Perspectives and problems of opportunistic and dynamic spectrum management

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Abstract

Possibly the most fundamental change ever is happening in the history of spectrum regulation – the allowing of secondary users to share spectrum with primary users, for free – subject to the condition that the secondary users, with licence-exempt equipment, do not interfere with the primary users. Cognitive Radio (CR) is an enabling technology that allows such sharing without causing interference to the primary users or to other secondary users. It opens the way for opportunistic and dynamic spectrum management, where wireless equipment is required to interface with cognitive algorithms, sensing mechanisms and databases. The first opportunity for spectrum sharing by secondary users is occurring with the UHF Digital TV spectrum, in what is commonly called TV Whitespace (TVWS). Use-cases for secondary use of spectrum broadband include access to rural and underserved communities, coverage of the street from inside buildings and future home networks. These are discussed and conclusions drawn regarding feasibility and commercial importance of these use-cases.

1. Introduction

Some cognitive behavior is already built into Femtocells and WiFi access points, where they auto-select the channel and transmit power depending on what other radio signals they detect around themselves. These devices operate in licensed and unlicensed frequency bands respectively, what they have in common is that they are unplanned. Taking this a step further, with unplanned unlicensed wireless systems being allowed to share spectrum with licensed users, it requires a new set of Cognitive Radio technologies such as database integration, sensing and very flexible software-defined radio (SDR) platforms. These technologies are being intensively researched as the enabling technology for this so-called secondary spectrum sharing [1, 2]. One of the first examples of spectrum being opened up for secondary sharing is the TV Whitespace, which comprises large portions of the UHF spectrum, that is becoming available on a geographical basis as a result of the switchover from analogue to digital TV.

TDD systems are preferable to FDD for opportunistic access. Suitable standard air interfaces are WiMAX and TD-LTE. The commercial case for opportunistic spectrum use will depend upon the amount of spectrum that becomes available for sharing, upon how the availability of this spectrum varies with location and upon transmit power allowed by cognitive devices. The rest of this paper is organized as follows. In Section 2 there is a discussion of sensing and database structures to control interference. This is followed by a brief review of the regulatory situation and challenges in Europe. In Section 3 some use-cases are described. The paper concludes with a summary and a list of challenges to be overcome and some projects that are working on them.

2. Controlling the Interference: Sensing or Databases or Both?

It is our belief that both are needed. Let us focus upon the UHF TVWS bands, where one of the primary users is wireless microphones, that operate using analogue FM. The spectrum mask for wireless microphones is shown in Figure 1. The bandwidth B here is taken to be 200kHz. The -20dB points of the signal energy is contained in the region +/- 0.35B = 140kHz. The fraction of signal energy between these points is 99%. Therefore, there is little to be gained (and much to be lost through increasing noise) by having a sensing receiver of greater bandwidth than this, if energy collection is the means by which the signal is to be sensed. It seems from this figure that a sensing receiver of 140kHz bandwidth is the maximum that is needed. The spectrum is shown in Figure 2. It can be seen that the -10dB points are at +/-50kHz, meaning that about 90% of the signal energy is contained within the central 100kHz bandwidth. So we can now say that there is no significant benefit by a sensing receiver having a bandwidth of more than 100kHz. A wider bandwidth receiver will collect more noise than it will signal. As the spectrum is dome-shaped, the narrower the better in this regard, but narrowing excessively returns less and less benefit but increases the time taken for the sensor to take a measurement. Our estimate is that 10kHz is a reasonable compromise.

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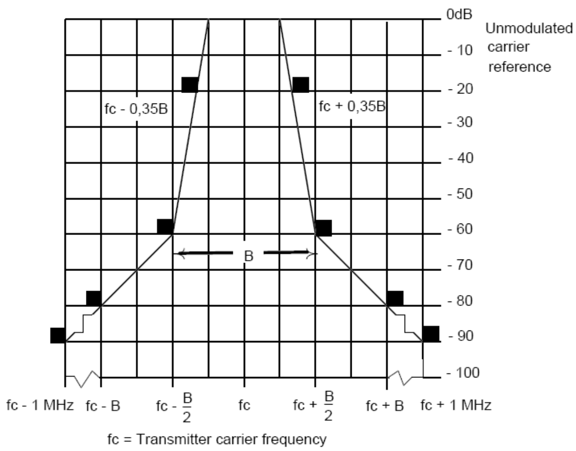

Figure 1. Transmission mask for UHF analogue FM wireless microphones (ETSI ETS 300 422. 1995)

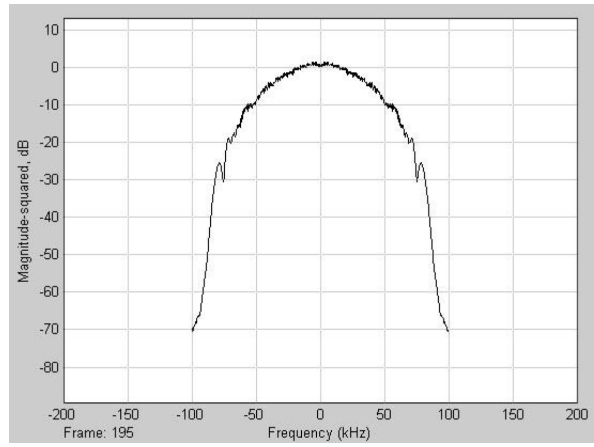

Figure 2. Actual spectrum of UHF analogue FM radio microphones (from Matlab simulation)

Let us estimate the distance over which sensing might be possible. The waveform is featureless, so that energy detection is the only option, that requires a positive SNR, say 6dB. Assume a bandwidth of 10kHz, so that the signal energy in the sensing bandwidth is 9% of the total transmitted energy, which is 0.09*10mW = 0.9mW or roughly 0dBm. At the sensor, the noise in 10kHz is -174dBm/Hz + 10Log(10kHz) + noise figure (2dB) = -132dBm. The required signal power is -126dBm to achieve the SNR of 6dB. The path loss tolerance is then 126dBm since the transmitted power is 0dBm. At UHF this path loss translates to a distance of around 500 - 800 maximum in an urban environment. This is not considered adequate for all TVWS use-cases, for example for rural broadband access the typical size of the network will be several km. The purpose of sensing, then, is not so much to detect wireless microphones, but to detect other secondary users of the spectrum. Sensing and databases should work together, and sensing will enable databases to achieve more efficient management of the spectrum. Regarding databases, Figure 3 shows a database structure, where the national regulator either owns or contracts the supply of a central database. Several secondary databases are also included, typically owned by network operators. The regulator will certify the algorithms used in the databases to determine which channels for the secondary devices and the transmit power without causing interference. The regulator is concerned only with protection of primary services. However, negotiation is required for reasons of fairness, and this will be built into etiquette between the secondary databases.

Primary users are the only ones that can book or reserve channels in the central database. The secondary databases can allocate spectrum, co-ordinate with each other, accept inputs from sensing. They can also be aware of the topologies of the secondary wireless networks and the QoS and mobility needs. If a user is moving, then the need for spectrum can be predicted and booked ahead. This two-step database approach is exactly what being developed in European collaborative framework 7 project QoSMOS [3] of which BT is co-coordinator. Another European project where BT plays is a leading role, QUASAR [4] is developing techno-economical decisions to support methodologies and tools that can support operators in quantifying the value of TVWS and other secondary spectrum to their business, based on specific service provision requirements and future customer's demand.

3. Regulation

Regulation is a major challenge to be overcome with opportunistic use of spectrum. The role of the regulator is to encourage competition and maximize the efficiency of spectrum use, but it is also to protect primary (licensed) users. In the previous section, we have seen one method by which the regulator can fulfill the protection role through the control of databases. However, the attitude of regulators varies. The US has already made available TV Whitespace for sharing. The UK, Dutch and Swedish regulators are keen to introduce sharing, but France and Germany are currently very cautious about enabling spectrum sharing. The broadcasters and especially radio microphone manufacturers are concerned that they will suffer interference from secondary users. In order to improve the alignment of the regulatory position across Europe, we are working with the Spectrum Policy office at the EU and making some studies in the EC project QoSMOS to provide input to the Radio Policy Spectrum Group (http://rspg.groups.eu.int). The principal aim is to increase the confidence of primary users that mechanisms can be put in place to prevent secondary users from causing harmful interference.

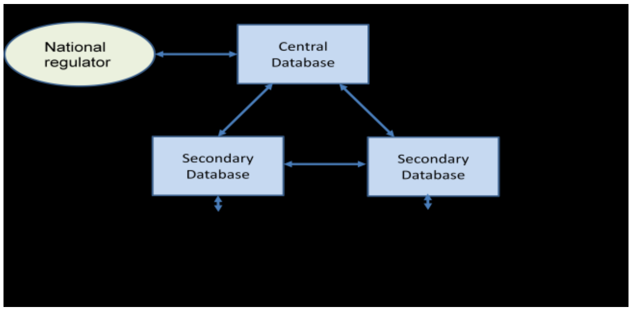

Figure 3. A possible database structure

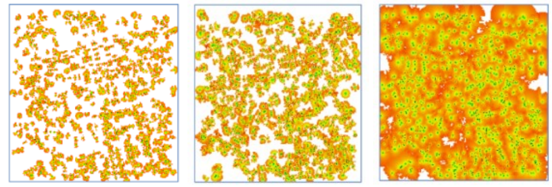

Figure 4. Achievable indoor-outdoor broadband coverage using access points operating at 5GHz (left) 2.4 GHz (centre) and 1GHz (right).

4. Use cases

There are three scenarios (contexts) into which the use-cases are assumed to fit, as follows:

- Indoor services which generally require small coverage and low power
- Outdoor coverage from indoor equipment with medium range coverage (a few hundred metres)
- Outdoor services which may require significantly higher transmit power levels

Most indoor applications of TVWS can already be realized using WiFi and Zigbee technology operating in the 2.4 GHz and 5 GHz. The main advantage of using opportunistic spectrum in the indoor context is to relieve congestion, in particular in the 2.4 GHz band. Use of lower frequencies results in better indoor propagation of signals through the home and lower energy consumption. The following describes three use-cases in detail, with a discussion of the modeling and trials by BT to examine their technical feasibility and potential business benefits.

4.1 Wireless multimedia streaming for connected homes

Currently operators are rolling out next generation access networks. This means that optical fibres are being installed either all the way to homes or to street cabinets. This enables broadband speeds of 40-100 Mbps on uplink from and downlink to homes. Such connection speeds are required in order to support streaming of high definition multimedia content to homes via the Internet, including high-definition TV (HDTV) and on-demand AV content. The high-data rate content is a challenge for wireless is to provide distribution within the home environment. Furthermore, some users wish to view content on mobile terminals which typically has a low resolution screen while others use a HDTV terminal and a set-top box which in many cases need to be connected wirelessly to the Internet.

Currently wireless multimedia streaming insides homes is supported using WiFi technology operating in the 2.4 GHz band. In urban areas this band suffering from capacity limitations due to a combination of interference caused by the high density of devices which use the band and inefficiencies of WiFi's distributed coordination mechanisms. One potential solution is the non-congested 5 GHz licence-exempt band, which has 380 MHz. One problem with using the 5 GHz for whole-home content distribution is that it doesn't deliver high bandwidths into all rooms in even a medium sized house, in particular into rooms that are on a different floor to the access point. Simulations and tests by BT indicate that 5 GHz WiFi (802.11n) deliver less than 10 Mbps into rooms above or below the access point, and less than 1 Mbps if there is a combination of floors and walls to penetrate. Opportunistic use of spectrum is intensely considered by players in the CogNea alliance [5], which has developed a TVWS standard focused on whole-home multimedia distribution [6]. The challenge is to select spectrum for the link on an as-needed basis, with say 1GHz for house-wide links and >5GHz for when the link is constrained to one room.

4.2 High-Speed Broadband Wireless acess from the 'Inside-Out'

The outdoor use of WiFi home networks is of high interest for telecom operators and attractive for mobile network offload. Unfortunately, the coverage provided by community WiFi networks is rather patchy hence limiting the usefulness and commercial success. This is due to a combination of the relatively stringent regulatory caps on transmit power levels of WiFi in the UK and the rest of Europe. Now, if opportunistic spectrum below say 1GHz is utilised, a range of several hundred metres is possible (similar in fact to the wireless microphone example in section 1, but here we are talking about wanted signals). Possible coverage with type oiif system, from the inside out, is shown in Figure **4** for area of Bayswater in London, a square with 1km sides. We assume here that 20% of the premises have a small base-station installed (like a femtocell) and the coverage along the street is shown for 5GHz, 2.4GHz and 1GHz from left to right. The transmit power is 20dBm in each case.

From Figure 4 it can be seen that coverage is very patchy when the system operates at 5 GHz and some improvement is gained by switching to 2.4 GHz. The most striking result is achieved when home access points switch operation to 1GHz where, with only a 20% deployment density, a blanket 2Mbit/s indoor-outdoor coverage is achieved. Note that this broadband coverage level at 2 Mbps data rate is 25 times higher than that achievable with 3G technologies such as HSPA. It is economically much more viable than the broadband coverage that could be offered by 4G cellular technologies due to the relatively low infrastructure and site acquisition costs.

4.3 Rural broadband

EU statistics show that 30% of the EU's rural population has no access to high speed Internet. The problem is caused by long copper lines, either between the street cabinet and the house, between the cabinet and the exchange, or in the backhaul to the exchange itself. For some situations, the cost of upgrading the lines or backhaul is very high when considering the relatively few users who would benefit. Opportunistic spectrum below about 1GHz is attractive for use with rural broadband, since losses due to diffraction and building penetration are low. Since it is fixed point-to-multipoint, there is also a low probability that other secondary users will cause interference, although of course mechanisms must be in place to avoid this such as sensing and database structures.

5. Conclusion

Sensing and database structures have been discussed as mechanisms to prevent harmful interference to primary (licensed) users. Opportunistic use of spectrum is a significant new opportunity for operators to provide a range of improved and new wireless services. Three use-cases have been discussed, which are links within the home, links from indoor to outdoor and rural outdoor to outdoor. A regulatory framework for opportunistic use of spectrum is developing with important steps being taken within the reguilators themselves and with the EC RSPG.

The challenges to be overcome include:
- Quantifying the amount of available TVWS spectrum, addressed by CogEU and QUASAR [12],
- Provision of reliable service and managed mobility and QoS, addressed by QoSMOS,
- Agreement across Europe and US on regulatory aspects

Other challenges that have not been mentioned in this paper include:
- Many overlapping standards emerging from ETSI, IEEE and the ITU lead to fragmentation of the market
- The growth of the necessary eco-system so that terminals and equipment are available at reasonable cost,
- CR equipment certification procedures
- A new value chain including databases and services based on location.
- Optimisation of fall-back spectrum methods,
- Database structure and etiquette,
- Flexibility of radio devices including MAC layer development and its interaction with the databases

6. References

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