

Pluralistic Licensing

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Abstract—We introduce the concept of “pluralistic licensing”, which we describe as the award of licenses under the assumption that opportunistic secondary spectrum access will be allowed, and that interference may be caused to the primary with parameters and rules that are known to the primary at the point of obtaining the license. A key aspect of the concept is that the primary will choose from a range of offered “pluralistic licenses” each with associated fees, and each specifying alternative opportunistic access rules and associated interference characteristics. Our proposal is a novel means to take forward spectrum licensing which is fair to both primary and secondary users and takes into account the requirements of both parties. The objective is to incentivize the primary to obtain this type of license through means such as a reduced license fee, whereby the opportunistic secondary spectrum access will use “cognitive radio” mechanisms to avoid causing interference to the primary or to otherwise keep interference within known parameters.

We discuss that our proposed concept can propel more robust or better design of both primary and secondary devices. For primary devices it can lead to the ability to cope with an increased degree or risk of interference among other benefits, and for secondary devices might lead to the ability to better share spectrum opportunities. Both of these aspects greatly improve spectrum usage efficiency and fairness. Our concept is also highly flexible dependent on the case-by-case deployment context, even so far as allowing solutions such as spectrum sensing and primary beacon transmissions which would otherwise not be practical or desirable, while defaulting to safe mechanisms such as a geolocation database in cases where a lower interference variance is required. Many other benefits of our concept and its extensions are discussed.

We argue that “pluralistic licensing” should become the *de facto* form of license awarded in newly designated bands, and should also be offered to the primary as a licensing option in existing bands in cases where interference to legacy devices that might exist in the band can be avoided.

Index Terms—licensing, opportunistic spectrum access

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I. INTRODUCTION

SPECTRUM management is a difficult balancing act, presenting the key challenge of realizing market demands and technical innovation without adversely affecting existing licensed users, while maintaining fairness in spectrum usage.

Since the inception of radio spectrum regulation, management of it has primarily been through “command and control” means [1]. Licenses awarded through such means have the benefit of allowing reliable services, some examples of which include near-ubiquitous voice connectivity in public land mobile, reliable and highly innovative data-capable services such as UMTS and LTE, high-quality broadcast services able to cope with even the cheapest or most poorly configured receiver hardware (or indeed analogue operation), and guaranteed clean spectrum for critical services (e.g., military, air traffic control, emergency services, etc.). However, the efficiency of such means is questionable, leading to the frequency bands in which they are applied being sparsely used at many times/locations [2]–[4].

At the other extreme are license-exempt bands [1], which have proven to be a hot-bed of innovation in the wireless field as well as an entry point for “free” wireless communications, among many other benefits. However, the resulting rich ecosystem in such bands is built on just one caveat, namely limited (low) transmit power on the premise of limited propagation (especially at higher frequencies). This hampers the scope/range of wireless services in license-exempt bands, and although it is partially effective as a rudimentary method of coexistence ensuring frequency reuse, it does not effectively handle interference in busy areas.

Spectrum sharing essentially involves a blended approach that fits between these extremes. The conditions for spectrum sharing, e.g., primary user protection requirements, are based on high level analyses and decisions by the spectrum management authority. These analyses tend to be geared for “worst-case” scenarios, leading to situations where in real-world sharing conditions they result in sub-optimal use of the spectrum.

Light-licensing can be viewed as a coordinated sharing mechanism. It is a means of supporting primary and secondary services in a common band. This scheme is used to ease the burdens of registration, licensing, and interference potential between primary and secondary users sharing a band, and can involve set license fees. It is used in cases where there is a need to coordinate with an incumbent user or as a private commons approach where individuals and licensed users set the conditions for license-exempt access [5].

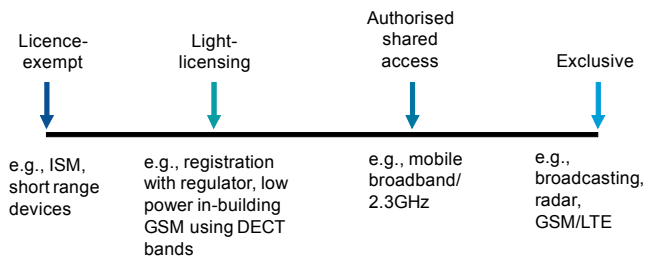


Fig. 1. Relative placing of various licensing concepts between the extremes of exclusive access and license-exempt frequency bands.

Webb & Cave discuss the push for more widespread sharing and investigation of optimal interference levels between licensed and unlicensed use [6]. They outline that spectrum usage rights should have the flexibility to be traded in time. Two of the dimensions upon which they may be traded include the level of interference and priority of access, which underpins the pluralistic licensing concept proposed in this paper. Over the past decade, we have witnessed a growing trend towards this approach through the introduction of more flexible licensing concepts to support new services and fluid market mechanisms, and to promote the more efficient use of spectrum [7]–[10]. These early concepts on the regulatory evolution path include light-licensing and authorized shared access (ASA), sometimes known as licensed shared access (LSA).

ASA/LSA is an approach proposed by Qualcomm and Nokia [11]. This is a relatively new concept in spectrum management, driven by industry. The concept involves licenses holders authorizing secondary usage of spare spectrum within their licensed bands but under tight controls to prevent any disruption. It was originally intended to support business cases for the build-out of mobile broadband network infrastructure, where it is both economically and technically feasible. The RSPG acknowledged LSA in a recent report stating that an LSA user can be granted a right to utilize under-used spectrum without interfering with the incumbent user. It is argued that LSA allows licensees to maintain a certain level of quality of service [5].

Figure 1 illustrates the relative placing of these various licensing concepts. These concepts demonstrate that all stakeholders are beginning to realize the value of more flexible approaches to spectrum licensing and usage. One key impetus of such flexible spectrum usage has been opportunistic/dynamic spectrum access (OSA/DSA), enabled by cognitive radio (CR) technologies [12], [13]. These technologies are a way to more efficiently use spectrum by pushing for coordination and awareness at the same level that interference occurs, i.e., between the spectrum users that can have direct radio interaction or effect on each other.

The market requirements for OSA/DSA are still emerging and inherently linked with a slowly evolving spectrum regulatory environment. These requirements are largely dictated by the measures that regulators apply to protect other services in target frequency bands. For example, OSA has

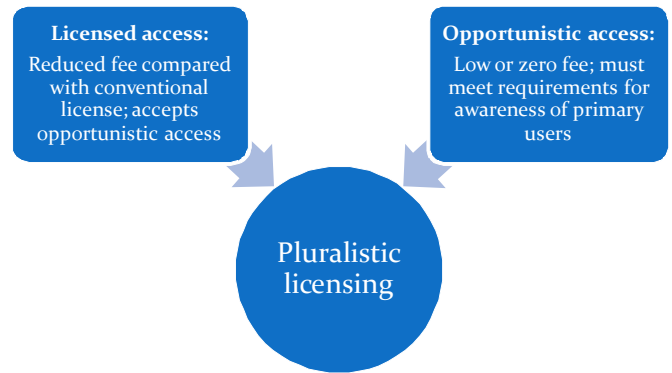


Fig. 2. Pluralistic licensing.

enforced upon it extremely onerous technical requirements to protect incumbents from interference if techniques such as “sensing” are used for spectrum information acquisition, and has significantly reduced opportunities for access if a “database” is alternatively used. These technical requirements are additional barriers to emerging wireless technologies and prospective market entrants. There is also the issue of resistance of incumbents due to the “fairness factor”, i.e., “why should someone should use for free what I paid billions for?”. Such technologies further suffer from fears of competition and disruption of existing business models, anxiety of spectrum being “encroached”, as well as severe and yet to be defined certification requirements.

In order to resolve the above observations and allay concerns such as fairness and business model disruption adversely affecting current primary spectrum users, this paper takes an innovative step in the realm of spectrum licensing through proposing the concept of “pluralistic licensing”. Section II of this paper describes this novel concept in detail. Section III discusses some of the considerations that be taken into account in fine-tuning the concept based on the deployment context, such as the characteristics of primary/secondary services and market conditions. Section IV discusses deployment opportunities for the concept, particularly some options for possible spectrum bands and choices of primary/secondary services, before Section V concludes the paper.

II. GENERAL CONCEPT

This paper proposes an innovative means to improve spectrum licensing, which is fair to both primary and secondary users and takes into account the requirements of both parties. The concept is termed “pluralistic licensing”, described as the award of licenses under the assumption that opportunistic secondary spectrum access will be allowed, and that interference may be caused to the primary with parameters and rules that are known to the primary at the point of obtaining the license. The concept is illustrated in Figure 2.

Before going into further detail on the concept, it is worthwhile introducing the unambiguous definitions of primary and secondary users that will be adopted for the rest of the work, which extend ITU definitions or understanding.

This inherently assists specifying the concept. First, a primary user is defined as a user that meets the following criteria:

- Its technical characteristics and geographic location (or location bounds) are available from an authoritative register or database of radiocommunications licences,
- It may or may not be required to adopt a technique for awareness assistance such as transmission of beacons, or to support other users in the coexistence process,
- It operates under the assumption that all other users will put in place mechanisms for detecting its presence with a minimum required detection performance, whereby the definition of such minimum performance, and likely also precise detection metrics required by the secondary to achieve that detection performance, will be specified in the license that the primary user has obtained.

Conversely, a secondary user meets the following criteria:

- It uses devices equipped with adequate means to achieve awareness of and guarantee coexistence with the primary user, at least being capable of meeting the minimum required primary detection performance, and likely achieving better than that dependent on incentivization,
- It operates with no guarantee whatsoever of quality of service, although it is noted that secondary users may in some cases be required to detect one another to improve secondary-coexistence. Secondary users might use probabilistic methods to understand exactly which levels of service they might be achieve with which probabilities, but this is as far as they can go regarding “guaranteeing” service.

Under our concept, primary users who obtain the license, which might be on a very short-term or longer-term basis or even geographical (e.g., per-transmitter), are allowed to access the spectrum at will. A coordination mechanism among primary assignments would nevertheless need to be decided by the regulator in cases where there are multiple primaries coexisting. Secondary users must use a “cognitive” mechanism to access the band, whereby the detail of the “cognitive” mechanism (e.g., the use and configuration of a spectrum sensing approach and/or a geolocation database, etc.), as well as its radio characteristics, are very much dependent on the context within which the band is chosen to operate. This context might include the expected types of primary services(s) in the band (perhaps also expected secondary services(s)), an assessment of an appropriate “burden” on the primaries in terms of acceptance of a slightly higher probability or net amount of interference while still achieving adequate performance, the degree to which the primary and secondary should negotiate or even in some foreseeable cases the degree to which the primary be expected to take proactive measures such as the transmission of beacons, among other aspects. Of course, such a context defines the extent to which the secondary must avoid interfering with the primary, hence the associated rules on the

secondary.

The goal of the proposed approach is to increase efficiency in spectrum utilization by incentivizing, on one hand, primary users to accept a certain degree of interference, and on the other hand, secondary users to reduce the impact of their transmissions. As will be discussed in Section III, incentives will be provided in the form of a reduction in the fee paid to access the spectrum, either collected through licensees or administered on a per-device basis at the manufacture or certification stage. Such solutions could, alternatively, be enforced in bands in which pricing wouldn’t apply, such as government-administered (e.g., emergency services) bands for example. Such pricing or otherwise direction of such solutions will lead to significantly higher spectrum efficiency, as primary users will be more open to acceptance of reuse of their frequencies and secondary users will be able to maximize the efficiency in the use of transmission opportunities.

The bands to which this concept applies can be newly designated by the regulator specifically for the purpose of such a licensing concept. Such a concept might also apply in existing bands through the option of new licenses being introduced or new primary users entering those bands. Of course, it might be difficult for new and old licenses to coexist, given that the new licenses might mean a trading-off for interference which would also affect the owners of older licenses. Nevertheless, in many cases the awardees of the different types of licenses will be separated in space or time, in which case the risk of such interference on legacy devices is not an issue. Discussion of such deployment opportunities for the concept is given in Section IV.

A. Benefits of the Proposed Concept

The proposed concept has a large number of benefits. For example, under this scheme particularly in green-field scenarios, there is no need for the secondary to cope with the inefficiencies of legacy primary systems. In obtaining the license, primary users implicitly accept the rules of the band hence will be designed and manufactured with better technical capabilities that are able to cope with those rules. For instance, primary users holding such licenses might better reject adjacent-channel interference, or might be engineered to employ an adaptive rate and error correction mechanism in cases where the opportunistic secondary spectrum access mechanism might imply a higher probability of an interference limit being violated or a higher variance in the experienced interference to the primary. Nevertheless, despite such possibilities, it is important to note that the primary remains in full control of its service quality through the choice it takes among the range of licenses offered to it.

A further more general benefit of the concept is that it satisfies need for spectrum sharing between more established users and incumbents, giving the primary system better quality (guaranteed) spectrum access with a given quality level as specified dependent on the rules for that particular band, while still allowing free access when/where the spectrum is not used for the secondary system. It might therefore be said that this

concept strikes a good balance between those that want to pay for quality, and those that want access freely.

An additional benefit is that the concept very likely implies significantly improved performance, e.g., in terms of spectrum efficiency, than prospective TV white space rules for example could achieve (with or without sensing being required). This is of course in addition to the vast improvements in spectrum efficiency through opportunistic access being allowed *per se* under the approach. The concept likely implies a very small additional interference effect on the primary system(s), as compared with the equivalent “primary” system in TV white space, whereby several studies have shown that only a very small implied increase in interference on incumbent systems can lead to a vastly improved performance in opportunistic access. This is indeed intuitive, given that achievable rate goes as the logarithm of the SINR, meaning that at the low-power limit in particular a very small increase in transmission power (hence received SINR) can lead to a very large increase in achievable rate for the secondary system.

A further benefit of the concept is scalability. Such a concept is highly scalable to progressive deployment in more spectrum bands as the spectrum becomes available, with the rules for each deployed band (e.g., the use of spectrum sensing, the geolocation database, or potentially even a beaconing mechanism being employed by the primary) being determined based on the intended context for that band (e.g., the expected primary services(s), expected burden on the primary, etc.). This is of course in addition to the possibility of carefully deploying the concept in some legacy bands, the effect on legacy devices permitting. Moreover, such a concept lends well to progressive deployment of primary transmitters as a network invests, for example, using a licensing regime similar to light-licensing.

Another benefit is that it supports the deployment of CR mechanisms, which has thus far been lacking. Through such a concept, opportunistic access technologies can be introduced to the market in a way that doesn’t violate regulations. Moreover, technologies such as spectrum sensing which have recently been forced into the background as regards opportunistic access can be brought to the limelight once again as a viable means of spectrum information acquisition in avoiding the primary system.

A final benefit discussed here is that the primary user now has an incentive to make more efficient use of spectrum, and to make unused spectrum available. The current regulatory system does not give such an incentive to primary users to cooperate in the sharing of spectrum. This leads to a long and cumbersome process when a spectrum management authority wants to introduce sharing to a band. The end result is based on a worst-case scenario in which the amount of interference that can be accepted by the primary user is much more restrictive than necessary. Pluralistic licensing has the potential to make more spectrum available for secondary usage than is possible within a “command and control” licensing scheme.

B. Drawbacks of the Proposed Concept

To our reckoning, there are few drawbacks of the proposed concept. One drawback is the complexity of the approach: instead of a simple license and pre-defined rules, this concept (or particularly its advanced implementation options) is proposing a far more dynamic mechanism potentially both temporally and spatially, which requires technology for its management (e.g., a geolocation database, with more advanced capabilities than current proposed database implementations), and more intricate assessment (pre-deployment) and monitoring (post-deployment) of the correct operation of the concept. The proposed concept can, nevertheless, operate in far simpler guises, ultimately down to a level that is no more complicated than currently TV white space rules with some of the parameterizations simply adjusted to account for more robust primary designs. Hence, the extent of this drawback is very much in the hands of the regulator depending on the specific band and services that the concept is being considered for deployment with.

Another drawback is that despite the vast improvement in the situation for secondary users that many aspects of the concept imply, it cannot guarantee a given level of service for secondary users. Such a lack of guarantee is, nevertheless, largely a characteristic of “secondary” status *per se*, and not something that it is possible to fully address through such a scheme. Probabilistic methods can nevertheless be used by the secondary to understand what will be available at certain times and locations with a given probability, and this understanding is a significant part of the problem that we are attempting to solve—especially if the secondary access is combined with other more predictable spectrum access means, such a secondary access being used to supplement primary access by the same system.

III. FINE-TUNING BASED ON DEPLOYMENT CONTEXT

A number of considerations must be taken into account in the determination of the operational rules for deployment of such a concept. These include:

1. Study of the new rules that secondary systems will have to follow to participate in the band dependent on the deployment context, such as detection sensitivity if spectrum sensing is used, the rate of updates of spectrum information (e.g., rates of sensing, rate of cross-checking with a centralized database), the allowable transmission power and mask, etc. This has direct implications for the capabilities that would be reasonably expected of the primary systems to participate in the band while still achieving acceptable performance, such as rejection of adjacent-channel interference, expected performance/SINR ratio requirement, ability to cope with a given probability of an interference threshold being violated, etc.
2. Selection of the spectrum information acquisition means (e.g., spectrum sensing, reference to a database, etc.) for secondary access, dependent on the

deployment context. This, again, has implications for expected “resilience” of the primary access, such as ability to accept a given probability of an interference threshold being violated temporarily.

3. Study of coexistence of primary users, e.g., resource allocation and contention mechanisms, perhaps pricing in allocation of transmission rights/licenses.
4. Perhaps coexistence of secondary users (e.g., the politeness expectations among the systems using low-priority access, such as “sense before transmit”, etc.).

In assessing these rules, a first essential step is the understanding and proper specification of the context within which such a band will operate. This includes definition of the target primary and secondary services that will access the band (e.g., broadcast, broadband, satellite, etc.), and the expectation of the burdens on the associated systems. It is noted here that although the concept should be specified based on the expected primary (and likely secondary) services, it is highly likely that other secondary services will still be allowed to use the band as long as they meet the technical requirements in terms of transmission characteristics, etc.

Such considerations lead to a number of secondary implications which fundamentally affect the way in such a band will operate and which must be taken into account in fine-tuning the concept dependent on the deployment context. Two of these are studied here, specifically:

- Consideration of the characteristics of the primary and secondary services that will access the band,
- Pricing for licenses.

A. Characteristics of the Primary and Secondary Services

This is the most important consideration in fine-tuning of the concept based on types of services that are going to access the band. This subsection discusses some key characteristics.

1) Fixed vs. Mobile

The assessment of whether the primary and secondary systems are fixed or mobile clearly affects the means that must be chosen for the secondary to be aware of the primary system, and likely also other rules that must be specified such as allowable secondary transmission power. Moreover, the distinction must be drawn between transmitters and receivers in the assessment of mobility: if the secondary system only has mobile receivers, for example, then there is little or no chance of it causing interference to the primary so long as the primary coverage area is already known and avoided through specifications given to or determined by the secondary transmitters. However, if the secondary system has mobile transmitters, then the risk is greatly increased. Moreover, if the high priority system has mobile transmitters hence mobile coverage areas, then the low priority system must usually take measures to avoid causing interference to those moving coverage areas.

2) Packet-Data Based or Not?

We believe that a distinction should be drawn between services that are packet-data based and other digital services. Moreover, should such packet-data based services be

primarily best-effort in nature, that distinction can be enhanced. Packet-data based services, and especially best-effort such services, are often more flexible in what they can accept as regards fluctuation in SINR hence achievable rate due to interference, as they are usually adaptive through means such as coding and modulation variation and able to correct errors through link layer and/or transport layer retransmissions. This is, of course, highly linked to the simplex vs. duplex question addressed later.

Considering higher layers, applications running above such services generally exhibit enhanced ability to cope with and adapt to the given performance fluctuations. For example, streaming services through progressive download can buffer in advance to protect against such fluctuations, and will commonly even vary the higher layer codec characteristics to cope with variations in the average achievable rate. Conversational VoIP and video conferencing applications will also adapt the codec characteristics to take into account these fluctuations. Taken to the extreme, software downloads, for example, are able to cope with almost any level of achievable rate fluctuation, especially delay-tolerant software downloads such as software upgrades. Moreover, web browsing services are generally lesser of a concern as their data amounts are small, whereby such services act, in effect, as composite file downloads.

Due to their increased robustness and adaptability in coping with variations in available capacity and connectivity, it is expected that such packet-based and particularly best-effort services are highly suited to deployment as the secondary system. Such packet-based services may, however, also be chosen as the primary system. In this case, aspects of the increased robustness of such services as covered above might make them compatible with spectrum sensing being used for the secondary system spectrum information acquisition mechanism, thereby opening up new possibilities to consider such sensing technologies with all their associated benefits as compared with the use of a geolocation database.

3) Duplex vs. Simplex

The assessment of duplex vs. simplex services has implications for the ability of that service to recover lost data and adapt, e.g., its coding and transmission rate to changing conditions such as interference/SINR. Simplex services have no back-channel hence are unable to cope with such issues. Hence, simplex services should require a higher guarantee of protection than duplex services, although this statement is clearly case-specific. Simplex applications might nevertheless still allow a high interference or low SINR per se, just that it is very likely that it will be necessary for the probability of that allowed interference level being violated to be kept low.

Given the lack of ability of simplex applications to change their characteristics dependent on the scenario or to recover from errors, it is expected that these applications will likely be most compatible with deployment as the high-priority system. Low-priority access will almost certainly entail significant changes in spectrum availability hence channel rates.

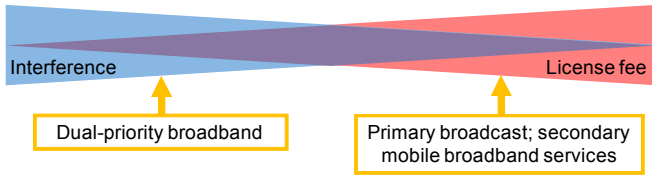


Fig. 3. Balance between license fee and accepted interference for primary users taking into account the intended primary/secondary services to access the band.

4) Digital vs. Analogue

It is, perhaps, a foregone conclusion that the secondary services are extremely likely to be digital, and that primary services are slightly less likely but still highly likely to be digital. However, the possibility of analogue operation, particularly for the primary, should not be entirely overlooked—this is exemplified by the continuation of viable primary applications such as FM/AM radio for example.

Given the increased radio capability of the secondary system and the extent to which that capability links in to digital operation, it is considered almost certain that the secondary system will be digital. However, the primary system has an increased, albeit still very small, chance of being analogue due to the lack of “complexity” requirement on such a system compared with the secondary.

Should such an analogue primary system exist, such systems are usually more affected by interference as there is no hard definition of the information being transferred, i.e., any level of interference potentially has an observable effect on the transmission as observed by the end-user. Should such an analogue system be deployed, the utmost protection of it by the secondary access would likely be necessary.

B. Pricing for licenses

As anticipated in Section II, pricing is a key tool under our proposed approach to incentivize the primary particularly but potentially both classes of users to take measures that maximize efficiency and fairness in spectrum usage. This is aside from direct-down enforcement of such measures by the regulator, which might also facilitate the concept in some bands to which pricing may not apply such as military bands for example. Detail on how pricing might be determined for each class of user is provided as follows.

1) Pricing for Primary Access

Primary users are required to pay a fee in order to:

- (a) Acquire the right to use the frequency without necessarily putting in place mechanisms for coexistence with other users,
- (b) Obtain the guarantee of a minimum level of quality of service, as defined for example defined by a maximum level or minimum probability of interference.

Detailed definition of the pricing mechanism is the subject of future work, but in the context of this paper it is worth observing that in particular for point (b) above, the fee reduction that the user will obtain as a function of the tolerance to interference by other users can be interpreted in two ways, depending on the behavior of the user:

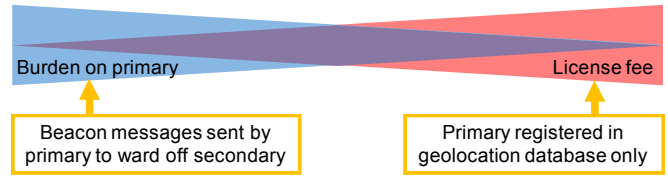


Fig. 4. Balance between license fee and burden on the primary through the use of proactive interference avoidance mechanisms (in this case, beacon transmissions).

- Users that allow higher interference without compensating for such additional disturbance in their technical equipment will receive a fee reduction as compensation for the reduced quality of service they experience, or,
- More interestingly, users adopting more sophisticated (and thus more expensive) hardware to cope with a higher interference level, that will not experience significant degradation in the quality of service as a result but will receive a fee reduction as “subsidization” for the higher costs incurred in adopting that hardware.

In both cases, the net result will be to favor users that, either by accepting a lower quality of service or by acquiring better hardware, will allow higher interference. An example result of such a pricing mechanism is depicted in Figure 3, in this case applied to the particular services, namely dual-priority (primary and secondary) broadband, and primary broadcast with secondary broadband. In the dual-priority broadband case, the primary (also broadband) will have a return channel so be able to feedback information on channel quality to the transmitter for adaptation purposes, and trigger retransmissions of lost data, thereby being able to accept a higher variance of interference. It should therefore, in this case, pay a lower licensing fee. Primary broadcast, on the other hand, will usually not be able to adapt and can therefore accept a much lower variance of interference, so must therefore pay a higher fee. Nevertheless, primary broadcast could accept a higher level of interference through increased coding at a cost to its channel usage efficiency; this would be one way of implementing a reduced fee for that primary broadcast service.

It is noted that as well as implementing changes in its transmission and hardware design to cope with increased interference or risk thereof, the primary might take more proactive steps to ward off interference, generally resulting in far greater spectrum efficiency performance than is reliably achievable though cognitive radio mechanisms such as geolocation databases and sensing. Figure 4 depicts a case where the primary transmits beacons to ward off the secondary, in turn receiving a significant reduction in license fee paid. Through reciprocity, such an approach allows the accurate assessment of the channel quality between the secondary transmitter and the primary receiver [14], allowing the secondary to squeeze every last drop of capacity from the channel through appropriate transmission power setting, while

still achieving a predicable interference effect on the primary.

Another important consideration in assessing pricing is the coexistence among primaries and the resulting effect they will have on each other in the band. In all such sharing cases, the license fee paid should be dependent on how busy the spectrum is in the area, a good measure for which is the number of deployed high-priority transmitters attributed to operators other than the one that the license fee is being assessed for. Setting the fee as being in inverse proportion to this appropriately sets it to be in proportion (on average) to the SINR that the high-priority transmitter will achieve at its receiving radios. Moreover, at a higher level of complexity it might be in inverse proportion to the average actual interference power that would be received at the radios in the area. This would again take into account the path loss between the interfering radios, summing the implied power over area and normalizing by the size of that coverage area.

2) Pricing for Secondary Access

The optional solution of pricing for secondary access under our concept, as anticipated in Section II, will have the goal of incentivizing the adoption of devices that guarantee high accuracy in the detection of both primary users and (at least in most cases, depending on the detection technique) of other secondary users, so to reduce the “interference footprint” that they imply. In this case, again, the user may perceive the fee in two different ways, depending on how the goal of increasing detection accuracy is achieved.

- Users that adopt hardware that guarantees better detection at the price of reduced efficiency in secondary access (e.g., a device that needs longer sensing times to guarantee better detection accuracy) will perceive the fee reduction as a compensation for the degradation of throughput due to reduced transmission opportunities,
- Users that adopt more complex (and more expensive) hardware that achieves better detection accuracy without reducing secondary transmission opportunities will perceive the fee reduction as a subsidization of the higher costs incurred to adopt better devices.

Synonymously to the case of primary users, the result will be in any case to favor users that increase their detection accuracy, either by scarifying secondary performance or by adopting better hardware. An example of this is shown in Figure 5, whereby the secondaries that implement higher-capability sensing, e.g., for secondary access politeness, in addition to cross-checking with a geolocation database, are charged a lower fee for spectrum access.

Pricing for secondary access might sound far-fetched, as licenses are not awarded in such access. However, one means that this pricing might realistically be achieved is through the manufacturer of secondary devices paying, e.g., at certification stage, for the assessed impact of the device on spectrum over its lifetime, then passing on that cost to the user. As another possibility, it is noted that under current geolocation database rules of the FCC and Ofcom [15]–[17], virtually all means already exist to be able to implement a

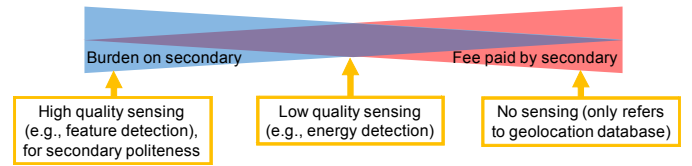


Fig. 5. Burden accepted by secondary to assist, in this case, secondary-secondary coexistence, and resulting variation of fee for secondary access.

form of charging for secondary access should it be desired to do so. At least as regards fixed secondary devices, the geolocation database maintains a record of the IDs and allowed powers (as an additional parameter in the case of Ofcom) of the secondaries, hence could ultimately charge a fee based on such information.

IV. DEPLOYMENT OPPORTUNITIES

A key element affecting deployment opportunities of the proposed licensing concept is, of course, the choice of appropriate frequency bands. The authors would argue that regulators should take the proposed concept as their prime “default” licensing option for any bands that are considered for re-deployment or re-allocation. Because such a scheme is offering an elegant solution of making a truly technology-neutral band assignment, where any radiocommunications service could in principle be deployed, thus overcoming a perennial struggle of most optimal band allocation to some specific (set of) applications based on administrative review and decision of a “beauty contest” type. It has long been shown that such administrative process is too rigid and inefficient [18], and even the latest studies confirm the need for some innovative approaches in the way the spectrum is accessed and shared [19]. The licensing approach scheme proposed here would be adding another possible tool to provide for more efficient, flexible and technology neutral allocation of frequency bands.. Moreover, by being sufficiently generic but nevertheless precisely specifiable dependent on the context, the proposed scheme is appropriate for deployment in almost any available band. In fact, the authors see this concept as something that should be progressively perpetuated to an increasing number of frequency bands, in each case considering the context within which it is deployed.

As regards to short-term selection of specific candidate bands for this concept, it is noted that even a comparatively narrow band of few tens of MHz could be sufficient to bring this new concept to reality. Important consideration though is that the incumbent/primary service may be imposed the suitable obligations for accepting a degree of interference risk unavoidably linked to the operation of secondary cognitive devices. It is obvious, that it would be easiest to accomplish in case of introducing the new scheme in the green field band, such as the one that is empty of incumbent users at the start of the process. Examples of such green field bands that may become available for re-deployment in the near future include:

- UHF TV band slots freed by transition to more

spectrally-efficient digital broadcasting (i.e., the “Second Digital Dividend”);

- The still largely unused TDD portions in land mobile frequency plans at 2 GHz (see, e.g., [20], cf. ongoing EC and CEPT/ECC reviews);
- The little-used 1452-1492 MHz L-band that was originally earmarked by regulators for T-DAB but never used (an example of administrative decision that turned out inefficient). The similar largely unused T-DAB band exists in VHF band.

Other than green field bands, we posit that such a concept may be also introduced in bands with an existing user base, as long as the incumbent radiocommunications services are either immune to the risk of interference from secondary cognitive users through, e.g., being placed in a different location, or might join the scheme as fully participating primary users. Examples of the former might be found in the many bands now used for Fixed/Fixed Satellite Services, where the risk of interference from secondary use would be greatly mitigated by the highly directional antennas of primary users. For instance some portions of the 3.4-4.2 GHz band would be of interest as they are positioned pretty close to existing mobile bands and also provide possibility for technologically-neutral reformation of existing WiMAX licensing assignments in parts of this band in some countries.

The examples of the latter candidate bands may be found in cases when the incumbent user base (the licenses they hold) tends to renew rather frequently. The most obvious example of such spectrum would be the bands used for the Professional Mobile Radio (PMR) users. Due to the nature of their operation by predominantly small companies (taxi, logistics companies, etc.), the licenses tend to have short time frames and to change frequently, due to either an owner going out of business or needing to update the equipment. Thus the new primary license conditions could be phased in into the base of primary users gradually, over several years. Moreover, the pattern of PMR usage itself (characterized by a single cell serving large area with bursty push-to-talk transmissions) is well suited to generate “spectrum holes” both in geographic and time domain that could be efficiently utilized by secondary users. An example of such PMR band that could be considered for pluralistic licensing could be the 410-470 MHz band which clearly represents a prime-quality piece of radio spectrum. Increasing the efficiency of utilization of this frequency band would be of paramount value both to wireless industries and governments/societies at large.

In any case, it is important to stress that the introduction of pluralistic licensing does not go against the principles of international allocation of frequency bands as embodied by the ITU Radio Regulations (RR). This is to say that it would be easy in the proposed scheme to set the safeguards that both the primary and the secondary user comply with any relevant provisions of the RR, be it in terms of type of services allowed, or any other associated requirements such as power limits etc. Eventually, as more experience of pluralistic band use is gathered, this may give a positive feedback to the re-

design of the RR Article 5, i.e. such as only the primary band allocations might be listed for less critical bands whereas secondary use would be allowed flexibly, subject to compliance with the rules of cognitive radio access.

A. Combinations of Primary and Secondary Services

Clearly, as well as the choice of frequency band, the configuration of such a concept depends on the combinations of primary and secondary services expected to access the band, as well as other requirements such as the market sector that the scheme is aimed at. Given such considerations, this sub-section performs a very quick analysis of the combinations of primary and secondary services that might be chosen to coexist in such spectrum, as well as a mention of possible requirements for each of them.

The first case we consider is that of dual-priority broadband, where both the primary and secondary systems are providing wireless packet-data broadband connectivity with duplex connectivity, with the exception that the primary system has a guarantee of service quality while the secondary must of course use opportunistic means for spectrum access. This case is particularly amenable to a guarantee of only an average service quality for the high-priority system and an increased variance of interference, hence the use of secondary system spectrum information acquisition schemes such as spectrum sensing. Such an assumption does, however, depend on the higher-layer applications that the primary user is using: some streaming video applications, for example, would be less compatible with such a case, unless they were through progressive download and through codecs that were adaptive to the underlying provided rate.

Such a case can be considered in contrast with another option for primary service, namely the fixed rate requirement primary service digital terrestrial TV. This is now a highly understood scenario that is extensively investigated in the scope of TV white space. In this case, the primary system is likely constrained to a certain fixed data rate as it will have no feedback link for channel quality assessment and retransmission request purposes, hence will require a very high predictability of interference level (i.e., low variance) from secondaries. In such a case, a geolocation database may be the only appropriate means that can guarantee that given level of interference certainty, hence may be enforced as the spectrum information acquisition means of the secondary. There are, however, some differences that can be applied here as compared with legacy systems in TV bands. A more robust handling of the primary system design and manufacture can improve opportunities for the secondary; for example, by the primary better rejecting adjacent channel interference the secondary may still be able to transmit on adjacent channels, of course with an appropriately stringent transmission mask.

As is the case in TV white space, alternative secondary access services might apply. One example is machine-to-machine (M2M) communications. M2M encompasses device communications used for smart meter infrastructure, telematics, health monitoring, security, environmental sensor

monitoring, and a wide variety of networks that operate independently of direct human interaction [21]. Machine communications traffic is characterized by very low per-device data demands, extremely low duty cycles and power usage, and an operating lifetime measured in years using battery power for power-constrained applications. Low-latency is not a prime requirement. The primary system could be incentivized through such a licensing scheme to better reject potential interference caused by periodic bursty nature of wireless M2M traffic and allow machine communications in the background in such cases, thereby facilitating hierarchical sharing. Moreover, the M2M devices could be incentivized to better refine their transmission (e.g., in terms of power output) to minimize the potential for interference.

Another type of service that needs guaranteed access to spectrum, but only in a very local area and for a short period of time, is related to public safety. Public safety organizations have their own network for day-to-day operations. However during an emergency situation they have a huge demand for communications on the spot. This additional spectrum usage can be based on the local conditions and the use of means such as beaconing by the primary user. This is of course only possible if the primary service doesn't have ubiquitous spectrum usage requirements [12].

Finally, it is noted that this type of sharing broadens the amount of accessible spectrum for users who need a guaranteed quality of service although only local and temporarily. This makes licensing a perfect fit for Electronic News Gathering and other Programme Making and Special Events services. Electronic News Gathering only requires spectrum for short periods of time and for a restricted local area, but it requires guaranteed access during the event.

V. CONCLUSION AND FURTHER WORK

This paper has presented the concept of "pluralistic licensing", which essentially comprises the award of licenses under the assumption that opportunistic secondary spectrum access will be allowed, with rules and parameters hence associated interference characteristics that are known to the primary at the point of obtaining the license. We have argued how the concept might work in practice, e.g., through incentives to the primary to purchase this type of license, and have argued the many benefits of such a concept such as the potential for significantly enhanced spectrum efficiency and fairness in spectrum access, with the performance expectation still being firmly under control of the license holder.

Further work must be performed to quantify the precise benefits and drawbacks of the concept, and its implementation complexities, covering areas such as (among others): -

- Study of pricing and associated complexities,
- Study of configurations under different combinations of primary/secondary services, and,
- Study of geographical harmonization challenges, e.g., ensuring that devices don't interfere when travelling to different regions.

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