

Chapter 2

Overview of Dynamic Sharing of Wireless Spectrum

The dynamic sharing of wireless spectrum has received significant attentions currently due to the fact of highly underutilized allocated spectrum resource and wireless spectrum scarcity for widely emerged bandwidth-hungry wireless applications. There are two basic approaches of dynamic sharing of wireless spectrum: (1) spectrum agile cognitive radio enabled dynamic sharing technology of wireless spectrum, which can be leveraged to allow new wireless access applications to dynamically share the currently allocated spectrum-band on a “do no harm” basis. In this way, cognitive radio enabled dynamic sharing technology of wireless spectrum will significantly improve the spectrum utilization in an efficient way without interfering the existing legacy wireless systems. (2) FCC has introduced a Geolocation database assisted unlicensed usage of TV White Spaces spectrum to meet ever increasing demand of mobile users for high quality communications and bandwidth-hungry wireless applications, namely database enabled dynamic spectrum sharing technology. With the abundant unlicensed TV White Spaces spectrum resource at VHF/UHF bands and superior propagation characteristic of TV White Spaces spectrum, TVWS Geolocation database enabled dynamic spectrum sharing technology can provide a wide-coverage, high-rate, yet cost-effective connectivity for diverse wireless applications.

The remainder of this chapter is organized as follows. In Sect. 2.1, we first survey the CR enabled dynamic spectrum sharing technology. In Sect. 2.2, we survey the database enabled dynamic spectrum sharing technology. In Sect. 2.3, we introduce the dynamic spectrum sharing standardization. Section 2.4 introduces the dynamic spectrum sharing applications. Finally, Sect. 2.5 closes the chapter with conclusions.

2.1 CR Enabled Dynamic Spectrum Sharing

The core technical issue of CR enabled dynamic spectrum sharing technology is to avoid any interference to the existing legacy systems through cognitive spectrum sensing and dynamic spectrum access approaches in a cooperative and noncooperative way [1, 2]. During the dynamic spectrum access process of wireless commu-

nications, the time-varying characteristic of wireless channel demands the realtime negotiation among cognitive wireless users. Spectrum sensing is to detect dynamic access opportunities for SUs [3]. In [4, 5], the joint spectrum sensing and dynamic access approaches are studied using coalitional games. However, in cellular networks, the spectrum usage tends to exhibit much more temporal and geographical variations [6], the internal spectrum sensing scheme including some centralized or distributed sensing technologies cannot handle it efficiently. To increase the spectrum vacancy detection probability and accuracy while decreasing the sensing time [7–9], external sensing agents aided spectrum sensing schemes become more popular to accurately acquire and predict the available spectrum resources in the cellular bands [10, 11]. Under the external-aided spectrum sensing scenarios [12], external sensing agents can act as the sink nodes in the spectrum sensor networks for cooperative sensing and centralized processing. From this point of view, dynamic spectrum sharing process plays like the Medium Access Control (MAC)-like functions. In addition, the coexisting interference among cognitive secondary users and primary users, and multi-dimension joint resource optimization problem would make the cognitive radio enabled dynamic spectrum sharing approach challenging. As shown in Fig. 2.1, the current cognitive radio enabled dynamic spectrum sharing research basically focus on the following three research directions: dynamic spectrum sharing architecture, dynamic spectrum allocation behavior, and dynamic spectrum access technology, which can be given as follows for details.

There are two types of CR enabled dynamic spectrum sharing approaches in terms of dynamic spectrum sharing architecture in wireless networks, i.e., centralized dynamic spectrum sharing architecture and distributed dynamic spectrum sharing architecture, which can be given as follows for details:

- Centralized dynamic spectrum sharing architecture. In the centralized architecture, both the spectrum allocation process and spectrum access process are controlled by a centric spectrum management entity. Generally, after sensing the users’ demand

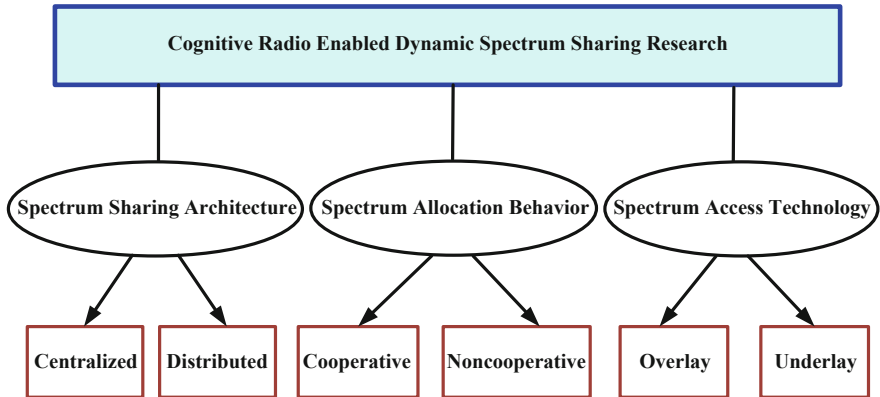


Fig. 2.1 CR enabled dynamic spectrum sharing research classification

and network scenario information, the centric dynamic spectrum management entity will make an optimal spectrum sharing objective based on the spectrum allocation demand of cognitive secondary users and current network status, and then provide realtime spectrum allocation results to each cognitive secondary user.

- Distributed dynamic spectrum sharing architecture. In the distributed architecture, each cognitive wireless user will realize the dynamic spectrum allocation and access process in a distributed way, according to the independently sensed and acquired wireless scenario and policy information. Generally, distributed dynamic spectrum sharing approaches emphasize the flexibility and simplicity of real-world dynamic spectrum sharing operations. Compared with the centralized architecture, even though the complicated centric spectrum management entity is not a necessity, it requires higher sensing ability of individual cognitive secondary user and flexibility of dynamic spectrum sharing approaches.

There are two types of CR enabled dynamic spectrum sharing approaches in terms of dynamic spectrum allocation behavior in wireless networks, i.e., cooperative dynamic spectrum allocation approach and noncooperative dynamic spectrum allocation approach, which can be given as follows for details:

- Cooperative dynamic spectrum allocation approach. For the cooperative approaches, the interference measurement information of each user will be shared among all the users, which can provide the guidance on how to make dynamic spectrum allocation and spectrum access strategy. Currently, most of the investigated dynamic spectrum sharing approaches focus on the cooperative clustered sensing and local interference information sharing. In this way, the requirements of central processing ability, interference coordination ability of cognitive end users, and communication overhead in both fully centralized and fully distributed schemes can be effectively balanced.
- Noncooperative dynamic spectrum allocation approach. Compared with the cooperative approach, noncooperative dynamic spectrum allocation solutions only consider the users' own utilities. Since there is no comprehensive consideration for other nodes' interferences, this kind of "selfish" spectrum sharing approach can reduce the communication overhead of nodes in factual applications to a certain degree while decrease the spectrum utilization.

There are two types of CR enabled dynamic spectrum sharing approaches in terms of spectrum access technology in wireless networks, i.e., underlay dynamic spectrum sharing technology and overlay dynamic spectrum sharing technology, which can be given as follows for details:

- Underlay dynamic spectrum sharing technology. In the underlay technology, there is no overlapped spectrum bands for primary users and secondary users, and secondary users will communicate over the acquired spectrum holes in primary users. As we know that, the spectrum hole is defined as the resource block with time-frequency-space three-dimension parameters. Generally, spectrum holes can be centrally controlled in a centric architecture, for example, spectrum pool concept

proposed by Mitola, and Geolocation database concept for IEEE 802.22 TV White Spaces standard. In addition, the spectrum holes can also be acquired through the cooperative sensing from local cognitive users, and dynamically access to those spectrum holes in a distributed way. Here, underlay dynamic spectrum sharing technology is only constrained by the transmission power of secondary cognitive users, and secondary users only focus on the utilization time and location parameters of spectrum holes.

- **Overlay dynamic spectrum sharing technology.** Overlay dynamic spectrum sharing technologies are more suitable for certain fixed spectrum bands sharing among primary users and secondary users. Through the complicated Spread Spectrum Communications (SSC), for example, ultra-wideband (UWB) technology, and by controlling the transmission power of secondary users, primary users can maintain the normal communication level. Compared with the overlay dynamic spectrum sharing approach, secondary users can acquire the larger spectrum bandwidth.

In essential, cognitive radio enabled dynamic spectrum sharing approach can be formulated to a multi-objective optimization problem, i.e., how to make the best dynamic spectrum allocation and access strategy, and optimize the multi-dimension time-frequency-space-power variables in different wireless application scenarios. Since all the participators including primary users and secondary users have their own targeted objectives and utility functions, all their spectrum access behaviors and spectrum sharing decisions are mutually effected, and have both potential competition and cooperation relations, it is crucial to carefully consider the spectrum usage rules and according spectrum access schemes, coordinate all the participators' behaviors and meet their different utility requirements in the dynamic spectrum sharing approach design. As shown in Fig. 2.2, we summarize the current research directions of cognitive radio enabled dynamic spectrum sharing technologies from

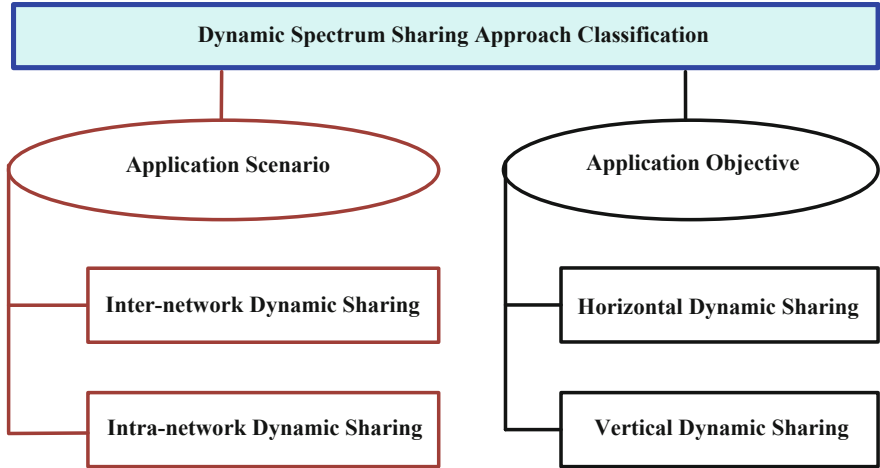


Fig. 2.2 CR enabled dynamic spectrum sharing approach classification

the perspective of both application scenario and application objective. For specific, from the perspective of application scenario, the cognitive radio enabled dynamic spectrum sharing technology can be divided into intra-network dynamic spectrum sharing technology and inter-network dynamic spectrum sharing technology considering if both primary user networks and secondary user networks are belonged to one network or not; from the perspective of application objective, we can divide the cognitive radio enabled dynamic spectrum sharing technology into horizontal dynamic spectrum sharing and vertical dynamic spectrum sharing based on the role of cognitive users in the cognitive radio networks.

From the perspective of application scenario, there are two types of cognitive radio enabled dynamic spectrum sharing technologies: cognitive inter-network dynamic spectrum sharing and cognitive intra-network dynamic spectrum sharing, which is shown in Fig. 2.3. Cognitive inter-network dynamic spectrum sharing in cognitive radio networks means that the spectrum will be allocated among secondary users, and each secondary user can access to the primary user networks in the condition that they do not interfere the normal communications of primary users. Dynamic spectrum sharing scenario among primary users and secondary users is the typical scenario in the cognitive radio enabled dynamic spectrum sharing technology. For the cognitive inter-network dynamic spectrum sharing scenario, when there are multiple systems that they are geographically overlapped or sharing some part of the same spectrum bands in the cognitive radio architecture, the spectrum resource in different systems can be mutually scheduled. Therefore, in this way, the scheduling of resource

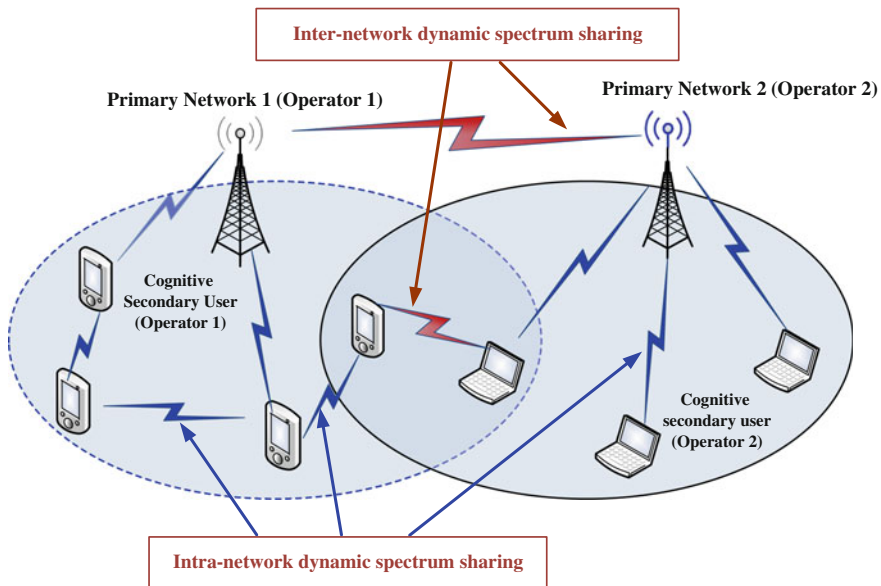


Fig. 2.3 CR enabled dynamic spectrum sharing application scenario classification

not only includes the resource sharing among primary-primary users, but also the cross-network resource sharing among secondary-secondary users in different cognitive systems. Taken the dynamic spectrum sharing in cellular networks for example, typically, there are two main challenges for the dynamic spectrum access application in cellular bands: (i) different SUs have various resource requirements, in terms of the wireless access duration, bandwidth, etc.; and (ii) compared with TV spectrum, the spectrum usage in licensed spectrum tends to exhibit much more temporal and geographical variations, and for different spectrum usage behaviors and service requirements, the pre-allocated spectrum resources for PUs are composed of variant Time-Frequency Blocks (TFBs), especially in existing heterogeneous communication systems. Considering that the explored available TFBs in cellular networks have different number of continuous subchannels with different holding slots [6], the improper resource management and utilization approach will lead to low resource utilization. In [13], H. Mutlu et al. investigated efficient pricing policies for resource providers to price the excess cellular spectrum bandwidths to SUs. In [14], Y. Liu et al. proposed an adaptive resource management framework to improve spectrum utilization efficiency and mitigate the interference to PUs. To quickly and properly match those variant and scattered time-frequency blocks with various demanders in cellular DSA, the problem of dynamic resource supply with various demanders should be well investigated [15]. From the perspective of quality of service for SUs' demands, in [16], Alshamrani et al. proposed a spectrum allocation framework for heterogeneous SUs in real time and non-real time (NRT) applications, respectively. In [17], Sodagari et al. proposed a time-optimized and truthful dynamic spectrum rental mechanism. In [18], H. Zhou et al. introduced a packing approach to fast and optimally allocate the time-frequency blocks. In [19], Yuan et al. discussed a dynamic time-spectrum blocks allocation problem in cognitive radio networks. In [20], C. Singh et al. introduced a provider-customer matching resource allocation strategy based on the coalitional games. In [21], N. Zhang et al. investigated a maximum weight matching problem for the cooperative DSA in multi-channel cognitive Radio Networks. However, none of these work are specific for cellular networks and consider the aforementioned features of cellular DSA.

2.2 Database Enabled Dynamic Spectrum Sharing

Considering the abundant unlicensed spectrum resource at VHF/UHF bands and its greater transmission range and better penetration property for long range wireless broadband access, dynamic sharing of TV White Spaces spectrum has received significant attentions. In terms of TVWS utilization for TV White Spaces networking, current dynamic TV White Spaces utilization is mainly based on the Geolocation database access technology. Even though there have been active theoretical researches on TVWS spectrum allocation and channel configuration by leveraging the spectrum sensing technology [22–24], spectrum sensing is expensive in terms of cost, energy consumption and complexity of the circuitry. Furthermore, the problem

of TV signals detection accuracy using spectrum sensing remains. In contrast, the Geolocation database assisted dynamic spectrum sharing approach does not require any hardware and is easier to implement. Devices only need to report their locations to a web service, which in turn returns a list of TV spectrum channels that can be used at their current locations. FCC has approved the IEEE 802.11af standard to provide Geolocation database assisted dynamic White Spaces spectrum sharing [25]. For the up-to-date research works, R. Murty et al. [26] indicated the Geolocation database assisted TV White Spaces networking can provide mobile users with more convenient and stable dynamic access. B. Gao et al. [27] proposed the Geolocation database-driven opportunistic spectrum access approach to support the mobile users, which is designed for the vehicle-to-vehicle communication scenario. X. Chen et al. [28] proposed the single-channel TV White spaces networking deployment with the support of Geolocation database. M. Madhavan et al. [29] introduced the utilization approach of low-power TVWS channels for small-coverage-range cellular networks. In addition, P. Ameigeiras et al. [30] investigated how to dynamically deploy the small cells in TV White Spaces, The proposed small-coverage White Spaces networking solutions are more suitable to support the static users due to the limited communication coverage range. Both of those two above proposed small cell White Spaces networking solutions are more suitable to support the static users due to the limited communication coverage range.

There have emerged many efficient infrastructure-based dynamic TV White Spaces spectrum sharing applications, for example, TV White Spaces spectrum access for both vehicular content distribution applications and wireless multimedia networking applications [31, 32]. For the up-to-date research works, in terms of the vehicular content distribution with the support of TV White Spaces infrastructure, Yu et al. [24] studied the bandwidth-efficient and rate-adaptive video delivery by using the dynamically sensed TVWS channels. By fully considering the spatial TVWS spectrum reuse, Chen et al. [33] introduced a vehicular Infotainment service provisioning approach with the goal of maximal content delivery throughput and enhanced spectrum utilization efficiency. A. Achtzehn et al. [34] considered the delay-sensitive Emergency Safety Message (ESM) dissemination by fully utilizing the superior propagation characteristics of TVWS channels. It is worth mentioning that Achtzehn et al. [35] further investigated the feasibility of TVWS secondary networks and presented the analysis and quantitative results of cellular and Wi-Fi-like TVWS deployments. Reference [35] shows that DCF based secondary deployments in TVWS limits the system capacity since the increased coverage range will lead to more congestion.

2.3 Dynamic Spectrum Sharing Standardization

The dynamic wireless spectrum sharing technologies have been widely applied in different wireless communication systems. Various standardization organizations and industry alliances have conducted extensive related research activities, including the

Institute of Electrical and Electronics Engineers (IEEE) and Internet Engineering Task Force (IETF). In this section, we will present the dynamic spectrum sharing standardizations of IEEE and IETF for details.

2.3.1 IEEE Standard

Currently, many active IEEE Working Groups have proposed dynamic spectrum sharing technologies, regulations and standards to support both the cognitive radios and database enabled dynamic spectrum access, and efficient dynamic spectrum resource management. The IEEE spectrum sharing standardization activities include: IEEE 802.11af standard for Wireless Local Area Networks (WLAN), IEEE 802.15.4m standard for Wireless Personal Area Networks (WPAN), IEEE 802.19.1 standard for dynamic coexistence, IEEE 802.22 standard for Wireless Regional Area Networks (WRAN) and enabling technologies, and IEEE P1900 standard for dynamic spectrum access networks. In the following, we will give the details of IEEE spectrum sharing standardization activities.

IEEE 802.11af standard defines technologies, regulations, and specifications for spectrum sharing in wireless local area networks among unlicensed TV White Spaces devices and licensed services in the VHF and UHF TV White Spaces bands [25]. Based on the IEEE 802.11ac physical layer, IEEE 802.11af standard can support multiple concurrent downlink transmissions by leveraging the multi-user multiple-input multiple-output (MU-MIMO) technology and is featured with multiple operating modes in 6, 7, 8 MHz bandwidth TV channels. For specific, Fig. 2.4 shows the protocol to access TV White Spaces database in IEEE 802.11af standard. For the IEEE

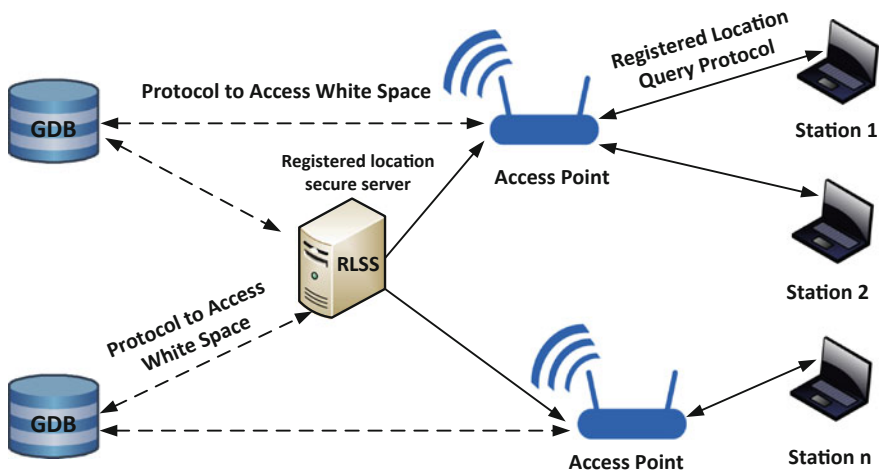


Fig. 2.4 The illustration of protocol to access TV white space database in IEEE 802.11af standard

802.11af operation in the TV White Spaces bands, IEEE 802.11af standard regulates the dynamic access to the TV White Spaces spectrum via Geolocation database.

IEEE 802.15.4m standard is the first low-rate wireless personal area networks standard operating in TV White Spaces bands [36]. IEEE 802.15.4m standard specifies three types of TVWS Physical layers (PHYs) including the Frequency Shift Keying (TVWS-FSK) PHY, Orthogonal Frequency Division Multiplexing (TVWS-OFDM) PHY, and Narrow Band Orthogonal Frequency Division Multiplexing (NB-OFDM) PHY. By leveraging the enabling technologies for low-rate wireless personal area networks in TV White Space bands. IEEE 802.15.4m standard proposes TVWS Multichannel Cluster Tree PAN (TMCTP) technology for cost-effective and spectrum-efficient communications and principally targets on low-data-rate TVWS networking applications in sensor, smart grid/utility, and machine-to-machine networks.

IEEE 802.19.1 standard specifies radio technology independent methods for coexistence among dissimilar TV Band Devices (TVBDs) and dissimilar or independently operated networks of TVBDs [37]. It is the first intersystem coexistence standardization effort for TV White Spaces utilization in IEEE 802.19 standard, and develops coexistence wireless scenarios in TVWS and potential coexistence metrics. Figure 2.5 shows the IEEE 802.19.1 algorithms [38]. The proposed IEEE 802.19.1 algorithms include coexistence discovery algorithms and coexistence decision algorithm. As shown in Fig. 2.5 for specific, the coexistence discovery algorithm will find White Spaces object including a White Spaces device or a network that may affect each other's performance. In addition, coexistence decision algorithm will make decision on the channel and power allocation through negotiations.

IEEE 802.22 standard is the first standard to specify the air interface and enabling cognitive radio technologies for wireless regional area networks communication systems to share the spectrum resource in the VHF/UHF TV White Spaces bands [39].

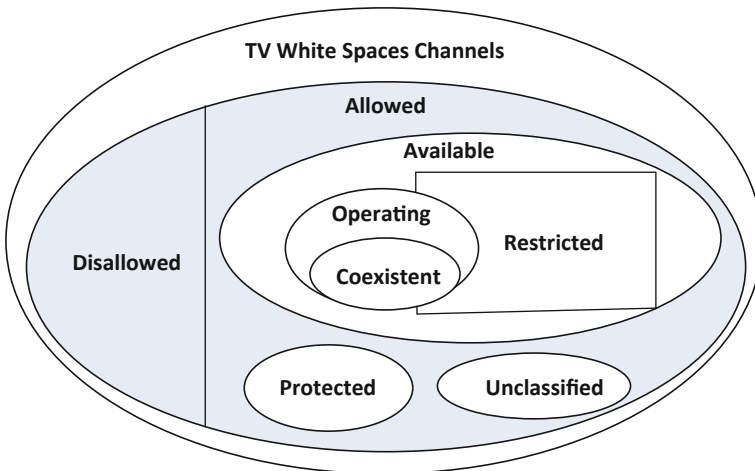


Fig. 2.5 The illustration of IEEE 802.19.1 algorithms

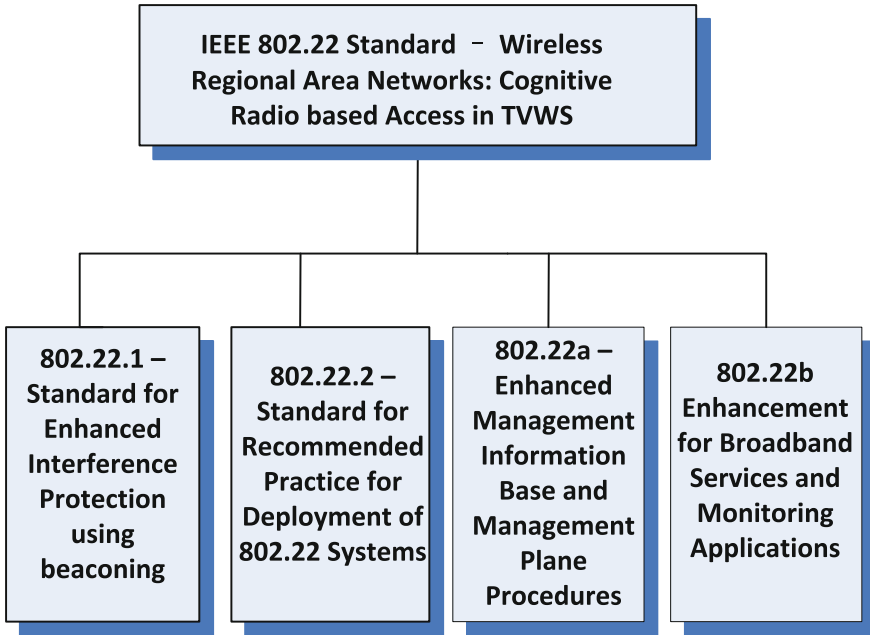


Fig. 2.6 The illustration of IEEE 802.22 standard development

Figure 2.6 shows the IEEE 802.22 standard development. The primary target of IEEE 802.22 standard is to support many other applications, for example, smart grid, and deliver wireless broadband access to rural and remote areas. Both the physical layer and MAC layer policies and procedures are considered on a strict non-interference basis. IEEE 802.22 can provide a typical operating range of 17–30km and up to a maximum of 100km, with a data rate up to 22 Mb/s. As shown in Fig. 2.6, current IEEE 802.22 standards development includes: (1) IEEE 802.22.1 standard specifies the enhanced interference protection using beaconing; (2) IEEE 802.22.2 standard specifies the recommended practice for deployment of IEEE 802.22 systems; (3) IEEE 802.22a standard specifies the enhanced management information Base and management plane procedures; (4) IEEE 802.22b standard targets the enhancement for broadband services and monitoring applications.

IEEE P1900 standard focuses on the dynamic spectrum access radio systems and networks with the targets of improved use of spectrum, new techniques and methods of dynamic spectrum access, and coordination of wireless technologies, which includes a series of dynamic spectrum utilization standards [40, 41]. For specific, The definitions and concepts of spectrum resource management and advanced radio system technologies are given in IEEE 1900.1 standard; the recommended practice for the interference and coexistence analysis is specified in IEEE 1900.2 standard; The recommended practice of software modules analysis for Software Defined Radio (SDR) that can make sure the compliance with regulatory and operational require-

ments is specified in IEEE 1900.3 standard; the architectural building blocks and distributed decision making of enabling network devices for optimal radio resource usage in heterogeneous wireless access networks are defined and specified in IEEE 1900.4 standard; the policy language and architectures to realize dynamic spectrum access applications and cognitive radio management are defined in IEEE 1900.5 standard; the interfaces and data structures to exchange the dynamic spectrum sensing information of spectrum access systems are defined in IEEE 1900.6 standard; finally, the radio interface regulations of dynamic TV White Spaces spectrum access systems to support both the fixed and mobile operations are defined in IEEE 1900.7 standard.

2.3.2 IETF Standard

IETF Working Group defines a Protocol to Access TV White Spaces (PAWS) which can communicate with the geospatial database and obtain available spectrum information by a device with Geolocation database query capability [42]. There are two types of devices defined and regulated in the TV White Spaces access protocol for IETF, i.e., master TV White Spaces device and slave TV White Spaces device. The master TV White Spaces device can be directly connected to Geolocation database while the slave TV White Spaces device can only get information from master TV White Spaces devices. As shown in Fig. 2.7, TV White Spaces protocol covers the protocol requirements that allows devices to access a Geolocation database and

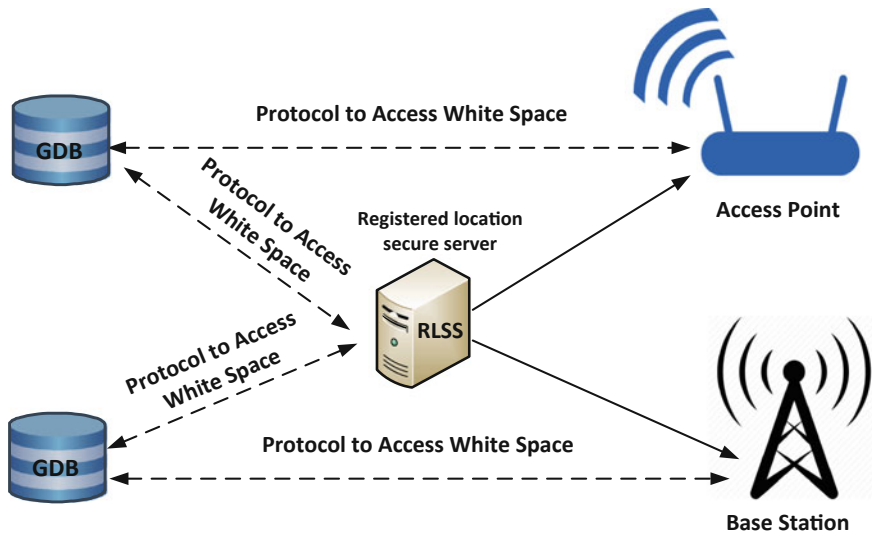


Fig. 2.7 The illustration of protocol to access TV White Space database in IETF standard

obtain the availability information of TV White Spaces spectrum, which includes: (1) Determine the relevant database to query the availability of TV White Spaces spectrum information; (2) Connect to and optionally register with the Geolocation database; (3) Provide geospatial data and other related data to the Geolocation database by using a well-defined database query format; (4) Receive in response to the query a list of available TV White Spaces channels at the specified Geolocation using a well-defined format for the related information; (5) Send an acknowledgment to the Geolocation database with device operation parameters and selected channels information for use.

2.4 Dynamic Spectrum Sharing Application Cases

In the following section, we will introduce three emerging dynamic spectrum sharing application cases by leveraging the CR enabled dynamic spectrum sharing technology and database enabled dynamic spectrum sharing technology, respectively, which are given as follows: (1) cognitive cellular spectrum sharing cloud; (2) vehicular TV White Spaces spectrum access; (3) TV White Spaces spectrum auction.

2.4.1 *Cognitive Cellular Spectrum Sharing*

We present a Cognitive Wireless Cloud (CWC) application case for dynamic cellular spectrum sharing scenario, which is studied by National Institute of Information and Communications Technology (NICT) [43]. As shown in Fig. 2.8, CWC application case is based on the idea of IEEE 1900.4 architecture and studies the optimal radio access networks and the cellular operators selection. The proposed Radio Access Technologies (RATs) in cognitive cellular spectrum sharing cloud are based on collaboration between Cognitive Terminal Manager (CTM) and Cognitive Network Managers (CNMs) for spectrum resource utilization and interference avoidance from heterogeneous access networks. Considering that there are several radio access networks, and each radio access network can utilize at least one type of radio access technology which may share the common spectrum resource together. It assumes that the base station and access point have the spectrum sensing function if multiple RATs will share the common frequency bands. In addition, the cognitive user terminal with spectrum sensing and reconfiguration function can be adaptive to the radio operational environment surrounding the terminal.

For specific, Fig. 2.8 shows the detailed cognitive wireless cloud concept for cellular spectrum resource sharing, which includes the following six realization steps: (1) Cognitive users will sense the radio link information/quality of surrounding radio operational environment and send the sensing results from cognitive terminal managers to the cognitive network managers; (2) Cognitive network managers will collect the users' sensing information and status information of radio access networks

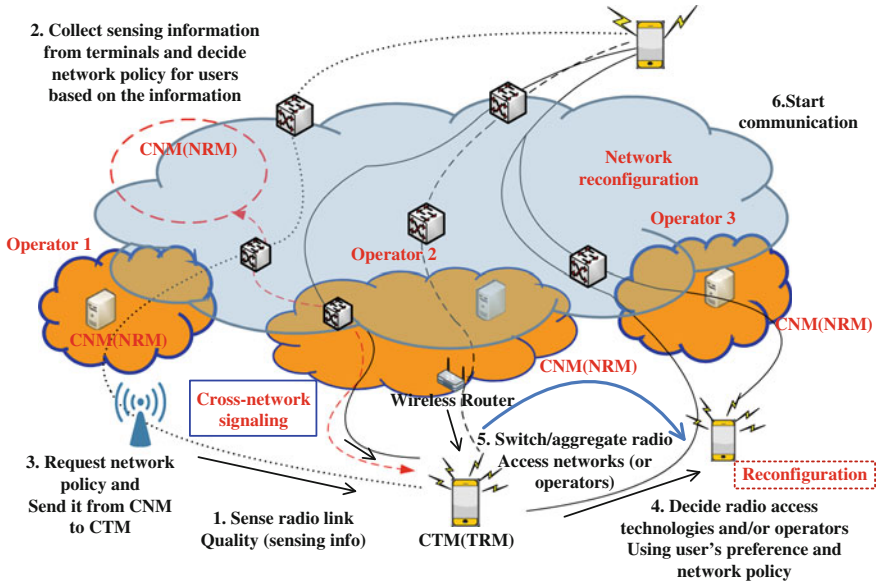


Fig. 2.8 Cognitive wireless cloud enabled cellular spectrum sharing application

from base station and access points; (3) Cognitive network managers will request network policy and send it to cognitive terminal manager; (4) Cognitive network managers will analyze the sensing and status information and decide radio access technologies and/or operators utilizing users' preferences and network policy; (5) Cognitive network managers will switch/aggregate radio access networks or operators; (6) Cognitive terminal manager will make system reconfiguration and start communications.

2.4.2 Vehicular White Spaces Spectrum Access

As shown in Fig. 2.9, we introduce TV white Spaces enabled vehicular access and application case. Compared with the higher frequency bands, such as 2.4 and 5 GHz ISM bands [25], the abundant unlicensed spectrum resource at VHF/UHF bands has better signal penetration property for long-range wireless broadband access. Therefore, vehicular TV White Spaces spectrum access has opened up a promising opportunity for many potential benefits on the road such as vehicular safety applications, efficient road traffic management and ubiquitous services for mobile Internet access. With specially deployed Internet-based TV White Spaces infrastructure, referred to as WhiteFi, diverse vehicular access applications can be realized in the dynamic TV White Spaces sharing networks [32]. By leveraging the IEEE 802.11af standard based vehicular access infrastructure, Geolocation database assisted dynamic TV

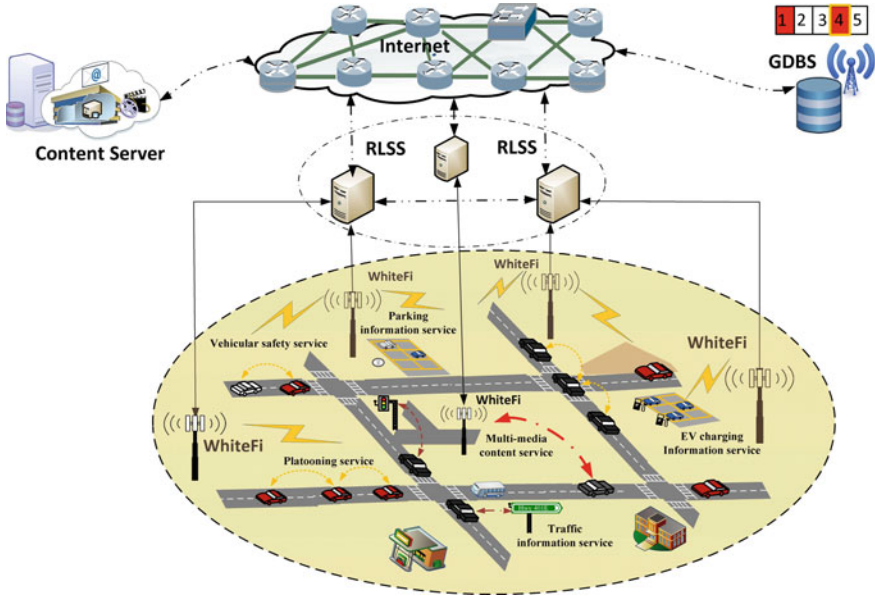


Fig. 2.9 TV white Spaces enabled vehicular application

White Spaces sharing networks can alleviate the spectrum scarcity in vehicular communications. Technically, TV White Spaces enabled vehicular access infrastructure is composed of the Geolocation database server, registered location secure server and WhiteFi nodes. GDDBS can perform the local vacant TVWS channel query to the Geolocation database via Internet. RLSS can coordinate the optimal dynamic TVWS spectrum resource utilization among different WhiteFi nodes, including the TVWS spectrum assignment/coordination for the co-channel and adjacent channel interference avoidance. Specifically, Geolocation database server is considered to function as Geolocation database. Registered location secure server can be considered as the implementation entity of TV White Spaces planning for dynamic TV White Spaces spectrum sharing. WhiteFi nodes will provide the Internet-based long-range broadband access for diverse vehicular applications considering different vehicular service requirements.

Generally, there are two types of connected vehicular communication application scenarios by leveraging the TV White Space spectrum resource, i.e., Vehicle-to-Infrastructure (V2I) communication scenario and Vehicle-to-Vehicle (V2V) communication scenario, which can be shown in Fig. 2.9. Specifically, TV White Spaces enabled WhiteFi nodes can support various infrastructure supported vehicular services from Internet, e.g., vehicular Internet content distribution ranging from multi-media file download to road traffic data management and to location-aware vehicular advertisements broadcasting. In addition, the abundant TV White Spaces spectrum resource can be available for feeding a number of bandwidth-hungry V2V commu-

nication applications, e.g., V2V live video streaming in vehicular social networks. Particularly, TV White Spaces spectrum with excellent propagation characteristics is especially suited for long-distance streaming to moving vehicles and supporting various road safety related on-board applications with reduced multi-hop transmission delay and vehicular service quality guarantee.

2.4.3 White Spaces Spectrum Auction

As shown in Fig. 2.10, we present an auction based TV White Spaces spectrum sharing case, which can maximize the revenue of TV White Spaces spectrum owner and at the same time regulate the spectrum usage behavior of spectrum leasing users during the dynamic spectrum access periods. As an economics design paradigm for TV White Spaces spectrum sharing, economic techniques based TV White Spaces spectrum trading is the process of exchanging TV White Spaces spectrum through auction and pricing mechanisms, which can be performed based on the exchange of different TV White Spaces spectrum resources (e.g., frequency band, time slot and

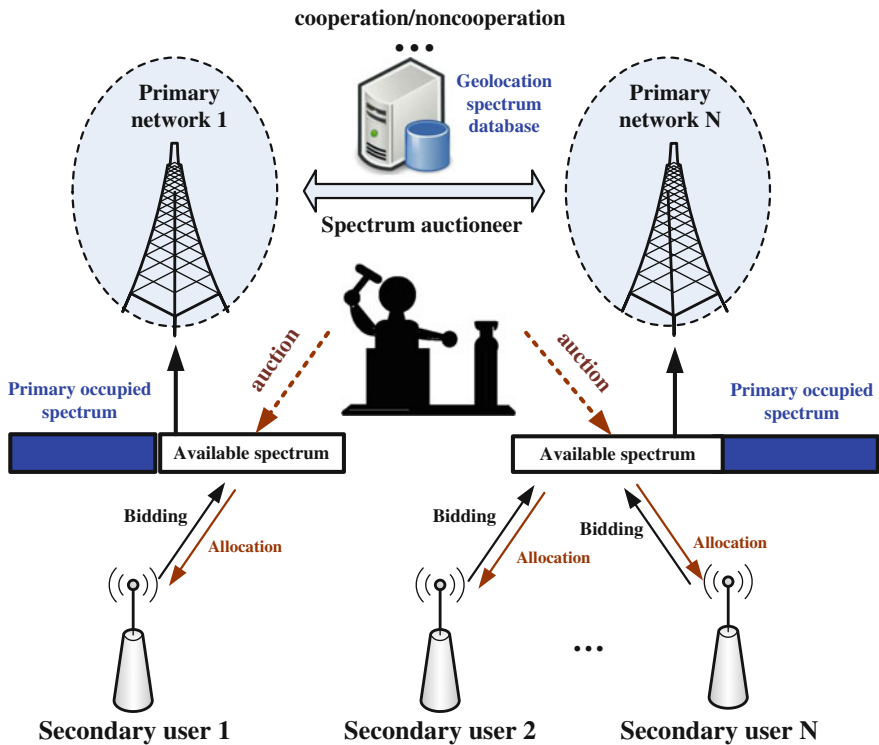


Fig. 2.10 Auction based TV White Spaces spectrum sharing application

transmission power) or money. TV primary users will share the available TV White Spaces spectrum information and store them into the Geolocation spectrum database in a cooperative or noncooperative way. The Geolocation database is usually considered as the spectrum auctioneer in the auction based TV White Spaces spectrum trading market, which can auction the available TV White Spaces spectrum for TV primary networks. For secondary users with spectrum access demands, they will compete for the TV White Spaces spectrum through bidding approaches. Once won the spectrum usage bid, secondary users will be scheduled for the dynamic spectrum access to the according TV White Spaces channels and charged for the spectrum access with allowed durations.

Auction based TV White Spaces spectrum sharing architecture allows multiple secondary users to access the TV White Spaces resource to achieve their targeting optimal objectives through auctions [44]. As shown in Fig. 2.11, TV White Spaces spectrum access encompasses network functionalities including available TV White Spaces query, cognitive medium access control to avoid the interferences from the TV primary users, routing, and other higher-layer protocols. Spectrum trading can be regarded as one of its components dealing with the economic aspects of dynamic TV White Spaces spectrum access, which establishes the structure of vacant TV White Spaces resource selling and buying (e.g., direct trading between seller and buyer or via a broker) [45, 46]. Pricing is a major issue in spectrum trading market that determines the value (or worth) of the TV White Spaces spectrum to the spectrum seller and buyer. Each secondary user can bid any TV White Spaces spectrum with different prices depending on the defined spectrum utility [47].

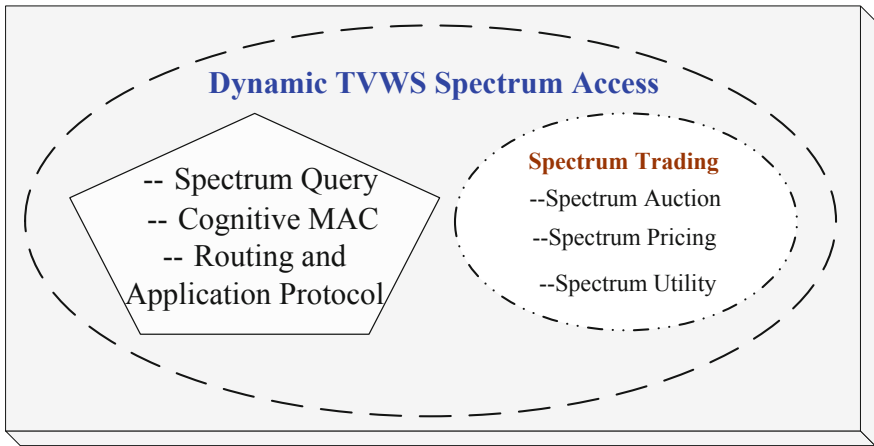


Fig. 2.11 Dynamic TV White Spaces spectrum access and spectrum trade

2.5 Summary

This chapter has surveyed both the CR enabled dynamic spectrum sharing technology and database enabled dynamic spectrum sharing technology. It has also introduced the dynamic spectrum sharing standardization and dynamic spectrum sharing application cases for a better understanding of the related researches.

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