.
Email: i.rashid@exeter.ac.uk

Corresponding Author:

Seamus Simpson,
Professor of Media Policy,
University of Salford,
MediacityUK,
Salford,
M502HE.
Email: s.simpson@salford.ac.uk
Phone: 0044 1612056206

Abstract

Huge increase in the demand by the wireless sector to use the airwaves has trained focus on the classic policy problem of resource scarcity in the field. This article illuminates a part of wireless communication – unlicensed spectrum – where a particularly fractious debate over the future usage of such space has developed between incumbent Wi-Fi interests and new entrants from the field of licensed mobile communication. The case is novel in that private technical standards making has become a site aimed at resolving what is a contest for co-existence in unlicensed spectrum. In its conceptualisation of private technical standards making processes as communication policy activity, the article illuminates both their affordances and limitations. It also shows the enduring utility of public regulatory steer in what are, in effect, private self-regulatory processes aimed at creating solutions to problems with a complex socio-technical character.

Keywords:

spectrum, policy, standards, co-existence, multiple streams

Introduction

Rapid growth in wireless communication has been one of the most outstanding features of the development of the communications sector in recent decades. Mobile communication, which this facilitates, for example, now comprises both standard voice telephonic and, for many users, Internet-based communication in all its forms. Added to this, customer access to the Internet in the home, organisations and outdoor public spaces often takes place through local area network (LAN) wireless communication (Wi-Fi), in the first instance. Such a huge increase in the demand by the wireless sector to use the airwaves has placed renewed focus on a classic communication policy problem: spectrum scarcity. Spectrum historically has been viewed as a highly limited resource whose allocation and use required careful management in the public interest through direct regulation. Yet one particularly interesting - though under-explored in public policy analysis - aspect of the burgeoning demand for wireless communication relates to a part of the spectrum reserved for use without a regulatory body-issued licence. Here, strong differences between Wi-Fi and mobile cellular telecommunications players over the future of this space have developed. The ensuing contestation and the nature of efforts to resolve it constitute the focus of this article.

Wi-Fi interests are historic incumbents of the part of the unlicensed spectrum environment under consideration here (namely 2.4 and 5 GHz), taking advantage of the open entry operational approach to the use of available capacity. Mobile cellular players, by contrast, hail from a comparatively closed, proprietary, control-centric licensed operational environment, whose cultural characteristics they have wished to introduce into unlicensed spaces as their interest in exploiting them (because they are free to enter), alongside their licensed allocation, has intensified. In such contentious

circumstances, direct public regulatory policy interventions might be expected to occur to resolve the future of the unlicensed spectrum space. Yet the article shows how this has not been the case. Instead, ongoing, competing technical work undertaken in several private standards development organisational contexts has dominated efforts to determine the future of the currently uneasy relationship between Wi-Fi and mobile broadband players. The article thus contends that private technical standards development has assumed a public policy making role. Activity of this kind, though poorly understood, is important in policy terms since technical standards establish the context for the development and use of new products and services. The article shows evidence of competing technical (which we conceive as policy) solutions to the co-existence problem, which have aimed to shape the co-existence agenda, in an incompletely resolved policy process, in our terms. It illustrates, ultimately, how private technical standards making alone is unable to address complex socio-technical problems like co-existence.

We illustrate and explain how organisational venues dominated by interests from the mobile broadband business have led work to develop technical specifications which articulate and present particular versions of co-existence. Historically, the Institute for Electrical and Electronics Engineers (IEEE) played the lead role in standards-making in the 2.4 and 5 GHz unlicensed bands. However, in the co-existence debate, it has merely been able to add its own updated technical standard – and thus techno-cultural version of co-existence - to a group of competing techno-policy co-existence solutions. The article shows how standards development processes failed to resolve the key technical issue of energy detection levels (EDL) and mechanisms for accessing transmission channels in unlicensed spectrum to ensure the avoidance of collisions

between transmitted packets in the jointly used space. Whilst an arcane technical issue in one sense, in another, it demarcates essential differences in operational and cultural approaches of licensed mobile communications and Wi-Fi players.

The article thence provides evidence of the importance of public legislative steer in the privately driven journey towards addressing co-existence. Here, the EU, through its mandating of the European Telecommunications Standards Institute (ETSI), has provided an organisational venue for Wi-Fi actors to exert pressure on licensed broadband interests to reach agreement on energy detection levels that would provide fairer access to unlicensed spectrum for Wi-Fi services. In Europe, Wi-Fi functioning is based on the EN 301 893 ETSI standard, authorised politically by the EU. ETSI's current standards making activity is likely to ensure that technical parameters sufficient to deliver - albeit uneasy - co-existence between licensed mobile and Wi-Fi interests will be written into its amended EN 301 893 wireless standard to ensure that devices using this standard will be operable across the EU in the future. This contains added resonance because of the influence of ETSI standards making for communications in unlicensed environments globally.

To illustrate and explain its case, the article adapts and applies features of work on Multiple Streams (Kingdon, 1984) to the field of private technical standards making to illuminate why and how the co-existence problem has materialised and developed into a shared agenda for policy action through technical standards making. The framework explains the existing controversies in the wireless local area network co-existence debate (defined as the problem stream); examines potential solutions to the problem which have emerged (defined as the policy stream); and analyses pressures encountered

and responded to by the involved actors in the chosen standards development processes (defined as the political stream).

The article is structured as follows. The next section sets out the main features of Multiple Streams analysis. This is followed by an exploration of the main organisational contexts for unlicensed spectrum standards making. Drawing on and applying the core elements of the previous two sections, the remainder of the article proceeds to illustrate the case of technical standards for co-existence in unlicensed spectrum through the problem, policy and political streams of the Multiple Streams approach.

Analysing Standards Development as a Policy Process in Communications

The arcane process of writing and securing agreement on technically robust, efficacious standards underpins future development of a plethora of new information and communication products and services with economic and societal ramifications. Such processes are multi-faceted in character and often subject to time constraints. They can be highly contested by a range of different actors and may evolve across a variety of national and international fora.

In political science, the Multiple Streams approach has been developed to understand policy in similarly complex environments, though it has not been deployed to date in the field of international specification and standards making in communications. Multiple Streams was, rather, in its first iteration, devised by Kingdon (1984) to assist the understanding of agenda setting in government policy-making. This work focused mostly on national level contexts and provided a detailed understanding of policy

environments in which the state was a prominent actor. We propose in this article that its features can be extended to understand international organisational environments in which various forms of private self-regulatory governance processes operate, in this case technical standards development for spectrum co-existence. We argue that is the case since Multiple Streams is driven by three central concerns: first, the emergence and nature of key policy problems; second, the contexts within which key policy protagonists present potential competing policy solutions to the existing policy problems; and, third, key political factors that are at work in influencing the circumstances which lead to the linking of policy problems to potential policy solutions, thus setting a course of future policy action. With origins in the ‘garbage can’ model of Cohen et al. (1972), Multiple Streams offers a lens to explain how the policy processes evolve (Ackrill and Kay, 2011) ‘under conditions of ambiguity’ (Ackrill, Kay and Zahariadis, 2013: 871). Mintrom and Norman (2009) emphasise the incremental nature of most changes (after Lindblom, 1968) which they attribute to the need to deal with inherent issue complexity. This includes unclearly defined actor (in our case technical) preferences, fluid and thus unstable participation in policy processes (in our case taking place across standards development organisational contexts), and ideologically motivated institutional settings (displaying techno-cultural differences between Wi-Fi and licensed operators, in our case). In respect of the latter, there are times when policy problems are not solvable in designated policy settings leading to the search for alternatives. This can intensify as the time-based need for a solution to be achieved becomes more apparent. Zahariadis (2016: 6-7) notes that institutions, which we view broadly to incorporate organisational contexts for policy development constitute ‘an imperfect guide for action’ thus providing opportunity for flexibility and experimentation. In our case, the Broadband Random Access Networks (BRAN)

committee of ETSI emerged as a key venue to consider the co-existence problem and displayed enough organisational flexibility to allow development of the co-existence agenda in the direction of a solution.

The Streams approach is particularly apposite for illuminating the co-existence case in that it envisions policy activity as developing in three initially *independent* streams. The problem stream focuses on the key issues of concern - and often dispute - in policy processes. Here, focus is trained on the origins of policy problems, as well as their core features. Here policy problems become apparent as a consequence of evidence that a problem exists. This can also occur through so-called focusing events, landmark occurrences which highlight the problem at hand. In our case, evidence of the intensifying deployment of licensed mobile broadband traffic in the unlicensed space, thus increasing the likelihood of conflict with Wi-Fi operators, as well as technical work of standards setting bodies with implications for co-existence, were central to awareness of the co-existence problematic in the 2.4 and 5Ghz bands.

Separate - though ultimately closely related - to the problem stream, the policy stream explores the range of proposed solutions - or alternatives in Kingdon's terms - that may exist to address policy problems. An important feature of the policy stream is that these solutions are not necessarily generated in a *directly responsive mode* to the problem at hand. This points to a history of often detailed work leading to products or outcomes whose value, in respect of a problem at hand, only becomes realised at an apposite moment in time. This implies that the alternatives presented in the policy stream may have been developed with a different initial purpose than to address directly the evident problem. They may, in fact, assume that the latter does not exist. This feature of

Multiple Streams makes it a particularly insightful tool to understand the case of co-existence. Technical standards to exploit unlicensed Wi-Fi and licensed mobile broadband spectrum environments, respectively, were developed in separate – though also overlapping – technical (or policy, in Streams terminology) communities across an incremental historical trajectory. The primary aim was to exploit the available resource for communication purposes. It was implicitly assumed that the technical standards in question could ensure co-existence with other users.

Yet, the problem stream, in our case, indicated that this was not so. As the article shows, further action was needed to ensure the linking of the co-existence problem stream with a potential policy solution. Understanding this linkage mechanism, termed coupling, is a key focus of Multiple Streams analysis, which aims to illuminate the circumstances when the problem and policy streams are ready to connect with each other. This could occur when both a problem is widely recognised as being significant enough to search for a solution and that it is understood that a range of potential policy solutions may be in existence. However, for coupling to occur effectively, the Streams approach argues that the intervention of a policy entrepreneur is necessary.

Policy entrepreneurs, which for us can be individual or organisational (Cram, 1994), expend significant resources to advocate for policy development in a direction they favour (Kingdon, 2011). In complex and ambiguous situations they can ‘craft contestable meaning’, which for us can include technological meaning. They also ‘pursue strategies to join together problems and policies into attractive packages’ (Ackrill, Kay and Zahariadis, 2013: 873), through the coupling process. We extend the idea of ‘attractive packages’ to mean acceptable technical standards. The policy

entrepreneur plays a key active role in coupling problems to potential solutions when the time for doing so is appropriate or, in Multiple Streams terms, when a policy window exists. Policy windows are moments or contexts when change is ripe to take place and can form in the problem stream. These ‘constitute triggers that delimit and/or help frame the way issues are debated’ (Ackrill, Kay and Zahariadis, 2013: 873; Kingdon, 1995). Here problems and policies become clear and their potential linkage to create a change in future policy action becomes an issue considered vital to resolve. Policy windows serving the same purpose also form in what the Multiple Streams literature refers to as the political stream.

In Kingdon’s (1984) original work, two core elements of the political stream are the actions of national governments or parliaments and what was termed as the national mood. We argue that these features are particularly useful in understanding the evolution of the case of co-existence. First, it is important to acknowledge that the world of international standards making is different from the issues of national policy making envisioned in the political stream originally. However, in the case of co-existence in unlicensed spectrum, we show that political-legislative change in wireless communications at the European Union level in the shape of the 2014 Radio Equipment Directive (European Parliament and Council, 2014) was a key political condition leading to the development of the work on co-existence analysed in this article, since it necessitated technical standards making activity to ensure compliance with it.

Second, the idea of the ‘national mood’, or perspectives and preferences of citizenry, as a key political factor in policy change is also important in understanding co-existence. Applied to the context of technical standards making in this article, we

extend its definition into the specific context of common consumer and user behaviours and preferences in wireless communication. Technical standards development, conducted in specialist organisational contexts, takes place away from the day-to-day experience of consumers. Yet, those leading it are highly cognisant of - and sensitive to - current and likely future consumer preferences and usage patterns. Here, as more people use their mobile phones to access the Internet, the practice of 'offloading' has become popular, where users switch between licensed mobile and Wi-Fi services, when the latter are available. It has been predicted that offloading will have risen from 54% to 59% of all total mobile data traffic from all mobile connected devices between 2017 and 2022 (Cisco, 2019). Coupled with the established feature of regular mobile handset upgrading, the need for new handsets to incorporate the latest licensed and Wi-Fi based functionality is an important feature of the political stream of the co-existence debate. The article shows how political-legislative and consumer public factors provided a window of opportunity in the political stream to allow it to be coupled with the problem and policy streams in the consideration of co-existence. We develop this analysis in detail in the remainder of the article.

Standards Development for Co-existence: Organisational Contexts and Salience

Spectrum capacity in the so-called ISM (industrial, scientific and medical) bands (e.g. 902-928 MHz, 2.4 GHz, 5.7-5.8 GHz frequency bands) was highly exclusive initially in its uses (e.g. cordless phones, microwave ovens, military radars) (Guvenc et al., 2011, p. 6-7). In 1985, however, the US Federal Communications Commission (FCC) undertook the key regulatory measure to open the ISM bands for wireless communications on a licence-exempt basis, provided that they did not create interference with primary and secondary occupancy rights holding users of spectrum,

such as the military and, by contrast, terrestrial broadcasters. In 1997, the FCC made a second important intervention through releasing an additional 300 MHz of frequencies for unlicensed use by short range, high-speed wireless communication devices in the 5GHz band (Cooklev 2004: 10).¹ Whilst monitoring the development of unlicensed communication, it thereafter adopted a hands-off role in the sector's evolution which has persisted to the time of writing (confirmed by authors' interviews, July 2017 and July 2018). Instead, the IEEE's Committee 802, Subcommittee 11 (hereafter IEEE 802.11) developed as a key private venue for standards development work that would shape wireless short-range communications. Created in 1990, IEEE 802.11 introduced its first standard in 1997 and, by 2000, the organisation had two standards for the use of unlicensed spectrum - IEEE 802.11a and IEEE 802.11b (Greenstein, 2007: 13-14). These and the subsequently developed versions of the 802.11 standard (most importantly for the ongoing co-existence contestation, the 802.11ax standard) became commonly known as Wi-Fi. From this account, it is clear that standards have a tendency to evolve in an incremental fashion, developing strong path developmental characteristics.

In Europe, the European Telecommunications Standards Institute (ETSI), created in 1988 by the European Conference of Postal and Telecommunications Administrations (CEPT), developed a key role in the introduction of Wi-Fi. ETSI includes state administrations as well as major telecoms companies, manufacturers, network operators, service and content providers, universities and research bodies, user organisations, and consultancies (ETSI, 2016a). It is a 'pay to play' organisation with

¹ The regulation of the bands falls within FCC's Part-15 Rules, stipulated in Title 47 of the Code of Federal Regulations (CFR).

a stratified membership where members buy voting rights and weight through subscription (authors' interview, 2017; ETSI, 2018). ETSI is one of the organisations officially recognised by the EU (European Parliament and Council, 2012) as a provider of European Standards (ENs). Within ETSI, the Broadband Radio Access Networks (BRAN) committee has played a role in the promotion of the 802.11 standard family historically (ETSI, 2016b). In fact, the EN 301 893 standard was written in part with the IEEE 802.11 standard in mind (authors' interview, 12/10/16). The ETSI EN 301 893 standard 'instructs' devices operating in unlicensed bands how precisely to access a channel. Thus, in contrast to the US, the EU, through legislation and standards development activity, has played a significantly more hands-on role in the development of Wi-Fi. It also is important to note that ETSI's resonance for co-existence goes beyond the EU since it comprises as many as 865 members from 66 countries across five continents (ETSI 2018) and its technical specifications are thus copied by states beyond Europe.

WiFi aside, the growth of licensed mobile communications and attendant capacity pressures led players in the sector to move towards developing technical specifications and standards to allow use of unlicensed spectrum space, through a process known as offloading, based on the Long Term Evolution (LTE) technical standard which underpinned licensed operators' services historically. This involved technical work aimed at creating new LTE-based specifications to secure a more controlled use of the unlicensed space in the less crowded 5 GHz bands. To utilise the available capacity in these bands, key initiatives have occurred in the LTE-U (Long Term Evolution – Unlicensed) Forum and a formal institutional standard setting process undertaken within the much larger 3rd Generation Partnership Project (3GPP) (see below).

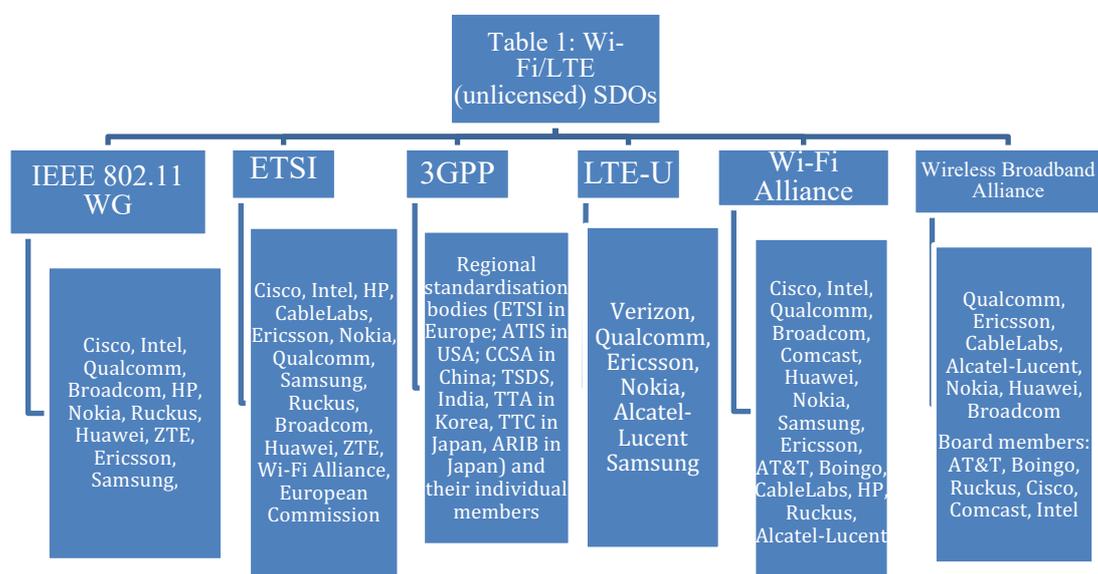
Established in 1998, 3GPP has defined technical specifications for advanced cellular communications, originating from ‘a 3rd generation mobile system based on evolved Global System for Mobile Communications (GSM™)’ (ETSI, 2016c). 3GPP work, building on LTE, focused on Internet Protocol (IP) based technical solutions to transport voice, messaging and data services over cellular networks (3GPP, 2016a). 3GPP unites under its structure seven telecommunications standardisation bodies from across the world that serve as its Organisational Partners and ‘determine [its] general policy and strategy’ (3GPP, 2016b). Very importantly for the current co-existence debate, one of these partners is ETSI (see Table 1).

Thus, the standards development organisation (SDO) world overall is organisationally nexus-like and overlapping. The membership of 3GPP is diverse and includes almost all major cellular, but also many Wi-Fi, related companies and alliances (see 3GPP 2016c). The members of the LTE-U Forum are part of 3GPP. The Wi-Fi Alliance² industry group is also an individual member of 3GPP, while the diverse Wireless Broadband Alliance (WBA)³ is one of 3GPP’s partners (3GPP, 24/10/16). The landscape, in policy terms, is thus interconnected and multi-forum (see Table 1). This interconnectedness, in theory at least, provides the opportunity for the resolution of conflict that might arise from different technical standards development processes.

²Created in 1999, the Wi-Fi Alliance has provided interoperability certification and approved backward compatibility of Wi-Fi CERTIFIED™ products (Wi-Fi Alliance, 2016a, 2016b). As seen further in this paper, the Wi-Fi Alliance has been particularly active in the planning of technical tests for measuring fair coexistence between LTE and Wi-Fi devices.

³Founded in 2003, the Wireless Broadband Alliance (WBA) focuses on next generation Wi-Fi, connected cities, wireless innovation and testing, as well as on trials of LTE devices in unlicensed spectrum (WBA, 2016).

There is a notable difference in the participation cultures of these organisations, most particularly between 3GPP and IEEE 802 (authors’ interviews, 12/10/16 and 12-13/07/17). While participation in both organisations is undoubtedly motivated by corporate business goals, in IEEE 802 attendees at standards development meetings hailing from a range of high tech corporate telecommunications players, when voting in any standards development process, are required to act in a personal capacity using their expertise to make decisions in the general or common interest of technological progress (see IETF RFC 7241, 2014; authors’ interviews 12-13/07/17). Attempted expansion of this cultural norm beyond IEEE – in the form of individual policy entrepreneurship - would create a crucial window of opportunity to resolve the co-existence problem (see p.25).



Source: Authors

The Problem Stream: Defining the Terms of Co-Existence between LTE and Wi-Fi in Unlicensed Spectrum Space

Spectrum usage undertaken on the basis of cellular and Wi-Fi standards (LTE and IEEE 802.11 respectively) differs markedly. These technical differences have created different operational cultures and distinct tension in terms of co-existence. This can be understood in respect of the idea of fairness, in particular in relation to access to network capacity. Some brief technical explanation is needed to illustrate this.

Wi-Fi devices gain access to spectral channels in a so-called ‘contention-based’ process, using the carrier sense multiple access with collision avoidance (CSMA/CA) technical protocol (Jeon et al., 2015: 2321). Here, an automatic ‘clear channel assessment’ process is performed before signal transmission occurs (Kwon et al., 2016: 4). The contention mechanism operates by a process of trying to avoid collision using the so-called listen before talk (LBT) algorithm, whereby a station attempting to transmit selects a random listening time duration. After it has detected no user transmitting during this random duration, it proceeds to transmit (authors’ interview, 12/10/2016). This is known as Wi-Fi’s ‘random backoff’ mechanism (Google, 11/06/15). The Wi-Fi 802.11 standard family includes an additional backoff mechanism, called ‘exponential backoff’. Here, if a signal collision occurs, the length of the random backoff interval referred to above is automatically increased before transmission recommences, thus minimising (though not removing entirely) the risk of further signal interference in densely populated (known as densified) network environments (Jindal and Breslin, 2015 in Google (2015); see also DSA, (2015: 3); Public Interest Organizations, (2015: 14).

By contrast, cellular communication through LTE operates on a so-called ‘contention-free’ or schedule-based system, ‘designed to transmit persistently as long as there are [data] packets awaiting to be served’ (Jeon et al., 2015: 2321). This provides better throughput for LTE based signals (Public Interest Organizations, 2015: 14) and thus better quality of service to the user but is problematic for co-existence since the reserved space it monopolises can leave Wi-Fi devices operating in the unlicensed environment starved of access to transmission channels, because LTE does not allow flexibility for the free or ‘idle’ periods of opportunity (Cano et al., 2016: 2) on which Wi-Fi capitalises for communication. Therefore, the inherent techno-cultural ‘politeness’ in the design of Wi-Fi devices creates a distinct disadvantage when operating in proximity to LTE transmitters as is increasingly the case in the unlicensed space, something exacerbated by the control-centric modus operandi of LTE. This is important, since historically:

It is the combination of all three of these politeness protocols, (LBT, initial wait, exponential backoff) and [its] ability to sense extremely weak signals...that make [Wi-Fi] such a good neighbor to other technologies. (DSA, 2015a: 3).

Wi-Fi stakeholders have frequently pointed out that these ‘good neighbour’ characteristics have also provided opportunities for innovation and deployment of other technologies to operate efficaciously next to it. Examples include coexistence with Bluetooth, Zigbee, and cordless phones in the 2.4 GHz band (DSA, 2015a: 5; Nwana 2016: 2). The perception of ‘fair’ coexistence between Wi-Fi and licensed providers differs markedly. The results of technical simulation exercises conducted by proponents of LTE are often disputed by the Wi-Fi community (Alderfer, 2015; Andreoli-Fang, 2015).

A key focusing event in highlighting the co-existence problem occurred in 2014, when a closed group of mobile carrier, chipset, and equipment manufacturers (led by Verizon and also comprising Qualcomm, Ericsson, Nokia/Alcatel, and Samsung) formed in the United States and put forward a technical specification (LTE-U) for the deployment of LTE in unlicensed spectrum bands. LTE-U was intended for use by licenced mobile carriers only (Feld, 2015a) and excluded other players with major stakes in the Wi-Fi sector, including Cisco, Broadcom, Microsoft, Cablelabs, and Google, all part of the Wi-Fi Alliance. It operated according to a so-called ‘duty-cycle approach’, which performed a particularly narrow, self-first techno-cultural articulation of sharing, by ‘owning’ spectrum for a chosen period of time and then allowing other devices (such as Wi-Fi) to use it in the remaining time (authors’ interview, 12/10/16; Paolini and Fili, 2015: 12). This amounted to the cultural antithesis of WiFi based communication. Whilst LTE-U incorporated the Wi-Fi originated backoff mechanism, it was absent the ‘listen before talk’ (LBT) technique (WBA, 2015). Its activated duty cycle mechanism would share the selected channel based on ‘on and off’ periods, which would be determined, crucially, by the LTE-U operators themselves on a self-regulatory principle (DSA 2015a: 4).

The Dynamic Spectrum Alliance (DSA), an industry association sympathetic to the position of WiFi in the co-existence debate, argued that the mechanism would give control to LTE-U players to determine allocated time to Wi-Fi based counterparts, and would impact negatively on the real time voice and video communications opportunity of the latter (DSA 2015: 4). By contrast, Qualcomm refuted accusations of unfair coexistence (Qualcomm, 2015) by arguing that LTE-U did not impact on the

performance of a Wi-Fi device any more than would another Wi-Fi neighbour (Cablevision et al., 2015).

Functionality and fairness aside, the entrance of LTE-based technology into the incumbent Wi-Fi space pointed up the thorny issue of international regulatory differences of approach to unlicensed spectrum use. In Europe and Japan, licensed cellular transmitters are required to deploy LBT when using unlicensed bands, something not specified in North America, South Korea and China (Giupponi, 2016). Since the ETSI EN 301 893 harmonised standard, mandated by the EU's Radio Equipment Directive, required the use of LBT, LTE-U could be deployed in the key markets of the US, China, and India, but not in Europe. Despite creating this fraction, as we show below in the Political Stream section, the role of European level political preferences expressed through legislation was a key factor in setting the agenda for action to address the co-existence problem.

True to their well-known laissez-faire approach, the FCC (in line with the US Congress) maintained the position that discussions should be carried out within and between the formal private technical standard-setting bodies (Feld, 2015b) (mostly 3GPP and IEEE 802) and the relevant industry alliances (LTE-U, the Wi-Fi Alliance, and the Wireless Broadband Alliance). It nonetheless decided to withhold the certification of the LTE-U devices for operation in the United States until industry parties resolved contested technical claims they held. This proved an important focusing event in highlighting the extent of the co-existence problem. A subsequent joint coexistence test plan exercise developed under the auspices of the Wi-Fi Alliance. Though initially announced as a compromise solution, the test produced proved an unsuccessful policy window since it

was not endorsed by key stakeholders and there was no obligation on service providers and vendors to run it. The process delayed the emergence of LTE-U based products on the market by a year which might have been considered as a victory in policy terms for the Wi-Fi community but merely served to highlight the persistence of the coexistence problem.

In February 2017, the US FCC finally authorised the operation of LTE-U devices. Whilst potentially a key focusing event, the core issue of contestation in the Wi-Fi problematic remained: disagreement on the inherent mechanism for spectrum use by LTE-U technology (LBT) and the energy detection levels necessary to prevent interference and enable 'fair' access to spectrum. Energy detection levels are crucial since they determine the decision taken on whether or not a channel or medium is busy and thus whether or not the device concerned is able to transmit a signal. Nevertheless, by this stage co-existence as a key techno-political problematic had become widely recognised among licensed and unlicensed spectrum players.

The Policy Stream: LTE-LAA, 802.11ax and the Development of Unlicensed Spectrum Use

The development of the LTE-U standard served to epitomise the co-existence problem rather than resolve it. However, a separate LTE-based standard development process - known as LTE-LAA (Licence Assisted Access) was undertaken in an alternative organisational venue. This standard evolved simultaneously to - and became closely connected with - work within the Wi-Fi community of the IEEE to create the next

generation of the Wi-Fi standard, known as 802.11ax. Both standards developed into potential policy options to address co-existence.

The LTE-LAA development process was undertaken in 3GPP (whose membership included the founders of the LTE-U Forum) with the aim of creating a ‘single global solution’ that responded to the challenge of overcoming the international regulatory differences noted above on use of unlicensed spectrum (Paolini, 2015: 11; Flore, 2015) as well as technical differences over communication protocol and energy detection. Unlike LTE-U, a formal standard creation process commenced within 3GPP. Yet, the LTE-LAA standard had a particularly closed techno-cultural underpinning in that it catered only for licensed providers through aiming to allow aggregation, by a primary licensed carrier, of one or more supplemental unlicensed channels (WBA, 2015: 1). It did crucially, however, include the LBT mechanism for functioning in the 5 GHz band (Qualcomm, 2015: 2; see IEEE, 2015, also Paolini 2015: 11). In March 2016, 3GPP announced the near completion of work on LTE-LAA (3GPP 2016b) and devices using it were approved by the FCC in September 2016 (Brenner, 2018). Despite the incorporation of LBT, a key difference between LTE-LAA and 802.11ax remained in respect of the detailed specifics of energy emission.

Throughout 2016 and 2017, a potential policy window opened when 3GPP and IEEE 802.11 took part in a resolution seeking process, by communicating through liaison statements, initiated by the policy entrepreneurship of the IEEE 802.11 committee. The core of the contestation between the two sides was the seemingly obdurate employment by Wi-Fi and LTE-LAA of different means of detecting energy from transmissions by nearby devices.

In essence, the system used in Wi-Fi devices is more noise sensitive than that of LAA. This increases the risks of ‘unfair’ access and use of spectrum when both operate in the same bands. Whilst LAA underpinned devices are designed to operate by detecting and avoiding interference with transmissions using the Energy Detection (ED)-only mechanism with a threshold of -72 dBm (decibel-milliwatts), Wi-Fi incorporates a more sensitive two stage ED (at a threshold of -62 dBm) and Preamble Detection (PD) (at a threshold of -82 dBm) process. This PD accounts for Wi-Fi’s exceptional ‘politeness’ characteristics.

The politics of the interaction proved fractious and the policy window proved unsuccessful. IEEE 802 argued that 3GPP should incorporate a lower (more sensitive) ED threshold or include in LAA’s design a PD system for increasing the detection sensitivity of devices operating according to it. The 3GPP rejected this argument and returned a counter proposal to IEEE 802 that the latter should consider the application of a less sensitive ED-only mechanism with a detection threshold chosen as optimal by the 3GPP (i.e. -72 dBm) in the IEEE’s ongoing work on the 802.11ax standard. Negotiations ended in deadlock when IEEE 802 rejected this counter proposal citing the long established and widely deployed Wi-Fi technological legacy of which dual detection was an integral part. The new IEEE 802.11ax standard, first vaunted in 2013, and commenced formally in 2014, was scheduled for formal ratification by the end of 2019. The standard addresses the key technological challenge of managing in a more controlled and more effective fashion signals in the increasingly crowded, ‘densified’,

spaces of unlicensed spectrum⁴. In this respect, 802.11ax can be regarded as a direct technical response to the concerns of licensed communications providers about the variable service quality of user experience in the unlicensed space, though it differed distinctly from LTE-LAA in respect of energy detection levels as a policy option to deliver co-existence.

The ETSI Policy Window, Policy Entrepreneurship and Efforts to Couple the Co-Existence Problem and Policy Streams

Despite the seemingly implacable impasse in potential coupling of the problem and policy streams of the co-existence debate, a policy window of opportunity emerged in Europe, drawing on its more public regulatory interventionist character in technical standards making (see next section). This led to a process to revise ETSI's EN 301 893 harmonised standard, which establishes the essential requirements for radio equipment to use spectrum efficiently and to avoid harmful interference. In an attempt to seek an alternative organisational venue to address the ongoing co-existence problematic, Wi-Fi stakeholders focused on the work undertaken in ETSI's technical committee on Broadband Radio Access Networks (BRAN). Importantly - in a situation of policy deadlock where existing standards making venues yielded merely articulations of difference - ETSI BRAN created a policy window by acting as a more 'neutral' forum for altering the unlicensed space technical standards making agenda towards the meaningful pursuit of fair coexistence terms between LAA and Wi-Fi through the EN 301 893 revision process.

⁴ Specifically, the 802.11ax project aimed to increase traffic throughput per user by a factor of four in dense user contexts through 'implementing mechanisms to serve more users a consistent and reliable stream of data (average throughput) in the presence of many other users' (National Instruments, 2017, p. 1).

Here, a detailed - and at times fractious - debate began at the beginning of 2016. By mid-2017, two spectrum access options for radio equipment in unlicensed bands were developed and presented. Recognisable as an attempt to couple the problem and policy streams, these counterpart technical solutions were packaged as a co-existence policy compromise. This stipulated both a single energy detection threshold and a dual detection threshold of ED and PD, and covered versions of the Wi-Fi standard up to - but not including - the IEEE 802.11ax standard. The coupling process commenced with the initial acceptance of the package as a pragmatic outcome, as ‘it was not possible to allow a “carve out” for 802.11ax given it did not exist at the time’ (authors’ interview, July 2017). Given the importance of 802.11ax, it was, however, agreed that the rules would be revisited. In the latter process, there was initially no sign of movement to a new technical understanding on energy detection levels, merely a trenchant tactical re-statement of preferred positions: the licensed cellular industry in 3GPP was still motivated to remove the dual threshold option used by Wi-Fi, while the Wi-Fi industry hoped that it could convince ETSI BRAN to remove the single (ED-only) threshold. However, central for the Wi-Fi industry remained its desire to ensure that the 802.11ax standard was covered by the revised ETSI standard to allow the use of dual thresholds in its future products and services, as had been the case for existing similar Wi-Fi standard variants in ETSI’s Harmonised Standard.

Evidence of collective policy entrepreneurship emerged with efforts to address the loggerheads at which the protagonists found themselves, through pressure exerted by Cisco, Intel, Broadcom, and HPE, from the Wi-Fi stakeholders’ side. These firms proposed to keep rules to continue with the status quo (i.e. allow both options) as already defined in the previous revision of the ETSI standard, but to extend these rules

to cover IEEE 802.11ax. Some licensed mobile network operators among 3GPP's LTE stakeholders initially opposed the proposed compromise and the discussions at the March 2018 ETSI meeting showed no signs of consensus (authors' interview, 2018). However, the position changed unexpectedly with a key piece of individual policy entrepreneurship from a participant associated with Ericsson (a company strongly interested in LTE initiatives in unlicensed spectrum), who suggested, in his personal capacity, a way to exit from the deadlock. This action was not in line with the established company membership-based decision taking cultural norm of ETSI BRAN. Instead, it was reminiscent of the cultural norm and modus operandi of the IEEE 802.11 committee. In essence, the policy entrepreneur proposed that all parties take the bold step of accepting the still unfinalised 802.11ax standard as a so-called 'market reality' (authors' interview, 09/05/18).⁵ This proposal was accepted and completed the coupling process between the problem and policy streams. Furthermore, in a signal of clear agenda shift in the direction of the practical pursuit of co-existence, participants in ETSI BRAN reached a common position agreeing on the need to test real world coexistence performances of 802.11ax and LTE-LAA. Both ETSI and Wi-Fi Alliance members were requested to make coexistence test reports available, which, according to multiple participants, would 'provide the industry the best hints' on enabling acceptable coexistence (IEEE, 2018).

⁵ Interestingly, Ericsson (as a company) has since proposed the ED/PD option to be defined as an 'exception', but the proposal seems to have been refused by ETSI BRAN (IEEE 802.11 Coexistence SC, 2018).

The Political Stream in the Debate on Co-Existence: Policy Windows of Opportunity and Coupling with the Problem and Policy Streams

The EU governmental stimulus provided to the standards making process in Europe by the 2014 Radio Equipment Directive exerted an important pressure in the political stream on standards developing parties. This directive replaced the 1999 Radio and Telecommunication Terminal Equipment Directive and, as a consequence, required the European Commission to mandate ETSI to revise the European EN 301 893 Harmonised Standard. The directive was scheduled to come into effect in June 2016, with a mandatory compliance among EU Member States of June 2017. The EN 301 893, however, needed to be revised earlier, in 2016, to allow approval and transition processes to be executed in time, thus precipitating the activity in ETSI BRAN analysed in the previous section. Thus, EU level political-legislative change created an important window of opportunity in the political stream which contributed to its coupling with the co-existence problem and policy streams.

The second vital aspect of the political stream for standards making parties was awareness of the consumer public's preferences for mobile communication in licensed and Wi-Fi spaces. This article has earlier outlined the interconnected nature of the licensed mobile broadband and Wi-Fi sectors in terms of standards making. As usage of laptops, tablets and mobile phones has grown, wireless communications users have become a vital international consumer public. Regularly upgraded wireless devices are now often both Wi-Fi and LTE enabled. This is particularly important for mobile phones, which are used increasingly to access the Internet, often through utilising the process of switching or 'offloading' between licensed and Wi-Fi services. Design and

manufacture of new dual mode enabled equipment is thus both costly and something subject to significant commercial time pressures, yet at the same time potentially highly lucrative. Industry analysis predicted that whilst latest fifth generation (5G) licensed mobile services will provide customers with increased data allowances and connection speeds, ‘new application demands on 5G are also going to move upwards...encouraging similar behaviours of offload as 4G’ (Cisco, 2019) in the future. As pointed out at IEEE 802.11, the dual threshold was included in an earlier version of the EN 301 893 Harmonised Standard and acknowledgment made that any drastic change of rules would jeopardise existing economic and social benefits of Wi-Fi to European citizens (IEEE, 2017). EU policy makers have advocated a technological neutrality approach in regulating electronic communications. The IEEE 802.11 community argued that extension of the dual threshold in the revision of EN 301 893 would achieve such neutrality without putting at risk the socio-economic value associated with the additional benefits of IEEE 802.11ax for the European community (IEEE, 2017).

The previous section has shown how, as the coupling process between the problem and policy streams unfolded, the crucial latest version of the 802.11 standard, according to which a raft of new equipment would be built and sold, could not be covered initially as the standards making process had not yet been completed. The incomplete 802.11ax standard development process raised the prospect of devices underpinned by it not being operable in Europe. This, in theory, would have knock on consequences for devices, such as laptops, incorporating the 802.11ax standard, but also LTE-based use in the case of dual mode mobile phones. The latter devices might not be ascribed as enabled with the latest WiFi technology, making them considerably less attractive to

customers as a whole. Awareness among standards making interests of the two crucial public preferences for regular device upgrades, on the one hand, and smooth transition and interoperability on mobile devices between licensed and unlicensed Wi-Fi environments (authors' interview, 2017; pwc, 2015) created another important window of opportunity in the political stream.

Thus, commercial pragmatism based on evidence of public consumer preference (or public mood in Multiple Streams parlance) was a key factor alongside the legislative compliance requirements of the EU Radio Equipment Directive, in coupling the co-existence political stream to the problem and policy streams. As Qualcomm, a key advocate of LAA, asserted 'Wi-Fi connectivity is in hundreds of millions of Qualcomm chips sold each year and embedded into the smartphones and tablets that [licensed] service providers and manufacturers sell to consumers', therefore LTE stakeholders 'have every incentive to achieve fair coexistence' (Qualcomm, 2015).

A contested policy environment in which the material interests of the protagonists are understood to be linked and common and in need of time pressured attention is more likely to lead to compromise shared policy agendas. The overall features of the three streams in respect of the co-existence debate analysed in this article are summarised in Table 2.

Table 2: Applying Multiple Streams to the Case of Co-Existence in Unlicensed Spectrum

| | Technical Standards | |
|-------------------------|--|---|
| | LTE | IEEE 802 |
| Problem stream | contention free Space control Quality of service No LBT Single EDT | contention based Space sharing Provision of access LBT Dual EDT |
| Policy Stream | LTE-LAA LBT Single EDT | 802.11ax LBT Dual EDT |
| Political Stream | EU Radio Equipment Directive (Parliamentary/legislative) ETSI standard EN 301 893 revision (technical/legislative) Seamless licensed-unlicensed use through offloading (consumer/public preferences) Regular reception equipment upgrades (consumer/public preferences) | |

Source: Authors

Conclusion

The technical standards for co-existence process amounts to a European legislation mandated, consumer public driven, compromise based on acceptance of two incrementally developed standards families, likely to sit uneasily aside each other in the unlicensed environment. In other words, the co-existence agenda set by this compromise is unlikely to assuage immediately concerns about fair access to communication space. It appears that IEEE 802.11 has achieved its goals of ensuring that LBT remains a predominant communication protocol in unlicensed spectrum and of convincing ETSI BRAN members to allow the use of traditional ED and PD mechanisms through the newly designed IEEE 802.11ax standard. Yet, at the same time, Wi-Fi interests had to accept the single energy detection threshold (of -72 dBm) for LAA devices as adopted by 3GPP as a feature of the landscape of co-existence in an increasingly utilised unlicensed spectrum space. The opportunity ETSI has opened as a seemingly more neutral venue for coexistence decision-making, provided a policy window to set in train the first steps of consensus-building and, most importantly, a common agenda on the need for generation and consideration of in-practice coexistence test data.

The co-existence case shows that private technical standards making, like complex policy processes, can create compromise technical outcomes. Fractious policy development processes can lead in the end to a clearer understanding of common interests, the ultimate one in this case amounting to commercial risk in a highly lucrative sector. The technically arcane co-existence debate has provided a vital way of setting the ground for an understanding of the direction in which the wireless communications environment is proceeding in user terms. Put simply, consumers are

unlikely to know or care about the technical standard that underpins their core preference for affordance of ready and efficient access to data rich, interactive mobile communications through regularly upgraded reception equipment.

The historic mandating of LBT in Europe, through the EU and ETSI, inserted it as the established and predominant cultural and operational norm of unlicensed communication in Europe and beyond. This created a window of opportunity for negotiation on the seemingly insolvable issue of energy detection. Policy flexibility and compromise were necessary to achieve regulatory compliance, where the Wi-Fi community accepted inclusion of the LTE community's less sensitive EDL; the LTE community accepted the 802.11ax standard, though not complete, as a market reality. Applying the Multiple Streams approach to the co-existence case allows us to see clearly how private technical standards-setting on its own when viewed through a policy process lens, struggles to solve, unaided, complex socio-technical problems like co-existence with issues of control and quality of user experience versus openness and equality of opportunity in communication at their core.

References

Ackrill, R., Kay, A. (2011). Multiple streams in EU policy-making: the case of the 2005 sugar reform, *Journal of European Public Policy*, 18(1), 72-89.

Ackrill, R., Kay, A. and Zahariadis, N. (2013). Ambiguity, multiple streams, and EU policy. *Journal of European Public Policy*, 20(6), 871-887

Alderfer, R. (2015). 'Fair LTE-U coexistence far from proven in CableLabs/Qualcomm testing', INFORMED blog, 11 November. Retrieved from <https://www.cablelabs.com/fair-lte-u-coexistence-far-from-proven-in-cablelabs-qualcomm-testing>

Andreoli-Fang (2015) 'Wi-Fi vs. duty cycled LTE-U: In-home testing reveals co-existence challenges', INFORMED blog, November. Retrieved from <https://www.cablelabs.com/wi-fi-vs-duty-cycled-lte-u-in-home-testing-reveals-coexistence-challenges>

Brenner, D. (2018). From LTE-U/LAA to 5G Spectrum Sharing. Retrieved from <https://www.lightreading.com/mobile/spectrum/from-lte-u-laa-to-5g-spectrum-sharing/a/d-id/743015>,

Cablevision et al. (2015) Contribution to 3GPP LAA Workshop. 29 August. Retrieved from available at ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/, LAA-150006.zip

Cohen, M.D., March, J.G., and Olsen, J.P. (1972). "A garbage can model of organizational choice". *Administrative Science Quarterly*. 17 (1): 1–25

Cano, C. et al. (2016). Using LTE in Unlicensed Bands: Potential Benefits and Co-existence Issues. Retrieved from https://www.scss.tcd.ie/Doug.Leith/pubs/lteWi-Fi_2015.pdf

Cisco (2019) 'Cisco Visual Networking Index: Global Mobile Data Traffic Forecast 2017-22 White Paper'. Document id: Document ID:1486680503328360, 18 February. Retrieved from <https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.html>

Cooklev, T. (2004). *Wireless Communication Standards: A Study of IEEE 802.11, 802.15, 802.16*, New York: IEEE Press.

DSA (2015). Response to Public consultation on the Draft RSPG Opinion on Common Policy Objectives for WRC-15. Retrieved from <http://rspg-spectrum.eu/public-consultations/>

DSA (2015). Letter: Re: ET Docket No. 15-105: Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology. 11 June. Retrieved from <https://ecfsapi.fcc.gov/file/60001077791.pdf#viewer.action=download>

ETSI (2016a). The Third Generation Partnership Project (3GPP). Retrieved from <http://www.etsi.org/about/what-we-do/global-collaboration/3gpp>

ETSI (2016b). The Birth of ETSI'. Retrieved from <http://www.etsi.org/about/what-we-are/landmarks/creation>

ETSI (2016c). What we are. Retrieved from <http://www.etsi.org/about/what-we-are>

ETSI (2016d). Who we are. Retrieved from <http://www.etsi.org/about/who-we-are>

ETSI (2018). What does membership cost? Retrieved from <https://www.etsi.org/membership/fees>

European Parliament and Council (2014) 'Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC', OJL153/62, 22 May.

Feld, H. (2015a). Part I: Spectrum Game of Thrones. Retrieved from <http://www.wetmachine.com/tales-of-the-sausage-factory/my-insanely-long-field-guide-to-the-lte-u-dust-up-part-i-spectrum-game-of-thrones/>

Feld, H. (2015b). Part II: A Storm of Spectrum Swords. Retrieved from <http://www.wetmachine.com/tales-of-the-sausage-factory/my-insanely-long-field-guide-to-the-lte-u-dust-up-part-ii-a-storm-of-spectrum-swords/>

Flore, D. (2015). On LAA Capabilities and Scope. Liaison from 3GPP TSG RAN, LS on LAA capabilities and scope (25-Jun-15). Retrieved from <http://www.ieee802.org/Communications.shtml>

Giupponi, L. et al. (2016). Simulating LTE and Wi-Fi Coexistence in Unlicensed Spectrum with ns-3, Retrieved from <https://arxiv.org/pdf/1604.06826.pdf>

Google (2015) 'Comments of Google. ET DKT 15-105'. 11 June. Retrieved from <https://ecfsapi.fcc.gov/file/60001078145.pdf#viewer.action=download>

Greenstein, Sh. (2007). Economic Experiments and Neutrality in Internet Access. Working Paper 13158, NBER Programs, June 2007. Retrieved from <http://www.nber.org/papers/w13158>

Guvenc, I., Gezici, S., Sahinoglu, Z. and Kozat, U. C. (2011). *Reliable Communications for Short-range Wireless Systems*. Cambridge, UK: Cambridge University Press

IEEE (2015) Follow-up Liaison Statement Regarding LAA. 18 May. Retrieved from <http://ieee802.org/secmail/pdfuYWRYdEDz5.pdf>

IEEE 802.11 Coexistence SC (2017). Agenda for IEEE 802.11 Coexistence SC meeting in Berlin in July 2017. Retrieved from https://mentor.ieee.org/802.11/documents?n=2&is_dcn=DCN%2C%20Title%2C%20Author%20or%20Affiliation&is_group=coex

IETF RFC 7241 (2014). IEEE 802/IETF Relationship. Available at <https://datatracker.ietf.org/doc/rfc7241/>

Jeon, J. et al. (2015). LTE with Listen-Before-Talk in Unlicensed Spectrum. Retrieved from <http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7247527>

Kingdon, J. W. (1984) *Agendas, Alternatives and Public Policies* Harlow: Longman.

Kingdon, J. W. (1995). *Agendas, alternatives and public policies* (2nd ed.). New York: Harper Collins

Kingdon, J. W. (2011). *Agendas, alternatives and public policies* (Updated 2nd ed.). Boston: Longman

Kwon, H-J. (Eddy) et al. (2016). Licensed-Assisted Access to Unlicensed Spectrum in LTE Release 13. Retrieved from <https://arxiv.org/pdf/1604.08632.pdf>

Lindblom, C. (1968) *The Policy Making Process*. Englewood Cliffs, N.J.: Prentice-Hall

Quotient Associates (2017). 'Wi-Fi Spectrum Needs - Final Report to Wi-Fi Alliance', February, Retrieved from <https://www.QuotientAssociates.com>

Mintrom, M. and Norman, Ph. (2009). Policy Entrepreneurship and Policy Change. *The Policy Studies Journal*, 37(4), 649-667.

National Instruments (2017). Introduction to 802.11ax High-Efficiency Wireless. Retrieved from <http://www.ni.com/white-paper/53150/en/>

Nwana, H. (2016). Letter Re: Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology. 4 February. ET Docket No. 15-105. Retrieved from <https://ecfsapi.fcc.gov/file/60001422974.pdf#viewer.action=download>

Open Technology Institute at New America, Public Knowledge, Free Press and Common Cause (2015) 'Reply Comments In the Matter of Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology', 26 June, Washington DC, ET Docket No.15-105.

Paolini, M. (2015). LTE unlicensed and Wi-Fi: Moving beyond coexistence. Retrieved from <https://ecfsapi.fcc.gov/file/60001076664.pdf>

Public Interest Organizations (2015). Reply Comments of Open Technology Institute at New America, Public Knowledge, Free Press, Common Cause. 26 June, ET DKT 15-105. Retrieved from <https://ecfsapi.fcc.gov/file/60001105564.pdf#viewer.action=download>

Pwc (2015) 'Are Wi-Fi and 4G LTE on a Collision Course?', *Communications Review*, April. Retrieved from https://www.pwc.com/id/en/publications/assets/ticpublications/pwc-communications-review-wi-fi-4g-lte_final.pdf

Qualcomm Incorporated (2015). Letter Re: Office of Engineering & Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U

and LAA Technology. 23 July. ET Docket No. 15-105. Retrieved from <https://ecfsapi.fcc.gov/file/60001117759.pdf#viewer.action=download>

WBA (2015). Wireless Broadband Alliance (WBA) response to Federal Communications Commission (FCC) Office of Engineering of and Technology and Wireless Telecommunications Bureau public seek of Information on Current Trends in LTE-U and LAA Technology. 29 June. ET Docket No. 15-105. Retrieved from <https://www.fcc.gov/ecfs/filing/60001086066/document/60001105679>

WBA (2016). Current members. Retrieved from <http://www.wballiance.com/join-us/current-members/>

Wi-Fi Alliance (2016). Who we are. Retrieved from <http://www.wi-fi.org/who-we-are>

Zahariadis, N. (2016). Delphic oracles: ambiguity, institutions, and multiple streams. *Policy Sciences*, 49, 3-12.

Zahariadis, N. (2003). *Ambiguity and Choice in Public Policy: Political Manipulation in Democratic Societies*. Washington, DC: Georgetown University Press.

3GPP (2016a). The Evolved Packet Core. Retrieved from <http://www.3gpp.org/technologies/keywords-acronyms/100-the-evolved-packet-core>

3GPP (2016b). Release 13 frozen in Gothenburg. 15 March. Retrieved from http://www.3gpp.org/news-events/3gpp-news/1769-rel-13_tsg71

3GPP (2016c). New Partners at London 3GPP meeting. 24 October. Retrieved from http://www.3gpp.org/news-events/3gpp-news/1800-pcg_37