Spectrum Allocation for Cognitive Radio Use

Emmanouil A. Panaousis and Christos Politis Wireless Multimedia & Networking (WMN) Research Group
Kingston University London
KT1 2EE London, United Kingdom
{e.panaousis, c.politis}@kingston.ac.uk

***Abstract*—One of the most regulated and scarce natural resources of all time is *radio spectrum*. Access to it has been chronically bounded ever since RF transmissions were first regulated in the early 20th century. There are several efforts to reduce interference with the most important and effective the allocation of spectrum to specific technologies. Additionally, new technologies that use spectrum more efficiently and more cooperatively, analogue switch-off and spectrum refarming, may help to overcome the spectrum shortage. These technologies come with great advances in the field of wireless communications and networking.**

In this paper we discuss the situation of the current spectrum allocation. Additionally, we explain the reasons of the growth need for utilisation of the *license-exempt* (LE) spectrum bands. The vast allocations of the latter could be enforced by using the technology of cognitive radios (CRs).

***Index Terms*—Spectrum, licensed, license-exempt, cognitive radios**

I. Introduction

FROM TV broadcasting to cellular networks and from Wi-Fi and Bluetooth to satellite communications, recent years have witnessed the proliferation of the emerging wireless services and the corresponding devices. Inevitably, the inherent demand for wireless services has led to an increased demand for radio spectrum. The necessary sharing of this finite resource has traditionally been regulated by governmental agencies. Spectrum is divided into fixed size portions which can be *licensed* or *license-exempt* (LE) [1]. In UK around five per cent of the spectrum is set aside for LE use and 95% for licensed use at present. LE spectrum is the spectrum that may be used freely without the need for a specific licence from the regulator or an authorised spectrum manager. In figure 1 we highlight the most well known wireless technologies and the band in which they operate. The LE spectrum is categorised into *segregated* and *spectrum commons* [2]. The former is allocated exclusively to one application while the latter is allocated to a multiple of different applications, or any application.

II. Spectrum Issues

A. How the process work and its time constants

If access to spectrum was not regulated there would be unaffordable interference among the different technologies and the different users. Therefore, the role of a spectrum manager is essential. This can ensure that two or more users do not transmit at the same time, on the same frequency and within the same area. Licensed bands are currently allocated with

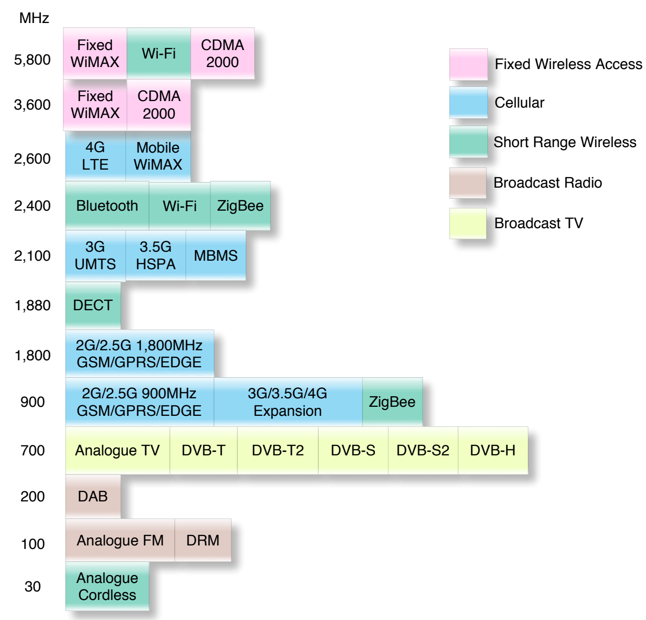

Fig. 1. Example of allocation of spectrum to well known technologies.

long term licenses to particular radio standards. Allocation is the process of determining how a particular band of frequencies can be used. Licensed bands are further divided into assignments to individual operators which thereby hold exclusive access rights to them. These rights are acquired via auctions [3] or beauty contests. The winner of an auction in fact gains the exclusive rights to use the spectrum keeping a list of predefined rules for a certain time period. This period has the potential to be expanded if the winner firms restore their licenses with a fractional charge. On the other hand, access to LE bands is unrestricted and this is one of the main reasons for the proliferation of certain wireless technologies such as the popular Wireless-Fidelity (Wi-Fi) technology. Despite the fact that no imposed restrictions follow the LE utilisation power-limit per device should be kept to respect health and environmental issues.

B. Evaluation of the current spectrum allocation

Indeed, the current mode of licensing procedure has too many problems: (i) a critical weakness of the current licensed assignment is the long payback time on infrastructure. Result of this assignment is that during that period only one operator has the monopoly of this bandwidth, (ii) if an operator does

TABLE I
ABBREVIATIONS OF VARIOUS WIRELESS TECHNOLOGIES.

3G	3rd Generation - International Mobile Telecommunications-2000
3.5G	High-Speed Downlink Packet Access (HSDPA)
4G	4th Generation - International Mobile Telecommunications-Advanced
BT	Bluetooth
CDMA2000	Code division multiple access 2000 (hybrid 2.5G/3G)
DAB	Digital Audio Broadcasting
DECT	Digital Enhanced Cordless Telecommunications
DRM	Digital Radio Mondiale
DVB-H	Digital Video Broadcasting - Handheld
DVB-S	Digital Video Broadcasting- Satellite
DVB-S2	Digital Video Broadcasting - Satellite - Second Generation
DVB-T	Digital Video Broadcasting - Terrestrial
DVB-T2	Digital Video Broadcasting - Second Generation Terrestrial
EDGE	Enhanced Data rates for GSM Evolution
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HSPA	High Speed Packet Access
LTE	Long Term Evolution
MBMS	Multimedia Broadcast Multicast Service
UMTS	Universal Mobile Telecommunications System
Wi-Fi	Wireless-Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

not achieve to attract many users it will not utilize the allocated spectrum efficiently. The larger portion of spectrum consequently remains unused instead of being exploited by any other technology, (iii) the expensive policies of acquiring the licensed spectrum makes the situation more difficult for small stakeholders. Therefore, several innovators could not participate in the spectrum allocation process and they can not deliver their ideas and products into the market. Novel ideas hence can not be exploited because they can not be deployed in the market. Finally, (iv) government agencies policies for spectrum handling are currently obsolete and new ways to allocate this spectrum or refarm it have to be proposed by the regulators. Additionally, in the UK, the Cave Audit [4] discusses the band-sharing concept to be adopted by spectrum managers (MoD, CAA, Police).

C. *Operating at LE bands*

On the other hand, the advantages of the LE spectrum utilisation make the situation promising for innovative LE technologies. Among these advantages, it is worth mentioning the following;

- the deployment of any LE technology is fast due to the fact that there is no SURs [5] (Spectrum Usage Rights)[1] associated with the process. The usage of spectrum hence is simple and efficient.
- the deployment of any LE technology is usually cheaper than the deployment of licensed technologies. Therefore, from a sociopolitical view, the LE spectrum bands could be utilised in poor and under developed countries.
- LE spectrum deployment encourages the spectrum sharing ability. Consequently, two or more technologies could be exploited within a shared spectrum. Interference cancellation and fair access of the wireless spectrum however should be enforced.
- LE spectrum deployment encourages the development of innovations, experimentations and implementations of new technologies and business models. This arises from the fact that the rules governing the use of LE spectrum are usually not as complicated as those governing the use of licensed spectrum.

Although the utilisation of LE spectrum bands is very important and essential seems that operators are not willing to invest their money in business plans of LE spectrum bands allocations. The reason for this is that it is difficult to provide Quality of Service (QoS) guarantees to their customers. This situation has the potential to be happened due to interference caused among different LE technologies which are deployed in a shared spectrum area. It is always possible that a wireless system will experience intolerable levels of interference from its neighbours and there is always a risk that too many systems will be deployed in close proximity. Therefore, if there are no constraints on the number of devices sharing the spectrum in a given location, at the same time, there can be no guarantee that the provided QoS will be adequate.

Additionally, operators have acquired licenses by paying vast amount of money. Consequently, they do not want to release or retain any portion of the spectrum for LE usage. The situation becomes more difficult for the deployment of LE if we consider the vast amount of money operators are willing to spend for innovative and upcoming licensed technologies such as the Long Term Evolution (LTE) [6].

[1]SURs can be considered as a set of core components and choices made for each band as we depict in figure 2.

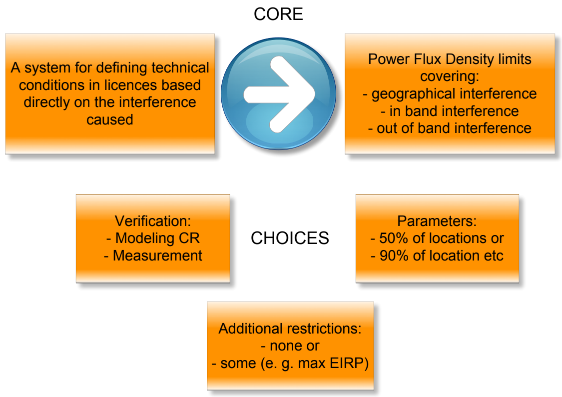

Fig. 2. The SURs (Spectrum Usage Rights) concept.

D. Control of interference

Examining the operation of wireless networks it is not infrequent to observe that every transmitter generates interference at other system's users which is treated as noise. Interference in LE bands is inevitable and also is going to be a more important problem over time as it can slow connections or shut them down completely.

Due to negative effects the higher the requirements of a user are the less users can be coexist into a system. The action of interference in a given system depends on the relative signal strength of the wanted signal and the effective aggregate of the unwanted signals and noise strengths detected by the receiver. Certainly interference depends on the power level, modulation characteristics, height and directionality of the antenna, and location of wanted and unwanted signals.

A conflict between two transmitters has the potential to occur due to physical proximity. Additionally, it may occur the *hidden node problem* [7]. Hidden nodes are not visible to each other and as a result they cause harmful interference correspondingly to each other.

Another well known term is the *interference susceptibility* (IS). This refers to the impact of the applications which are located in the same area. The three levels of IS are high, medium and low. For instance, high IS appears in systems that use spread spectrum, adaptive modulation and high dynamic frequency selection techniques.

Considering the LE allocation, the absence of a regulator causes a lot of problems. The regulator would be responsible for monitoring the wireless network and enforce rules. On the other hand in order to achieve proper operation without the existence of a regulator, self enforced and distributed rules, strategies and mechanisms should be should be designed and applied.

A basic approach to efficient use the LE bands is to punish selfish or greedy nodes whenever these do not behave according to pre-established rules. What is needed therefore is to design a mechanism for controlling the interference which every selfish node causes to its neighbours. Finally, with the implementation of proper mechanisms that mitigate the interference we will achieve higher performance and interference resistance for the *open spectrum wireless networks*.

E. Segregated vs. spectrum commons allocation

Research done in [2] establishes the technical and economic advantages and disadvantages of having segregated LE spectrum for certain applications rather than adopting a spectrum commons approach for new LE band allocations. Authors conclude that technologies which support the different applications are not compatible at present. These technologies mutually interfere in the physical (PHY) layer. The authors believe that the only way to have physical compatibility of the aforementioned technologies is when they are geographically, temporally or electromagnetically separated. Even though polite or temporal synchronisation protocols [8] alleviate the problem of the interference the most of the wireless applications do not support these protocols. Hence, towards the mitigation of the interference and the increment of compatibility lower power and more intermittent operations have to take place.

Additionally, critical wireless applications require segregated LE spectrum allocations to avoid totally the interference caused by co-located systems. On the other hand, whenever spectrum commons allocations or a new application for shared band scenarios are proposed, it is essential to carry out compatibility studies.

It is worth mentioning that the same research concludes that allocation of unrestricted spectrum commons for non-crucial use is acceptable as fas as the involved parties have knowledge of the potential harmful interference caused by co-located systems. Finally, applications which support the use of polite protocols they should anywise use spectrum commons allocation.

III. Cognitive Radios

Our opinion is that the necessity for devices which operate in the LE bands, seems to exist in view of the growing demand for radio spectrum. The current regulation regime of fixed assignment is clearly not enough and surely far from optimal. With most of the spectrum being already allocated, it is nowadays difficult to find a vacant frequency band for the deployment of a new wireless service or the enhancement of an existing one. Additionally, most of today's radio systems do not have any mechanism to keep them aware of their radio spectrum environment. The same systems operate in a specific spectrum band by using a specific Media Access Control (MAC) layer protocol.

According to the literature [9], it may be achievable to find non-utilised portions of spectrum through the exploitation of new technologies that allow LE users to operate in the same spectrum with licensed users of traditional radio technology, without interfering with those users. There are two ways to implement this.

One requires the use of a low-power radio technology such as Ultra WideBand (UWB) that underlies existing licensed users and operates at such a low power level but across a wide bandwidth that the licensed users experience no interference. It is worth mentioning that UWB has been proposed and allowed in the US.

The other is based on studies that show both temporal and geographical underutilization of the spectrum [10] . This means that, in certain areas and/or periods of time the available spectrum is partially occupied by primary users i.e. license owners, or it is not occupied at all. Therefore, a more intelligent approach could allow secondary users, i.e. LE users, to access the spectrum opportunistically.

But at the same time a problem is emerging. The LE users may cause interference to licensed or legacy users. To overcome this harmful situation the technology of *Cognitive Radios* (CRs) [11] has the potential to be used in the future. These radios sense the wireless spectrum and recognise if a frequency band is idle or it is occupied by a licensed technology. In this case, they inform the LE users that they have to change their transmission band before they cause any harmful interference to the licensed users. However, there are drawbacks such as the hidden node problem.

A. Definition

The IEEE 802.22 WG has defined CR in [12] as: ”A Cognitive Radio is a radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into (and out of, as necessary) the temporarily-unused spectrum very rapidly, without interfering with the transmissions of other authorised users”. In other words, a CR system enables devices to operate efficiently in multiple different frequency bands of the radio spectrum, including those with existing users.

The main characteristics of a CR are the following:

- CR senses the radio frequency environment in which it operates
- CR knows communications requirements of the users
- CR considers the different network policies that are applied in each specific case.

Especially, CRs could take decisions about how users access the spectrum in a flexible way. Briefly, the research project published in [12] investigated CR to (i) identify applications which have the potential to be used for time share spectrum or space shared spectrum, (ii) identify low cost control methodologies with low complexity which could be easily integrated into the existed technologies and (iii) take into account the impact of CR on regulators with the aim to increase their profits and launch their new ideas subsequently and quickly.

B. Security in CRs

Due to their sensitive role to decide about the use of the spectrum, CRs have to be protected against malicious activities. CRs are more open to attacks such as (i) jamming and (ii) selfish node behaviour. Security in this case is important to be applied in the case of CRs [13].

A sort of a jamming attack is when CRs have the potential to face the *Licensed User Emulation Attack* where an attacker pretends to be a license user by jamming the licensed band. For instance, a jammer can generate a signal that seems like the TV signal. Consequently, LE users postpone their transmission until the jammer stops the launch of the attack. The situation becomes worst when this attack targets a broad area of frequencies. In this case the LE users they can not find any white space to communicate with each other.

Another example that is worth to be mentioning is the case when there exists a *centralised spectrum manager* in a shared spectrum area. The manager transmits false control frames have the potential to launch finally a Denial of Service (DoS) attack. This selfish behaviour causes frequent exchange of control packets saturating the control channel.

Potential countermeasures for different kind of attacks, included the aforementioned, against the CRs could, generally speaking, be the following:

- authentication of the users to prevent the use of the network by unauthorised users
- strong data encryption at the physical layer
- use of labels name-pseudonyms to provide sender anonymity.

IV. Conclusions

To conclude, the operation of license-exempt spectrum networks is critical and essential. It is anticipated that many licensed spectrum technologies will be superseded by license-exempt technologies after years.

Unregulated use of the spectrum may lead to interference between transmissions. Hence, it is crucial to define some restrictions on users' rights to transmit. The existing approaches to defining restrictions on spectrum use, protect users against interference indirectly. However, these approaches assume the existence of a certain application or technology. SURs would directly impose limits to the emissions that a user may transmit in neighbouring bands or locations.

Security issues in CRs can affect the performance of any CR-enabled network. Apart from the aforementioned security issues, security vulnerabilities can appear to the enablers of any CR called Software Defined Radios (SDR) [14]. For instance a SDR may act as malicious if unintenional or intentional reconfiguration of its radio frequency or link layer stack parameters happens.

References

[1] C. Bazelon, "Licensed or unlicensed: the economic considerations in incremental spectrum allocations," *IEEE Communications Magazine*, vol. 47, no. 3, pp. 110–116, March 2009.

[2] "A study into licence exempt application specific bands for ofcom," *Ofcom report*, March 2007.

[3] M. Kelley, "The spectrum auction: Big money and lots of unanswered questions," *IEEE Internet Computing Magazine*, vol. 12, no. 1, pp. 66–70, Jan.-Feb. 2008.

[4] [Online]. Available: http://www.spectrumaudit.org.uk/final.htm

[5] Ofcom, "Spectrum usage rights technology and usage neutral access to the radio spectrum," April 2006.

[6] M. H. Ng, S.-D. Lin, J. Li, and S. Tatesh, "Coexistence studies for 3gpp lte with other mobile systems," *IEEE Communications Magazine*, vol. 47, no. 4, pp. 60–65, April 2009.

[7] C. Politis, "The role of cognitive radio in future spectrum use," *IEEE Vehicular Technology Magazine*, May 2009.

[8] Ofcom, "Study into the introduction of polite protocol controlled spectrum - final report," December 2006.

[9] S. Srinivasa and S. A. Jafar, "Cognitive radios for dynamic spectrum access - the throughput potential of cognitive radio: A theoretical perspective," *IEEE Communications Magazine*, vol. 45, no. 5, pp. 73–79, 2007.

[10] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey," *Comput. Netw.*, vol. 50, no. 13, pp. 2127–2159, 2006.

[11] J. Mitola and G. Maguire, "Cognitive radio: making software radios more personal," *IEEE Personal Communications Magazine*, vol. 6, no. 4, pp. 13–18, 1999.
[12] Ofcom, "Cognitive radio technology: A study for ofcom volume 1," February 2007.
[13] J. Burbank, "Security in cognitive radio networks: The required evolution in approaches to wireless network security," *3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, pp. 1–7, May 2008.
[14] M. Sadiku and C. Akujuobi, "Software-defined radio: a brief overview," *IEEE Potentials Magazine*, vol. 23, no. 4, pp. 14–15, Oct.-Nov. 2004.