Chapter 18

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ABSTRACT
The growing demands of radio spectrum urgently require more efficient and effective spectrum exploitation and management technologies. Cognitive radio technology and its networking not only explores the potential white spectrum resources temporally and geographically, but also enables an extensive efficient utilization and optimization of the current allocated spectrum resources. Therefore, rapid progress has been made in the research on cognitive radio and its networking technologies to facilitate more flexibilities in spectrum utilization and management. In this chapter, the authors first summarize the current various advanced and flexible spectrum management schemes, including spectrum trading, leasing, pricing, and harvesting, and analyze their advantages and disadvantages. Then, they take the viewpoints of both the spectrum marketing perspective and spectrum technical perspective, and they propose the centralized and distributed dynamic spectrum sharing schemes, respectively. In particular, the authors introduce many novel advanced spectrum sharing scheme and summarize the open and possible research problems.

BASICS OF COGNITIVE RADIO AND SPECTRUM MANAGEMENT
The rapid growth in wireless services over the past decade has illuminated the growing demands for radio spectrum, and we know the potentially-rich spectrum resource is limited, valuable and increasingly congested. Current traffic and high user experience quality, which also challenges the current spectrum management and allocation schemes allover the world. According to Cisco Visual Networking Index (VNI), mobile video traffic is already over 50 percent of mobile data traffic, and is expected to account for 66 percent of global mobile data demand by 2017. In addition, the global mobile data traffic grew 70 percent in 2012 with strongest growth in countries such as Japan and Korea where 4G penetration is high. According to this Cisco report, the global mobile data traffic is expected to grow steadily at CAGR
of 66 percent from 2012 to 2017, which means a 13-fold increase over 2012 and over 11.2 exabytes per month by the end of 2017 (4G Americas, 2013).

All the information and traffic growth predictions are showing demand for data that could overwhelm the wireless network resources due to finite and limited spectrum availability even though technology evolution is improving the efficiency and capacity of the wireless networks. To be ready to accommodate the growth, the wireless industry needs additional spectrum and associated policy innovation.

On the other hand, recent spectrum measurement campaigns indicate that most of the licensed spectrum has been under-utilized. Even in the most crowded area near downtown Washington, DC, where both government and commercial spectrum use is intensive, only 38% of the licensed spectrum remains occupied and the rest of spectrum resource, white space/spectrum hole is wasted. These statistics and studies spur the FCC to open up licensed spectrum bands and pursue new innovative technologies to encourage dynamic use of the under-utilized spectrum (Mitola & Maguire, 1999).

On the ITU 5D working group meeting in October 2012, some countries and organizations proposed the IMT system frequency demand situation in 2015 and 2020, as shown in the Table 1, in 2020, all countries have larger demand of frequency (ITU, 2013).

Current spectrum allocations of TDD frequency band in China, Japan and Taiwan are shown as follows:

- In China, Band38, Band40, Band34 and Band39 are assigned as TD-LTE or TD-SCDMA. China Mobile gets access to 130MHz of spectrum (1880-1900 MHz, 2320-2370 MHz, 2575-2635 MHz), China Unicom gets 40MHz (2300-2320 MHz, 2555-2575 MHz) and China Telecom has 40MHz (2370-2390 MHz, 2635-2655 MHz) for TD-LTE operation.
- In Japan, a part of Band41 is assigned as AXGP (TD-LTE) and WiMAX, while PHS uses a part of Band39.
- In Taiwan, a part of Band41 is assigned as WiMAX. Also, a part of Band39 is used by PHS and 3G TDD system.

To deal with the dilemma between spectrum congestion and spectrum under-utilization, cognitive radio technology and its networking has been proposed and advocated (Mitola, 1999, 2000; Haykin, 2005). The cognitive radio technology promises to improve the network spectrum utilization efficiency. The basic way is by allowing cognitive (also in term of secondary) users to intelligently sense and opportunistically access those spectrum holes. And these spectrum resources are temporarily unused by license-holding primary users.

Table 1. The IMT system frequency demand situation in 2015 and 2020 (ITU, 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Frequency Demand by 2015/2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>The United States</td>
<td>Need to add 175 MHz by 2015</td>
</tr>
<tr>
<td>Australia</td>
<td>Need to add 300 MHz by 2020</td>
</tr>
<tr>
<td>Russia</td>
<td>Need to add 385 MHz by 2020</td>
</tr>
<tr>
<td>Japan</td>
<td>Total demand is 2020 MHz by 2020</td>
</tr>
<tr>
<td>Huawei, Ericsson, Nokia</td>
<td>Total demand is 1880 MHz by 2020</td>
</tr>
<tr>
<td>GSMA</td>
<td>Total demand is 1600 to 1800 MHz by 2020</td>
</tr>
<tr>
<td>India</td>
<td>Need to add 500 MHz by 2020</td>
</tr>
</tbody>
</table>
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