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Managing Spectrum Commons in Thailand: Allocation and Assignment Challenges

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Abstract

Spectrum is a natural and limited resource that needs to be handled both internationally and nationally because of its characteristic of propagation. Once transmitted, it propagates until the power runs out, and it does not recognize borders between countries. Spectrum is administered internationally by the International Telecommunication Union (ITU). The Radio Regulations (RR) is an international treaty that provides international guidelines on spectrum management to keep interference manageable by allocating spectrum to services internationally. Further, spectrum assignment for the provision of rights to use frequency is carried out nationally by the National Regulatory Authority (NRA). Three typical approaches of spectrum assignment are common-and-control, market-based, and spectrum commons.

The purpose of this study is to demonstrate the relationship between international and national regulations on how to implement spectrum commons in Thailand. It also illustrates the development of frequency allocation for spectrum commons at the international level and the transfer of international regulation for spectrum commons to Thai national regulation.

The results of this study present the connection between international regulation in the form of the RR and national regulation in the form of the National Broadcasting and Telecommunications Commission (NBTC) regulation in Thailand with regard to spectrum commons. The study also highlights challenges for Thailand in implementing spectrum commons in order to respond to the rapid growth of technology.

Spectrum commons is one of three typical assignment approaches providing non-exclusive rights to use frequency, i.e. no one owns the frequency. Spectrum commons regulation was established internationally by the RR during the international negotiations at the World Radiocommunication Conference (WRC) by allocating spectrum to industrial, scientific and medical (ISM) applications. The majority of applications are in low-power devices or short-range devices. The relevant technologies concerning spectrum commons at the WRC-12 were software-defined radio (SDR) and cognitive radio systems (CRS) which encourage the sharing of spectrum with existing services and increase spectrum utilization. However, the transfer of international regulation of spectrum commons belongs to the NRA at national level.

The study uses the institutional analysis and development (IAD) framework to illustrate the relationship between international and national regulations in terms of world of actions: constitution, collective-choice, and operational level. However, the IAD framework only provides a list of questions that should be considered, not the detailed content regarding the implementation of spectrum commons.

To implement spectrum commons regulation, an understanding of the RR at international level assists local implementation at national level. The timely transfer of international regulation to national regulation provides opportunities to benefit from device innovation and technological advancement. Once economies of scale are achieved, the general public benefits from the reasonable price of devices. As it is not a manufacturing country for such devices, Thailand should follow spectrum commons regulation and prepare national regulation changes in order to gain the benefits of spectrum commons.

Keywords: Radio Regulations (RR), World Radiocommunication Conference (WRC), institutional analysis and development (IAD) framework, spectrum commons, spectrum management, spectrum allocation

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Chapter 1 Introduction

This study is about the transformation of international regulation as the Radio Regulations (RR) into national regulation for spectrum commons in Thailand. However, the study only focuses on the development of spectrum commons in RR in ISM footnotes, the application for short-range devices, and technology for software-defined radio and cognitive radio systems. The challenges of the transformation of spectrum commons regulation are only presented in the context of Thailand.

1.1 Background

Spectrum is a natural and limited resource that requires both an international and national approach because of its characteristic of propagation. Once transmitted, it propagates until the power runs out and it does not recognize borders between countries.

For spectrum to be administered internationally by the International Telecommunication Union (ITU), the international treaty the RR provides the guidelines on spectrum management to keep interference manageable through service allocation and allotment of spectrum with the relevant constraints.

ITU uses the RR as a tool to manage spectrum internationally. The ITU allocates spectrum to radiocommunication services with particular frequency bands. Radiocommunication services, in short, services, represent the purpose of frequency uses. There are more than 40 services currently in use in the RR2012. The individual frequency bands are defined by the start and stop frequencies. The start and stop frequencies represent the allowable edges of the frequency to be used for specified services.

The RR is revised every three to four years via the WRC. The current RR is the RR2012, which was revised by the WRC-12. The RR2012 defines usable frequency up to 3,000 GHz and divides the frequency use into services, including terrestrial and space services such as broadcasting, mobile, satellite, maritime, aeronautical, fixed, and earth exploration. All the services can share frequency bands, although sharing requires services to be designated as primary or secondary. The table of frequency allocation (TFA) contains both primary (capitalized) and secondary (lower case) services. Secondary services must not interfere with primary services and cannot claim protection from interference by primary service transmission and reception.[1]

The RR divides the world into three regions. Region 1 covers the European and African continents, Region 2 covers North America and South America, and Region 3 covers Asia and Australasia. The RR2012 regions are shown in Figure 1.[2]

The frequency allocated in one region can be used in others: reuse of frequency. For example, frequency band A is allocated to Region 3 but can be reused in Region 1 or 2 for the same or different services.

[1] 5.23-5.32, Article 5, Radio Regulations
[2] Information obtained from 5.2-5.9, Article 5, Radio Regulations (2012)

Reuse of frequency has an indirect relationship with coverage area. A large coverage area has a low reuse of frequency, while a small coverage area has a high reuse of frequency. Spectrum reuse characteristics vary by service, frequency, location, time, and transmitting power.

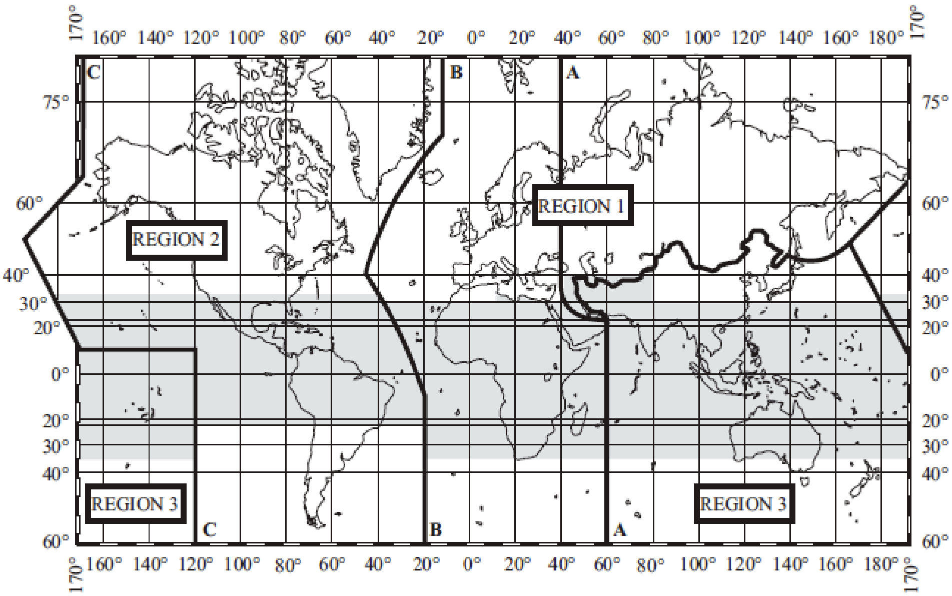

Figure 1. Regions in Radio Regulations 2012

Frequencies are further divided into bands. A wavelength equals its speed of propagation (normally that of light) divided by its frequency ($\lambda = c/f$). Each frequency band has its own propagation characteristics, such as sea-surface communication, stratospheric scattering, and long-range communication.

Table 1 shows the TFA for the 1 710-2 170 MHz band, the global as well as the regional allocations captured from the RR2012. The purpose of the TFA is to provide an overview of the use of frequency bands by service, with the relevant regulations, including services, frequency bands, and footnotes. The functions of the TFA are similar to a map that provides an overview of the RR.

Regions and frequency bands

Within the TFA, the main components are regions, frequency bands, services, and footnotes. When a frequency allocation has the same frequency band (the same start and stop frequencies) for three regions, it is called a global or worldwide allocation. For example, Table 1 shows the frequency band 1 710-1 930 MHz, which is a global allocation. However, the frequency band 1 930-1 970 MHz is allocated to Regions 1, 2, and 3. These three allocations are regional allocations.

Services

Within each frequency band, services are allocated as either primary or secondary. For example, in the 1 970-1 980 MHz band, the fixed and mobile services are allocated as primary services.

Table 1. Table of Frequency Allocation, 1 710-2 170 MHz

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td>1 710-1 930</td><td colspan="2">FIXED
MOBILE 5.384A 5.388A 5.388B
5.149 5.341 5.385 5.386 5.387 5.388</td></tr>
<tr><td>1 930-1 970
FIXED
MOBILE 5.388A 5.388B
5.388</td><td>1 930-1 970
FIXED
MOBILE 5.388A 5.388B
Mobile-satellite (Earth-to-space)
5.388</td><td>1 930-1 970
FIXED
MOBILE 5.388A 5.388B
5.388</td></tr>
<tr><td>1 970-1 980</td><td colspan="2">FIXED
MOBILE 5.388A 5.388B
5.388</td></tr>
<tr><td>1 980-2 010</td><td colspan="2">FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space) 5.351A
5.388 5.389A 5.389B 5.389F</td></tr>
<tr><td>2 010-2 025
FIXED
MOBILE 5.388A 5.388B
5.388</td><td>2 010-2 025
FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space)
5.388 5.389C 5.389E</td><td>2 010-2 025
FIXED
MOBILE 5.388A 5.388B
5.388</td></tr>
<tr><td>2 025-2 110</td><td colspan="2">SPACE OPERATION (Earth-to-space) (space-to-space)
EARTH EXPLORATION-SATELLITE (Earth-to-space) (space-to-space)
FIXED
MOBILE 5.391
SPACE RESEARCH (Earth-to-space) (space-to-space)
5.392</td></tr>
<tr><td>2 110-2 120</td><td colspan="2">FIXED
MOBILE 5.388A 5.388B
SPACE RESEARCH (deep space) (Earth-to-space)
5.388</td></tr>
<tr><td>2 120-2 160
FIXED
MOBILE 5.388A 5.388B
5.388</td><td>2 120-2 160
FIXED
MOBILE 5.388A 5.388B
Mobile-satellite (space-to-Earth)
5.388</td><td>2 120-2 160
FIXED
MOBILE 5.388A 5.388B
5.388</td></tr>
<tr><td>2 160-2 170
FIXED
MOBILE 5.388A 5.388B
5.388</td><td>2 160-2 170
FIXED
MOBILE
MOBILE-SATELLITE (space-to-Earth)
5.388 5.389C 5.389E</td><td>2 160-2 170
FIXED
MOBILE 5.388A 5.388B
5.388</td></tr>
</table>

For the 2 120-2 160 MHz band in Regions 1 and 3, there are fixed and mobile services on a primary basis.

For the 2 120-2 160 MHz band in Region 2, there are fixed and mobile services on a primary basis and mobile-satellite (space-to-Earth) services on a secondary basis.

Footnotes

The footnotes contained in the TFA can be used in several situations, including for the status of services (on a primary or secondary basis), additional allocation, alternative allocation, and miscellaneous provisions.

Apart from capital and lower-case letters in the TFA, footnotes can indicate the priority of services. For example, footnote 5.385 indicates that the 1 718.8-1 722.2 MHz band is allocated for radio astronomy service on a secondary basis for spectral line observations.[3]

The additional allocation footnote has the same service as indicated in the TFA, but in an area smaller than the region. For instance, footnote 5.386 is allocated to the 1 750-1 850 band for space operation (Earth-to-space) and space research (Earth-to-space) services in Region 2, in Australia, Guam, India, Indonesia, and Japan on a primary basis.[4]

The alternative allocation footnote replaces the service indicated in the TFA, but in an area smaller than the Region. For example, footnote 5.315 is allocated to the 790-838 MHz band for broadcasting service on a primary basis in Greece, Italy, and Tunisia.[5]

The miscellaneous provision footnote represents specific operation constraints, such as footnote 5.388 in the 1 885-2 025 MHz and 2 110-2 200 MHz band that provides International Mobile Telecommunications (IMT), on condition that these bands do not preclude the use by other services to which they are allocated.[6]

Footnotes can also be used for a particular service, in which case they are located next to the service, or the entire frequency band, when they are placed at the bottom of the band, as indicated in the TFA. The band footnote is applied to all services allocated in this band. For example, in the 2 025-2 110 MHz band, the use of mobile service has the specific footnote 5.391. The band footnote is 5.392 and it applies to all services in this band, including space operation, Earth exploration-satellite, fixed, mobile, and space research services.

In Regions 1 and 3, the 2 120-2 160 MHz band has two specific footnotes for mobile service; 5.388A and 5.388B. The fixed service is allocated on a primary basis and does not have a specific footnote. Footnote 5.388 is applied to both fixed and mobile services as a band footnote.

In Region 2, the 2 120-2 160 MHz band has two specific footnotes for mobile service 5.388A and 5.388B. The fixed service is allocated on a primary basis but the mobile-satellite (space-

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[3] 5.385 *Additional allocation:* the band 1 718.8-1 722.2 MHz is also allocated to the radio astronomy service on a secondary basis for spectral line observations. (WRC-2000)

[4] 5.386 *Additional allocation:* the band 1 750-1 850 MHz is also allocated to space operation (Earth-to-space) and space research (Earth-to-space) services in Region 2, in Australia, Guam, India, Indonesia and Japan on a primary basis, subject to agreement obtained under No. 9.21, having particular regard to troposcatter systems. (WRC-03)

[5] 5.315 *Alternative allocation*: in Greece, Italy and Tunisia, the band 790-838 MHz is allocated to the broadcasting service on a primary basis. (WRC-2000)

[6] 5.388 The bands 1 885-2 025 MHz and 2 110-2 200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications (IMT). Such use does not preclude the use of these bands by other services to which they are allocated. The bands should be made available for IMT in accordance with Resolution 212 (Rev.WRC-07) (See also Resolution 223 (Rev.WRC-07)*). (WRC-12)

to-Earth) service is allocated on a secondary basis. Footnote 5.388 is applied to fixed, mobile, and mobile-satellite (space-to-Earth) services as a band footnote.

The TFA represents the frequency allocation at the WRC to allocate radiocommunication services by frequency bands. The services represent the purpose of frequency use that is defined in Article 1: Terms and Definitions.

However, the use of radiocommunication devices is managed at national level by the national regulatory authority (NRA). The NRA assigns the frequency to the assignee, in other words, the NRA provides the right to use frequency to frequency users. This is known as spectrum assignment. The typical spectrum assignment methods are command-and-control, market-based, and spectrum commons. The NRA assigns the frequency to the user on a first-come first-serve basis, imposing the technical specification for the use of frequency in the form of command-and-control. As for the market-based method, the NRA uses a market mechanism to assign the frequency, such as spectrum auction or secondary trading. Both command-and-control and market-based methods provide the exclusive right to use a frequency to users, whereas spectrum commons provides non-exclusive rights to use a frequency. With spectrum commons, the NRA assigns the frequency for public use. No one owns the frequency. Everyone shares the frequency and the risk of harmful interference.

Spectrum commons has developed both allocation at the WRC as part of the RR and assignment under national regulations. It is interesting to understand the transformation of spectrum commons from allocation under international regulation to assignment under national regulation.

1.2 Motivation

The motivation of this study comes from the implementation of international regulation in the form of the RR in national regulation in the form of the National Broadcasting and Telecommunications Commission (NBTC) regulation for spectrum commons in Thailand. Moreover, the study attempts to combine two previous studies: I) Spectrum Assignment Policy: Towards an Evaluation of Spectrum Commons in Thailand, and II) Information and Coordination in International Spectrum Policy: Implication for Thailand.

The development of spectrum commons allocation applies the development of RR from Paper II to explore the ITU archive for industrial, scientific, and medical (ISM) applications in terms of the development of definition and frequency allocation in footnotes 5.138 and 5.150. The development of spectrum commons allocation illustrates international regulation for spectrum commons.

The spectrum assignment for spectrum commons in Thailand captures the development of spectrum assignment for spectrum commons in Thailand since 1875 in Paper I, which provides the history of spectrum commons development in Thailand in terms of the development of national regulation for spectrum commons.

This study combines spectrum allocation and assignment for spectrum commons in Thailand by demonstrating how to implement international regulation into national regulation for spectrum commons in Thailand. The study applies the Institutional Analysis and Development (IAD) framework to illustrate the interaction and relationship between levels of analysis and outcome: from the RR to NBTC regulations. Moreover, the study also highlights the challenges for spectrum commons (advantages and disadvantages for spectrum commons from Paper I) and IAD application for spectrum management.

1.3 Purpose

The purpose of this study is to demonstrate the relationship between international and national regulations on how to implement spectrum commons in Thailand. It also illustrates the development of frequency allocation for spectrum commons at international level and the transfer of international regulation for spectrum commons to Thai national regulation.

This study is limited to spectrum commons in footnotes 5.138 and 5.150 for the development of spectrum commons. The main application of spectrum commons for the purposes of this study is short-range devices. The main technologies focused on are software-defined radio (SDR) and cognitive radio systems (CRS). The study focuses on the transfer of spectrum commons regulation for Thailand.

1.4 Research question

To fulfill the purpose of this study, the main research question is: **How are the Radio Regulations transformed into the National Broadcasting and Telecommunications Commission regulation for spectrum commons in Thailand?** In order to answer this research question, the five sub-research questions are as follows:

Sub-research question 1: *What are the main applications and technologies for spectrum commons?*

The relevant literature in the SCOPUS database and ITU archives has been explored to understand the main applications and technologies for spectrum commons. The main applications are short-range or low-power devices such as garage-door openers, baby monitors, remote controls, cordless telephones, wireless microphones, wireless earphones, Wi-Fi, RFID tags, and smart cards. The main technologies are SDR and CRS. These technologies provide the ability to use spectrum non-exclusively. No one owns the spectrum. This is the main characteristic of spectrum commons.

Sub-research question 2: *What is the spectrum allocation for spectrum commons and ISM applications, and how did it develop?*

The ITU archives have been explored to understand the development of spectrum commons allocation in terms of ISM application: definition and frequency allocation.

The results of the exploration illustrate the development of spectrum commons regulation in terms of ISM application development and frequency allocation for the development of footnotes 5.138 and 5.150. The first allocation for low-power stations was in 1938 for the European region only, although it was terminated in 1947. The current ISM bands are: 6 765-

6 795 kHz, 433.05-434.79 MHz, Region 2, 61-61.5 GHz, 122-123 GHz, 244-246 GHz, for 5.138; and 13 553-13 567 kHz, 26 957-27 283 kHz, 40.66-40.70 MHz, 902-928 MHz, Region 1, 2 400-2 500 MHz, 5 725-5 875 MHz, and 24-24.25 GHz for 5.150.

Sub-research question 3: *What is the spectrum assignment, especially spectrum commons, in Thailand, and how did it develop?*

This study explores the NBTC regulations in terms of the National Frequency Management Board (NFMB), Post and Telegraph Department (PTD), National Telecommunications Commission (NTC) and NBTC regulations since 1875 in order to demonstrate the development of spectrum assignment for spectrum commons in Thailand.

The development of spectrum commons in Thailand was initiated by the NFMB to authorize the PTD to allow the use of 1-watt transmitters for pagers and anti-theft equipment. However, the use of such radiocommunication equipment required relevant radiocommunication licenses. The current unlicensed regulation for spectrum commons was developed in 2004, i.e. the Ministerial Regulation of the Exemption of Radiocommunication Licenses – Ministry of Information and Communication Technology. This regulation was adopted by the NTC as its regulation in 2007 and is still valid today.

Sub-research question 4: *How should spectrum commons regulation be transformed from the RR into the national NBTC regulation? What are the challenges?*

In order to understand the relationship between the RR and the NBTC regulation, the study applies the IAD framework that was used in Paper II to understand the interaction during the decision-making process at the WRC. Moreover, the IAD framework has the ability to understand the relationship between rules-in-use at different levels of analysis and outcome represented at international level by the RR and at national level by the NBTC.

This study demonstrates the transformation of international regulation into national regulation in terms of the ISM definition, footnotes 5.138 and 5.150, and frequency allocation for spectrum commons in the Table of Frequency Allocation (TFA). The results are the adoption of ISM definition implicitly in the Thai TFA and the adoption of footnotes 5.138 and 5.150 explicitly in the Thai TFA with additional Thailand footnotes in the form of the NBTC regulation for spectrum commons. Apart from footnotes 5.138 and 5.150, Thailand allows several frequencies for spectrum commons, including the frequency band lower than 135 kHz, 1.6-1.8 MHz, 30-50 MHz, 54-74 MHz, 88-108 MHz, 165-210 MHz, 300-500 MHz, 920-925 MHz, 5.150-5.350 GHz, 5.470-5.725 GHz, 10-10.6 GHz, 76-81 GHz, 72-72.745 MHz, 78-79 MHz, 245-246 MHz, 510-790 MHz, and 794-806 MHz.

This study also examines the advantages and disadvantages of spectrum commons in Paper I in terms of the challenges for managing spectrum commons: allocation and assignment. The challenges are grouped in terms of allocation and assignment with relevant stakeholders. The study also examines the long process at the WRC for the allocation of spectrum commons, and the loss of revenue for the assignment of spectrum commons at national level. The main challenge is to keep the advantages and reduce the disadvantages of spectrum commons.

Sub-research question 5: *How is the IAD framework relevant to spectrum management?*

To understand the relevance of the IAD framework to spectrum management, the study applies the IAD framework to spectrum management activities.

The result illustrates that the IAD framework enables categorization of spectrum management activities into three levels of analysis and outcome: constitutional, collective-choice, and operational situation. Moreover, the IAD framework also explains the relationship between spectrum management activities in terms of the elements of the IAD framework.

1.5 Structure of the study

This study consists of nine chapters, starting with an introduction in Chapter 1, which includes the background and research questions. Chapter 2 provides the theoretical framework for this study. Chapter 3 deals with the methodology. The application and technology for spectrum commons are provided in Chapter 4. The allocation of spectrum commons is presented in Chapter 5. Chapter 6 describes the frequency assignment for spectrum commons in Thailand. Chapter 7 demonstrates how spectrum commons of the RR is transformed into national regulation in Thailand and the challenges involved. The relevance of the IAD framework to spectrum management is illustrated in Chapter 8. Finally, the conclusion of the study is presented in Chapter 9. Figure 2 gives an overview of the study, including the contents of each chapter in brief.

Chapter 1 Introduction	The study background, motivation and problem, purpose and limitation, and research questions
Chapter 2 Theoretical framework	A theoretical framework including the IAD framework, three worlds of action in spectrum management, and bundles of rights to use frequency
Chapter 3 Methodology	The available data, the mode of data collection, and methods used in data analysis
Chapter 4 Application & technology	Main application and technology for spectrum commons
Chapter 5 Allocation of spectrum commons	Spectrum allocation for spectrum commons from the RR in ISM footnotes
Chapter 6 Assignment of spectrum commons in Thailand	Spectrum assignment for spectrum commons in Thailand in terms of unlicensed regulation and its development
Chapter 7 International to national	The transformation of international regulation in the form of the RR into the national regulation in the form of the NBTC for spectrum commons in Thailand
Chapter 8 Relevance of IAD framework	The IAD application for spectrum management activities
Chapter 9 Conclusion	Conclusion of the study, challenges of spectrum commons allocation and assignment for Thailand

Figure 2. Structure of the study

Chapter 2 Theoretical framework

This chapter provides a theoretical framework for this study, i.e. the institutional analysis and development (IAD) framework, three worlds of action in spectrum management, and bundle of rights for frequency use. This chapter uses some parts of Chapter 2 of Ard-paru (2012), an updated version of Ard-paru (2011), and Chapter 2 of Ard-paru (2010).

2.1 The IAD framework

Elinor Ostrom, among others, developed the IAD framework. The details of the IAD framework are discussed below.

The IAD framework has its roots in classical political economy, neoclassical microeconomic theory, institutional economics, public choice theory, transaction-cost economics, and non-cooperative game theory (Ostrom, Gardner, & Walker, 1994, p. 25). The IAD framework orients the analyst to ask particular questions. The questions generated by the IAD framework are the most important contributions. These questions are used to diagnose, explain, and prescribe action situations during decision-making processes (Ostrom et al., 1994).

The IAD framework was originally developed by Kiser and Ostrom (1982) and provides three worlds of action: the operational, collective choice, and constitutional choice levels. Kiser and Ostrom (1982) provide a metatheoretical framework to explain the relationships between institutional arrangements and the individual in terms of the transformation of rules into individual behavior. Institutional arrangements are rules used by individuals to determine who and what is included in decision situations, how information is structured, what actions can be taken and in what sequence, and how individual actions will be aggregated into a collective decision (Kiser & Ostrom, 1982, p. 179). Field (1992) has a similar level of analysis but with different names, i.e. three economic institutions: the operational, institutional, and constitutional levels.

In other words, the IAD framework explains phenomena attributed to the aggregation of individual actions that they have decided to take or strategies (plans of action) based on situations and the individual. The situation depends on rules, events, and the community. This framework also captures the dynamic situation through feedback from the phenomena that influence the community, situation, and individuals.

According to Kiser and Ostrom (1982), each world of action has five working parts in an institutional structure: the decision-maker or individual, the community, the event (or goods and services), the institutional arrangement, and the decision situation. The results of the institutional structure are individual actions or strategies, and the aggregation of individual actions.

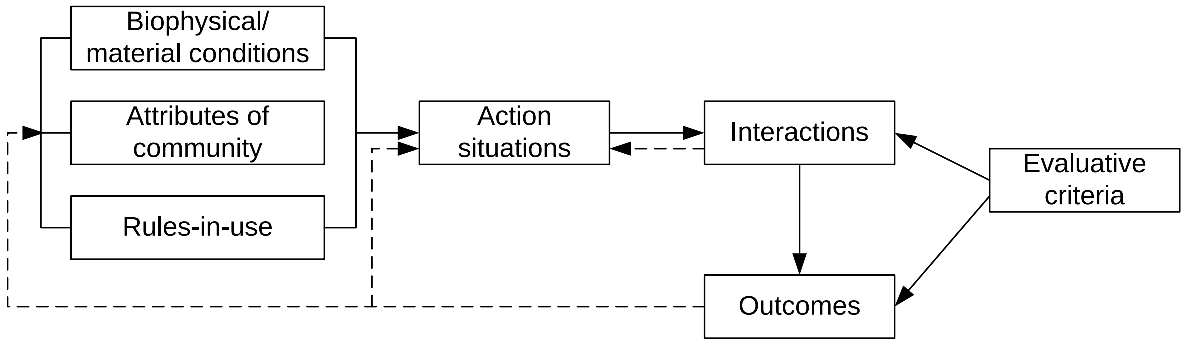
Each level or world of action: metaconstitutional, constitutional, collective, and operation situations, comprises an IAD framework for an institutional analysis. The linkage between levels is, in part, the rules-in-use at each level (see Figure 7).

The three worlds of action were developed by Ostrom from 1982 to 2011 (Kiser & Ostrom, 1982; Ostrom, 2005a; 2005b, 2007, 2011). The differences between the old version from 1982 and the current version from 2011 are the consideration layers, the names of the elements, and the details of the internal rules. The old version has three worlds of action, but the new version has four levels of analysis and outcomes.

The names of the elements in 1982 were changed in 2011: aggregated results to outcome; actions, activities, and strategies to interaction; attributes of decision situation to action situation; attributes of institutional arrangement to rules-in-use; and attributes of events to biophysical conditions. The attributes of the individual were merged into an action situation. The evaluative criteria were added in 2011.

The names of rules-in-use in 1982 were changed in 2011: authority rules to choice rules. The unchanged rules are boundary, scope, position, aggregation, and information rules. The procedural rules were removed. The payoff rules were added in 2011.

The IAD framework provides consideration levels, or worlds of action, for the decision-making process, i.e. operational, collective-choice, constitutional, and metaconstitutional situations. Moreover, the IAD framework provides exogenous variables and an internal action situation at each situation level. The exogenous variables include biophysical/material conditions, attributes of community, and rules-in-use. The internal action situation structure comprises boundary, position, choice, payoff, information, aggregation, and scope rules. Figure 3 shows the IAD framework.



Source Ostrom (2011, p. 10), Figure 1

Figure 3. Framework for an institutional analysis

Interaction (action and strategy)

When an individual wants to take action or implement a strategy, he or she must know the consequences of the action or strategy, or the outcome and value of the alternative actions or strategies. A tennis player makes a decision to charge at the net or wait for the ball to bounce and use a groundstroke: the outcome of the actions differs. In order to predict actions, a minimum of the following assumptions must be made: the level of information about the decision situations, the valuation of the potential outcomes, the alternative actions within the situation, and the process of calculation to act from alternative actions or strategies.

Action situations (or decision situations)

According to Kiser and Ostrom (1982), the decision situation is determined from interdependent relationships. Interdependent relationships depend on more than one input from the exogenous variables. The IAD framework separates the exogenous variables from the action arena or action situation. The exogenous variables include biophysical/material conditions, attributes of community, and rules-in-use.

Biophysical/material conditions

The biophysical/material conditions describe the type of goods. Goods can be further refined into four groups: private goods, toll goods, common-pool goods, and public goods. Each group has different characteristics, defined by the level of subtractability and the cost of exclusion (Kiser & Ostrom, 1982). Table 2 shows four categories of goods.

Table 2. Categories of goods

Level of subtractability / Cost of exclusion	High	Low
Low	Private goods	Toll goods
High	Common-pool goods	Public goods

Source Kiser and Ostrom (1982, p. 198), Table 7.1

The level of subtractability and cost of exclusion can also be explained in terms of four attributes of biophysical conditions that individuals seek to produce and consume: jointness of use or consumption, exclusion, measurement, and degree of choice, in order to define private goods, tool goods, common-pool resources, and public goods.

Jointness of consumption explains separable and joint consumption goods. One individual consumes separable consumption goods, while several individuals consume joint consumption goods. Joint consumption goods are defined as public goods that are non-subtractable, while separable consumption goods are private goods.

The exclusion attributes explain the difference between private and public goods. Public goods are non-excludable goods that an individual can consume without exclusion. Private goods are excludable goods that the individual can consume with exclusion.

The measurement is the degree of packaging and unitization. Public goods are hard to package and unitize in contrast to private goods. The calculation of private goods is more precise than that of public goods.

The degree of choice for the consumer differs between public and private goods. Public goods are non-subtractable and non-excludable, so there is not much choice, while private goods can produce many choices from subtractable and excludable goods.

The level of subtractability is defined by the characteristics of the goods that can be separated. Private goods can be separated by individual consumption, but public goods cannot. For example, rice can be consumed from a bowl by taking a spoon, as private goods. Air in the park is a public good. People can breathe, but no one can separate air for individual consumption.

Ostrom and Ostrom (1997) use the level of subtractability and the cost of exclusion to classify private goods, tool goods, common-pool resources, and public goods. Private goods, such as bread, milk, automobiles, and haircuts, have a low cost of exclusion and a high level of subtractability. Toll goods, for example, theaters, nightclubs, telephone services, cable TV, electric power, and libraries, have a low cost of exclusion and a low level of subtractability. World Cup football is tool goods at a low level of subtractability, because football players and spectators jointly benefit from football matches, whereas the cost of exclusion is low but managed by selling tickets to matches. Common-pool resources, e.g. water pumped from a ground basin, fish taken from an ocean, and crude oil extracted from an oil pool, have a high cost of exclusion and a high level of subtractability. Public goods, such as peace and security of a community, national defense, mosquito abatement, air pollution control, and weather forecasts have a high cost of exclusion and a low level of subtractability.

Attributes of community

The attributes of community comprise levels of common understanding, common agreement, and distribution of resources. The common understanding between people in the action situation could be the norm, culture, or tradition in each community that has a direct influence on the decision situation.

After setting the rules, the individual or member of the community must have a common understanding of them, i.e. the allowable actions and outcomes. Without a common understanding of the rules, they cannot be exercised.

Real actions must be evaluated with a common understanding of the rules. If community members obey the rules, allowable actions, and outcomes, the need for rule enforcement is low. If, on the other hand, the individual disagrees, the need for enforcement is high.

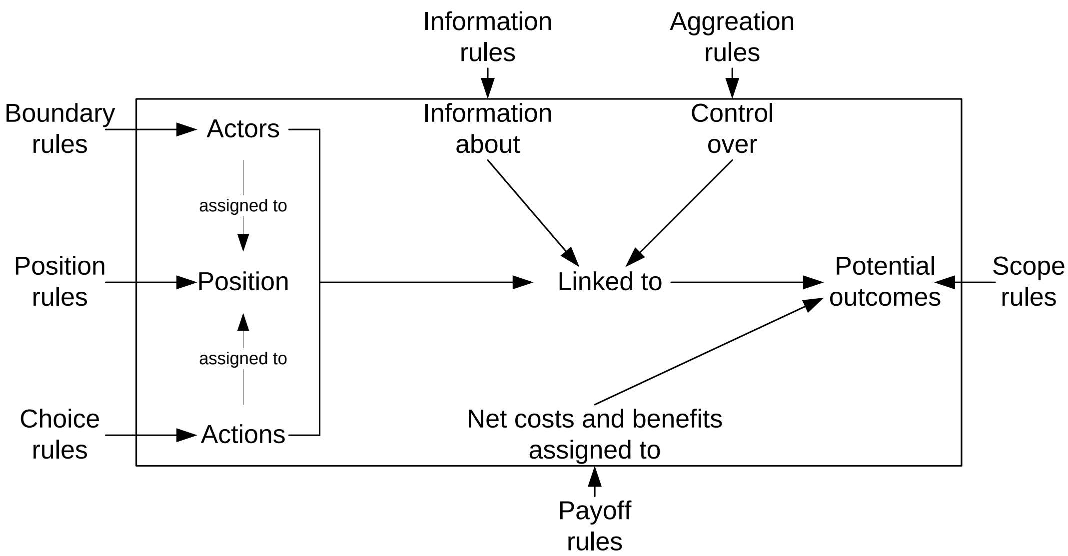
The distribution of the resource represents a situation in the market or community. If resources are distributed equally, a competitive environment arises. Otherwise, oligopoly or monopoly may arise.

Rules-in-use

The rules-in-use provide an institutional arrangement in a decision-making situation, including boundary, position, choices, payoff, information, aggregation, and scope rules. Generally, rules-in-use can be thought of in terms of “do and don’t” rules, for example, when a new member of staff arrives at the office on the first day, the first thing he/she should ask his/her colleagues about is the “dos and don’ts” in the office. This is more important than the rules-in-form that are written down (Ostrom, 2007, pp. 36-37).

A detailed discussion regarding the action situations is provided below. These rules help to explain the action arena or action situation. Figure 4 shows the rules-in-use and the action situation.

Boundary rules: who is eligible to participate in a decision-making or action situation? These rules provide the list of participants or actors. For example, in the French Open, tennis players with a higher rank automatically go to the first round, while newcomers have to win qualifying matches to enter the first round.



Source Ostrom (2011, p. 20), Figure 3

Figure 4. A rules-in-use and action situation

Position rules: what role does each participant perform in his/her position or what authority is given to each position? In each match, there are referees, line-persons, ball boys or girls, and two or four tennis players. Each position has its own task or responsibility to perform.

Choice rules: what actions should be taken? During the game, after one game of serving, the opponent has to strike back. There are many choices, e.g. whether to wait and hit a groundstroke or to go forward to volley. Even for the server, there are many choices when it comes to hitting the ball, e.g. whether to direct it to the corner, to the right, to the left, or to go for an ace on the first serve.

Payoff rules: what is the cost and benefit of the choice that is taken? During the game, if player A plays a drop shot at the net, player A expects player B to rush to the net to get the ball back.

Information rules: what information is available when making the decision? In the game, the information about players, weather conditions, changing to new balls or a new racket, medical breaks, and player injury are available to both players.

Aggregation rules: what level of control does the participant have in his/her action situation? During the game, the player has the ability to control his/her action to move forward, backward, to serve, or to hit the ball in order to win a point. Moreover, the player should control his/her performance to win the match in a normal game or a tiebreak.

Scope rules: what is the rule to delimit the potential outcome that is linked to a specific outcome? During the match, the winner has to win two out of three sets or three out of five sets. Both players can play a point in the specified court, including the height of the net, and the type and size of the court.

Outcomes

The terms 'outcomes' in Figure 3 and 'potential outcomes' in Figure 4 describe the same concern. The outcomes are the result of actions or strategies by the decision-maker in a decision-making process. Moreover, the evaluative criteria in Figure 3 should be used to find the net costs and benefits of the outcomes in Figure 4.

Evaluative criteria

Ostrom (2011) also provides evaluative criteria, including economic efficiency, equity through fiscal equivalence, redistributional equity, accountability, conformance to the values of local actors, and sustainability.[7] The evaluative criteria are the possible outcomes under the alternative institutional arrangements (Ostrom, 2011, p. 15).

Levels or worlds of action

The IAD framework provides consideration levels, or worlds of action, for the decision-making process, i.e. operation, collective-choice, constitutional, and metaconstitutional situations. Figure 5 shows the level of analysis in the IAD framework.

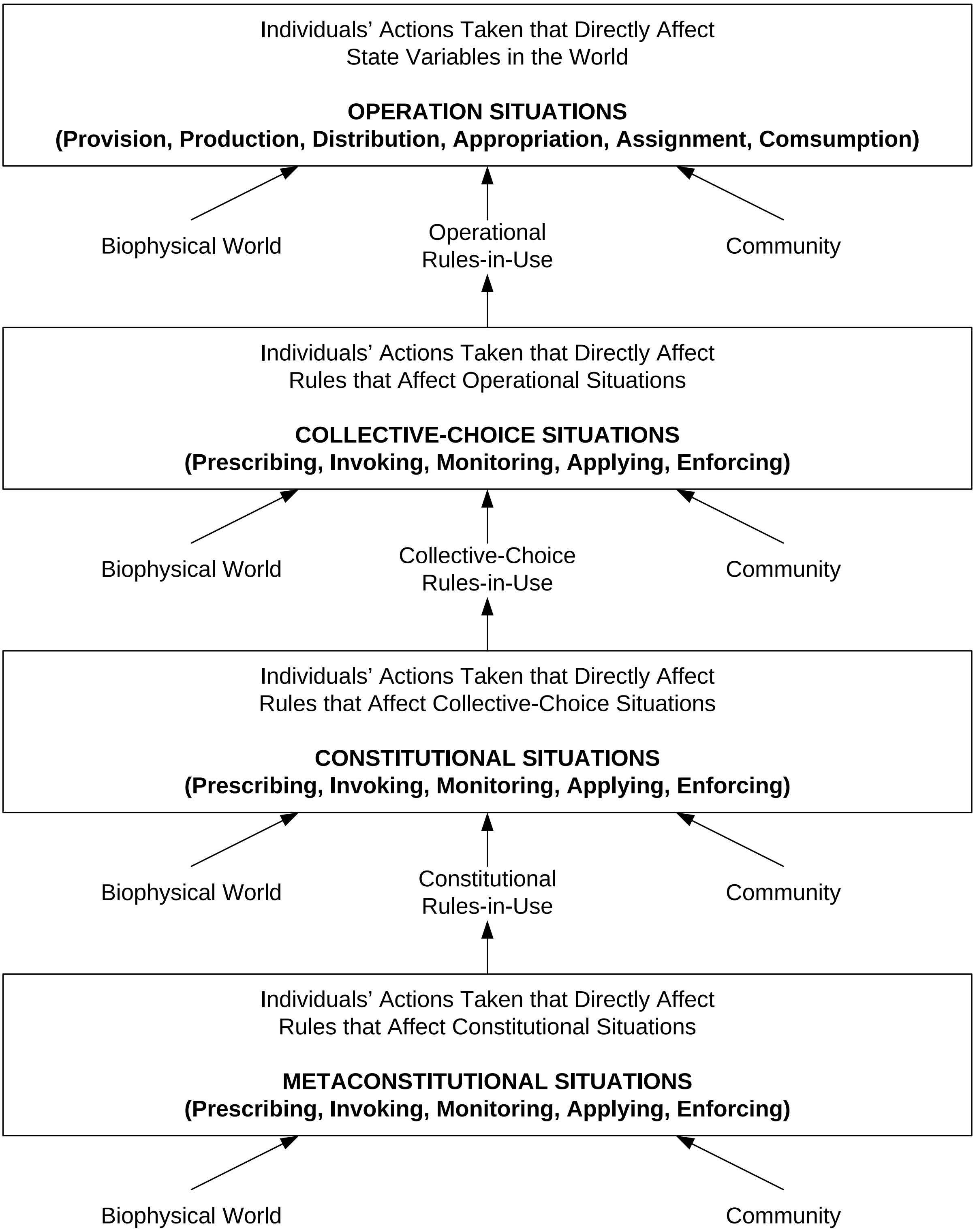
Each level or analysis comprises an internal action situation, as mentioned above. The seven parts of the IAD framework are contained in each level of the analysis. They are biophysical/material conditions, attributes of community, rules-in-use, action situations, interactions, evaluative criteria, and outcomes.

At an operational level, the situation is affected by the operational rules of day-to-day decision-making by the participant. The decision is made according to the operational rules, which are defined at the collective-choice level. For example, in the State of Maine's lobster industry, the day-to-day work is to fish or obtain lobster from the inland shore. The fishermen have to fish with specified tools and a time slot.

In a collective-choice situation, the collective-choice situation is affected by the operational rules to determine who is eligible, and it defines rules to change the operational rules. For example, if someone wants to change who can fish, and the tools and the time to fish lobster, they have to revise the operational rules at the collective-choice level.

In a constitutional situation, the situation is affected by the collective-choice rule of who is eligible and can change collective-choice rules, and it has consequences for the operational rules. For example, in the telecommunication industry, the national regulatory agency defines the set of rules allowing the use of Wi-Fi devices. The rules specify a frequency of 2.4-2.5 GHz with transmitting power of up to 100 milliwatts. These rules work as constitutional-choice rules with room for manufacturers or standard-setting agency to produce technology and standards to fit these rules. The standard for Wi-Fi devices is set at the collective-choice level. After that, Wi-Fi devices are on the market and available to use. Users buy and use Wi-Fi devices according to the standard.

[7] For more information, see Ostrom (2011, pp. 16-17).



Source Ostrom (2007, p. 45), Figure 2.2

Figure 5. Level of analysis and outcomes

As a constitutional decision-maker, Fédération Internationale de Football Association **(**FIFA) determines the rules of football at a high level. European or national football associations use FIFA's rules for their tournaments, such as EUROPA and the Premier League. Football teams must obey the rules to participate in tournaments.

At a metaconstitutional level, the situation is the deepest layer of analysis, underlying all three of the above levels. The metaconstitutional level should contain the fundamental rules like customs, tradition, norms, and religion (Williamson, 2000).[8]

2.2 Three worlds of action in spectrum management

The concept of three worlds of action and the property rights regime mentioned above provide an understanding of the interaction between the decision-maker and the decision situation within and between three levels.

An analysis of decision-makers at each level of spectrum management reveals the relevant stakeholders shown in Table 3.

Table 3. Level of analysis and stakeholders

Stakeholders	Level of analysis
Administrator / Regulator / Authority	Constitutional situation
Operator / Provider / Standard-setting Organization	Collective-choice situation
User	Operational situation

Source Ard-paru (2010), Table 7

Constitutional situation level

A high level of regulation conducted directly will influence the collective-choice level. In radiocommunication, the constitutional level starts with the regulator, administrator, or authority in each country up to the ITU level. The constitutional level gives the overall regulation and broadly influences the collective choice (or institutional level).

Collective-choice situation level

After the administrator, authority, or regulator outlines technical specifications, the operators, providers, or standard-setting units have to create technology according to the regulation (constitutional-choice level). For example, in the 2 400-2 500 MHz band there are two popular technologies, Wi-Fi and Bluetooth. These technologies provide personal and local connectivity with a peer-to-peer connection for Bluetooth and a Wi-Fi infrastructure for Internet connection, respectively.

Wi-Fi technology has been developed by the Institute of Electrical and Electronics Engineers (IEEE), and the current standard is 802.11n. This standard provides many technical specifications on how to use this frequency, e.g. medium access control (MAC) and physical layer (PHY) specifications.

Bluetooth has been developed to replace cable connectivity for personal area networks (PANs). The Bluetooth standard uses the frequency hopping spread spectrum for radio technology. PANs can connect mobile phones, faxes, printers, computers, laptops, GPS receivers, video recorders, and cameras.

At a collective-choice or institutional level, technology or standard rules show how the frequency should be used by the provider, operator, or standard-setting unit and determine

[8] Williamson explains this as Level 1 (social theory), which is taken as given. Institutions at this level change very slowly: 100-1000 years.

which devices can access their network.

Operational situation level

At this level, users can choose to select devices and use them. After selecting the devices, however, users have collective-choice or institutional level rules. For example, once the users access Wi-Fi hotspots in hotels, they must have devices with a specified Wi-Fi connection and an account to access the Internet defined by the operator. If, on the other hand, the user connects to the Wi-Fi router at home, the user specifies the access rule by password to determine who can connect to his or her router.

2.3 Bundle of rights to use frequency

With regard to the right to use a frequency, the access and withdrawal right depends on the devices (transceiver: transmitter and receiver), which are similar and cover access as in the fishing ground example. When users access a resource, they withdraw the product or consume the frequency. Frequency is a non-depletable resource, however. Thus, the access right is sufficient to explain the access to frequency. For example, the user makes a call from his or her mobile phone. The phone connects to the base station via a selected frequency. The selected frequency is occupied by the user. After hanging up, the selected frequency can be used by others.

The access right at operational level is defined by the network operator that defines the network rule to access the frequency in terms of the technical specification or standard. The network operator acts as both proprietor and claimant with regard to the management and exclusion right to define how, when, where, and who can access the frequency. For example, when a user makes a call from his or her mobile phone, the operator specifies which standard and technology the phone and the SIM card will use.

An alienation right is defined as ownership that can be sold, leased, or transferred. For example, the frequency auction in the primary market and frequency trading in the secondary market provide ownership of frequency for the owner to trade. Normally, the alienation right is defined by the authority, regulator, or administrator.

In Table 3, stakeholders are divided into the three levels. Applying the idea from Table 3, the bundle of rights for each stakeholder reveals the rights to use frequency shown in Table 4.

Table 4. Bundle of rights associated with telecommunication stakeholders

Stakeholders / **Rights**	**Regulator**	**Operator A**	**Operator B**	**Advanced user**	**General user**
Access and withdrawal	x	x	x	x	x
Management	x	x	x		
Exclusion	x	x	x	x	
Alienation	x	x			
Assignment approach		Market-based	Command-and-control	Spectrum commons	Spectrum commons

Source Ard-paru (2010), Table 12

At a constitutional level, the regulator, administrator, or authority holds all the rights to frequency use, including access, withdrawal, management, exclusion, and alienation rights.

Once the regulator delegates authority, using the market mechanism to assign frequency, the alienation right passes to a collective-choice or institutional level, i.e. Operator A. Operator A is able to sell, lease, or transfer frequency to another party. Operator B, however, cannot sell because the regulator still holds the alienation right. Thus, frequency assignment using the command-and-control approach means that Operator B must ask the regulator for approval to transfer the frequency, e.g. 2G frequency assignment in Thailand. Operator A represents frequency assignment using the market-based approach, including primary trading (auction) and secondary trading (resale). Operator A has the freedom to transfer frequency without regulatory approval, e.g. 3G auction in the UK and the USA.

At a collective-choice or institutional level, the management and the exclusion rights are held by the providers, operators, or standard-setting units. They set up their network rules on how, when, and where to harvest frequency reflected by technology or device choices. For example, mobile phone operators set their standard of network and equipment to allow only their consumers to use the network. The advanced user (at the operational level), however, sets his or her own rules that allow access to the frequency. For example, advanced users of Wi-Fi routers can set their own security code for network access.

At an operational level, access and withdrawal rights are held by users. Users have to use devices according to the standard preset by the operators.

As for the right to use frequency, the assignees, and command-and-control and market-based approaches have the exclusive right to use frequency, but spectrum commons have a non-exclusive right. For the exclusive right, assignees have priority to use it free of interference. For the non-exclusive right, however, users have to share and accept interference. Exclusivity should be added to the property rights for the right to use frequency.

The level of deregulation of the right to use frequency from the regulator at the constitutional level can be delegated to operators at the collective-choice or institutional level, and users at operational level. The regulator can use the market-based approach to delegate alienation rights to operators. Thus, the operator can obtain the frequency from primary and secondary markets. The operator has the flexibility to sell, lease, or transfer frequency. At the operational level, the regulator can delegate its authority of self-regulation after defining the necessary conditions, including frequency, power limitation, and standard of devices. Thus, users have to manage the use of frequency. Table 5 shows the rights to use a frequency and the regulated level.

Table 5. The rights to use frequency

Property right / **Regulated level**	**Exclusive use**	**Non-exclusive use**
Centralized by regulator / state agency	Command–and-control	Public commons
Middleman/Operator	Market-based	Private commons
Self-regulated/User	-	Unlicensed

Source Ard-paru (2010), Table 13

The command-and-control assignment approach means that regulators hold all the rights to use frequency while assigning frequency to assignees. The assignee has the exclusive right to use the frequency with all the imposed conditions. Assignees have limited opportunities to change the use of frequency.

The market-based approach is the assignment method in which assignees can buy frequency from the primary and secondary market. The assignee has the exclusive right to use the frequency. The regulator gives away the alienation right to the assignee and this right can be sold, leased, and transferred. Thus, it is more flexible than the command–and-control approach. Some necessary conditions should be imposed on the use of frequency, however, such as the standard of devices.

The next three categories have non-exclusive rights to use frequency. This means that users have to share frequency. At the regulated level, it includes management and exclusion rights. If a state agency or government manages the frequency use, it is public commons. If the operator manages the frequency use, it is private commons. If users manage the frequency use, it is unlicensed.

2.4 Summary

This chapter presents the IAD framework, three worlds of action in spectrum management, and bundles of rights to use a frequency.

This study describes the elements of the IAD framework, including exogenous and endogenous variables. Exogenous refers to the external variables that influence the action situation, including biophysical conditions, attributes of community, and rules-in-use. Endogenous refers to the internal variable that is directly connected to rules-in-use. There are seven rules, including boundary, position, choice, payoff, information, aggregation, and scope rules.

Moreover, three worlds of action provide the interrelation between levels of action: constitutional, collective-choice, and operation situation. These levels of action provide the link as to how the rules-in-use in the higher level influence the lower level.

This study illustrates three worlds of action in spectrum management by mapping the levels of action and stakeholders. For the constitutional situation, the administrator, regulator, and authority provide international and national regulation as the scope of spectrum management. In the collective-choice situation, the operator, provider, and standard-setting organization comply with the given regulation from the constitutional situation in order to create their collective-choice situation regulation such as the network rules or standard of equipment. For the operational situation, users buy the equipment and use it according to the specified standard and regulation.

This study demonstrates the bundle of rights to use a frequency as the application from the IAD framework in the collective-choice and operational situation. The bundled rights to use a frequency can also be divided into five rights: access, withdrawal, management, exclusion, and alienation rights. The access and withdrawal rights to use a frequency can be combined, however, due to the technical characteristics of the transmitter, receiver, and transceiver. When the transceiver is switched on, the transceiver operates or accesses the specified frequency and uses the frequency for the specified service. This means that transceivers combine access and withdrawal rights to use the frequency at the same time.

At an operational level, general users hold access and withdrawal rights to use frequency by selecting devices (transmitter, receiver, or transceiver) that follow specified conditions. Advanced users hold an additional exclusion right to determine who can use the frequency by applying a specified username and password.

At a collective-choice or institutional level, operators, providers, and standard-setting organizations hold additional management and exclusion rights that specify how, when, and where a frequency can be used in terms of the standard of device, technology, SIM card, etc.

At a constitutional choice level, the authority, administrator, or regulator has all the rights to the frequency use and to specifying regulations. If, however, the regulator decentralizes the alienation right by using the market mechanism, the operator at the collective choice level can obtain the frequency from primary and secondary markets.

The exclusive right to use frequency is a key point to separate the three spectrum assignment approaches: command-and-control, market-based and spectrum commons. The command-and-control and market-based approaches have an exclusive right to use frequency, but spectrum commons has a non-exclusive right. The regulated level indicates the decentralization of regulators. Regulators may give away some rights to the operator or end-user. Thus, both the exclusive right and the regulated level help to explain the differences between these approaches.

In the exclusive right to use frequency, the regulated level depends on the degree to which the alienation right is decentralized. If the regulator holds the alienation right, the approach is command-and-control. If the regulator delegates the alienation right via primary and secondary markets, the approach is market-based.

In the category of non-exclusive rights to use frequency, the regulated levels range from regulator, operator, and end-users, i.e. public commons and private commons, to unlicensed. Public commons have a state agency to manage frequency, such as a municipality or local administrator, etc. Private commons have private entities to manage frequency, such as a Wi-Fi operator in a hotel, airport, department store, etc. Unlicensed spectrum is self-regulated.

Chapter 3 Methodology

This chapter concerns the available data, the mode of data collection, and methods used in data analysis.

The data are secondary and qualitative in nature. Secondary data are sourced from the ITU, and NBTC archives. The secondary data archive approach was developed by Rutkowski (2011). Rutkowski downloaded principal data from the ITU History Portal. The data allowed examination of versions of the regulations to enable the identification of key definitions and provisions by RR versions. Rutkowski's analysis enabled the identification and links to detect any differences in the text. Rutkowski applied this method to cyber security, and to find where such text amendments arose.

The benefit obtained from applying the Rutkowski approach is that mapping the archive over time improves the understanding of the context in which regulations developed.

Accordingly, the study is based on data obtained from archived documents and information derived from meeting attendance. The ITU archives include all versions of the RR, including 1906, 1912, 1927, 1932, 1938, 1947, 1959, 1968, 1971, 1976, 1982, 1986, 1990, 1994, 1996, 1998, 2001, 2004, 2008, and 2012.

3.1 Data and data collection method

Secondary data are obtained from the ITU and NBTC archives outlining the timeline of RR changes by agenda item. In order to use documents as secondary data, Flick (2009) provides guidelines on how to select suitable analysis documents by the criteria: authenticity (applied to both primary and secondary data), credibility (official or personal), representativeness (typical or non-typical), and meaning (text clarity).

Document authenticity depends on the data source. If information is obtained from primary data sources and is documented by witnesses, then authenticity is 'high'. When data are obtained from a secondary data source and documented from primary data, the authenticity of the document is 'medium' or 'low'. Document credibility depends on the type of document. For official documents, credibility is 'high'. Naturally, for personal documents, credibility is 'low'. Representativeness is measured by document type. When documents are recorded for specific purposes, representativeness is non-typical. If the document is for general purposes, representativeness is typical. The document's meaning depends on its clarity.

There follows a brief summary of data collection methods. To gain an appreciation of how the RR and WRC developed over time, the archive of the ITU is the principal source of input and output documentation for all RR versions. These data are used to construct a database of TFA to track changes of key definitions and the WRC process to alter the RR.

All ITU documents can be accessed through the ITU History Portal (http://www.itu.int/en/history/Pages/default.aspx), including the PP (complete list of Plenipotentiary Conferences), Radiocommunications collection (complete list of

Radiotelegraph & Radiocommunication conferences), and the RR (complete list of the Radio Regulations).

The application and technology for spectrum commons in Chapter 4 is described from the relevant literature, including the ITU-R report and SCOPUS database.

The allocation of spectrum commons in Chapter 5 is illustrated by relevant ISM provisions in the RR, including definition, footnotes 5.138 and 5.150, and relevant frequency bands. Keyword mapping for ISM applications helps to identify the change and how changes developed over time.

The frequency assignment for spectrum commons in Thailand in Chapter 6 is described based on the relevant regulations in the NBTC archive, including the Radiocommunication Act, NTC and the NBTC established Act, PTD, NTC, and NBTC regulation.

The transformation of spectrum commons from international to national regulation in Chapter 7 applies the IAD framework to understand the relationship between the RR and NBTC regulation in terms of the RR and Thai TFA, footnotes, relevant frequency band, and national regulations.

To summarize, secondary data obtained from the ITU and NBTC archives provide a high degree of authenticity and credibility. Further, documents' representativeness depends on their purpose. The purpose may be general (typical) or specific (non-typical). In this study, the documents are specific. The representativeness of this study is also mainly non-typical. Furthermore, the meaning of documents is measured by document clarity.

3.2 Data analysis

Data analysis explains the level of analysis and outcomes, i.e. how international regulation is transformed into national regulation. This study starts from a level of analysis and outcomes that includes the constitutional, collective-choice, and operational situation, to understand the transformation from the RR into NBTC regulation.

The IAD framework provides seven elements of institutional analysis: biophysical conditions, attributes of community, rules-in-use, action situation, interactions, outcomes, and evaluative criteria. Moreover, the interaction between level of analysis and outcomes provides four levels: metaconstitutional, constitutional, collective-choice, and operational situation to understand the influence of rules-in-use in the deeper layer for other layers. However, this study applies three levels of analysis, namely constitutional, collective-choice, and operational situation for the transformation of international regulation into national regulation.

Moreover, the IAD framework assists in understanding spectrum management activities in terms of the interaction between stakeholders at each level of analysis and outcome.

3.3 Approach

The empirical work of the study consists of the exploration of the ITU and NBTC archives. Together with relevant literature, the study presents spectrum commons allocation development in terms of ISM application definition and footnotes 5.138 and 5.150. Moreover, the study also demonstrates the development of spectrum assignment for spectrum commons in Thailand. The results of empirical findings are deduced from the exploration of ITU and NBTC archives.

In order to understand the transformation from international to national regulation, the author applies the level of analysis and outcomes of the IAD framework to understand the relationship between international and national regulation in terms of the RR and the Thai TFA, footnotes, and frequency bands. The analysis is deduced from the IAD framework.

To summarize, the study uses deductive IAD framework and the results of the empirical findings to understand the transformation of international into national regulation and the development of spectrum commons, both allocation and assignment, in Thailand.

3.4 Summary

This study uses secondary data. Secondary data are from the ITU and NBTC archives.

This study analyzes secondary data according to the IAD framework to understand the transformation of international into national regulation and the interaction between the level of analysis and outcome for spectrum management activities and relevant stakeholders.

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Chapter 4 Spectrum commons application and technology

This chapter presents the main application and technology for spectrum commons in terms of short-range devices and software defined radio and cognitive radio system. The study concentrates on the application and technology relating to the industrial, scientific and medical (ISM) application, which use the frequency band according to RR No. 5.138 and 5.150.

4.1 Short-range devices

Short-range devices (SRDs) are used in many aspects of human daily life such as in the home, in offices, factories, on roads, airplanes, ships and so on. The study uses the definition of SRDs from the Report ITU-R SM.2153, including purpose of use, permitted operation, antenna, standard, and license. This definition covers the overall characteristics of SRDs.

Definition

"The short-range radio device is intended to cover radio transmitters which provide either unidirectional or bidirectional communication and which have low capability of causing interference to other radio equipment.

Such devices are permitted to operate on a non-interference and non-protected basis.

SRDs use either integral, dedicated or external antennas and all types of modulation and channel pattern can be permitted subject to relevant standards or national regulations.

Simple licensing requirements may be applied, e.g. general licences or general frequency assignments or even licence exemption, however, information about the regulatory requirements for placing short-range radiocommunication equipment on the market and for their use should be obtained by contacting individual national administrations" (ITU, 2009b, p. 2).

Technical characteristics

From the definition, the first characteristic is either transmitter or transceiver. The transmitter provides one-way communication or broadcasting signals, such as remote controls and garage door openers. The transceiver, comprising transmitter and receiver, provides two-way communication, such as a radio data transfer between routers and computers.

The second characteristic is a low interference or non-interference with other radio equipment. Moreover, the SRD cannot claim any protection from other radio equipment on a non-protected basis.

The third characteristic is an antenna, either an integral, dedicated, or external antenna. The integral antenna is built into SRDs, such as smart cards and keyless cars. The dedicated antenna has a special piece of equipment dedicated as an antenna, such as Wi-Fi router antenna. An external antenna is a separate antenna that can connect with SRDs, such as an antenna that is connected to a walkie-talkie, which increases the communication range. However, the permitted type of antenna depends on the standard and national regulations.

Licensing

Whether the use of SRDs requires a specified licence or is unlicensed depends on the country and varies between countries. The licensing could be a general license, frequency authorization, or license exemption.

Noticeably, the overall definition of SRD does not specify communication ranges because the range depends on frequencies and transmitting powers. Generally, at the same transmitting power, a lower frequency can propagate longer than a higher frequency. Moreover, the ranges also depend on the purpose of SRDs, which reflects on the applications. For example, a smart card with a RFID tag requires a few centimeters between a card and reader. Conversely, inventory in a warehouse requires high transmitting power and an antenna to broadcast the signal and receive the data from the tag.

Application

There are several applications for SRDs, which vary according to the purpose of use. Table 6 shows the categories of SRD application by function and samples of applications from Report ITU-R SM.2153 (ITU, 2009b, pp. 2-5).

The applications for SRDs presented in Table 6 use both ISM band and other frequency bands. SRDs are mostly concentrated on the personal area network (PAN) or local area network (LAN). The approximate distance is a few meters between transceivers.

For example, household applications for SRDs include telecommand, voice and video, broadband radio local area network, model control, and wireless audio applications such as remote controls, baby monitors, walkie-talkies, Wi-Fi, computers, home entertainment, and toys.

Transportation applications are included in railway applications, road transport and traffic telematics, equipment for detecting movement and equipment for alerts, and inductive applications such as the intelligent transport system (ITS), millimeter radar while driving, and keyless car access.

Factory and warehouse applications include telemetry, inductive application, RFID, and RF (radar) level gauges, such as inventory management, barcode replacement, and monitoring at power plants.

The safety of life applications include equipment for detecting avalanche victims, alarms, and ultra-low-power active medical implants, as well as search and rescue beacons for victims, crime surveillance and monitoring, medical equipment at hospitals and implant devices for patients.

Table 6. SRD applications

Categories	Application
Telecommand	Remote controls or remote access
Telemetry	Distance recording
Voice and video	Walkie-talkies, baby monitors, citizen band (CB)
Equipment for detecting avalanche victims	Search and rescue for avalanche victims
Broadband radio local area network	RLANs, Wi-Fi devices, Bluetooth devices
Railway application – train and track communication	Automatic vehicle identification (AVI) Balise system Loop system
Road transport and traffic telematics	ITS, navigation, automatic toll-collection, route and parking guidance, collision avoidance
Equipment for detecting movement and equipment for alerts	Determination of position, velocity
Alarms	Home or office security, calling doctor or fire department
Model control	Toys: cars, airplanes, and boats with remote control
Inductive application	Car immobilizers, car access systems or car detectors, animal identification, alarm systems, item management and logistic systems, cable detection, waste management, personal identification, wireless voice links, access control, proximity sensors, anti-theft systems including RF anti-theft induction systems, data transfer to handheld devices, automatic article identification, wireless control systems and automatic road tolling
Radio microphone	Wireless microphone
RFID	Tags, smart cards, credit cards, barcode replacement
Ultra-low-power active medical implants	Medical implant communication system (MICS)
Wireless audio applications	Portable compact disc players, cassette decks or radio receivers carried on a person, cordless headphones for use in a vehicle, for example for use with a radio or mobile telephone, etc. in-ear monitoring, for use in concerts or other stage productions
RF (radar) level gauges	Level measurement gauges in refineries, chemical plants, pharmaceutical plants, pulp and paper mills, food and beverage plants, and power plants

Source Report ITU-R SM.2153 (ITU, 2009b, pp. 2-5)

Technology

This study explores the relevant literature regarding SRD in the ISM bands. Table 7 presents some of the technologies that are used for SRD. However, no description can be exhaustive. There are, for example, also Bluetooth, SAW filter, frequency hopping (FH), ZigBee, 802.11 a/b/g/n (Wi-Fi), 802.15.3 and 4: high data rate (HDR) and low data rate (LDR), ultra wide band (UWB), complementary metal oxide semiconductor (CMOS), near field communication (NFC), cognitive radio system (CRS) and software defined radio (SDR).

Table 7. Example of SRD technologies

Technology	**Literature**
802.11 a,b,g,n	Hao and Yoo (2011)
802.15.3, 4 (HDR and LDR)	Hao and Yoo (2009)
Bluetooth	Valenzuela, Hermandes and Valdovinos (2005)
CMOS and NFC	Cenger (2009), Teo and Yeoh (2008)
CRS and SDR	Fadda, Murroni, and Popescu (2012)
FH	Popovski, Yomo and Prasad (2006)
SAW filter	Alexander (2004)
UWB	ITU (2006)
ZigBee	De Francisco, Huang, Dolmans, and De Groot (2009), Ling (2007)

These technologies enable SRDs to perform on a non-interference and non-protection basis. The nature of SRDs is to share the frequency between other services and cannot cause harmful interference to other services. The frequency sharing represents the non-exclusive right to use the frequency. It is an important characteristic of spectrum commons. Therefore, SRDs are deemed to be an example of spectrum commons devices.

This study focuses on CRS and SDR for further explanation because they are included in the WRC-12 agenda item 1.19 that is relevant to spectrum commons.

Frequency band

Most SRDs use the frequency band under the ISM band. However, there are other frequency bands commonly used for SRD. Table 8 presents the frequency bands for SRDs that are taken from Table 1 of Report ITU-R SM. 2153 (ITU, 2009b, p. 7).

Table 8. Common frequency bands for SRDs

5.138	**5.150**
6 765-6 795 kHz 61-61.5 GHz 122-123 GHz 244-246 GHz	13 553-13 567 kHz 26 957-27 283 kHz 40.66-40.70 MHz 2 400-2 483.5 MHz 5 725-5 875 MHz 24-24.25 GHz
Other commonly used frequency ranges	
9-135 kHz:	Commonly used for inductive short-range radiocommunication applications
3 155-3 195 kHz:	Wireless hearing aids (RR No. 5.116)
402-405 MHz:	Ultra-low-power active medical implants Recommendation ITU-R RS.1346
5 795-5 805 MHz:	Transport information and control systems Recommendation ITU-R M.1453
5 805-5 815 MHz:	Transport information and control systems Recommendation ITU-R M.1453
76-77 GHz:	Transport information and control system (radar) Recommendation ITU-R M.1452

Source Table 1 of Report ITU-R SM. 2153 (ITU, 2009b, p. 7)

The ISM band in Table 8 excludes the 433.05-434.79 MHz in Region 1 for 5.138 and 902-928 MHz in Region 2 for 5.150. Other commonly used frequency ranges are 9-135 kHz, 3 155-3 195 kHz, 402-405 MHz, 5 795-5 805 MHz, 5 805-5 815 MHz, and 76-77 GHz. Two frequency bands are used for medical purposes: hearing aids and active medical implants. Three frequency bands are used in transportation.

The frequency bands for SRD may not be permitted for radio astronomy, aeronautical mobile, radionavigation and safety of life service (ITU, 2009b, p. 6)

Power

Power limitation for SRD depends on national regulation, which varies between countries. Power limitation can be defined as radiated power, magnetic field, or electric field strength. Table 9 shows the example of power limitation in European countries and the United States, which is taken from Table 2, Table 3 and Table 4 of Report ITU-R SM.2153 (ITU, 2009b, pp. 8-11).

Table 9. Common frequency bands for SRD

European countries	
Magnetic field strength	**Frequency bands**
42 dB(μA/m) at 10 m	59.750-60.250 kHz 9070-119 kHz 135-140 kHz 6 765-6 795 kHz 13.553-13.567 MHz 26.957-27.283 MHz
Maximum power level	**Frequency bands**
100 mW (Levels are either effective radiated power (e.r.p.) (below 1 000 MHz) or equivalent isotropically radiated power (e.i.r.p.) (above 1 000 MHz) or maximum mean e.i.r.p.)	26.990-27.000 MHz 27.040-27.050 MHz 27.090-27.100 MHz 27.140-27.150 MHz 27.190-27.200 MHz 34.995-35.225 MHz (for flying models only) 40.660-40.700 MHz 865.0-865.6 MHz(2) 2 400-2 483.5 MHz (for RLANs only) 17.1-17.3 GHz 24.050-24.250 GHz 61.0-61.5 GHz 122-123 GHz 244-246 GHz

USA		
Frequency (MHz)	**Electric field strength (μV/m)**	**Measurement distance (m)**
0.009-0.490	2 400/*f* (kHz)	300
0.490-1.705	24 000/*f* (kHz)	30
1.705-30.0	30	30
30-88	100	3
88-216	150	3
216-960	200	3
Above 960	500	3

Source Table 2, Table 3 and Table 4 of Report ITU-R SM.2153 (ITU, 2009b, pp. 8-11)

Table 9 presents power limitation in terms of the magnetic field strength and maximum power level for EU countries, for example the 13.553-13.567 MHz band has a magnetic field strength of 42 dB(μA/m) at 10 meters, and the 2 400-2 483.5 MHz band has a maximum power level of 100 mW (e.i.r.p.) for RLANs only. In the United States, the band above 960 MHz has maximum electric field strength of 500 (μV/m) at 3 meters' measurement distance, for example.

Health issue

Most SRD use involves sharing the frequency with ISM equipment. There are some concerns from Bozec, Robinson, Pearce and Marshman (2004) and Krishnamoorthy et al. (2003) regarding the fact that electromagnetic interference from SRDs might interfere with ISM or medical equipment in healthcare facilities, especially near emergency rooms, operating rooms, and intensive care units in hospitals. One concern relates to head absorption from Anguera et al. (2012), regarding the radiation from handheld equipment near the head.

These issues are relevant to the use of SRDs in the healthcare environment, which is raising the awareness of limiting SRD use so that SRDs cannot cause any harmful interference to ISM equipment.

Migration from national to international issue

The use of SRDs alternates between the international and national level in terms of the allocation of frequency bands into ISM footnotes, and between national and international level in terms of the circulation of SRD between countries. The allocation of frequency bands to the ISM footnotes is coordinated at the WRC, the international negotiations are between Member States, however, authorization or permission to use SRD is managed locally by the NRA of each country. When permission is granted to use a SRD without licences or unlicensed in one country, Country A, it can be transported to other countries: Country B. When Country B does not allow use of Country A's SRD, the operation of Country A's SRD will interfere with the existing service of Country B.

This situation migrates from a national to an international issue because the unlicensed SRD can be transportable between countries. There is no single solution for this issue. However, the possibility of harmonization for SRD frequency bands at regional and global level might be considered.

To summarize, two main characteristics of SRDs, i.e. non-interference and non-protection basis, are at the heart of using SRDs in order to share the frequency with other services, especially ISM equipment. Most SRD use involves sharing the ISM band, however, the use of SRDs cannot interfere with ISM equipment. Enabled technologies such as SDR and CRS are facilitating the use of SRDs. Shared use provides the non-exclusive right to use a frequency as the main characteristic of spectrum commons. Therefore, the main applications of spectrum commons are SRDs.

4.2 Software-defined radio and cognitive radio system

Two of several technologies that can be used for SRD are SDR and CRS. These two technologies are included in the WRC-12 agenda item 1.19, which is directly relevant to spectrum commons. The WRC provides the forum for Member States to negotiate possibilities to revise the RR. The study selects SDR and CRS for further explanation because they are relevant to spectrum commons and included in the WRC-12 agenda item 1.19, which has the possibility of reviewing and revising the spectrum allocation for spectrum commons.

Definition

The development of the definition of these two technologies has been conducted in the ITU-R SG WP1B in the study period of WRC-12: after WRC-07 and before WRC-12. The study adopts the definition of SDR and CRS from Report ITU-R SM. 2152:

"Software-defined radio (SDR): A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard.

Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained"(ITU, 2009a, p. 1).

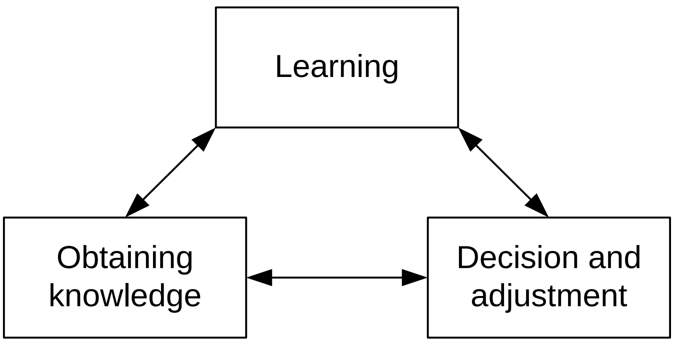
Technical characteristics

SDR is a technology that has the ability to change the RF operating parameters of the transmitter, receiver, or transceiver using software, such as frequency bands, modulation type and output power.

CRS is a combination of technologies that have the ability to obtain knowledge from the operational environment, learn from experience to establish the internal protocol, and adjust the operating parameters dynamically and automatically using software to improve performance.

Therefore, SDR is enabling technology for one function of CRS to change radio operating parameters using software. However, the remaining functions of CRS are still in their infancy: obtaining knowledge from the operational environment and learning from experience to establish the internal protocol for making decisions.

Figure 6 shows the cycle of CRS that displays the main functions: obtaining knowledge from the operational environment, adjusting the radio operational parameters simultaneously and automatically, and learning from the results.



Source Figure 1 of Matinmikko and Bräysy (2011, p. 18)

Figure 6. General cognitive cycle

Application

There are a number of applications using SDR, such as selection of frequency in Global Positioning System (GPS) receivers, noise cancellation in low noise amplifier (LNA) mixers, mobile dynamic channel selection in mobile phones, vehicular dynamic spectrum access in vehicles, and 5G terminals (Bajaj, Kim, Oh, & Gerla, 2011; Elyasi, Jannesari, & Nabavi, 2012; Li, Kaur, & Andersen, 2011; Raju et al., 2012; Rzayev, Shi, Vafeiadis, Pagadarai, &

Wyglinski, 2011). These applications use SDR to change the operational frequency both to avoid interference and increase spectrum efficiency.

Moreover, there are several applications applying CRS, especially for interference reduction and increasing spectrum efficiency. When interference is reduced, spectrum efficiency increases.

There are several applications for interference reduction, such as sharing the spectrum between primary and secondary users by interference constraint time slots, reducing a narrowband interference of orthogonal frequency division multiplexing (OFDM) by interference estimation and decoding (IED), and introducing spectrum sensing in Bluetooth and Wi-Fi (Dikmese & Renfors, 2012; Qu, Yi, Jiang, & Zhu, 2012; Sun et al., 2012; Xia, Ding, & Chen, 2012).

Further, Matinmikko and Bräysy (2011) provide four deployment scenarios for increasing spectrum efficiency using CRS: licensed spectrum, unlicensed spectrum, primary-secondary setting, and dedicated band for CRS.

For licensed spectrum, the licensee can utilize its licensed spectrum by introducing the CRS at the same frequency in different locations, for example frequency for mobile base stations can be introduced to home base stations without the need for additional regulation.

For unlicensed spectrum, i.e. ISM band, the CRS can be utilized while using the same frequency bands with other applications.

In a primary-secondary setting, the secondary users can implement the CRS as opportunistic spectrum access, while primary users do not use the frequency, such as the white space frequency in the US.

For CRS bands, it is similar to the ISM band but the equipment implementing CRS must share this band.

Generic and specific regulation issue

During the WRC-12 agenda item 1.19 regarding the use of SDR and CRS, there was the issue of regulation governing the use of SDR and CRS. The SDR issue was settled because this technology is at a mature stage and has been used in several services. There is no need for additional regulation. However, the CRS is in the process of development, and is not a mature technology. The CRS issue was debated, with two opposing views: whether the existing regulation is enough to govern the use of CRS, or whether new regulation is required. At the end of the WRC-12, the compromise result was that CRS required further study.

Benefit

These technologies increase spectrum access and efficiency in both licensed and unlicensed frequency bands. Moreover, interference while sharing between primary and secondary users is reduced. Not only is there sharing between primary and secondary users, but co-primary users also benefit from CRS. Further, network implementation has improved flexibility to provide capabilities for self-organization and self-healing (Matinmikko & Bräysy, 2011, pp. 19-20)

CRS can entirely change the exclusive right to a frequency scheme because it is unnecessary to have dedicated or licensed frequency bands to provide radiocommunication services. Therefore, CRS is the main technology for providing non-exclusive rights to use frequency as the main characteristic of spectrum commons.

In conclusion, the characteristics of CRS are obtaining knowledge from the operational environment, changing the radio operational parameters simultaneously and automatically using software, and learning from experiences to improve the performance. SDR is one of the main characteristics of CRS. The benefit of CRS is reducing interference, creating spectrum access opportunities, and increasing spectrum efficiency. The characteristic of CRS renders the exclusive right to use frequency unnecessary. Therefore, these technologies provide non-exclusive rights to use frequency schemes as spectrum commons.

4.3 Summary and discussion of research question

This chapter responds to sub-research question 1: *What are the main applications and technologies for spectrum commons?*

This study explores the relevant literature, including the report and recommendation of the ITU-R to illustrate the characteristics of the SRD, SDR and CRS.

The main characteristics of SRDs are use on a non-interference and non-protected basis. Most SRDs use the ISM band, especially 5.138 and 5.150. Moreover, power limitations in terms of magnetic and electric field strength and maximum power level vary from country to country. The allocation of frequency band to the ISM band is coordinated by the WRC. However, authorization of the use of SRDs is managed locally by the NRA. SRDs migrate national to international issues when unlicensed SRDs are transported from one country to other countries that do not allow the use of such SRDs. The use of unlicensed SRDs in countries that do not allow it creates interference with the existing services. There may be a solution through regional and global harmonization of frequency bands.

SRDs are the main application for spectrum commons, because the characteristic of non-interference and non-protection provides the non-exclusive use of frequency that is similar to spectrum commons.

SDR and CRS are enabled technologies for SRD. This study focuses on these two technologies because they are relevant to WRC-12 agenda item 1.19 and might present opportunities to review and revise the RR.

The characteristics of CRS are obtaining the operational environment, changing the radio operational parameters simultaneously and automatically using software, and learning from the experience to improve its performance. SDR is enabled technology for CRS because SDR can change the radio operational parameters simultaneously and automatically using software.

The development of SDR is at a mature stage that has already been implemented into several services, however the CRS is in its infancy and needs to further develop. The main benefits of CRS are providing spectrum access opportunities, increasing spectrum efficiency, and reducing interferences.

The characteristic of CRS provides the non-exclusive right to use frequency as the same as spectrum commons characteristic. Therefore, the SDR and CRS are the main technologies for spectrum commons.

This study presents the characteristics of SRD, SDR, and CRS in order to illustrate the non-exclusive right of use that is the same characteristic of spectrum commons. This chapter responds to the first sub-research question: what is the main application and technology for spectrum commons? The answer to this sub-research question provides fundamental information such as the main characteristics of SRDs, SDR, and CRS for spectrum in order to relate the spectrum allocation for spectrum commons at international level to spectrum assignment for SRDs at national level.

Chapter 5 Spectrum allocation for spectrum commons

This chapter presents the overview of frequency allocation within the RR and also describes the development of frequency allocation for spectrum commons in terms of the frequency allocation for ISM bands and its definition.

5.1 Spectrum allocation

Spectrum shows its characteristics when it is transmitted from a transmitter; it will propagate until the power runs out and does not recognize borders between countries. In order to manage spectrum internationally, the ITU, via the WRC, manages the spectrum according to the RR as the international treaty providing the guidelines on spectrum management internationally.

In order to manage the use of frequency, the WRC allocates radiocommunication services (purpose of frequency usage) to frequency bands with footnotes to the RR.[9] This activity is called spectrum allocation. Allocation can be either regional or global.

The allocation is presented in a Table of Frequency Allocation (TFA) contained in Volume 1 - Articles, sorted by frequency band with the services that are allowed to be used. The TFA is divided into three regions (Regions 1-3) and currently defines the usable frequency up to 3,000 GHz. The services can be either primary or secondary services. In the TFA, primary services are presented in upper case, while secondary services are in lower case. The reason for this division is to avoid harmful interference, with primary services always having priority over secondary services by way of station (network and device) construction.

For example, in the TFA of RR2012, the 2 300-2 483.5 MHz band in Table 10 shows the regional allocation. In Region 1, in the 2 300-2 450 MHz band, there are two primary services – fixed and mobile services, and two secondary services – amateur and radiolocation services. In Regions 2 and 3, in the band 2 450-2 483.5 MHz, there are three primary services – fixed, mobile, radiolocation services.

Apart from capitalized and lower-case letters in the TFA, the footnotes can also indicate the priority of services. For example, footnote 5.397 indicates the use of radiolocation services in the band of 2 450-2 500 MHz on a primary basis in France.[10]

The additional allocation footnote is the footnote that has the same service as indicated in the TFA, but in an area smaller than the Region. For instance, footnote 5.393 allocates the 2 400-2 450 MHz band to broadcasting-satellite services (sound) on a primary basis in Canada, the United States, India, and Mexico.[11]

[9] *Radiocommunication service:* A service as defined in this Section involving the transmission, *emission* and/or reception of *radio waves* for specific *telecommunication* purposes. This definition is taken from Article 1. Section III–Radio services, 1.19 of the RR edition 2012 (ITU, 2012).

[10] 5.397 *Different category of service:* in France, the band 2 450-2 500 MHz is allocated on a primary basis to the radiolocation service (see No. 5.33). Such use is subject to agreement with administrations having services operating or planned to operate in accordance with the Table of Frequency Allocations which may be affected.

[11] 5.393 *Additional allocation:* in Canada, the United States, India and Mexico, the band 2 310-2 360 MHz is also allocated to the broadcasting-satellite service (sound) and complementary terrestrial sound broadcasting service on a primary basis. Such use is limited to

Table 10. Table of Frequency Allocation, 2 300 – 2 483.5 MHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
2 300-2 450 FIXED MOBILE 5.384A Amateur Radiolocation 5.150 5.282 5.395	**2 300-2 450** FIXED MOBILE 5.384A RADIOLOCATION Amateur 5.150 5.282 5.393 5.394 5.396	
2 450-2 483.5 FIXED MOBILE Radiolocation 5.150 5.397	**2 450-2 483.5** FIXED MOBILE RADIOLOCATION 5.150	

The alternative allocation footnote is the footnote that replaces the service indicated in the TFA, but in an area smaller than the Region. For example, footnote 5.315 (not in Table 10) allocates the band 790-838 MHz for broadcasting services on a primary basis in Greece, Italy, and Tunisia.[14]

The miscellaneous provision footnote is the footnote that represents the specific operation constraints, such as footnote 5.396 in the 2 310-2 360 MHz band that provides the conditions for broadcasting-satellite services by a space station.[15]

Moreover, footnotes can be used for a particular service: the footnote is located next to the service, or entire frequency bands: the footnote is placed at the bottom of the band as indicated in the TFA. The band footnote is applied to all services allocated in this band. For example, in Region 1, in the 2 300-2 450 MHz band, the use of mobile services has a particular footnote, 5.384A. The band footnotes are 5.150, 5.282, and 5.395, which apply to all services in this band, including fixed, mobile, amateur, and radiolocation services.

In Regions 2 and 3, the 2 300-2 450 MHz band has a particular footnote for the mobile service: 5.384A. However, the band footnotes are 5.150, 5.282, 5.393, 5.394, and 5.395 which apply to all services in this band, including fixed, mobile, radiolocation, and amateur services.

All allocations at the WRC are based on Member States' contributions. The successful allocations are the outcome of international negotiations based on consensus or compromise among Member States.

The allocations, both services and footnotes, belong to Member States, which are the authority representing the government of each country. This implies that the allocation at the WRC reflects the command-and-control approach at international level among representatives

digital audio broadcasting and is subject to the provisions of Resolution 528 (Rev.WRC-03), with the exception of *resolves* 3 in regard to the limitation on broadcasting-satellite systems in the upper 25 MHz. (WRC-07)

[14] 5.315 *Alternative allocation*: in Greece, Italy and Tunisia, the band 790-838 MHz is allocated to the broadcasting service on a primary basis. (WRC-2000)

[15] 5.396 Space stations of the broadcasting-satellite service in the band 2 310-2 360 MHz operating in accordance with No. 5.393 that may affect the services to which this band is allocated in other countries shall be coordinated and notified in accordance with Resolution 33 (Rev.WRC-97)*. Complementary terrestrial broadcasting stations shall be subject to bilateral coordination with neighboring countries prior to their bringing into use.

from governments around the world. When allocations are in line with all government benefits, consensus is achieved. However, when allocation raises controversial and debatable issues, a compromise solution is reached.

5.2 Allocation of spectrum commons

Normally, the service allocation by the WRC provides both primary and secondary services by frequency bands. Among primary services, there are co-primary services, which need operating criteria when they are co-located in order to keep harmful interference manageable. Conversely, the secondary services cannot cause any harmful interference with the primary service.

The use of spectrum commons is neither allocated to primary nor secondary services in the TFA. Spectrum commons are allocated in the footnotes for industrial, scientific and medical (ISM) applications without priority. ISM footnotes provide the non-exclusive right to use frequency. ISM applications are locally operated with short-range devices. There are two footnotes regarding ISM applications, namely 5.138 and 5.150. The development of these two footnotes is presented in the next section.

5.3 Development of industrial, scientific and medical application band

Industrial, scientific and medical (ISM) applications have been defined in Article 1 – Terms and Definitions since RR1982 and remain unchanged up until the RR2012. Before 1982, ISM applications used different wording, such as purpose and equipment in the RR1947 and RR1959.

5.3.1 Definition

The current definition of ISM applications is found in RR2012, page RR1-2:

"1.15 industrial, scientific and medical (ISM) applications (of radio frequency energy): Operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications" (ITU, 2012, pp. RR1-2).[16]

The use of the ISM equipment is local, especially for industrial, scientific, medical, or domestic purposes, apart from telecommunication applications. Usually, the use of telecommunication applications via radio is allocated by services. However, most ISM applications are used locally, i.e. by short-range or low-power devices. The footnote allocating ISM frequency bands provides additional conditions of use.

5.3.2 ISM frequency bands

The current frequency bands with corresponding footnotes for ISM applications are provided in Table 11. The current provisions of ISM applications are in RR2012: 5.138 and 5.150 with relevant footnotes (ITU, 2012).[17, 18]

[16] This provision was used under provision No. 1.14 in RR1982 (ITU, 1982, pp. RR1-2), RR1990 and RR1994 (ITU, 1990; 1994, pp. RR1-3). Moreover, this provision was also used under provision No. S1.15 in RR1998 (ITU, 1998, p. 8) and No. 1.15 in RR2001, RR2004, and RR2008 (ITU, 2001, 2004; 2008, pp. RR1-2).

[17] These provisions were used in RR2001, RR2004, and RR2008 (ITU, 2001, 2004, 2008).

Table 11 presents a summary of frequency bands for ISM applications in footnotes 5.138 and 5.150, together with the allowable regions and main applications. There are five frequency bands for 5.138: 6,765-6,795 kHz, 433.05-434.79 MHz, 61-61.5 GHz, 122-123 GHz, and 244-246 GHz. There are six frequency bands for 5.150: 13 553-13 567 kHz, 26 957-27 283 kHz, 40.66-40.70 MHz, 902-928 MHz, 2 400-2 500 MHz, and 5 25-5 875 MHz. The total bandwidth of 5.138 and 5.150 is 3,778.15 MHz. This is only 0.126% of the whole usable spectrum of 3,000 GHz, however.

Table 11. Frequencies of ISM bands 5.138 and 5.150

Frequency	Footnote	Bandwidth	Region 1	Region 2	Region 3	Main application
6 765-6 795 kHz	5.138	30 kHz	✓	✓	✓	Inductive application
13 553-13 567 kHz	5.150	14 kHz	✓	✓	✓	RFID
26 957-27 283 kHz	5.150	326 kHz	✓	✓	✓	Railway application – Eurobalise
40.66-40.70 MHz	5.150	0.04 MHz	✓	✓	✓	Control signal
433.05-434.79 MHz	5.138	1.74 MHz	✓			Control signal
902-928 MHz	5.150	26 MHz		✓		Spread spectrum transmitter
2 400-2 500 MHz	5.150	100 MHz	✓	✓	✓	WLAN
5 725-5 875 MHz	5.150	150 MHz	✓	✓	✓	WLAN
24-24.25 GHz	5.150	250 MHz	✓	✓	✓	RF level gauge
61-61.5 GHz	5.138	0.5 GHz	✓	✓	✓	Millimeter-wave radar
122-123 GHz	5.138	1 GHz	✓	✓	✓	Non-specific SRDs
244-246 GHz	5.138	2 GHz	✓	✓	✓	Non-specific SRDs

Source: ITU (2009b) and (2012)

Most of the applications are short-range devices and have various applications, ranging from an inductive application to a millimeter-wave radar. Only two frequency bands of 433.05-

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[18] 5.138 The following bands:

6765-6 795 kHz	(center frequency 6 780 kHz),
433.05-434.79 MHz	(center frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. 5.280,
61-61.5 GHz	(center frequency 61.25 GHz),
122-123 GHz	(center frequency 122.5 GHz), and
244-246 GHz	(center frequency 245 GHz)

are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations.

5.280 In Germany, Austria, Bosnia and Herzegovina, Croatia, The Former Yugoslav Republic of Macedonia, Liechtenstein, Montenegro, Portugal, Serbia, Slovenia and Switzerland, the band 433.05-434.79 MHz (center frequency 433.92 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services of these countries operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 15.13. (WRC-07)

5.150 The following bands:

13 553-13 567 kHz	(center frequency 13 560 kHz),
26 957-27 283 kHz	(center frequency 27 120 kHz),
40.66-40.70 MHz	(center frequency 40.68 MHz),
902-928 MHz	in Region 2 (center frequency 915 MHz),
2400-2 500 MHz	(center frequency 2 450 MHz),
5725-5 875 MHz	(center frequency 5 800 MHz), and
24-24.25 GHz	(center frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. 15.13.

15.13 § 9 Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations[1].

[1] 15.12.1 and 15.13.1 In this matter, administrations should be guided by the latest relevant ITU-R Recommendations.

434.79 MHz and 902-928 MHz are allocated to Region 1 and Region 2, respectively. The rest of the ISM bands are global allocations.

The development of ISM bands is illustrated in Table 12. Table 12 provides three sections of ISM band development: kHz, MHz, and GHz. The relevant RR provisions and versions are also included.

Table 12. ISM frequency bands development

Initial RR	Lower frequency (kHz)	Upper frequency (kHz)	Bandwidth (kHz)	Footnote/Provision	RR removal
1959	60	80	20	161	1982
1947	13 553.22	13 566.78	13.56	164,217	1982
1947	26 957.28	27 282.72	325.44	171,225	1982
1982-2012	6 765	6 795	30	524,S5.138,5.138	
1982-2012	13 553	13 567	14	534,S5.150,5.150	
1982-2012	26 957	27 283	326	546,S5.150,5.150	
Initial RR	**Lower frequency (MHz)**	**Upper frequency (MHz)**	**Bandwidth (MHz)**	**Footnote/Provision**	**RR removal**
1938	30	32	2	Lower-power station	1947
1938	40.5	56	15.5	Lower-power station	1947
1947	40.65966	40.70034	0.04068	176,236	1982
1938	56	58.5	2.5	Lower-power station	1947
1938	58.5	60	1.5	Lower-power station	1947
1938	60	64	4	Lower-power station	1947
1938	70.5	74.5	4	Lower-power station	1947
1938	75.5	85	9.5	Lower-power station	1947
1938	95.5	110	14.5	Lower-power station	1947
1938	110.5	112	1.5	Lower-power station	1947
1938	112	120	8	Lower-power station	1947
1938	120	150	30	Lower-power station	1947
1938	162	170	8	Lower-power station	1947
1959	433.05216	434.787884	1.73568	321	1982
1947	890	940	50	212,340	1971
1947	5775	5925	150	228	1959
1982-2012	40.66	40.70	0.04	548, S5.150,5.150	
1982-2012	433.05	434.79	1.74	661,662,S5.138,S5.280, 5.138,5.280	
1971-2012	902	928	26	340,707,S5.150,5.150	
1947-2012	2 400	2 500	100	220,357,752,S5.150,5.150	
1959-2012	5 725	5 875	150	391,806,S5.150,5.150	
Initial RR	**Lower frequency (GHz)**	**Upper frequency (GHz)**	**Bandwidth (GHz)**	**Footnote/Provision**	**RR removal**
1959	22	22.250	0.25	410	1971
1971-2012	24	24.25	0.25	410C,881,S5.150,5.150	
1982-2012	61	61.5	0.5	911,S5138,5.138	
1982-2012	122	123	1	916,S5138,5.138	
1982-2012	244	246	2	922,S5138,5.138	

kHz band

The *60-80 kHz band* was allocated in the U.S.S.R. for industrial, scientific and medical purposes in the RR1959 and was used in the RR1968, RR1971 and RR1976. Unfortunately, this band was stopped in the RR1982.[19]

The *6 765-6 795 kHz band* was allocated initially in the RR1982 and continued to be used without changing the substance of the RR1990 and RR1994 under provision No. 524.[20]

Later on, this frequency band was consolidated in footnote S5.138 in the RR 1996 and also used in the RR1998.[21] In the RR2001, the provision number was changed to 5.138 and continued to be used in the RR2004, RR2008, and RR2012. The provision includes the frequency band for ISM applications and their conditions of use, i.e. obtaining special authorization by its administration and administrations concerned with relevant CCIR Recommendations.

The *13 553-13 567 kHz band* was allocated initially in the RR1947 under provision No. 164 by center frequency of 13 560 kc/s with the bandwidth ± 0.05% of this frequency. [22] The content of this provision continued to the RR1959 under provision No. 217. This provision was used in the RR1968, RR1971, and RR1976.[23] The provision includes the frequency band, the purpose of frequency use, and the conditions of use for other radiocommunication services that must accept harmful interference from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 534 in the RR1982, RR1990, and RR1994.[24] This provision, which adds the condition of use for ISM equipment, is subject to provision No. 1815. Provision No. 1815 mandated the

[19] 161 In the U.S.S.R., frequencies in the band 60-80 kHz may be used for industrial, scientific and medical purposes subject to the condition that interference is not caused to stations of services to which this band is allocated (ITU, 1959, 1968, 1971, 1976).

[20] 524 The band 6 765 - 6 795 kHz (center frequency 6 780 kHz) is designated for industrial, scientific and medical (ISM) applications. The use of this frequency band for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant CCIR Recommendations (ITU, 1982, 1990, 1994).

[21] S5.138 The following bands:

6 765- 6795 kHz	(center frequency 6780kHz),
433.05-434.79 MHz	(center frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. S5.280,
61 - 61.5 GHz	(center frequency 61.25 GHz),
122- 123 GHz	(center frequency·122.5 GHz), and
244-246 GHz	(center frequency 245 GHz)

are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations. S5.280 In Germany, Austria, Bosnia and Herzegovina, Croatia, The Former Yugoslav Republic of Macedonia, Liechtenstein, Portugal, Slovenia, Switzerland and Yugoslavia, the band 433.05-434.79 MHz (center frequency 433.92 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services of these countries operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815/S15.13 (ITU, 1996, 1998).

[22] 164 [50)] The frequency 13 560 kc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 0.05% of this frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).

[23] 217 The frequency 13 560 kc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±0.05% of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968, 1971, 1976).

[24] 534 The band 13 553-13 567 kHz (center frequency 13 560 kHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

administration to keep radiation from ISM applications to a minimum and not to cause harmful interference to radionavigation or other safety services by following the latest relevant CCIR Recommendation.[25] This provision was used in the RR1982, RR1990, RR1994, and RR1996. The number of the provision was changed to S15.13 in the RR1998, and changed to 15.13 in the RR2001 and continued to be used up until the RR2012.[26]

In 1996, the consolidated ISM band was initiated and the 13 553-13 567 kHz band was in footnote S5.150 in the RR1996 and RR1998.[27] After the RR2001, the provision was changed to 5.150 and continued to the RR2012.

The *26 957-27 283 kHz band* was allocated initially in the RR1947 under provision No. 171 by center frequency of 27 120 kc/s with the bandwidth ± 0.6% of this frequency.[28] The content of this provision continued to the RR1959 under provision No. 225. This provision was used in the RR1968, RR1971, and RR1976.[29] The provision includes the frequency band, the purpose of frequency use, and the condition of use for other radiocommunication services that must accept harmful interferences from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 546 in the RR1982, RR1990, and RR1994.[30] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and the 26 957-27 283 kHz was in footnote S5.150 in RR1996 and RR1998. After RR2001, the provision was changed to 5.150 and continued to RR2012.

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[25] 1815 § 10. Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations[1].
1815.1 [1] In this matter, administrations should be guided by the latest relevant CCIR Recommendations (ITU, 1982, 1990, 1994, 1996).

[26] S15.13 § 9 Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations[1].
[1] S15.12.1 and S15.13.1 In this matter, administrations should be guided by the latest relevant ITU-R Recommendation (ITU, 1998).

[27] S5.150 The following bands:

13 553- 13 567kHz	(center frequency 13 560kHz),
26 957 - 27 283 kHz	(center frequency 27 120 kHz),
40.66-40.70 MHz	(center frequency 40.68 MHz),
902- 928 MHz	in Region 2 (center·frequency 915 MHz),
2400-2500 MHz	(center frequency 2450 MHz),
5 725 -5875 MHz	(center frequency 5 800 MHz), and
24-24.25 GHz	(center frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. 1815/S15.13 (ITU, 1996, 1998).

[28] 171 [67)] The frequency 27 120 kc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±0.6% of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).

[29] 225 The frequency 27 120 kc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±0.6% of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968, 1971, 1976).

[30] 546 The band 26 957 - 27 283 kHz (center frequency 27 120 kHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

MHz band

The development of the lower-power station was initiated in the European region in RR1938 with twelve frequency bands: 30-32, 40.5-56, 56-58.5, 58.5-60, 60-64, 70.5-74.5, 75.5-85, 95.5-110, 110.5-112, 112-120, 120-150, and 162-170 MHz for both primary and secondary services. Unfortunately, these frequency bands were discontinued at the RR1947. None of them were developed to the current frequency for ISM applications.

The *40.66-40.70 MHz band* was allocated initially in the RR1947 under provision No. 176 by center frequency 40.68 Mc/s with the bandwidth ± 0.05% of this frequency.[31] The content of this provision was continued to the RR1959 under provision No. 236. This provision was used in RR1968, RR1971, and RR1976.[32] The provision includes the frequency band, the purpose of frequency use, and the conditions of use for other radiocommunication services that must accept harmful interferences from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 548 in RR1982, RR1990, and RR1994.[33] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and 40.66-40.70 MHz was in footnote S5.150 in the RR1996 and RR1998. After RR2001, the provision was changed to 5.150 and continued to RR2012.

The *433.05-434.79 MHz band* was allocated initially in RR1959 only in Austria, Portugal, the Federal Republic of Germany, Yugoslavia, and Switzerland under provision No. 321 by center frequency 433.92 Mc/s with bandwidth of ± 0.2% of this frequency. This provision was used in RR1968, RR1971, and RR1976.[34]

In RR1982, 433.05-434.79 MHz band coverage was extended to Region 1 except for the countries in provision No. 662. This frequency band was under provision No. 661 with similar conditions to the 6 765-6 795 kHz band with regard to obtaining special authorization by its administration and administrations concerned, with relevant CCIR Recommendations.

Provision No. 662 allowed the Federal Republic of Germany, Austria, Liechtenstein, Portugal, Switzerland, and Yugoslavia to use other radiocommunication services in this band, subject to provision No. 1815 that the use of other radiocommunication services must accept harmful interference by ISM applications. These two provisions were also used in RR1990

[31] 176 [62)] The frequency 40.68 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±0.05% of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).
[32] 236 The frequency 40.68 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 005% of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968, 1971, 1976).
[33] 548 The band 40.66 - 40.70 MHz (center frequency 40.68 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).
[34] 321 In Austria, Portugal, the F. R. of Germany, Yugoslavia and Switzerland, the frequency 433.92 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 0.2% of that frequency (ITU, 1959, 1968, 1971, 1976).

and 1994.[35]

Later on, the 433.05-434.79 MHz band was consolidated into footnote S5.138 in RR1996 and also used in RR1998. In the RR2001, the provision number was changed to 5.138 and continued to be used in the RR2004, RR2008, and RR2012. The provision includes the frequency band for ISM applications and their conditions of use, i.e. obtaining special authorization by its administration and administrations concerned, with relevant CCIR Recommendations.

The *902-928 MHz band* was allocated initially in RR1947 for Region 2 under provision No. 212 by center frequency 915 Mc/s with the bandwidth ± 25 Mc/s of this frequency.[36] The content of this provision was continued to RR1959 and RR1968 under provision No. 340.[37] However, in RR1971 the bandwidth of this provision was changed to ± 13 MHz and continued to be used in the RR1976.[38] The provision includes the frequency band, the purpose of frequency use, and the conditions of use for other radiocommunication services that must accept harmful interferences from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 707 in RR1982, RR1990, and RR1994.[39] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and 902-928 MHz was in footnote S5.150 in RR1996 and RR1998. After the RR2001, the provision was changed to 5.150 and continued to RR2012.

The *2 400-2 500 MHz band* was allocated initially in RR1947 for Region 2, Australia, New Zealand, Northern Rhodesia, Southern Rhodesia, the Union of South Africa, the territory under the mandate of Southwest Africa, and the United Kingdom, under provision No. 220 by center frequency 2 450 Mc/s with the bandwidth ± 50 Mc/s of this frequency.[40] The provision

[35] 661 In Region 1, except in the countries mentioned in No. 662, the band 433.05-434.79 MHz (center frequency 433.92 MHz) is designated for industrial, scientific and medical (ISM) applications. The use of this frequency band for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant CCIR Recommendations.
662 In the Federal Republic of Germany, Austria, Liechtenstein, Portugal, Switzerland and Yugoslavia, the band 433.05-434.79 MHz (center frequency 433.92 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services of these countries operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

[36] 212 [98)] In Region 2, the frequency 915 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±25 Me/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).

[37] 340 In Region 2, the frequency 915 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 25 Mc/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968).

[38] 340 In Region 2, the frequency 915 MHz is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 13 MHz of that frequency. Radiocommunication services operating within these limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1971, 1976).

[39] 707 In Region 2, the band 902 - 928 MHz (center frequency 915 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

[40] 220 [106)] In Region 2, Australia, New Zealand, Northern Rhodesia, Southern Rhodesia, the Union of South Africa, the territory under mandate of Southwest Africa, and the United Kingdom, the frequency 2 450 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±50 Mc/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).

was changed to cover global coverage and continued to RR1959 under provision No. 357, except in Albania, Bulgaria, Hungary, Poland, Romania, Czechoslovakia, and the U.S.S.R. This provision was used in RR1968, RR1971, and RR1976.[41] The provision includes the frequency band, the purpose of frequency use, and the condition of use for other radiocommunication services that must accept harmful interferences from ISM applications.

Finally, in 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 752 in RR1982, RR1990, and RR1994 without any exception of Member States and provided global allocation in this band.[42] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and 2 400-2 500 MHz was in footnote S5.150 in RR1996 and RR1998. After RR2001, the provision was changed to 5.150 and continued to RR2012.

The *5 725 - 5 875 MHz band* was allocated initially in RR1947 under provision No. 228 by center frequency 5 850 Mc/s with the bandwidth ± 75 Mc/s of this frequency.[43] The initial frequency band was 5 725-5 925 MHz. Moreover, this initial frequency band was allocated in Region 2, Australia, New Zealand, Northern Rhodesia, Southern Rhodesia, the Union of South Africa, the territory under the mandate of Southwest Africa, and the United Kingdom. This provision was stopped at RR1959.

In RR1959, the center frequency was changed to 5 800 Mc/s and coverage was expanded to global allocation. The updated provision number was 391. This provision was used in RR1968, RR1971, and RR1976.[44] The provision includes the frequency band, the purpose of frequency use, and the condition of use for other radiocommunication services that must accept harmful interferences from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 806 in RR1982, RR1990, and RR1994.[45] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and 5 725 - 5 875 MHz was in footnote

[41] 357 The frequency 2 450 Mc/s is designated for industrial, scientific and medical purposes except in Albania, Bulgaria, Hungary, Poland, Romania, Czechoslovakia and the U.S.S.R., where the frequency 2 375 Mc/s is used. Emissions must be confined within ± 50 Mc/s of the frequencies designated. Radiocommunication services operating within these limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968, 1971, 1976).

[42] 752 The band 2 400 - 2 500 MHz (center frequency 2 450 MHz) is designated for industrial, scientific and medical (ISM) applications. Radio services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

[43] 228[114)] In Region 2, Australia, New Zealand, Northern Rhodesia, Southern Rhodesia, the Union of South Africa, the territory under mandate of Southwest Africa, and the United Kingdom, the frequency 5 850 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±75 Mc/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1947).

[44] 391 The frequency 5 800 Mc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 75 Mc/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968, 1971, 1976).

[45] 806 The band 5 725 - 5 875 MHz (center frequency 5 800 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

S5.150 in RR1996 and RR1998. After RR2001, the provision was changed to 5.150 and continued to RR2012.

GHz band

The *22-22.25 GHz band* was allocated in RR1959 under provision No. 410 by center frequency 22.125 Gc/s with the bandwidth ± 125 Mc/s of this frequency.[46] Unfortunately, this frequency was stopped in RR1968.

The *24-24.25 GHz band* was allocated in RR1971 under provision No. 410C by center frequency 24.125 Gc/s with the bandwidth ± 125 Mc/s of this frequency, which shifted from the previous allocation of 22-22.25 Gc/s by 2 GHz. This provision was also used in RR1976.[47] The provision includes the frequency band, the purpose of frequency use, and the conditions of use for other radiocommunication services that must accept harmful interferences from ISM applications.

In 1982, the format of the frequency band was changed to provide an upper and lower frequency in order to define the frequency band. Further, the provision number was changed to 881 in RR1982, RR1990, and RR1994.[48] This provision adds the condition of use for ISM equipment subject to provision No. 1815, which is similar to the 13 553-13 567 kHz band.

In 1996, the consolidated ISM band was initiated and 24-24.25 GHz was in footnote S5.150 in RR1996 and RR1998. After RR2001, the provision was changed to 5.150 and continued to RR2012.

The *61-61.5 GHz band* was allocated initially in RR1982 under provision No. 911 by center frequency 61.25 GHz. This provision was used in RR1990 and RR 1994.[49]

Later on, the 61-61.5 GHz band was consolidated to footnote S5.138 in RR1996 and also used in RR1998. In RR2001, the provision number was changed to 5.138 and continued to be used in RR2004, RR2008, and RR2012. The provision includes the frequency band for ISM applications and their conditions of use, i.e. obtaining special authorization by its administration and administrations concerned, with relevant CCIR Recommendations.

The *122-123 GHz band* was allocated initially in RR1982 under provision No. 916 by center frequency 122.5 GHz. This provision was used in RR1990 and RR 1994.[50]

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[46] 410 The frequency 22.125 Gc/s is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ± 125 Mc/s of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1959, 1968)

[47] 410C (Spa2) The frequency 24.125 GHz is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits of ±125 MHz of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of industrial, scientific and medical equipment (ITU, 1971, 1976).

[48] 881 The band 24 - 24.25 GHz (center frequency 24.125 GHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815 (ITU, 1982, 1990, 1994).

[49] 911 The band 61 - 61.5 GHz (center frequency 61.25 GHz) is designated for industrial, scientific and medical (ISM) applications. The use of this frequency band for ISM applications shall be subject to special authorization by the administration concerned in agreement with other administrations whose radiocommunication services might be affected. In applying this provision administrations shall have due regard to the latest relevant CCIR Recommendations (ITU, 1982, 1990, 1994).

[50] 916 The band 122 - 123 GHz (center frequency 122.5 GHz) is designated for industrial, scientific and medical (ISM) applications. The use of this frequency band for ISM applications shall be subject to special authorization by the administration concerned in agreement with other

Later on, the 122-123 GHz band was consolidated into footnote S5.138 in RR 1996 and also used in RR1998. In RR2001, the provision number was changed to 5.138 and continued to be used in RR2004, RR2008, and RR2012. The provision includes the frequency band for ISM applications and their conditions of use, i.e. obtaining special authorization by its administration and administrations concerned, with relevant CCIR Recommendations.

The *244-246 GHz band* was allocated initially in RR1982 under provision No. 922 by center frequency of 245 GHz. This provision was used in RR1990 and RR 1994.[51]

Later on, the 244-246 GHz band was consolidated to footnote S5.138 in RR1996 and also used in RR1998. In RR2001, the provision number was changed to 5.138 and continued to be used in RR2004, RR2008, and RR2012. The provision includes the frequency band for ISM applications and their conditions of use, i.e. obtaining special authorization by its administration and administrations concerned, with relevant CCIR Recommendations.

5.3 Similarities and differences between 5.138 and 5.150

The development of both definition and frequency bands allocation for ISM applications in footnotes 5.138 and 5.150 is illustrated in the previous section. Table 13 shows the assessment of these two footnotes in terms of frequency bands, authorization requirement, sharing with other radiocommunication services abilities, and relevant ITU-R recommendations.

The "Frequency bands" column in Table 13 shows the differences between 5.138 and 5.150 in the number of frequency bands that are allowed to be used for ISM applications. Most frequency bands are allocated on a global basis, except the 433.05-434.79 MHz band in Region 2 and 902-928 MHz band in Region 1.

Table 13. Similarities and differences between 5.138 and 5.150

Footnote	Frequency bands	Authorization	Sharing	ITU-R recommendation
5.138	6 765-6 795 kHz 433.05-434.79 MHz, Region 2 61-61.5 GHz 122-123 GHz 244-246 GHz	Required	-	SM.1056-1: Limitation of radiation from industrial, scientific and medical (ISM) equipment
5.150	13 553-13 567 kHz 26 957-27 283 kHz 40.66-40.70 MHz 902-928 MHz, Region 1 2 400-2 500 MHz 5 725-5 875 MHz 24-24.25 GHz	-	Allow	

Special authorization from its administration and administrations concerned is required for using ISM applications only for 5.138. However, only footnote 5.150 allows other radiocommunication services to share the same frequency on condition that other

administrations whose radiocommunication services might be affected. In applying this provision administrations shall have due regard to the latest relevant CCIR Recommendations (ITU, 1982, 1990, 1994).

[51] 922 The band 244 - 246 GHz (center frequency 245 GHz) is designated for industrial, scientific and medical (ISM) applications. The use of this frequency band for ISM applications shall be subject to special authorization by the administration concerned in agreement with other administrations whose radiocommunication services might be affected. In applying this provision administrations shall have due regard to the latest relevant CCIR Recommendations (ITU, 1982, 1990, 1994).

radiocommunication services must accept harmful interferences from ISM applications.

Neither 5.138 nor 5.150 provide the implicit ITU-R recommendation in their footnotes for the use of ISM applications. Moreover, there is no ITU-R recommendation that is relevant to the ISM applications in Volume 4 of RR2012, ITU-R Recommendations incorporated by reference. That means the use of the relevant ITU-R recommendations for ISM applications is voluntary for Member States to implement. There is one recommendation that is relevant to the use of ISM applications, i.e. ITU-R SM.1056-1: Limitation of radiation from industrial, scientific and medical (ISM) equipment.

5.4 Summary and discussion of research question

This chapter responds to sub-research question 2: *What are the spectrum allocations for spectrum commons and ISM applications, and how did they develop?*

This study elaborates on the results of international negotiations or the results of the WRC in the form of the RR for spectrum allocation in terms of radiocommunication services. The WRC allocates services by frequency bands inside the TFA based on the Member States' contributions. The TFA is divided into three Regions: Regions 1, 2, and 3. Each service is either a primary or secondary service, with primary services in upper case and secondary services in lower case. Moreover, the footnotes indicate the primary and secondary services with the word "on a primary basis" or "on a secondary basis", respectively.

The spectrum allocation represents the result of negotiations at international level because the final allocation is the output of government representative negotiations among Member States.

Spectrum commons are allocated in the footnotes 5.138 and 5.150 of ISM applications. Most of the short-range or low-power devices use the frequency under these provisions with non-exclusive use of frequency.

This study illustrates the development of ISM applications, including definition and frequency bands allocated to ISM applications. The official definition of ISM applications has been developed in RR1982 and remains unchanged up until RR2012. Long before that, ISM applications used different wording: purpose and equipment in RR1947 and RR1959.

The current ISM bands are: 6 765-6 795 kHz, 433.05-434.79 MHz, Region 2, 61-61.5 GHz, 122-123 GHz, 244-246 GHz, for 5.138; and 13 553-13 567 kHz, 26 957-27 283 kHz, 40.66-40.70 MHz, 902-928 MHz, Region 1, 2 400-2 500 MHz, 5 725-5 875 MHz, and 24-24.25 GHz for 5.150.

For example, a popular ISM band is 2 400-2 500 MHz that can be used for Wi-Fi-enabled devices and Bluetooth devices. This 2 400-2 500 was originated in RR1947 and provided for Region 2 and some countries in Regions 1 and 3. Until RR1982, this band was allocated worldwide and continued to be used up to RR2012.

The first allocation was for low-power stations in the European region in RR1938 and was discontinued in RR1947. Most of the ISM bands were developed in RR1982 and continued to be used up to RR2012.

This study shows the development of each ISM band and indicates the differences between them. Footnote 5.138 requires special authorization to operate, while footnote 5.150 allows the other services to share the same frequency with acceptance of harmful interference from ISM applications. Neither 5.138 nor 5.150 provide the explicit ITU recommendation, however, the relevant ITU-R recommendation is Recommendation ITU-R SM.1056-1: Limitation of radiation from industrial, scientific and medical (ISM) equipment.

This chapter responds to the second sub-research question: What are the spectrum allocations for spectrum commons and ISM applications, and how did they develop? This provides an overview of spectrum allocation and the development of spectrum commons in terms of ISM band. The second sub-research question fulfills the main research question: How is international regulation – the RR – transformed into national NBTC regulation for spectrum commons in Thailand. As part of international regulation for spectrum commons, it is important to understand the scope of spectrum commons in international regulation – the RR – prior to implementation of such regulations in national NBTC regulation for Thailand.

Chapter 6 Frequency assignment for spectrum commons in Thailand

This chapter illustrates the overall spectrum assignment and approaches. The study also describes the development of spectrum assignment for spectrum commons in Thailand. The study uses and updates some parts of Ard-paru (2010) and (2012).

6.1 Background

Spectrum assignment is about giving a specific frequency band to users: providers, operator, or end-users. For example, the 1 920-1 935 and 2 110-2 125 MHz bands are assigned to Operator A for mobile services.

Spectrum assignment policy is limited to wireless or radiocommunication within a national territory. Each country has its own sovereignty. Spectrum assignment is a subset of spectrum management. Spectrum assignment is one of most important functions of spectrum management, besides other functions, such as planning and regulation, financing, allocation and allotment, national liaison and consultation, international and regional cooperation, standards, specifications and equipment authorization, monitoring, and enforcement (ITU, 2005).

Spectrum management policy is a subset of telecommunications policy. Telecommunications policy includes technical, economic, and social aspects. It overlaps with the natural sciences (technical) and social science (economics and society). Telecommunications policy often, but not always, deals with an institutional analysis. An institutional analysis is the analysis of an institutional arrangement or set of rules governing the number of decision-makers, allowable actions or strategies, authorized results, transformation from internal to decision situations, and linkages between decision situations (Kiser & Ostrom, 1982). Telecommunications policy also includes economic analysis of, for example, the social value or value to private players of the spectrum. The regulator may impose conditions on spectrum to make it excludable, which in turn makes frequency use a specific right for a designated entity or person.

In the language of telecommunication planning, the regulator has the right to assign frequency to assignees. If the frequency is assigned to specific entities, i.e. individuals and legal persons, it is called licensed frequency, in short, licensed. The entities that obtain this assigned frequency are called licensees. If the frequency is not assigned to specific entities, in other words, assigned to the general public, it is called unlicensed frequency or unlicensed. A characteristic of licensees is that they have the exclusive right to use a frequency. The unlicensed frequency, however, does not carry this right.

The typical approaches of spectrum assignment include command-and-control, market-based, and spectrum commons. There are two approaches to licensed frequency: the command-and-control and the market-based approach. These approaches grant the exclusive right to use frequency to licensees. Spectrum commons, however, is unlicensed. Brief details of each approach are described in Figure 7.

Property rights (maximize value)	Command and control (conserve state control)	Licence-free (avoid interference)
-Market knows best -Auctions/secondary trading -High flexibility -Pro big business	-Government knows best -First come, first served -Beauty contest -Low flexibility -Pro government (and its friends)	-Nobody knows best -No legal protection -Technical protection -High flexibility -Pro innovation -Optimistics
Economist	Regulators	Regulators

Source Geiss (2004)

Figure 7. Options for spectrum assignment

Historically, spectrum has been assigned by a command-and-control approach, an administrative approach in which the competent authority, usually government, uses its power of discretion to grant an exclusive right of use of some frequency bands to assignees, with conditions. These conditions include power limitation, antenna specification, and other technical requirements in terms of radiocommunication equipment, mainly for the purpose of avoiding harmful interference. Under this approach, spectrum is assigned on a first come, first served basis. This process raises the issue of transparency. If spectrum usage is requested by government agencies, it is usually assigned.

There is consensus among economists, lawyers, and engineers, however, that the command-and-control approach is inefficient (Wang, 2009). The flexibility of the use of frequency under this approach is limited. All frequency operations, including the location, working frequency, bandwidth, output power, antenna gain, modulation technique, and technology, are decided by the NRA. When users want to adopt new technology, they have to go through an administrative process to be approved before implementation.

Technological development, together with increased spectrum demand, makes spectrum scarce. Hence, a market-based approach has been introduced in many countries, because, under this approach it is believed that the market knows best. Here, spectrum is mostly assigned using an auction or secondary trading scheme. This approach creates more flexibility for regulators and operators to manage the spectrum and makes the process more transparent than a command-and-control approach.

The 3G auction in the UK in April 2000 was the largest auction to date. After BT won the spectrum auction, however, the business was not commercially viable and the spectrum was sold to O2. Although the market-based approach can maximize spectrum efficiency in some cases, the outcome may be competition between strong financial parties to buy most of the available spectrum on the market. As a result, the market may become monopolized if the regulator does not have proper control or “spectrum caps” (limit to obtaining spectrum).

The characteristics of spectrum as goods depend on the approach to spectrum assignment, with the market-based approach treating spectrum as goods that can be owned and the commons approach treating spectrum as being without ownership rights. In general, goods can be classified into two groups: private and public goods. Public goods are non-excludable goods that an individual can consume without prohibiting others from consuming. Private goods are excludable goods that an individual can consume while prohibiting others from consuming. The cost of exclusion for public goods is therefore higher than the cost of exclusion for private goods.

Goods can be further refined into four groups: private goods, toll goods, common-pool goods, and public goods. Each group has different characteristics defined by the level of subtractability and the cost of exclusion (Kiser & Ostrom, 1982).

The level of subtractability is defined by the characteristics of the goods that can be separated. Private goods can be separated by individual consumption, but public goods cannot. For example, rice can be consumed from a bowl by taking a spoon as private goods. Air in the park is a public good. People can breathe, but no one can separate air for individual consumption.

Private goods, such as bread, milk, automobiles, and haircuts, have a low cost of exclusion and a high level of subtractability. Toll goods, such as, theaters, nightclubs, telephone service, cable TV, electric power, and libraries, have a low cost of exclusion and a low level of subtractability. Common-pool goods have a high cost of exclusion and a high level of subtractability. Examples of common-pool goods include water pumped from a ground basin, fish taken from an ocean, and crude oil extracted from an oil pool. Public goods, such as peace and security of a community, national defense, mosquito abatement, air pollution control, and weather forecasts, have a high cost of exclusion and a low level of subtractability (Kiser & Ostrom, 1982).

Spectrum assignment can change the spectrum from public goods to private or common-pool goods. For command-and-control and market-based approaches, the spectrum has been treated as private goods with exclusive rights to use frequency. The spectrum can be transferred or sold to others by the regulator or the market. On the other hand, spectrum commons can be treated as common-pool goods that have non-exclusive rights to use frequency. No one owns the spectrum.

6.2 Frequency assignment development in Thailand

Thailand has a long history of spectrum management since 1875. Telecommunications developed from wired to wireless communication: from telegraph, telephone over telegraph infrastructure, and radiotelegraph for ship-to-shore communication, to radiocommunication for both broadcasting and telecommunication. At the initial stage (without regulations), the use of radiocommunication devices was limited to government agencies, particularly the Navy and the Army. Frequency assignment was initially made by His Majesty the King of Thailand. After December 10, 1932, this authority was transferred to the Prime Minister. The King delegated his authority to the responsible ministry. The ministry used the command-and-control approach on a first come, first served basis to authorize the use of radiocommunication devices. Thailand also endorsed the International Telegraph Convention in 1906 and 1912 (ITU, 1906, 1912) as national regulation. Most of the users were government agencies. Otherwise there was little usage and low demand, so there was no congestion of the use of radiocommunication.

After the Radio Act was enacted in 1914, all radiocommunication activities were prohibited, except with authorization granted by the authority in terms of radiocommunication licences. The authority was the Post and Telegraph Department (PTD) and it still used the command-and-control approach on a first come, first served basis to authorize the use of radiocommunication devices. However, the PTD functioned only for radiocommunication licences in technical respects, and did not take into consideration the growing demand for the use of radiocommunication devices until congestion led to harmful interference.

The government realized that “good” spectrum management of frequencies would provide efficient national allocations. On March 26, 1974, the National Frequency Management Board (NFMB) was established to determine the national technical standard; control, assign, and register frequency; examine the standard of radiocommunication devices; create efficient procedures; evaluate radiocommunication stations; and coordinate all radiocommunication users. The NFMB comprised several representatives from government agencies and it was chaired by the Minister of Transport (the NFMB came into force in 1975). The NFMB acted as the approval board before the PTD issued radiocommunication licences. The NFMB operated until 2002, when the PTD became part of the Ministry of Information and Communication Technology (MICT).

After the Act on Establishment of the National Broadcasting Commission (NBC) and the National Telecommunications Commission (NTC) was enacted in 2000, the NTC was established on 1 October 2004, and the PTD was dissolved by law to become the Office of the NTC on 1 January 2005. A new era of telecommunication with an independent regulator, the NTC, was founded in order to change the authorization process into a licensing process. It was not only the technical aspects, but also social and economic aspects that were included in the licensing process.

On 7 October 2011, the National Broadcasting and Telecommunications Commission (NBTC) was established, according to the Thai Constitution 2007 and the Act on Organization to Assign Radio Frequency and to Regulate the Broadcasting and Telecommunications Service 2010. The Office of the NTC (ONTC) was transferred to the Office of the NBTC (ONBTC) on 20 December 2010. The NBTC is responsible for both broadcasting and telecommunication industry and ensures transition from authorization to the licensing process.

The NBTC comprises eleven commissioners: one chairman, two vice chairman, and eight commissioners. The NBTC has two commissions: broadcasting and telecommunications. The broadcasting commission comprises a chairman (one of the vice chairman of the NBTC) and four commissioners. The telecommunications commission comprises a chairman (one of vice chairman of the NBTC) and four commissioners. Each group has its own authority on behalf of the NBTC such as licensing broadcasting or telecommunications licences. However, some tasks, such as frequency management master plan and table of frequency allocation, are managed by the NBTC.

Figure 8 shows the Thai spectrum management development profile: administrator, regulator, secretariat (an administrative unit), and operator.

	Administrator	Regulator	Secretariat	Operator
Before 1975	PTD			
1975-2002	PTD	NFMB	PTD	PTD/TOT/CAT
2002-2004	PTD		PTD	TOT/CAT
2004-2011	MICT	NTC	ONTC	TOT/CAT +licensees
2011-now	MICT	NBTC	ONBTC	TOT/CAT +licensees

Figure 8. Thailand spectrum management profile

The administrator represents the Thai government as the Thai delegation to international activities, such as international conferences, conventions, treaties, negotiations, and cooperation. The regulator acts as the NRA for frequency management. The secretariat is the regulator administrative office. The operator provides the services after obtaining the frequency and licenses from the regulator (TOT and CAT are state-owned companies).

Before 1975, the 1914 Radio Act only authorized the PTD to assign frequency to users. The PTD acted as the administrator, regulator, and operator.

To separate from the PTD, the NFMB worked as regulator to assign frequency to users until 2002, when it was dissolved by the MICT.

During 2002-2004, there was no regulator to assign new frequencies (according to the provision of the Act on Establishment of the NBC and NTC 2000).

The transition period from the monopoly by a state enterprise (or currently state-owned company) to market economies by licensees started with the NTC.

The NTC was founded in 2004 and established the licensing scheme for the Thai telecom sector. However, the NBC was never founded. The NTC did not have full authority to form the Joint Committee between the NTC and the NBC to approve the National Table of Frequency Allocation or National Master Plan. The Supreme Administrative Court decided on 23 September 2010 not to provide the NTC with any right to pursue the 3G auction until the establishment of the NBTC.

The NBTC was established on October 7, 2011 to combine both broadcasting and telecommunication into a single regulator with full authority to assign new frequencies. The 3G frequency assignment or auction can be done after the approval of the National Table of Frequency Allocation or National Master Plan.

Table 14 summarizes the important events of the Thailand spectrum assignment profile.

Table 14. Important events for Thailand spectrum management

Frequency transfer (alienation right)	NFMB in 1998 NTC in 2009
Auction	NFMB initiated in 1997 NTC attempted in 2010 NBTC in 2012
Spectrum commons	Authorization since 1974 Unlicensed since 2004

The frequency transfer representing the alienation right – the right to sell or sub-lease frequency – was initiated by the NFMB and the frequency transfer between CAT concessionaires in the 1800 MHz band was approved in 1998. In 2009, the NTC approved the frequency transfer between CAT and TOT in the 1900 MHz band.

The frequency auction was initiated by the NFMB in 1997, however, the first auction was attempted by the NTC in 2010. Unfortunately, the Administrative Court cancelled the auction. In 2012, the NBTC auctioned the 45 MHz in 2.1 GHz frequency for mobile services. Three companies qualified and entered the auctions. These companies are subsidiaries of the top three mobile operators in Thailand. Each company received 15 MHz each and the Telecommunications Commission approved the auction. However, it is debatable whether the auction process was anti-competitive. The Ombudsman filed a complaint with the Administrative Court in order to have an order to cancel the 3G auction. Finally, the court withdrew the case, allowing the NBTC to grant the 3G licences.

Frequency assignment for spectrum commons in Thailand has developed from authorization to unlicensed. The use of radiocommunication equipment required permission under the Radio Act. The use of spectrum commons was granted individually with authorization and relevant radiocommunication licences in 1974. In 2004, regulation changed, in order to increase flexibility for the general public to use the frequency and equipment without any relevant licences. Unlicensed regulation exempts the relevant licences such as import, usage, and installation licences.

6.3 Spectrum commons development in Thailand

This study explores the relevant regulations including the minutes of NFMB, ministerial regulations, NTC and NBTC regulation.[52]

[52] This section is mainly based on the minutes of meetings of the National Frequency Management Board (1974-2000) (PTD, 1974 - 2000) and a summary of the minutes of meetings of the National Frequency Management Board (2001)(PTD, 2001), the Ministerial Regulation of the Ministry of Transport No.24 (1993) (MOT, 1993), the Ministerial Regulation of the Ministry of Transport No.28 (1998) (MOT, 1998), the Ministerial Regulation of the Ministry of Transport No.30 (2001) (MOT, 2001), the Ministerial Regulation of the Ministry of Information and Communications Technology on the exemption of radiocommunication licences (2004)(MICT, 2004) , the National Telecommunications Commission Regulation of nature and categories of telecommunication business (2005) (NTC, 2005b), the National Telecommunications Commission Regulation of criteria and procedures for Internet service licence application (2005) (NTC, 2005a), the National Telecommunications Commission Regulation of exemption of radiocommunication licences (2007) (NTC, 2007b), the National Telecommunications Commission Regulation on the standard of telecommunication devices for radio local area network (RLAN) (2007) (NTC, 2007a), the National Telecommunications Commission Regulation on the standard of telecommunication devices (2008) (NTC, 2008a), and the National Telecommunications Commission Regulation on the standard of telecommunication devices – procedures and standards (2008) (NTC, 2008b).

The NFMB first attempted to delegate authority to the PTD to assign the use of frequency under one watt. The regulated level was transferred from the NFMB to the PTD. The decision-maker for frequency assignment under the power of one watt was therefore the PTD.

Using low-power devices in Thailand

The PTD authorized the use of low-power devices, depending on the technical characteristics, as a first priority to avoid harmful interference. Users had to obtain authorization from the PTD. The use of low-power devices still requires the relevant radiocommunication licences, however. The PTD realized the benefit to the general public and the initiation of the exemption of relevant radiocommunication licences pushed forward as the Ministerial Regulations. The exemption of licenses facilitated the use of low-power devices such as spectrum commons.

The stakeholders for low-power devices were the authority, users, and manufacturers or importers. The NTC also allowed the Internet service provider to use spectrum commons. The stakeholders were extended to the service provider as well.

In Thailand, there are two separate steps for unlicensed devices. Firstly, the devices must receive authorization under the Radio Act, according to the Table Frequency Allocation and related regulations in terms of technical specification or standard of devices. Secondly, when the use of these devices increases over time, the authority may consider exempting the related licences imposed on the use of these devices to reduce the burden for the general public by issuing a regulation to exempt the related licences in terms of the ministerial or NTC regulations. The authorization of the use of radiocommunication devices by command-and-control for frequency assignment and technical standard approval of devices was centralized by the authority.

Use of low-power devices before 1974

During the period when there was no regulation – without the Radio Act – there was no use of radiocommunication devices for the general public, only by government agencies. With the Radio Act enacted, all radiocommunication usage was prohibited, except for the authorization granted by the PTD since 1914. On March 26, 1974, the cabinet authorized the Ministry of Transport to set up the NFMB with the Ministry Order of 78/1974 on April 19, 1974, to double-check the work of the PTD. Thus, all the radiocommunication activities of the PTD had to ask the NFMB for approval. This was the centralized management style of the NFMB at the initial stage.

Use of low-power devices in 1975-1986

In 1975, the NFMB delegated some authority to the PTD at the first meeting in 1975 on January 8, 1975. The NFMB authorized the PTD to allow the private sector to install transmitters for paging services in the 26.92-27.23 MHz band in limited areas. The power of the transmitters could not exceed one watt. That was the starting point of decentralization in spectrum management and the initiation of allowing the general public to use low-power devices.

On January 22, 1975, at the second meeting in 1975, the NFMB authorized one company to make an anti-theft device with the frequency of 27.060 MHz and authorized the PTD to allow the use of anti-theft devices in cars and motorcycles for the general public.

At the first meeting in 1978 on January 25, 1978, the NFMB authorized the PTD to allow the private sector to use UHF transceivers in the 461.150-461.250 MHz band, with power of up to one watt. The UHF transceiver was the walkie-talkie application service.

On June 25, 1982, at the second meeting in 1982, the NFMB re-authorized the PTD to allow the use of radiocommunication devices with power of up to one watt for all applications and anti-theft devices in cars and motorcycles for any frequency.

At the third meeting in 1982 on July 8, 1982, the NFMB authorized the PTD to allow the use of the citizen band (26.96-27.23 MHz) for transceivers, cordless telephones, wireless microphones, wireless remote controls, such as model plane remote controls, anti-theft devices, garage-door openers, and radiocommunication devices in industrial science services that were not used for communication purposes such as microwave ovens.

The minutes of the NFMB's fourth meeting in 1982 on August 18, 1982, authorized the PTD to allow the installation of base stations for wireless telephones for one-to-one (one transmitter and one receiver) operation only. Wireless telephones used frequencies of 1.7/49, 27/49 MHz with power of up to 500 milliwatts for short-range communication (around 500 meters). Moreover, wireless telephones used frequencies of 27/49 MHz with power of up to five watts for long-range communication (around 10 kilometers).

Additional low-power devices introduced in 1986

On April 17, 1986, at the fifth meeting in 1986, the NFMB authorized the PTD to allow the use of radio warning devices with power of up to one watt and a 16 kHz bandwidth.

After the NFMB delegated authorization of all radiocommunication devices with power of up to one watt, the PTD allowed the use of transceivers in medical instruments with power of up to 10 milliwatts, and electronic and telecommunication measurement equipment.

Previous events concerned the authorization of the use of radiocommunication devices. Their use required related licences, however. The story of the exemption of licences was different because the power to waive licences belonged to the Ministry of Transport, which had to issue Ministerial Regulations according to the Radio Act of 1955 and its amendments.

Increased number of low-power devices after 1986

The PTD realized that the use of low-power devices had increased over time and wanted to facilitate the use of low-power devices for the general public. The PTD proposed that radiocommunication licences be exempt from Ministry of Transport Ministerial regulations. There were lengthy procedures from drafting to announcement, however. Firstly, the PTD drafted the Ministerial Regulations Then the draft of the Ministerial Regulations was sent to the Council of State in order to check the format and content and then sent back to the PTD for revision. Next the draft of the Ministerial Regulations, including revisions by the Council of State, was sent to the Ministry of Transport for consideration and signing. Then the final version of the Ministerial Regulations was sent to the *Royal Gazette* for formal publication. The process took almost two years.

Ministerial Regulations for radiocommunication license exemptions 1993-2004

Ministerial Regulation No. 24

Ministerial Regulation No. 24 – the first Ministerial Regulation for radiocommunication licence exemption – was published on March 12, 1993. It comprised five sections. Section 1 was an exemption on making, possessing, using, importing, exporting, and trading radiocommunication licences. Section 2 was an exemption on possessing, using, and exporting radiocommunication licences. Section 3 was an exemption on importing radiocommunication licences. Section 4 was an exemption on parts of radiocommunication devices when assembled with devices that already had a licence. Section 5 was an exemption on installing radiocommunication licences.

The unlicensed devices were in Section 1, which exempted all radiocommunication licences. They included: 1) wireless microphones with power of up to 10 milliwatts in the 33-50, 88-108, 165-210, and 470-490 MHz bands and with power of up to 30 milliwatts in the 902-960 MHz band; 2) wireless telephones with power of up to 10 milliwatts in the 1.6-1.8, 30-50, and 54-74 MHz bands; 3) radio-control models with power of up to 100 milliwatts in the 26.964-27.405 MHz band; 4) long-range radio control with power of up to 100 milliwatts in the 26.964-27.405 MHz band and with power of up to 10 milliwatts in the 300-500 MHz band; 5) transceivers of the citizen band with power of up to 100 milliwatts in the 26.964-27.405 MHz band, and warning devices with power of up to 10 milliwatts in the 300-500 MHz band; 6) transceivers in medical instruments with power of up to 10 milliwatts in the 300-500 MHz band; and 7) electronic and telecommunication measurement equipment.

Section 1 of Ministerial Regulation No. 24 exempted all radiocommunication with specified applications, power limitation, and operating frequency that were not flexible for use with the new applications.

On October 15, 1996, the PTD allowed the general public to use radiocommunication devices in the 2 400-2 500 MHz band with effected radiated power (E.R.P.) up to 100 milliwatts for indoor use only. These devices had to hold either licences for the possession, use or installation of radiocommunications. The devices had to be type-approved by the PTD.

Ministerial Regulation No. 28

On December 21, 1998, Ministerial Regulation No. 28 was published, as well as two additional items in Ministerial Regulation No. 24, one in Section 2 and one in Section 5. These allowed the use of cordless telephones for personal use with power of up to 10 milliwatts in the 1 900-1 906 MHz band and they could be used with digital enhanced cordless telecommunications (DECT) and personal handy-phone systems (PHS) technology, with a slight modification of frequency arrangements.

Ministerial Regulation No. 30

On January 17, 2001, Ministerial Regulation No. 30 was published and Section 3 of Ministerial Regulation No. 24 revised to allow cellular phone and radio paging that already had type approval from the PTD and international roaming agreements for device circulation.

After October 1, 2003, the PTD was transferred to the Ministry of Information Communications and Technology. On November 28, 2003, the PTD amended the regulation that allowed the general public to use radiocommunication devices in the 2 400-2 500 MHz band by deleting "for indoor use only." The limitation of power, the related radiocommunication licenses, and the type approval remained in place, however.

Change in Ministerial Regulation [2004]

There was a change in the format of the Ministerial Regulations that amended the substance of the regulation. Ministerial Regulations Nos. 24, 28, and 30 have been revised and called the Ministerial Regulations of the Exemption of Radiocommunication Licences, and were published on March 25, 2004.

The Ministerial Regulation on the Exemption of Radiocommunication Licences in 2004 consisted of ten sections. Section 1 revoked Ministerial Regulations Nos. 24, 25, 28, 29, and 30. Section 2 exempted the making, possession, use, import, export, and trade of radiocommunication licences. Section 3 exempted the possession, use, and export of radiocommunication licences. Section 4 exempted the possession, import, export, and trade of radiocommunication licences for cellular telephones, radio paging, and radiocommunication devices in global mobile personal communication by satellite (GMPCS), which had been type-approved by the PTD. Section 5 exempted the import and export of radiocommunication licences for cellular telephones, radio paging, and radiocommunication devices in GMPCS that had international roaming agreements. Section 6 exempted the possession and use of radiocommunication licences for transceivers of the citizen bands 78 and 245 MHz. These already had licences and they were transferred. Thus, the transferees did not require the possession and use of radiocommunication licences. This did not include the transfer of ownership of the radiocommunication device, however, which required a relevant licence. Section 7 exempted the possession and use of radiocommunication licences for transceivers of amateur radios that already had licences and been transferred. Thus, the transferees did not require the possession and use of radiocommunication licences. The operation of amateur radios required a separate amateur radio certificate, however, and it did not include transfer of ownership of the radiocommunication device, which had to be done legally with the relevant licence. Section 8 exempted the parts of the radiocommunication devices when assembled with other such devices. Section 9 and Section 10 exempted the installation of radiocommunication licences.

In the Ministerial Regulation of the Exemption of Radiocommunication Licences in 2004, Section 2 and Section 10 related to unlicensed devices. When comparing Ministerial Regulation No. 24 and the Ministerial Regulation of the Exemption of Radiocommunication Licences in 2004, there were several differences. Firstly, the Ministerial Regulation of 2004 added an exemption on installing radiocommunication licences from Ministerial Regulation No. 24 (the exemption of making, possessing, using, importing, exporting, and trading radiocommunication licences). Secondly, the Ministerial Regulation of 2004 added five items in Section 2. These were 8) the receiver in radio navigation services, radio navigation satellite services, radio location services and radio location satellite services, 9) the radar application in the 5.725-5.875, 10.0-10.6, 24.05-24.25, and 76-81 GHz bands with equivalent isotropically radiated power (E.I.R.P.) of up to 10 milliwatts, 10) devices in the band lower than 135 kHz with E.I.R.P. of up to 150 milliwatts, 11) devices in the 13.533-13.567 MHz band with E.I.R.P. of up to 5 milliwatts, and 12) devices in the 2 400-2 500 MHz band with E.I.R.P. of up to 100 milliwatts.

In the Ministerial Regulation of 2004, there was flexibility or neutrality of technology for radiocommunication devices in Section 2, Items 10, 11, and 12, which allowed all applications using the specified frequency band and the power limitation, including radio frequency identification (RFID), Tag, e-SEAL, Bluetooth, and Wi-Fi devices.

Establishing the National Telecommunications Commission and its regulations [2004-2007]

On October 1, 2004, the NTC was established and the PTD was dissolved by law to be transformed into the Office of the NTC from January 1, 2005.

The NTC regulation has the same rank as the Ministerial Regulations.[53] The procedure for publishing the regulation is much shorter than the previous procedure. The Office of the NTC drafts the new NTC regulation and prepares an agenda for NTC meetings in order to obtain approval from the NTC. After NTC approval, the Chairman of the NTC signs and sends it to the *Royal Gazette* for publication. The whole new procedure takes around six months.

On June 22, 2005, the NTC Regulations of Nature and Categories of Telecommunication Business (2005) and Criteria and Procedures for Internet Service Licence Applications (2005) were published to determine the nature and categories of telecommunication business, and provide clear and unambiguous criteria and conditions for Internet service licence applications, respectively. Wi-Fi service (public hotspots) falls into the "Type 1" Internet licence.

Adapting the Ministerial Regulation for exemptions by the NTC [2007]

On August 29, 2007, the NTC Regulation of the Exemption of Radiocommunication Licenses was published, adapting the Ministerial Regulation for the Exemption of Radiocommunication Licences in 2004 and indicating which radiocommunication licences were and were not exempt.

The NTC Regulation on the Exemption of Radiocommunication Licences in 2007 comprises eleven sections. Section 1 revokes all prior regulations against this regulation. Section 2 is similar to Section 2 and Section 10 of the Ministerial Regulation for the Exemption of

[53] The hierarchy of Thai law is Constitution, Act, Ministerial Regulations, Ministerial Announcements, Department Regulations, and Department Announcements. The NTC regulations have the same rank as Ministerial Regulations.

Radiocommunication Licences in 2004. The differences are: 1) the deletion of wireless microphones in the 902-960 MHz band, which is the same band as cellular phones (GSM 900 MHz); 2) the deletion of wireless telephones in the 54-74 MHz band, because the technology is obsolete; 3) open applications in the 26.965-27.405 MHz band with power of up to 100 milliwatts; 4) open applications in the 30-50 MHz band with power of up to 10 milliwatts; 5) open applications in the 300-500 MHz band with power of up to 10 milliwatts; 6) receivers in the meteorological aid service, meteorological satellite service, Earth exploration-satellite services, standard frequency and time signal services, standard frequency and time signal satellite services, space research services, radio astronomy services, and safety services. Section 3 has the exemption of possessing, using and exporting radiocommunication licences but still includes the production, import, and trading of radiocommunication licences. Sections 4, 5, 6, 7, 8, and 9 of the NTC Regulation on the Exemption of Radiocommunication Licences 2007 are the same as Sections 4, 5, 6, 7, 8, and 9 of the Ministerial Regulation for the Exemption of Radiocommunication Licences in 2004. Section 10 is the exemption of the import and export of radiocommunication licences for radiocommunication devices for experiments and research and is also used by United Nations specialists, the Red Cross, and foreign embassies. The use of these radiocommunication devices exempted the possession, use, and installation of radiocommunication licences for temporary use up to a period of three months. Section 11 is the enforcement date after publication in the *Royal Gazette*.

On January 26 and August 3, 2007, the NTC regulation of standard telecommunication devices for radio local area network (RLAN) allowed the use of RLAN in the 5 150-5 350 MHz band with E.I.R.P. of up to 200 milliwatts for indoor use only, and in the 5 470-5 725 and 5 725-5 850 MHz bands with E.I.R.P. of up to one watt.

On January 18, 2008, all short-range devices (according to the NTC regulation) were certified by suppliers according to the NTC Regulation of Standard of Telecommunication Devices (both procedure and standard). Suppliers must certify that the equipment has technical specifications according to the NTC Regulation, in the form of a Supplier’s Declaration of Conformity.

Since the establishment of the NBTC on October 7, 2011, there has been no new regulation for spectrum commons or additional unlicensed regulation. However, the NTC regulations are valid until they are replaced by the NBTC regulations.

To summarize this period, after the NFMB delegated power to the PTD, the development of short-range devices was gradually introduced. This proceeded from specific applications. Power limitation and specified frequency were still enforced, however, to avoid harmful interference in this limited area. The use of short-range devices was non-exclusive, i.e. no one had an exclusive right to use this frequency. The management of the use of short-range devices, or managerial right also started from self-regulation: users have to manage, with middleman management, service providers, or private commons, with the provider managing the use of commons, such as the Wi-Fi hotspot or public commons managed by the state agency.

Table 15 shows a summary of significant events for spectrum commons in Thailand.

Table 15. Spectrum commons events in Thailand

Time	Event
1955	The Radiocommunication Act enacted
1974	The National Frequency Management Board (NFMB) founded by ministry order
1975	The NFMB authorized the PTD to allow 1-watt transmitters (paging + anti-theft)
1978	The NFMB authorized the PTD to allow walkie-talkies
1982	The NFMB authorized the PTD to allow 1-watt transmitters for all applications, including Citizen Band (26.96-27.23 MHz) transceivers, cordless telephones, wireless microphones, wireless remote controls, such as model plane remote controls, anti-theft devices, garage doors
1986	The NFMB authorized the PTD to allow radio warning devices
1993	Ministerial Regulation No. 24 came into force – Ministry of Transport
1996	The PTD allowed WLAN on 2400-2500 MHz, indoor only
1998	Ministerial Regulation No. 28 came into force – Ministry of Transport
2001	Ministerial Regulation No. 30 came into force – Ministry of Transport
2003	The PTD allowed WLAN on 2400-2500 MHz, indoor and outdoor
2004	Ministerial Regulation of the Exemption of Radiocommunication Licences – Ministry of Information and Communications Technology
2005	Wi-Fi service provider – hotspot
2007	The NTC Regulation of the Exemption of Radiocommunication Licences RLAN 5150-5350/5470-5725/5725-5850 MHz allowed
2008	Supplier's Declaration of Conformity (SoD) for unlicensed devices

Source Ard-paru (2010),Table 19

In 1955, the Radiocommunication Act came into force and all radiocommunication equipment had to obtain permission before being used. In 1974, the NFMB was founded and began to act as the regulator for frequency assignment in Thailand. In 1975, the first initiative by the NFMB was to authorize 1-watt transmitters for paging services and anti-theft equipment, and walkie-talkies in 1978. In 1982, the NFMB allowed 1-watt transmitters for all applications, including Citizen band transceivers, cordless telephones, wireless microphones and wireless remote controls, and radio warning devices in 1986.

In 1993–2003, the authorization for spectrum commons in terms of low-power devices was changed to the Ministerial Regulation. In 1996, the PTD was first allowed using WLAN 2 400-2 500 MHz for indoor application only, extending to outdoor application in 2003.

The new era of unlicensed regulation in Thailand began in 2004 with the Ministerial Regulation of the Exemption of Radiocommunication Licences allowing low-power devices without relevant licences.

In 2005, the NTC allowed internet service providers to use WLAN, providing hotspots. In 2007 and 2008, the NTC added the RLAN in 5 GHz and supplier's declaration of conformity (SoD) for unlicensed devices.

In 2011, the NBTC established and allowed continuation of unlicensed regulation. There is no additional unlicensed regulation by the NBTC as of 2012.

6.4 Summary and discussion of the research question

This chapter responds to sub-research question 3: *What is spectrum assignment, especially spectrum commons, in Thailand, and how did it develop?*

This study illustrates the overall approach of spectrum assignment, which has three typical approaches: command-and-control, market-based, and spectrum commons. Spectrum assignment is managed by the national regulatory authority. Of the three typical approaches, only command-and-control and market-based provide exclusive rights to use frequency, but spectrum commons does not. However, the command-and-control approach is inefficient, i.e. lacking the flexibility of frequency use. The market-based and spectrum commons approaches are introduced to overcome such inefficiency. The market-based or spectrum auction in the UK in 2000 is an example of the largest auction where the winning bidder was not commercially viable and sold the spectrum at a later stage.

The spectrum can be treated as goods depending on the method of assignment. For command-and-control and market-based approaches, the spectrum has been treated as private goods that have exclusive rights to use frequency. The spectrum can be transferred or sold to others by regulator or market. On the other hand, spectrum commons can be treated as common-pool goods that have non-exclusive rights to use frequency. The general public own spectrum commons.

This study demonstrates the development of spectrum assignment in Thailand. Thailand has developed spectrum assignment from command-and-control to a market-based approach. Spectrum was initially for use by a limited group, only government agencies, and then extended to the general public. The development of spectrum assignment agencies in Thailand included the PTD, NFMB, MICT, NTC, ONTC, NBTC, and ONBTC in order to change authorization to a licensing scheme, or command-and-control to market-based economics.

The study also illustrates the development of spectrum commons in Thailand since the NFMB in terms of authorization of the use of 1-watt transmitters. The Ministerial Regulation allowed low-power devices with relevant licences. The PTD regulations allowed the use of WLAN indoor applications and extended this to outdoor applications. Finally, the Ministerial Regulation of the Exemption of Radiocommunication Licences as the first unlicensed regulation in Thailand in 2004 allowed low-power devices without relevant licences.

This chapter responds to sub-research question 3 “What is spectrum assignment, especially spectrum commons, in Thailand, and how did it develop?” on the development of spectrum assignment, and illustrates the development of spectrum commons in Thailand. This sub-research question provides useful information to understand the context of spectrum commons in Thailand and how it has developed. It helps to fulfill the main research issue of how to implement international regulation into national regulation for spectrum commons in Thailand.

Chapter 7 International to national regulations

This chapter demonstrates the transformation of international regulation in the form of the RR into national regulation in the form of NBTC regulation for spectrum commons in Thailand. Moreover, the challenges of allocation and assignment of spectrum commons are also included.

The RR is the international regulation of spectrum management for Member States as a guideline for managing the use of frequency without causing international harmful interference. The first phase of transforming the RR into national regulation, especially in Thailand, regards the adoption of spectrum commons regulation from the RR into the national TFA. The second phase is to have a national regulation that permits the use of radiocommunication devices for spectrum commons in Thailand.

7.1 From the RR to the Thai TFA

The spectrum commons regulations in RR2012 include a definition of ISM applications, frequency allocations in footnotes 5.138 and 5.150, and TFA.

ISM definition

The definition of ISM applications is found in RR No. 1.15 Terms and definition:

"1.15 *industrial, scientific and medical (ISM) applications* (of radio frequency energy)*:* Operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of *telecommunications*" (ITU, 2012, pp. RR1-2).

However, the Thai TFA does not explicitly include the definition of ISM. The Thai TFA only includes footnotes 5.138 and 5.150 in the TFA.

Footnotes 5.138 and 5.150

The RR footnotes 5.138 and 5.150 for ISM applications are found in RR No. 5.138 and 5.150:

"5.138 The following bands:

6 765-6 795 kHz	(centre frequency 6 780 kHz),
433.05-434.79 MHz	(centre frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. 5.280,
61-61.5 GHz	(centre frequency 61.25 GHz),
122-123 GHz	(centre frequency 122.5 GHz), and
244-246 GHz	(centre frequency 245 GHz)

are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations.

5.150 The following bands:

13 553-13 567 kHz	(centre frequency 13 560 kHz),
26 957-27 283 kHz	(centre frequency 27 120 kHz),
40.66-40.70 MHz	(centre frequency 40.68 MHz),
902-928 MHz	in Region 2 (center frequency 915 MHz),
2 400-2 500 MHz	(centre frequency 2 450 MHz),
5 725-5 875 MHz	(centre frequency 5 800 MHz), and
24-24.25 GHz	(centre frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference that may be caused by these applications. ISM equipment operating in these bands is subject to provisions No. 15.13" (ITU, 2012, pp. RR 5-24 and 29).

Thailand has also adopted these two footnotes into the Thai TFA, but it is translated into the Thai language (NBTC, 2012, pp. 142,146).

TFA frequency allocation for spectrum commons

The frequency allocations for spectrum commons in ISM applications are shown in footnotes 5.138 and 5.150 corresponding to the relevant frequency bands in the TFA. Tables 16, 18, and 20 show the relevant TFA containing footnotes 5.138 and 5.150.

Thailand has also adopted the frequency allocations for ISM applications and footnotes into the Thai TFA. Tables 17, 19, and 21 show the relevant Thai TFA containing footnotes 5.138 and 5.150.

Comparing frequency allocation for footnote 5.138 between the RR TFA in Table 16 and Thai TFA in Table 17, the frequency bands allocating footnote 5.138 are the same. However, the 432-438 MHz band is only allocated in Region 1. Thailand is in Region 3; therefore, the Thai TFA does not have this band for footnote 5.138. Moreover, Thailand does not have its own national footnote for the use of footnote 5.138.

When comparing frequency allocation for footnote 5.150 between the RR TFA in Table 18 and Thai TFA in Table 19, it is noted that the frequency bands allocating footnote 5.150 are not the same.

The 13 553-13 567 kHz band is contained in different bands between the RR and Thai TFA. The RR TFA is 13 550 – 13 570 kHz but the Thai TFA is 13 410 – 13 570 kHz. The starting frequency of this frequency band is different, however; they cover the 13 553-13 567 kHz band for footnote 5.150.

The 26 957-27 283 kHz band is contained in different bands between the RR and Thai TFA. The RR TFA is 26 350 – 27 500 kHz but the Thai TFA is 26 175 – 27 500 kHz. The starting frequency of this frequency band is different, however; they cover the 26 957-27 283 kHz band for footnote 5.150.

The 40.66-40.70 MHz band is contained in the same band both for the RR and Thai TFA. However, the 902-928 MHz band is only available in Region 2. Therefore, the Thai TFA does not have this band for footnote 5.150.

The 2 400-2 500 MHz band is contained in the same three bands both for the RR and Thai TFA, including 2 300-2 450, 2 450-2 483.5, and 2 483.5-2 500 MHz for footnote 5.150.

When comparing frequency allocation for footnote 5.150 between the RR TFA in Table 20 and Thai TFA in Table 21, it is noted that the frequency bands allocated to footnote 5.150 are the same.

The 5 725-5 875 MHz band is contained in the same three bands both for the RR and Thai TFA, including 5 725-5 830, 5 830-5 850, and 5 850-5 925 MHz for footnote 5.150.

The 24-24.25 GHz band is contained in the same two bands both for the RR and Thai TFA, including 24-24.05 and 24.05-24.25 GHz for footnote 5.150.

Spectrum commons of RR TFA in terms of ISM bands in footnotes 5.138 and 5.150 represent the IAD rules-in-use in the constitutional situation as the outcome of the international negotiations at the WRC. This RR TFA or rules-in-use in the constitutional situation directly influences the rules-in-use in the constitutional situation in Thailand in terms of the Thai TFA. Thailand adopts all frequency band allocations for footnotes 5.138 and 5.150 on ISM applications. The RR TFA for spectrum commons in terms of footnotes 5.138 and 5.150 represent one of the rules-in-use for Thailand. Moreover, Thailand also has its own rules-in-use in terms of the national regulation, such as the Radiocommunication Act and the NBTC Establishment Act.

The Radiocommunication Act does not permit the use of radiocommunication devices freely. The use of radiocommunication requires relevant licenses. In order to allow the use of ISM applications in Thailand, the national regulation has been implemented by the NBTC.

In the Thai TFA, Thailand has Thailand footnotes as national footnotes for the use of ISM band for footnote 5.150, i.e. T-unlicensed 1 and 2. The details of the Thailand footnotes will be described in the next section.

Table 16. RR TFA for 5.138

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">5 003-7 450 kHz</td></tr>
<tr><td>6 765-7 000</td><td colspan="2">FIXED
MOBILE except aeronautical mobile (R)
5.138</td></tr>
<tr><td colspan="3">410-460 MHz</td></tr>
<tr><td>432-438
AMATEUR
RADIOLOCATION
Earth exploration-satellite (active) 5.279A
5.138 5.271 5.272 5.276 5.277 5.280 5.281 5.282</td><td colspan="2">432-438
RADIOLOCATION
Amateur
Earth exploration-satellite (active) 5.279A
5.271 5.276 5.278 5.279 5.281 5.282</td></tr>
<tr><td colspan="3">55.78-66 GHz</td></tr>
<tr><td>59.3-64</td><td colspan="2">FIXED
INTER-SATELLITE
MOBILE 5.558
RADIOLOCATION 5.559
5.138</td></tr>
<tr><td colspan="3">119.98-151.5 GHz</td></tr>
<tr><td>119.98-122.25</td><td colspan="2">EARTH EXPLORATION-SATELLITE (passive)
INTER-SATELLITE 5.562C
SPACE RESEARCH (passive)
5.138 5.341</td></tr>
<tr><td>122.25-123</td><td colspan="2">FIXED
INTER-SATELLITE
MOBILE 5.558
Amateur
5.138</td></tr>
<tr><td colspan="3">200-248 GHz</td></tr>
<tr><td>241-248</td><td colspan="2">RADIO ASTRONOMY
RADIOLOCATION
Amateur
Amateur-satellite
5.138 5.149</td></tr>
</table>

Table 17. Thailand TFA for 5.138

Allocation to services		
Thailand		Thailand footnotes
5 003-7 450 kHz		
6 765-7 000	FIXED MOBILE except aeronautical mobile (R) 5.138	
55.78-66 GHz		
59.3-64	FIXED INTER-SATELLITE MOBILE 5.558 RADIOLOCATION 5.559 5.138	
100-123 GHz		
119.98-122.25	EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562C SPACE RESEARCH (passive) 5.138	
122.25-123	FIXED INTER-SATELLITE MOBILE 5.558 Amateur 5.138	
202-248 GHz		
241-248	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.138 5.149	

Table 18. RR TFA for 5.150

Allocation to services		
Region 1	**Region 2**	**Region 3**
13 360-18 030 kHz		
13 550-13 570	FIXED Mobile except aeronautical mobile (R) 5.150	
23 350-27 500 kHz		
26 350-27 500 FIXED MOBILE except aeronautical mobile 5.150	**26 420-27 500** FIXED MOBILE except aeronautical mobile 5.150	**26 350-27 500** FIXED MOBILE except aeronautical mobile 5.150
27.5-47 MHz		
40.02-40.98	FIXED MOBILE 5.150	
890-1 300 MHz		
	902-928 FIXED Amateur Mobile except aeronautical mobile 5.325A Radiolocation 5.150 5.325 5.326	
2 170-2 520 MHz		
2 300-2 450 FIXED MOBILE 5.384A Amateur Radiolocation 5.150 5.282 5.395	**2 300-2 450** FIXED MOBILE 5.384A RADIOLOCATION Amateur 5.150 5.282 5.393 5.394 5.396	
2 450-2 483.5 FIXED MOBILE Radiolocation 5.150 5.397	**2 450-2 483.5** FIXED MOBILE RADIOLOCATION 5.150	
2 483.5-2 500 FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIODETERMINATION-SATELLITE (space-to-Earth) 5.398 Radiolocation 5.398A 5.150 5.399 5.401 5.402	**2 483.5-2 500** FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIOLOCATION RADIODETERMINATION-SATELLITE (space-to-Earth) 5.398 5.150 5.402	**2 483.5-2 500** FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIOLOCATION RADIODETERMINATION-SATELLITE (space-to-Earth) 5.398 5.150 5.401 5.402

Table 19. Thailand TFA for 5.150

Allocation to services		
Thailand		**Thailand footnotes**
13 360-18 030 kHz		
13 410-13 570	FIXED Mobile except aeronautical mobile (R) 5.150	T-unlicensed1
23 350-40 020 kHz		
26 175-27 500	FIXED MOBILE except aeronautical mobile 5.150	T-unlicensed1 T-unlicensed2 T-PPDR
40.02-75.2 MHz		
40.02-40.98	FIXED MOBILE 5.150	T-unlicensed1 T-JTC2
2 170-2 520 MHz		
2 300-2 450	FIXED MOBILE 5.384A RADIOLOCATION Amateur 5.150 5.282 5.396	T-unlicensed1 T-BWA T-JTC2
2 450-2 483.5	FIXED MOBILE RADIOLOCATION 5.150	T-unlicensed1 T-JTC2
2 483.5-2 500	FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A RADIOLOCATION Radiodetermination-satellite (space-to-Earth) 5.398 5.150 5.402	T-unlicensed1

Table 20. RR TFA for 5.150

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">5 570-7 250 MHz</td></tr>
<tr><td>5 725-5 830
FIXED-SATELLITE
(Earth-to-space)
RADIOLOCATION
Amateur
5.150 5.451 5.453 5.455 5.456</td><td colspan="2">5 725-5 830
RADIOLOCATION
Amateur
5.150 5.453 5.455</td></tr>
<tr><td>5 830-5 850
FIXED-SATELLITE
(Earth-to-space)
RADIOLOCATION
Amateur
Amateur-satellite (space-to-Earth)
5.150 5.451 5.453 5.455 5.456</td><td colspan="2">5 830-5 850
RADIOLOCATION
Amateur
Amateur-satellite (space-to-Earth)
5.150 5.453 5.455</td></tr>
<tr><td>5 850-5 925
FIXED
FIXED-SATELLITE
(Earth-to-space)
MOBILE
5.150</td><td>5 850-5 925
FIXED
FIXED-SATELLITE
(Earth-to-space)
MOBILE
Amateur
Radiolocation
5.150</td><td>5 850-5 925
FIXED
FIXED-SATELLITE
(Earth-to-space)
MOBILE
Radiolocation
5.150</td></tr>
<tr><td colspan="3">22-24.75 GHz</td></tr>
<tr><td>24-24.05</td><td colspan="2">AMATEUR
AMATEUR-SATELLITE
5.150</td></tr>
<tr><td>24.05-24.25</td><td colspan="2">RADIOLOCATION
Amateur
Earth exploration-satellite (active)
5.150</td></tr>
</table>

Table 21. Thailand TFA for 5.150

Allocation to services		
Thailand		**Thailand footnotes**
5 570-7 250 MHz		
5 725-5 830	FIXED 5.453 MOBILE 5.453 RADIOLOCATION Amateur 5.150	T-unlicensed1
5 830-5 850	FIXED 5.453 MOBILE 5.453 RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150	T-unlicensed1
5 850-5 925	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Radiolocation 5.150	T-unlicensed1
22-24.75 GHz		
24-24.05	AMATEUR AMATEUR-SATELLITE 5.150	
24.05-24.25	RADIOLOCATION Amateur Earth exploration-satellite (active) 5.150	T-unlicensed1

7.2 Spectrum commons in NBTC regulations

Thailand has a long history of the spectrum commons development that is illustrated in Chapter 6. The explicit transformation of the RR to Thai TFA was first shown in Thai TFA in 1999.

Before 1999, the transformation was implicit in terms of preparation of national regulation by the PTD official. The PTD official checked the relevant provision of the RR, frequency band, and technical characteristics before processing the application for radiocommunication equipment approval.

The Radiocommunication Act B.E. 2498 (1955) and its amendments prohibit the use of all radiocommunication equipment, unless permission for use is obtained from the authority. In 1955, the authority was the PTD, however, the use of spectrum commons was initiated by the NFMB in 1975. The NFMB authorized the PTD to allow 1-watt transmitters for pagers and anti-theft devices. This was the first time that low-power devices were allowed as spectrum commons in Thailand, however, users of such devices had to have the relevant radiocommunication licences.

The development of spectrum commons in Thailand comprises two categories: technical characteristics and radiocommunication licences. The technical characteristics have included both heavy- and light-handed development. These characteristics still remain in the current regulation.

The heavy-handed technical characteristics are a specified frequency, maximum power, technology, and applications such as the RFID transponder in the 900 MHz band. The light-handed technical characteristics are a specified frequency and maximum power such as the use of 2 400-2 500 MHz with 100 miliwatts e.i.r.p. for all technologies and applications, such as Wi-Fi, Bluetooth, cordless earphones, and cordless printers. The technical characteristics in between heavy- and light-handed are a specified frequency, maximum power, and applications such as cordless telephones in the 54-74 MHz band and wireless microphones in the 88-108 MHz band.

Radiocommunication licences are tools for an authority to control the use of radiocommunication, not only radiocommunication licences for spectrum commons, but also radiocommunication licences for command-and-control and market-based assignment approaches, apart from the broadcasting and telecommunications business licences.

The radiocommunication licences for spectrum commons are mostly for low-power devices. The development of radiocommunication licences ranges from imposing to exempting all licences. The radiocommunication licences cover the licence to make, possess, use, import, export, trade, and install a radiocommunication station, radio operator's licence, and a licence to receive news from abroad.

The current regulation can be categorized into three categories: unlicensed 1, 2, and 3.

Unlicensed 1: the use of spectrum commons with licence exemption is shown in Table 22.

Table 22. Thailand footnote T-Unlicensed 1

Frequency Band	Maximum Output Power	Applications	Related NTC Notification(s)
<135 kHz	150 mW e.i.r.p.	Radio equipment	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 1010-2550
1.6-1.8 MHz	10 mW	Cordless telephones	NTC Notification dated Aug. 29, 2007
13.553-13.567 MHz	10 mW e.i.r.p.	Radio equipment	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 1010-2550
26.965-27.405 MHz	100 mW	Radio equipment	NTC Notification dated Aug. 29, 2007
30-50 MHz	10 mW	Radio equipment	NTC Notification dated Aug 29, 2007
54-74 MHz	10 mW	Cordless telephones	NTC Notification dated Aug. 29, 2007
88-108 MHz	10 mW	Wireless microphones	NTC Notification dated Aug. 29, 2007
165-210 MHz	10 mW	Wireless microphones	NTC Notification dated Aug. 29, 2007
300-500 MHz	10 mW	Radio equipment	NTC TS 1010-2550
920-925 MHz	4 W e.i.r.p.	RFID (Transponder/Tag)	1. NTC Notification dated Jan. 24, 2006 2. NTC TS 1010-2550
2 400-2 500 MHz	100 mW e.i.r.p.	Radio equipment	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 1010-2550 3. NTC TS 1012-2551
5.150-5.350 GHz	0.2 W e.i.r.p.	SRD	1. NTC BP 101-2550 2. NTC TS 1010-2550 3. NTC TS 1012-2551
5.470-5.725 GHz	1 W e.i.r.p.	SRD	1. NTC BP 101-2550 2. NTC TS 1010-2550 3. NTC TS 1012-2551
5.725-5.850 GHz	1 W e.i.r.p.	SRD	1. NTC BP 101-2550 2. NTC TS 1010-2550 3. NTC TS 1012-2551
5.725-5.875 GHz	10 mW e.i.r.p.	Radar	NTC Notification dated Aug. 29, 2007
10-10.6 GHz	10 mW e.i.r.p.	Radar	NTC Notification dated Aug. 29, 2007
24.05-24.25 GHz	10 mW e.i.r.p.	Radar	NTC Notification dated Aug. 29, 2007
76-81 GHz	10 mW e.i.r.p.	Radar	NTC Notification dated Aug. 29, 2007

Source: Thailand Table of Frequency Allocation, T-Unlicensed 1, (NBTC, 2012, pp. 241-242)

Unlicensed 2: the use of spectrum commons exempted from applying for 1) licence to possess, 2) licence to use, and 3) licence to export radio equipment is shown in Table 23.

Table 23. Thailand footnote T-Unlicensed 2

Frequency Band	Maximum Output Power	Applications	Related NTC Notification(s)
26.965-27.405 MHz	>100 mW < 500 mW	Radio equipment	NTC Notification dated Aug. 29, 2007
72-72.745 MHz	750 mW	Model control	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 007-2548
78-79 MHz	500 mW	Citizen band	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 002-2548
245-246 MHz	500 mW	Citizen band	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 002-2548
510-790 MHz	10 mW	Wireless audio/video transmitters	NTC Notification dated Aug. 29, 2007
794-806 MHz	50 mW	Wireless microphones	1. NTC Notification dated Aug. 29, 2007 2. NTC TS 006-2548

Source: Thailand Table of Frequency Allocation, T-Unlicensed 2,(NBTC, 2012, p. 242)

Unlicensed 3: the use of spectrum commons exempted from applying for 1) licence to possess 2) licence to use 3) licence to export radio equipment and 4) licence to install a radio station is shown in Table 24.

Table 24. Thailand footnote T-Unlicensed 3

Frequency Band	Maximum Output Power	Applications	Related NTC Notification(s)
925-920 MHz	0.5 W e.i.r.p.	RFID (Interrogator/ Reader)	1. NTC Notification dated Jan. 24, 2006 2. NTC TS 1010-2550
1900-1906 MHz	10 mW	Cordless telephone systems (private applications)	NTC Notification dated Aug. 29, 2007
76-77 GHz	10 W e.i.r.p.	Vehicle radar	1. NTC Notification dated Aug. 30, 2006 2. NTC TS 1011-2549

Source: Thailand Table of Frequency Allocation, T-Unlicensed 3,(NBTC, 2012, p. 243)

Tables 22 – 24 provide several national regulations for spectrum commons:

1. NTC Notification dated Jan. 24, 2006,
2. NTC Notification dated Aug. 30, 2006,
3. NTC Notification dated Aug. 30, 2007,
4. NTC TS 002-2548,
5. NTC TS 006-2548,

6. NTC TS 007-2548,
7. NTC TS 1011-2549,
8. NTC TS 1010-2550,
9. NTC BP 101-2550, and
10. NTC TS 1012-2551.

These national regulations provide for the use of spectrum commons, including specified frequency, maximum power, and relevant technical specification.

Tables 22-24 show the spectrum commons regulation in Thailand, including in the Thai TFA as T-Unlicensed 1, 2, and 3. The frequency bands in Table 24 are not in footnotes 5.138 and 5.150. Moreover, there are frequency bands in Table 22 and 23 that are not in footnotes 5.150, i.e. the frequency band lower than 135 kHz, 1.6-1.8 MHz, 30-50 MHz, 54-74 MHz, 88-108 MHz, 165-210 MHz, 300-500 MHz, 920-925 MHz, 5.150-5.350 GHz, 5.470-5.725 GHz, 10-10.6 GHz, 76-81 GHz, 72-72.745 MHz, 78-79 MHz, 245-246 MHz, 510-790 MHz, 794-806 MHz, 925-920 MHz, 1 900-1 906 MHz, and 76-77 GHz.

The fact that the national authority uses the RR as its guideline and implements its own regulation within its territory reflects the independence of the national regulation. Thailand has a disadvantage with regard to globally transportable devices in using local frequency as these frequencies are only used in Thailand. The devices must be tailor-made for the Thai market. When these frequencies cause harmful interference to neighboring countries, Thailand does not have the international right to claim protection because these frequencies are allocated outside the RR. However, there are also certain advantages in responding to national needs.

Tables 22-24 summarize the list of frequency bands with maximum power and application that can be used in Thailand. The column “Application” includes the technology and application for the use of radiocommunication devices such as cordless telephones, wireless microphones, RFID, SRD, Radar, model control, citizen band, and wireless audio/video transmitters. The radio equipment in this column represents all technologies and applications that can be used in these frequency bands with a specified maximum power. The last column shows the relevant national regulations.

The use of frequencies listed in Tables 22-24 as spectrum commons does not require the payment of the frequency usage fee and no one has the exclusive right to use these frequencies.

The transformation for spectrum commons in footnotes 5.138 and 5.150 from the RR TFA to the Thai TFA are mentioned in the previous section. This transformation has been done in the constitutional situation from international to national regulation. The RR TFA representing the rules-in-use influences the Thai TFA as the national regulation. The Thai TFA adopted the spectrum commons in footnotes 5.138 and 5.150 by establishing this in the Thai TFA. The transformation from the RR TFA to Thai TFA is complete.

However, the use of spectrum commons in Thailand must correspond to national regulation, i.e. the Radiocommunication Act B.E. 2498 (1955). The use of radiocommunication devices is prohibited unless authorization is given by the authority. The Radiocommunication Act represents the rules-in-use for national regulation in the constitutional situation.

The use of spectrum commons in Thailand was granted by the authority in terms of the Ministerial Regulation, NTC, or NBTC regulation allowing the use of radiocommunication devices with specified frequency bands and specifying the maximum power, technology, and application. These regulations have been decided by the national regulatory authority in the constitutional situation to provide the rules-in-use for the collective-choice situation so that operators, manufacturers, or innovators implement these rules in terms of the network rules for building radiocommunication devices according to the rules specified by the authority.

In the collective-choice situation, manufacturers or innovators create and produce any radiocommunication devices according to given specifications under national regulation. However, Thailand is not where the manufacturing is based, and most of the radiocommunication devices are imported. The importer must be aware of the specifications of national regulation that only permit the import of radiocommunication devices that meet the specifications stated by the national regulation.

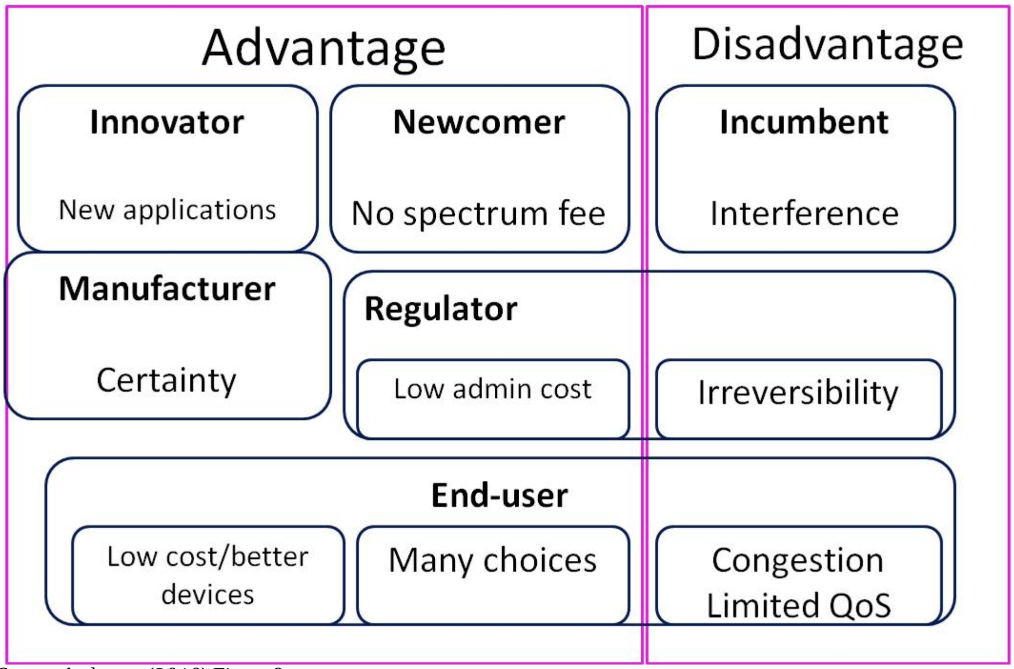
In the operational situation, users buy or select radiocommunication devices and use the devices according to the standard specified by the manufacturer at the collective-choice level. In Thailand, the users might need extra radiocommunication licences, however, as set out in Table 23 and 24.

Most of the spectrum commons regulations in Thailand adopt a bottom-up approach. Importers or users make a request of the authority to use new radiocommunication devices. The official in charge refers to the existing regulation in considering whether the new devices can be allowed to be used in Thailand. If the new devices are not allowed by the current regulation, the official must check whether the requested frequency is in line with the RR or Thai TFA as well as technical specifications and possible radiocommunication licences if necessary.

For example, if the requested frequency is used in other regions or countries but not in Thailand, the official must check whether existing users are on such a frequency and must refer to other countries' regulations in order to consider the possible use of such a frequency with the specified technical characteristics in Thailand. Once the requested frequencies and technical characteristics have been checked, regulatory approval according to the national regulatory process will be conducted. This process takes less time than the Ministerial Regulation process. Finally, the new national regulation will allow the use of new radiocommunication devices on the Thai market. The process time for new regulation always lags behind the rapid changes in technology for radiocommunication devices. The national regulatory authority has to deal with this challenge.

7.3 Allocation and assignment challenges

This study uses the advantages and disadvantages of spectrum commons from Ard-paru (2010). The challenges of spectrum commons are set out in Figure 9.



Source Ard-paru (2010),Figure 9

Figure 9. Stakeholders of spectrum commons

Figure 9 shows the advantages and disadvantages of spectrum commons with the relevant stakeholders.

There are three disadvantages of spectrum commons: harmful interference with existing service (incumbent), irreversibility once the frequency is given for spectrum commons (regulator), and congestion and limited quality of service when sharing with licensed application (end-user). The harmful interference, congestion and limited quality of service can be reduced by the advancement of technology such as the cognitive radio system. However, the irreversibility of spectrum commons is hard to eliminate because when the regulator gives such a frequency band for spectrum commons and it has been used widely by the public it is difficult to return such a frequency for spectrum refarming for new allocation or assignment. Moreover, it would not be worth it to get the spectrum back by collecting all the relevant radiocommunication devices as the cost of recollecting might be higher than the value of the frequency, for example, the 2 400-2 500 MHz frequency for Wi-Fi. Reducing irreversibility will be a challenge for both the allocation and assignment of spectrum commons by the regulator.

Figure 9 also shows the advantages of spectrum commons, including the low administrative cost for the regulator, no frequency usage fee for new-comers compared to spectrum auctions, new applications for innovators for all technologies and applications, global allocation and assignment for spectrum commons which creates certainty for manufacturers producing the devices, and a range of choices, low cost and better devices for end-users to buy. The challenges are to maintain the advantages of spectrum commons in a sustainable way.

Table 25 shows the relevant advantages and disadvantages of spectrum commons allocation and assignment.

Table 25. Spectrum commons allocation and assignment challenges

Allocation		
Irreversibility	Regulator	Disadvantage
Long process at the WRC	Regulator	Disadvantage
New application	Innovator	Advantage
Certainty	Manufacturer	Advantage
Assignment		
Irreversibility	Regulator	Disadvantage
Loss of revenue	Regulator	Disadvantage
Long process for national regulation	Regulator	Disadvantage
Low administrative cost	Regulator	Advantage
Interference	Incumbent	Disadvantage
No spectrum fee	Newcomer	Advantage
Many choices	End-user	Advantage
Low cost and better devices	End-user	Advantage
Congestion, limited QoS	End-user	Disadvantage

The challenges of spectrum commons allocation includes the irreversibility once it is allocated and the long allocation process at the WRC for the regulator and administrator, the creation of new applications by innovators, and creating certainty for manufacturers to produce the devices.

The long process for spectrum commons allocation has been illustrated in Ard-paru (2012), Chapter 7. It can take up to eight years for preparation and four years for study prior to a new allocation. The correct submission of agenda items must be prepared and submitted to the WRC, which then finalizes the next WRC agenda item. Moreover, active participation and contribution submission in the relevant ITU SG and WRC meetings are necessary to ensure that the preferred outcome is included in the Final Act or the RR at a later stage.

The challenges of spectrum commons assignment include spectrum irreversibility, loss of revenue in the event of frequency usage fee, a long process for the adoption of new national regulation, and a low administrative cost for the regulator, harmful interference with existing services for incumbents, no burden for newcomers to pay for a spectrum auction, diversity of choice, low cost, better devices, congestion and limited service quality while sharing license applications for end-users.

The challenges for spectrum commons assignment for the regulator are loss of revenue and a timely process for new regulation. There is a trade-off between the loss of a frequency usage fee and the benefit to society from using spectrum commons. It is difficult to measure both the direct and indirect value of spectrum commons.

The long process involved in adopting new regulation can be managed by keeping constraints, such as only specified frequency bands and maximum power, to a minimum to ensure that rapid technological change is sufficient, and does not specify applications and technology.

7.4 Summary and discussion of research question

This chapter responds to sub-research question 4: *How should spectrum commons regulation be transformed from the RR into the national NBTC regulation? What are the challenges?*

This study explores the current RR2012 and the Thailand Table of Frequency Allocations 2012 for ISM definition, footnotes 5.138 and 5.150, and the TFA. Moreover, the study demonstrates the transformation from international into national regulations:

There are two phases. Firstly, the footnotes 5.138 and 5.150 are adopted in the Thai TFA including ISM definition, footnotes, and frequency bands. However, the definition of ISM applications is not explicitly shown in the Thai TFA. Both footnotes 5.138 and 5.150 are adopted corresponding to frequency bands in Region 3 within the Thai TFA.

The RR TFA represents the IAD rules-in-use in the constitutional situation that influences the Thai TFA as rules-in-use in national regulation in the constitutional situation in Thailand. In addition to the RR TFA influencing the use of spectrum commons in Thailand, national regulation, i.e. the Radiocommunication Act B.E. 2498 (1955), also represents the rules-in-use in the constitutional situation in Thailand. The Radiocommunication Act prohibits the use of radiocommunication devices unless permission is granted by the authority.

Secondly, the development of national regulation allows the use of spectrum commons with regard to lower-power radiocommunication. In 1975, the first spectrum commons was granted by the NFMB to the PTD allowing 1-watt transmitters for pagers and anti-theft devices. However, the use of these devices required relevant radiocommunication licences. Several additional national regulations have been developed over time to allow more frequency bands for spectrum commons with a maximum power and technical specification. Ten current relevant NBTC regulations are shown in the previous section and categorized by Thailand footnotes: T-Unlicensed 1, 2, and 3 in Table 22-24 with relevant radiocommunication licences. In addition to the frequency bands specified by footnotes 5.138 and 5.150, additional frequency bands are allowed for use as spectrum commons in Thailand, including frequency bands lower than 135 kHz, 1.6-1.8 MHz, 30-50 MHz, 54-74 MHz, 88-108 MHz, 165-210 MHz, 300-500 MHz, 920-925 MHz, 5.150-5.350 GHz, 5.470-5.725 GHz, 10-10.6 GHz, 76-81 GHz, 72-72.745 MHz, 78-79 MHz, 245-246 MHz, 510-790 MHz, 794-806 MHz, 925-920 MHz, 1 900-1 906 MHz, and 76-77 GHz.

The challenges of transforming international regulation into national regulation for both allocation and assignment are reflected by the advantages and disadvantages of spectrum commons. The challenges for the advantages are to maintain these in a sustainable way. The challenges for the disadvantages are to reduce these as much as possible.

Allocation challenges: the challenges for the regulator are the irreversibility once a frequency has been allocated for spectrum commons (it is hard to return such a frequency for new allocation or assignment), and the long process for new allocation for spectrum commons at the WRC. For innovators, there is an opportunity to create new applications. For manufacturers, there is a certainty of mass production for global allocation.

Assignment challenges: the challenges for the regulator are the irreversibility of such frequency when assigning to spectrum commons and it is used widely (it is costly to recall such radiocommunication devices to refarm the frequency for new assignment), the loss of a frequency usage fee compared with the social benefit of spectrum commons, the long process of adopting national regulation, and the low administrative cost for spectrum commons. For an incumbent, there is harmful interference with its existing users or services. For new-comers, there is no spectrum fee to use spectrum commons. For end-users, there is a wide range of choices, low cost, and better devices to use on the market. However, harmful interference, congestion and limiting of service quality are manageable through the advancement of technology such as the cognitive radio system.

This chapter responds to sub-research question 4: How should spectrum commons regulations be transformed from the RR into the national NBTC regulation? What are the challenges? This study illustrates the transformation of international regulation into national regulation for spectrum commons in Thailand and demonstrates the challenges of the allocation and assignment of spectrum commons in terms of the advantages and disadvantages of spectrum commons for stakeholders. This sub-research question refers to the transformation of spectrum commons in the RR TFA to Thai TFA and the adoption of national regulation for the use of spectrum commons according to the Radiocommunication Act. This helps to answer the main research question of how to implement international regulation in national regulation for spectrum commons in Thailand.

Chapter 8 Relevance of IAD framework to spectrum management

This chapter discusses the IAD framework, especially the level of analysis outcomes for spectrum management activities in understanding the relevance of the IAD framework to spectrum management. This chapter combines spectrum assignment and allocation for spectrum commons in Thailand from Ard-paru (2010) and (2012) with regard to the activities of spectrum management and the IAD framework.

8.1 IAD framework level of analysis and outcomes

The IAD level of analysis and outcomes was presented in Chapter 2, describing the relationship and interaction between levels of analysis: operational, collective-choice, constitutional, and metaconstitutional. This study uses only three levels of analysis, i.e. operational, collective-choice, and constitutional to describe spectrum management activities.

Table 26 shows the activities at each level of analysis.

Table 26. Spectrum commons allocation and assignment challenges

Level of analysis and outcomes	Activities-action situation
Operational situations	Provision, production, distribution, appropriation, assignment, consumption
Collective-choice situations	Prescribing, invoking, monitoring, applying, enforcing
Constitutional situations	Prescribing, invoking, monitoring, applying, enforcing
Metaconstitutional situations	Prescribing, invoking, monitoring, applying, enforcing

Source Ostrom (2007, p. 45), Figure 2.2

In operational situations, day-to-day activities are conducted including provision, production, distribution, appropriation, assignment and consumption. For example, the use of radiocommunication devices by end-users is included in this level because the devices access and use the frequency.

In collective-choice situations, activities relate to managing and revising the rules for operational situations. For example, the rules on how to use devices, technical characteristics of devices, rules on who can use the frequency, and the ability to lease or sell the frequency are defined at this level.

In constitutional situations, activities include reviewing and revising the rules on the collective-choice situation, such as the revision of the Thailand Frequency Management Master Plan, the Table of Frequency Allocation, and the NBTC regulations.

The IAD framework suggests similar activities in both collective-choice and constitutional situations, including prescribing, invoking, monitoring, applying, and enforcing.

The same person can act differently at each level of analysis depending on the activities they perform or the action situations for which they are responsible.

8.2 Spectrum management activities

The handbook, National Spectrum Management, has been developed by ITU Study Group 1: spectrum management, based on contributions from ITU Member States and Sector Members and discussion at the meetings. There are two editions: 1995 and 2005. The current edition is from 2005. Although this handbook is not mandatory for Member States to implement, it describes the key elements of spectrum management, including spectrum management fundamentals, spectrum planning, frequency assignment and licensing, spectrum monitoring, spectrum inspection and investigation, spectrum engineering, spectrum economics, automation of spectrum management activities and measures of spectrum utilization and spectrum utilization efficiency.

The author has selected these spectrum management activities from the handbook because the activities described in the handbook reflect the practical activities of spectrum management in Thailand. The author has direct experience of how the Thai regulator has managed frequency since 1997 from the PTD, NTC, and NBTC. The key elements of spectrum management remain important, but the priority between activities varies over time. For example, at the PTD, spectrum management financing took responsibility for radiocommunication licences and frequency usage fee. After the NTC was established, this task was extended to business licenses and spectrum auction fees such as reserved price. At the PTD, national liaison and consultation was minimal due to budget constraints and the lack of requirements by law. After the NTC, public consultation became mandatory for new regulation.

Therefore, the author follows spectrum management activities from the ITU handbook, and follows national spectrum management according to experience of spectrum management in Thailand.

The handbook, National Spectrum Management (2005) (ITU, 2005), also provides activities such as functional responsibilities and requirements of spectrum management, as follows;[54]

a) Spectrum management planning and regulations;

b) Allocation and allotment of frequency bands;

c) Frequency assignment and licensing (including non-licensing allocations);

d) Spectrum management financing, including fees;

e) Standard, specifications, and equipment authorization;

f) Spectrum monitoring;

g) Spectrum regulation enforcement: inspections and investigations;

h) International and regional cooperation including frequency coordination and notification;

[54] This study uses text from Chapter 2, Ard-paru (2010)

i) National liaison and consultation; and

j) Spectrum management support functions including administrative and legal, computer automation, spectrum engineering, and training.

Spectrum management planning and regulations

The spectrum management organization should take account of the advancement of technology as well as the social, economic, and political realties when developing implementation plans, regulation, and policies. The Table of Frequency Allocation is the output of planning and policy-making efforts, reflecting the various radio services or uses. In the event of competing uses or interests, the spectrum management organization should determine the use or uses that would best serve public and government interests and how the spectrum should be shared.

In order to allocate frequency, the following factors should be taken into account: public and government needs, technical considerations, and apparatus limitations. Public and government needs and benefit considerations are a requirement of the service for radio frequencies, as are considerations regarding the probable number of people who will benefit from the service, the relative social and economic importance of the service, the probability of establishment of the service, the degree of public support expected for the service, the impact of the new applications on existing investment in the proposed frequency band, and government requirements for security, aeronautical, maritime, and science services. Technical considerations comprise the need for the service to use the frequency with particular propagation characteristics and compatibility within and outside the selected frequency band, the amount of frequency required, the signal strength required for reliable service, the amount of interference that is likely to be encountered, and the viability of the technology. Apparatus limitations comprise the upper useful or higher limit of radio frequency, operating characteristics of transmitters, types of antenna availability and practical limitations, receiver availability, and characteristics.

Allocation and allotment of frequency bands

The national allocation table should represent the current national frequency assignment as well as the national plan for future use. The national allocation table provides details of current national uses, including all data on terrestrial and space services and their applications. Each country uses the ITU allocation table as guidance for the region allocation to which the particular country belongs. It is not necessary for every country to follow exactly the ITU table, which deviates to a limited degree to satisfy national requirements, as long as this does not cause harmful interference and protection is not required. Reasons for following the ITU table include availability of equipment in the region according to the agreement of the allocation table, minimized interference from neighboring countries, conformity of equipment in the regional table, and global service such as aeronautical, maritime, and satellite service.

Normally, existing spectrum users oppose changes to frequency allocation tables because of the many costs incurred, including equipment costs, learning costs, and loss of customers. In order to develop national table frequency allocation, the spectrum management organization should follow the ITU Table of Allocation as closely as possible, develop the plan based on current use, not impede the advancement of future technology, allow efficient allocation for government and security, and align with other countries' allocation.

Frequency assignment and licensing (including non-licensing allocations)

Frequency assignment is routine work for spectrum management organizations. Analyses select the most suitable frequencies for radiocommunication systems and coordinate proposed assignments with existing ones.

The frequency assignment function includes the licensing function, national legislation, and regulations and related procedures to control the operation of stations by: 1) examining licence applications and related documents to determine the licensing eligibility of the application and the technical acceptability of the radio equipment proposed; 2) assigning the radio call signs to individual stations; 3) issuing licences and collecting fees, if appropriate; 4) establishing methods for administering system or network licences, as appropriate; 5) renewing, suspending, and canceling licences, as appropriate; and 6) conducting examinations of operators.

The related procedures should specify information to be supplied with frequency applications to allow spectrum managers to perform better. Unnecessary or difficult procedures may discourage radiocommunication development.

Spectrum management financing

Spectrum is a natural resource that is a valuable national asset and typically controlled by government. The primary objective of the spectrum management fee policy should be to: 1) improve the telecommunication infrastructure through the efficient and effective use of radio spectrum; 2) support spectrum management infrastructure via administrative fees for all users; 3) encourage spectrum efficiency by providing appropriate incentives, assessing the fees according to the amount of bandwidth usage and the number of transmitters in the network; 4) reflect economic principles and radio standards required in the RR and ITU-R Recommendations; and 5) release inefficient and ineffective use of spectrum.

Licence fees include application fees, construction permit fees (installation fee), spectrum usage or regulatory fees, operator certificate fees, and administrative fees.

Standard, specifications, and equipment authorization

In general, the spectrum management organization should follow the technical characteristics of the station in Article 3 of the RR, the maximum value for frequency tolerance and spurious domain emission, and other technical standards in Appendices 2 and 3 of the RR in order to avoid interference. Thus, administrators ensure that all the equipment characteristics within their territory conform to these regulations.

There are two main functions of the standard: standard setting and standard compliance. The standard setting can be national or international, depending on interests. Standard compliance spectrum management organization, however, can be by the administration itself or another party and comprises the compliance testing requirement and other administrative procedures related to compliance.

Administrative procedures, such as national acceptance of equipment test results from other administrations, self-certification, or private sector testing laboratories, help to reduce paperwork and cost, but spectrum management organization ensures that radiocommunication equipment meets standard requirements.

As for self-certification, the spectrum management organization should have its own test laboratory to perform spot checks, including transmitting and receiving equipment, laboratory testing according to type approval procedures, maintenance and calibration of laboratory test equipment, and other inspection and monitoring equipment, acceptance evaluation of equipment for inspection and monitoring, and outfitting special/purpose monitoring vehicles, and calibration of equipment to be fitted in such vehicles.

Equipment authorization is part of the global standard setting that helps avoid fragmentation of the market for the benefit of both consumers and industry. The ITU maintains principles of consensus, transparency, openness, impartiality, maintenance, public access to deliverables, consistent rules, efficiency, accountability, and coherence in order to maintain successful development of the global standard.

Spectrum monitoring

Spectrum monitoring feeds back to spectrum management, i.e., good frequency planning and assignment reduce the possibility of harmful interference. Spectrum monitoring responsibilities include routine monitoring of a wide range of frequency and special tasks to find illegal frequency uses or harmful interference. Monitoring provides actual use of spectrum as information for frequency assignment in order to compare spectrum planning with reality. The consequences are the adjustment of spectrum planning.

Information from monitoring also supports the enforcement approach to the ideal of interference-free, properly authorized, and harmonized use of the spectrum. Monitoring can also be used to identify and measure interfering signals, verify technical and operational characteristics of radiated signals, and detect illegal transmitters.

Spectrum regulation enforcement: inspections and investigations

The purpose of the enforcement inspection is to strengthen spectrum management processes to reflect the effective management of the spectrum, depending on the ability to control its use through the enforcement of relevant regulations. The authority should grant appropriate authority to the spectrum management organization in order to enforce regulation and set appropriate penalties.

Enforcement, inspection, and investigation should work closely with monitoring, assignment, and licensing units to collect information to investigate interference complaints, illegal operation, and operations not in accordance with the radio station licence, collect information for legal prosecution and law enforcement, ensure that the radio station complies with national and international regulations, and take technical measurements.

International and regional cooperation including frequency coordination and notification

When interference cannot be contained nationally, international and regional cooperation, in terms of activities within international bodies, and bilateral and multilateral discussions should be conducted. The cooperation is conducted by ITU world and regional radiocommunication conferences (WRCs and RRCs), together with the three ITU Sectors (Radiocommunication, Telecommunication Standardization, and Telecommunication Development). Moreover, the notifications from Member States to the Radiocommunication Bureau help to coordinate frequency authorization via the Bureau's International Frequency Information Circular (BR IFIC).

Moreover, discussions in other international organizations, such as the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the World Meteorological Organization (WMO), and the Special Committee of the International Electrotechnical Commission for Interference (CISPR), help to settle interference issues via negotiation. The administration must therefore also give consideration to participating in these organizations.

Bilateral cooperation between countries, especially neighboring countries, in terms of a joint committee, helps to relieve interference at operational level.

National liaison and consultation

The spectrum management organization should set up liaison units for communication and consultation with users, including businesses, telecommunication industries, the government and the general public to disseminate information on policy, rules and regulations, and practices and provide mechanisms for feedback to evaluate consequences. A liaison unit, as a focal point of spectrum management organization, maintains media relations, issues public notices, conducts meetings, and acts as a mediator to resolve interference problems. The form of the liaison unit ranges from informal to formal contact and depends on the tradeoff between efficient dialogue and quick results, and transparent administrative procedures that ensure fair and impartial treatment.

Spectrum management organizations are encouraged to establish procedures for individuals and organizations to revise spectrum regulations and assignment or allocation to meet the needs of the national constituency.

The spectrum management support function includes administrative and legal support, computer automation, spectrum engineering, and training

Spectrum engineering support provides adequate evaluation information, capabilities, and choices in the field of technology and engineering analysis of technical factors. Administrative, legal, and computer support provides an efficient facility for the spectrum management organization.

8.3 Applying IAD framework to spectrum management activities

Analyzing the layers of the IAD framework classifies the spectrum management activities into each level of analysis to understand the relevance of the IAD framework to spectrum management activities. Table 27 illustrates the outcome of the spectrum management activities at each level of analysis.

Table 27. Spectrum management activities with IAD levels of analysis and outcomes

Spectrum Management activities	Constitutional	Collective-choice	Operational
Spectrum management planning and regulations	x		
Allocation and allotment of frequency bands	x		
Frequency assignment and licensing		x Rule setting	x Compliance
Spectrum management financing		x	
Standard, specifications, and equipment authorization		x Setting	x Compliance
Spectrum monitoring		x	
Spectrum regulation enforcement		x	
International and regional cooperation	x Rule setting	x Rule setting	x Compliance
National liaison and consultation			x
Support function			x

In constitutional situations, the activities relate to creating, reviewing, and revising the RR, including allocation and allotment of frequency to services, international and regional coordination, National Frequency Management Master Plan, and the Table of Frequency Allocation. These spectrum management activities provide rules at the constitutional level that influence the rules for collective-choice and day-to-day activities at the operational situation.

In the collective-choice situation, the spectrum management activities that implement the rules from the constitutional situation create the rules for operational situation such as rules on how to assign the frequency: first-come first-serve or auction, rules on how to use a network or standard settings for permissible devices, and rules on how to coordinate between operators in neighboring countries when interference occurs. Moreover, the fee calculation formula for spectrum management financing activities is also established at this level.

Furthermore, spectrum monitoring for the use of frequency and spectrum regulation enforcement: inspection and investigation of the use of radiocommunication devices are included at this level to supervise day-to-day activities for frequency assignment and licensing and provide the information back for spectrum-planning activities.

In the operational situation, the day-to-day or routine activities of spectrum management comprise assignment, licensing, standard compliance, cooperative protocol compliance, consultation of rules, and supporting activities.

Assignment and licensing activities are carried out according to specified rules in the collective-choice situation, i.e. which frequency can be assigned with technical specification, which licences are applied, what fees are charged.

Radiocommunication equipment standard compliance is performed according to predefined standard setting and procedures carried out in the collective-choice situation, i.e. which standard or equipment is allowed to be used in Thailand.

During frequency coordination between countries, when the interference is found, the both the regulator and operator in the relevant countries must follow the rules as specified in the collective-choice situation to identify and eliminate such interference.

National liaison and consultation activities comprise day-to-day work to create a common understanding of the rules with regard to public consultation or focus groups. Output information would benefit from greater efficiency of rule implementation at higher levels.

The support activities aim to facilitate the main spectrum activities on a daily basis, including technical and administrative support.

This study classifies the spectrum management activities into the IAD level of analysis and outcomes to understand the interaction of each activity and relationships across levels. All spectrum management activities dealing with rule-setting are carried out in the constitutional or collective-choice situation. Day-to-day activities performed according to specified rules are in the operational situation.

According to the IAD framework set out in Figure 2, Chapter 2, spectrum management activities can be described as follows:

Biophysical conditions: This study deals with spectrum that can be public, private, or common-pool goods depending on the allocation and assignment approach. Spectrum allocation at the international level can be treated as public goods. On the other hand, spectrum assignment at the national level can be treated as private or common-pool goods, depending on the assignment approach used.

Attributes of community: Spectrum management involves many stakeholders from the international to national level including the ITU, Member States, manufacturers, operators, and end-users. Common understanding among them is essential in order to understand the regulation and properly implement it in order to ensure frequency efficiency without or with minimal harmful interference.

Rules-in-use: The rules-in-use of spectrum management are represented by the RR, national regulation, the network rules of operators, and manufacturers' equipment standards. These rules directly influence the action situation and interaction between stakeholders in spectrum management activities.

Action situation and interaction: Spectrum management activities represent the action situation and interaction between stakeholders in each activity representing various aspects of the decision-making process. From rule-setting to implementation of rules by the regulator, manufacturers, operators, and end-users, these represent the action situation and interaction in spectrum management.

Outcome: the ultimate outcome of spectrum management is the efficient use of spectrum with manageable harmful interference. Moreover, the outcome is directly influenced by the evaluative criteria that vary between countries and stakeholders. The challenge is to balance the benefit and outcome with the sustainable use of spectrum.

8.4 Summary and discussion of research question

This chapter answers the sub-research question 5: *How is the IAD framework relevant to spectrum management?*

This study applies the IAD framework in terms of the level of analysis and outcomes to demonstrate the relationship between levels of analysis in spectrum management activities. The study uses three levels of analysis and outcome, i.e. the constitutional, collective-choice, and operational situation.

The operational situation represents day-to-day or routine work corresponding to the rules that have been specified in the collective-choice situation. The spectrum management activities at this level comprise assignment and licensing, equipment authorization, international and regional cooperation, national liaison and consultation, and support functions.

The collective-choice situation represents the ability to review and revise operational rules, including how to assign or license frequency, authorize equipment, how to charge for licence fees, and how to coordinate when interference occurs. Moreover, standard-setting, assignment and licensing, and international and regional cooperation rule-setting have been carried out at this level. Furthermore, spectrum monitoring and regulation enforcement have been performed to provide information back to spectrum planning.

The constitutional situation consists of rule-setting, reviewing, and revising at the international and national level that is directly influenced to the collective-choice and operational situation, including the RR (allocation and allotment of frequency), the National Frequency Management Master Plan, the Table of Frequency Allocation (planning and regulation), and international and regional cooperation.

The study also illustrates the application of the IAD to the spectrum management activities by analyzing and describing spectrum management activities according to aspects of the IAD framework including biophysical condition (spectrum as public goods for allocation, spectrum as private and common-pool good for assignment), attributes of community (common understanding between stakeholders in spectrum management including ITU, Member States, manufacturers, operators and end-users), rules-in-use (the RR, national regulation, network rules, standard of equipment), action situation and interaction (spectrum management activities between stakeholders: regulator, operators, manufacturers, standard-setting body, and end-users), outcome, and evaluative criteria (efficient use of spectrum and balancing of the benefit between stakeholders).

This study applies the IAD framework to understand the transformation from the RR to NBTC regulation for spectrum commons in Thailand in terms of the definition of ISM applications, footnotes 5.138 and 5.150, and frequency bands in the TFA.

This chapter answers sub-research question 5: How is the IAD framework relevant to spectrum management? This study applies the IAD framework to describe and categorize spectrum management activities into three levels of analysis and outcome in order to demonstrate the relationship between stakeholders in spectrum management in each level of analysis. Moreover, spectrum management can be described by the IAD framework to understand the activities according to aspects of the framework. This sub-research question highlights the relevance of the IAD framework to the spectrum management activities. It also helps to fulfill the main aim of this research, namely how to implement international regulation in national regulation for spectrum commons in Thailand.

Chapter 9 Summary and findings

This chapter provides an overview of the findings of this study. It also provides an explicit answer to the research question.

9.1 Synthesis

There follows a summary of the complex issues associated with the transformation of international regulation into national regulation in terms of transforming the RR into NBTC regulation.

Purpose

The purpose of this study is to demonstrate the relationship between international and national regulations with regard to implementing spectrum commons in Thailand. It also illustrates the development of frequency allocation for spectrum commons at the international level and the international regulation transfer for spectrum commons to Thai national regulation.

Motivation

The study attempts to understand the relationship between the RR as the international regulation and the NBTC regulation as the national regulation for spectrum commons at the IAD constitutional situation.

The main research question of this study is: **How are the Radio Regulations transformed into the National Broadcasting and Telecommunications Commission regulation for spectrum commons in Thailand?** In order to answer this research question, the five sub-research questions are as follows:

1. What are the main applications and technologies for spectrum commons?
2. What is the spectrum allocation for spectrum commons and ISM applications, and how was it developed?
3. What is spectrum assignment, especially spectrum commons, in Thailand, and how did it develop?
4. How should spectrum commons regulation be transformed from the RR into the national NBTC regulation? What are the challenges?
5. How is the IAD framework relevant to spectrum management?

Method

The study uses deductive approaches and secondary data. The secondary data are obtained from the ITU and NBTC archives. Keyword mapping helps to track the relevant provisions across the RR versions.

The IAD framework provides a layer of analysis and outcomes to explain the connection between international regulations at the ITU, in the form of the RR, and national regulation in the form of the NBTC.

9.2 Findings to the research questions

The study's findings corresponding to the relevant research questions are as follows:

(1) Spectrum commons application and technology (Chapter 4) corresponding to the first sub-research question: What are the main applications and technologies for spectrum commons?

This study responds to the first sub-research question by providing the main application and technology for spectrum commons in terms of short-range devices and software-defined radio and cognitive radio system. The study concentrates on applications and technology relating to industrial, scientific and medical (ISM) applications using the frequency band according to RR No. 5.138 and 5.150.

The study explores the relevant literature, including the report and recommendations of the ITU-R to illustrate the characteristics of SRDs, and SDR and CRS.

The main characteristics of the SRDs are non-interference and non-protection. Most SRDs use the ISM band, especially 5.138 and 5.150. Moreover, power limitation in terms of magnetic and electric field strength and maximum power level vary from country to country. Allocation of frequency band to the ISM band is done at the WRC. However, authorization of the use of SRDs is granted locally by the NRA. SRDs migrate the national to international issues when unlicensed SRDs are transported from one country to other countries that do not allow the use of such SRD. The use of unlicensed SRDs in countries where it is not permitted creates interference with existing services. However, regional and global harmonization of frequency bands might be possible.

SRDs are the main application for spectrum commons because the characteristic of non-interference and non-protection provide the non-exclusive use of frequency that is similar to spectrum commons.

SDR and CRS are enabled technologies for SRD. The study focuses on these two technologies because they are relevant to WRC-12 agenda item 1.19 and might offer possibilities to review and revise the RR.

The characteristics of CRS are obtaining the operational environment, changing the radio operational parameter simultaneously and automatically by software, and learning from experience to improve its performance. SDR is enabled technology for CRS because the characteristic of SDR is the ability to change the radio operational parameter simultaneously and automatically by software.

The development of SDR is at a mature stage that has already been implemented for several services, however CRS is in its infancy and needs further development. The main benefit of CRS is that it provides spectrum access opportunities, increasing spectrum efficiency and reducing interference.

The characteristic of CRS provides the non-exclusive right to use a frequency that is the same as a spectrum commons characteristic. Therefore, SDR and CRS are the main technologies for spectrum commons.

(2) Spectrum allocation for spectrum commons (Chapter 5) corresponding to the second sub-research question: What is the spectrum allocation for spectrum commons and ISM applications, and how did it develop?

The study responds to the second sub-research question by elaborating on the result of international negotiations or the result of the WRC in the form of the RR revision for spectrum allocation for radiocommunication services. The WRC allocates service by frequency bands inside the TFA based on Member State contributions. The TFA is divided into three Regions: Regions 1, 2, and 3. Each service consists of either primary or secondary services, which can be written in capital letters for primary services while secondary services are lower case. Moreover, the footnotes can indicate the primary and secondary services with the words “on a primary basis” or “on a secondary basis”, respectively.

The study explores the ITU archive with relevant RR and WRC proceedings to capture the development of the allocation of spectrum commons in the RR.

Spectrum allocation represents the result of negotiations at international level because the final allocation is the output of governmental negotiations between Member States.

Spectrum commons are allocated in ISM application footnotes 5.150 and 5.138. Most of the short-range or low-power devices use the frequency under these provisions with non-exclusive use of frequency.

This study illustrates the development of ISM applications, both in terms of definition and frequency bands allocated for ISM applications. The official definition of ISM applications has been developed in RR1982 and remained unchanged until RR2012. Long before that, ISM applications used different words: purpose and equipment in RR1947 and RR1959.

The current ISM bands are: 6 765-6 795 kHz, 433.05-434.79 MHz, Region 2, 61-61.5 GHz, 122-123 GHz, 244-246 GHz, for 5.138; and 13 553-13 567 kHz, 26 957-27 283 kHz, 40.66-40.70 MHz, 902-928 MHz, Region 1, 2 400-2 500 MHz, 5 725-5 875 MHz, and 24-24.25 GHz for 5.150.

The first allocation was for low-power stations in the European region in RR1938 and ceased in RR1947. Most of the ISM bands were developed in RR1982 and continued to be used until RR2012.

This study shows the development of each ISM band and indicates the differences between them. Footnote 5.138 requires special authorization to operate, while footnote 5.150 allows other services to share the same frequency with acceptance of harmful interference from ISM applications. Neither 5.138 nor 5.150 provide the explicit ITU recommendation, however the relevant ITU-R recommendation is Recommendation ITU-R SM.1056-1: Limitation of radiation from industrial, scientific and medical (ISM) equipment.

(3) Frequency assignment for spectrum commons in Thailand (Chapter 6) in response to the third sub-research question: *What is the spectrum assignment especially spectrum commons in Thailand, how did it develop?*

This study responds to the third sub-research question by exploring the NBTC archives, including the relevant NFMB minutes, and PTD, NTC, NBTC, MOT, and MICT regulation.

The study illustrates overall spectrum assignment which has three typical approaches: command-and-control, market-based, and spectrum commons. Spectrum assignment is managed by the national regulatory authority. Among the three typical approaches, only command-and-control and market-based provide an exclusive right to use a frequency, whereas spectrum commons does not. However, the command-and-control approach is inefficient as it lacks the flexibility of frequency use. The market-based and spectrum commons approaches were introduced to overcome such inefficiency. The market-based or spectrum auction in the UK in 2000 was an example of the largest auction in which the winning bidder was not commercially viable and later sold the spectrum.

The spectrum can be treated as goods, depending on the method of assignment. For command-and-control and market-based approaches, the spectrum is treated as private goods with an exclusive right to use a frequency. The spectrum can be transferred or sold to others by the regulator or the market. On the other hand, spectrum commons can be treated as common-pool goods with a non-exclusive right to use a frequency. The ownership of spectrum commons belongs to the general public.

The study demonstrates the development of spectrum assignment in Thailand. Thailand has developed spectrum assignment from a command-and-control to a market-based approach. Spectrum was initially for use by a limited number of parties, first only the government agency and then extended to the general public. The development of the spectrum assignment agency in Thailand included the PTD, NFMB, MICT, NTC, ONTC, NBTC, and ONBTC in order to change the authorization to a licensing scheme or command-and-control to market-based economics.

The study also illustrates the development of spectrum commons in Thailand since the NFMB in terms of authorization of the use of 1-watt transmitters. The Ministerial Regulation allowed low-power devices with relevant licences. The PTD regulations allowed the use of WLAN indoor applications and extended this to outdoor applications. Finally, as the first unlicensed regulation in Thailand, the Ministerial Regulation of the Exemption of Radiocommunication Licences in 2004 allowed low-power devices without relevant licences.

(4) International to national regulation (Chapter 7) in response to the fourth sub-research question: *How should spectrum commons regulation be transformed from the RR into the national NBTC regulation? What are the challenges?*

The study responds to the fourth sub-research question by exploring the current RR2012 and Thailand Table of Frequency Allocations 2012 for ISM definition, footnotes 5.138 and 5.150, and TFA. Moreover, the study demonstrates the transformation from international to national regulations:

There are two phases. First, the footnotes 5.138 and 5.150 are adopted in the Thai TFA, including ISM definition, footnotes, and frequency bands. However, the definition of ISM applications is not explicitly shown in the Thai TFA. Both footnotes 5.138 and 5.150 are adopted corresponding to frequency bands in Region 3 within the Thai TFA.

The RR TFA represents the IAD rules-in-use in the constitutional situation that influences the Thai TFA as rules-in-use in national regulation at the constitutional level in Thailand. In addition to the RR TFA influencing the use of spectrum commons in Thailand, national regulation, i.e. the Radiocommunication Act B.E. 2498 (1955), also represents the rules-in-use in the constitutional situation in Thailand. The Radiocommunication Act prohibits the use of radiocommunication devices unless permission is granted by the authorities.

Second, the development of national regulation allows the use of spectrum commons with regard to lower-power radiocommunication. In 1975, the first spectrum commons was granted by the NFMB to the PTD allowing 1-watt transmitters for pagers and anti-theft devices. However, the use of these devices required relevant radiocommunication licenses. Several additional national regulations have been developed over time to allow more frequency bands for spectrum commons with maximum power and technical specification. Ten current relevant NBTC regulations are shown in the previous section and categorized into Thailand footnotes: T-Unlicensed 1, 2, and 3 in Table 22-24 with relevant radiocommunication licenses. In addition to the frequency bands specified by footnotes 5.138 and 5.150, other frequency bands were allowed to be used as spectrum commons in Thailand, including the frequency band lower than 135 kHz, 1.6-1.8 MHz, 30-50 MHz, 54-74 MHz, 88-108 MHz, 165-210 MHz, 300-500 MHz, 920-925 MHz, 5.150-5.350 GHz, 5.470-5.725 GHz, 10-10.6 GHz, 76-81 GHz, 72-72.745 MHz, 78-79 MHz, 245-246 MHz, 510-790 MHz, 794-806 MHz, 925-920 MHz, 1 900-1 906 MHz, and 76-77 GHz.

The challenges of transforming international into national regulation both in terms of allocation and assignment are reflected by the advantages and disadvantages of spectrum commons. The challenges of the advantages are to maintain them in a sustainable way. The challenges of the disadvantages are to reduce them as much as possible.

Allocation challenges: the challenges for the regulator are irreversibility once such frequency has been allocated for spectrum commons (it is hard to return such frequency for new allocation or assignment), and the long process for new allocation for spectrum commons at the WRC. For innovators, this is an opportunity to create a new application. For manufacturers, this offers the certainty of mass production for global allocation.

Assignment challenges: the challenges for the regulator are the irreversibility of such frequency when assigning to spectrum commons, and the fact that it is widely used (it is costly to recall such radiocommunication devices to refarm the frequency for new assignment), the loss of a frequency usage fee compared with the social benefit of spectrum commons, the long process of adopting national regulation, and the low administrative cost for spectrum commons. For an incumbent, the challenge is the harmful interference with its existing users or services. For a new-comer, there is no spectrum fee to use spectrum commons. For end-users, there is a wide choice, low cost, and better devices to use on the market. However, harmful interference, congestion and limited quality of service are manageable through advancements in technology such as the cognitive radio system.

(5) International to national regulation (Chapter 8) in response to the fifth sub-research question: *How is the IAD framework relevant to spectrum management?*

The study responds to the fifth sub-research question by applying the IAD framework in terms of the level of analysis and outcomes to demonstrate the relationship between spectrum management activities at different levels of analysis. The study uses three level of analysis and outcome, namely constitutional, collective-choice, and operational situation.

The operational situation represents day-to-day or routine work corresponding to the rules that have been specified in the collective-choice situation. The spectrum management activities at this level are assignment and licensing, equipment authorization, international and regional cooperation, national liaison and consultation, and support functions.

The collective-choice situation represents the ability to review and revise operational rules, including how to assign or license frequency, authorize equipment, how to charge licence fees, and how to coordinate if interference occurs. Moreover, standard-setting, assignment and licensing, and international and regional cooperation on the setting of rules are done at this level. Furthermore, spectrum monitoring and regulation enforcement are performed to provide information back to spectrum planning.

The constitutional situation represents rule-setting, reviewing, and revising at the international and national level that is directly influenced to the collective-choice and operational situation including the RR (allocation and allotment of frequency), National Frequency Management Master Plan, Table of Frequency Allocation (planning and regulation), and international and regional cooperation.

The study also illustrates the IAD application to spectrum management activities by analyzing and describing the spectrum management activities according to aspects of the IAD framework, including biophysical condition (spectrum as public goods for allocation, spectrum as private and common-pool goods for assignment), attributes of community (a common understanding among stakeholders in spectrum management including ITU, Member States, manufacturers, operators, and end-users), rules-in-use (the RR, national regulation, network rules, standard of equipment), action situation and interaction (spectrum management activities between stakeholders: regulators, operators, manufacturers, standard-setting bodies, and end-users), outcome, and evaluative criteria (efficient use of spectrum and the balance of benefit between stakeholders).

The study applies the IAD framework to understand the transformation from the RR into the NBTC regulation for spectrum commons in Thailand in terms of definition of ISM applications, footnotes 5.138 and 5.150, and frequency bands in the TFA.

9.3 Benefit for Thailand

This study provides an overall view on the implementation of spectrum commons regulation in Thailand. This includes the development of spectrum allocation for spectrum commons in the RR, the main application and technology for spectrum commons, the development of spectrum assignment for spectrum commons in Thailand, and the practical transformation from the RR into NBTC regulation.

The study helps us understand that the process of transformation from international into national regulation is a time-consuming process through spectrum allocation at the WRC and implementation of the national NBTC regulation to allow the use of spectrum commons both with the relevant licences and unlicensed.

This study proposes looser regulation for spectrum commons in order to gain advantages or benefit from the rapid change in technology because the process of reviewing and revising both international and national regulation is a time-consuming process.

9.4 Recommendations for future research

Further studies on the transformation of other services such as mobile services from the RR into national regulation would be interesting to explore.

Comparative studies between countries in different region could also form the basis for other future studies to understand the differences and similarities between countries.

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List of abbreviations

General

AVI	Automatic vehicle identification
CB	Citizen band
CMOS	Complementary metal oxide semiconductor
CRS	Cognitive radio system
DECT	Digital enhanced cordless telecommunications
e.i.r.p.	Equivalent isotropically radiated power
e.r.p.	Effective radiated power
FH	Frequency hopping
GHz	Giga Hertz
GPS	Global positioning system
HDR	High data rate
Hz	Hertz
IAD	Institutional Analysis and Development
IFIC	International Frequency Information Circular
IED	Interference estimation and decoding
IMT	International Mobile Telecommunication
ISM	Industrial science and medical application
ITS	Intelligent transport system
kHz	Kilo Hertz
LDR	Low data rate
LNA	Low noise amplifier
MAC	Medium access control
MHz	Mega Hertz
MICS	Medical implant communication system
NFC	Near field communication
OFDM	Orthogonal frequency division multiplexing
PANs	Personal area networks
PHS	Personal handy-phone system
PHY	Physical layer
PP	Plenipotentiary conference
RF	Radio frequency
RFID	Radio-frequency identification
RLAN	Radio local area network
RR	Radio Regulations
RRC	Regional radiocommunication conference
SDR	Software defined-radio
SG	Study group
SIM	Subscriber identification module
SoD	Supplier’s declaration of conformity
SRD	Short-range devices
TFA	Table of frequency allocation
UWB	Ultra wide band
WLAN	Wireless local area network
Wi-Fi	Wireless fidelity
WRC	World Radiocommunication Conference

Administration and organization

BR	Radiocommunication Bureau
CCIR	International Radio Consultative Committee
CISPR	Special committee of the international electrotechnical commission for interference
FIFA	Fédération Internationale de Football Association
ICAO	International Civil Aviation Organization

IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
ITU	International Telecommunication Union
MICT	Ministry of Information and Communication Technology
NBTC	National Broadcasting and Telecommunication Commission
NFMB	National Frequency Management Board
NRA	National regulatory authority
NTC	National Telecommunications Commission
ONBTC	Office of the NBTC
ONTC	Office of the NTC
PTD	Post and Telegraph Department
WMO	World Meteorological Organization