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NATTAWUT ARD-PARU Spectrum Assignment Policy: Towards an Evaluation of Spectrum Commons in Thailand 2010

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Department of Technology Management and Economics
Division of Technology and Society
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2010

THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

SPECTRUM ASSIGNMENT POLICY: TOWARDS AN EVALUATION OF SPECTRUM COMMONS IN THAILAND

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ISSN 1654-9732 Licentiate thesis
Report number L2010:045
Division of Technology & Society
Department of Technology Management and Economics
Chalmers University of Technology
SE-41296 Göteborg, Sweden

Printed by Chalmers Reproservice

Göteborg, 2010

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Abstract

There is consensus among economists, engineers, and lawyers that a traditional command-and-control approach to spectrum assignment is inefficient and that a market-based or commons approach can be more efficient. The purpose of this thesis is to find the benefits of using spectrum commons for frequency assignment in Thailand. To satisfy this purpose, four main contributions are provided: 1) a framework to understand the institution of spectrum commons and its application to Thailand, 2) an approach to explain the advantages and disadvantages of spectrum commons, 3) an exploration of the use of a framework for a benefit and cost analysis to valuate the spectrum commons, and 4) possible implications of using spectrum commons in Thailand. These contributions will serve as information for a regulator to make better-grounded decisions on frequency assignment and on whether to license or unlicense spectrum.

The thesis uses history, content analysis, and literature critique as its main sources. The content analysis and literature critique are based on the public consultation in 2008 by the European Radio Spectrum Policy Group. It addresses the aspects of a European approach to the collective use of spectrum and identifies the advantages and disadvantages of spectrum commons. To describe the institution of spectrum commons, the property rights regimes by Schlager and Ostrom (1982) are used. This is based on three economic institutions originally described by Kiser and Ostrom (1982) and later adopted by Field (1992). This information is examined, together with the benefit and cost analysis based on the research by Campbell and Brown (2003), Indepen (2006), and Sweet et al. (2002). Data from this examination contribute to defining a framework that can be used to valuate spectrum commons in Thailand.

The institution of spectrum commons in Thailand comprises technical and non-technical aspects. The technical aspects are power limitation and use of the specified frequency band, and the non-technical ones are frequency sharing among users and no endowed rights to request compensation from interfering parties.

The advantages of spectrum commons are lower entry barriers for new entrants, a reduction in administration work (such as defining property rights to use frequency, auction process, etc.), and enhancing social benefits. These attributes contribute to increasing the potential for innovation and stimulating further demand for new technologies. The main disadvantage of spectrum commons is irreversibility after spectrum assignment, congestion, and limited quality of service. Even these eventual limitations can be solved with the advancement of technology, while the threats, e.g., lack of innovation while sharing with licensed services, are questionable.

The thesis argues that spectrum commons has more strengths and opportunities than weaknesses and threats. In order to implement the spectrum commons and valuate the usefulness of this approach in practice, a framework of benefits and costs is defined. The output of this thesis can be used as information for regulators to decide whether the frequency should be licensed or unlicensed and to evaluate the consequences of implementing spectrum commons.

Keywords: spectrum management, spectrum assignment, spectrum commons, collective use of spectrum, benefit and cost analysis

Acknowledgements

I would like to thank Commissioner Sudharma Yoonaidharma who initiated the collaboration between the National Telecommunications Commission, Thailand, and Chalmers University of Technology and offered the opportunity for Ph.D. study. I would also like to thanks the Office of the National Telecommunications Commission for providing my scholarship.

I would like to thank Dr. Duangtip Surintatip who reviewed my statement of purpose for my Ph.D. study at the time when I was applying for my scholarship.

I would like to thank Khun Sethaporn Cusripituck, my former big boss at the Post and Telegraph Department and at the National Telecommunications Commission, who has advised me regarding work and study.

I would like to thank my former boss and friend Khun Dumrong Watsotok, who supports my ideas and the information for my study, and Khun Supinya Jampee, who has always updated information for me. I would also like to thank Khun Chalermchai Kokkeadtikul, my colleague who suggested the idea of the model to me.

I would like to thank my colleagues in the Office of the National Telecommunication Commission, including the Information Technology Bureau, the Telecommunications Technology and Engineering Bureau, the Non-Business Licensing Bureau, the Business Licensing Bureau, the Telecommunications Enforcement Bureau, the Legal Affairs Bureau, the Policy and Regulatory Development Bureau, the Human Resource Bureau, the Telecommunications Economics Bureau, the International Economics Cooperation Bureau, the International Organizations Bureau, the Numbering Management Group, the Broadcasting Group and the Interconnection Institute for friendly working atmosphere.

Without my fellow friends here at Chalmers, I would not have made it through my Ph.D. study. I am lucky to have them with me. Special thanks go to P'Nam Orada, Jack and Fone-Srinuan family, and Tsani and Ibrahim, my Indonesian friends. I would also like to thank Yvonne who I go to talk to about many things, and Anna and Lillimore for their administrative support during my stay here at Chalmers. I would also like to thank Gustav and Ann-Sofie for being here and sharing their friendship in our division.

During my stay here at Chalmers, I have had great opportunities for discussion with outstanding professors, including Simon Forge, Gary Madden, and Martin Cave. I do not know how to thank them enough for their advice and suggestions.

I have asked myself many times if it has been worth it to study for my Ph.D. It has been the hardest thing in my life. I am an engineer-type person who loves to solve problems as quickly as possible, and I do not usually have long-term waits for outcomes, like the four years for a Ph.D. Starting from scratch with the academic writing for my Ph.D. was quite difficult. I have overcome it with enormous help from Professor Erik Bohlin, my advisor, who always persuades, encourages, and guides me along the way of my study. Professor Erik Bohlin said that we had to build my Ph.D. brick by brick, and that was absolutely true for me. Without him, I would not have had any reason to stay here. I would like to thank him a million times for his supports, which I could not have received from elsewhere.

I would like to thank Associate Professor Ilona Heldal, my co-advisor, who has helped me work through literature, dissertations, assignments, and presentations. Associate Professor Ilona Heldal has always given helpful suggestions to improve my study. I would like to thank her once again for her kindness and generosity, and everything she has done for me.

I would like to thank my mom, my dad, and my two sisters for supporting me in so many ways, and I love them all. I would also like to thank my social network, Facebook, and Hi5 for sharing my tears and joy whenever I faced them.

Finally, I would like to thank myself for having the stamina and perseverance to study at Ph.D. level. The more obstacles I faced on my way, the deeper and more unforgettable my memory.

"We only know the time we were born but we do not know the time we will die.

Life is too short, if you would like to do a good thing, please DO it."

"Happiness is here and now
I have dropped my worries
Nowhere to go, Nothing to do
No longer in a hurry"
Song from "Plum village," France

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Chapter 1 Introduction

Nowadays, telecommunication devices and services are mandatory tools in both business and the household. Wireless technology, in particular, with its increasing mobility, is the key. Wireless devices using radiocommunication are part of day-to-day activities, ranging from garage openers, remote controls, toys, closed circuit television (CCTV), navigation systems (land, air, and sea), earphones, cordless telephones, and card readers, to Internet connection (Wi-Fi) in smart phones. Most of these are low-power, unlicensed devices whose uses are increasing. The unlicensed devices use frequency or spectrum as a carrier of communication and share frequency or spectrum with other devices or uses. Spectrum is a limited resource. Understanding the nature of spectrum will therefore help to use it efficiently.

1.1 What is spectrum?

Spectrum is an electromagnetic wave comprising electric and magnetic fields that can be characterized as properties of light and particles. It can also be referred to as radio, radio wave, radio frequency, or frequency. Spectrum refers to the subset of the electromagnetic wave spectrum that is below 3,000 GHz (Radio Regulations 2008). According to the propagation characteristic, spectrum using higher frequencies reaches shorter distances but has a larger carrying capacity. Conversely, spectrum using lower frequencies reaches longer distances but has a lower carrying capacity. This characteristic limits the application of spectrum. The spectrum is a non-depletable resource. It can be reused by dividing it into frequencies, time, angle of arrival, polarization, geography, and uses. Spectrum cannot be controlled for transmission. Due to its nature, transmission will propagate across country borders until the power runs out. The spectrum services are not only useful in telecommunications, fixed and mobile services, but also in broadcasting, satellite, maritime, and aeronautical services.

1.2 Why manage spectrum?

In terms of technical aspects, the spectrum is similar to roads carrying traffic. It needs rules or regulations to control the use of each application to prevent disorder and harmful interference. In addition, proper spectrum management can maximize spectrum use by allowing for the maximum number of users, while keeping interference and congestion manageable.

In terms of social aspects, in some countries, such as Thailand, spectrum is a national resource of public interest. As stated in the Thai Constitution 2550 ("The Constitution of Thailand," 2007), there must be an independent regulatory body with the duty of distributing frequency and supervising its use. There shall be regard for maximum public benefit at national and local levels in education, culture, State security, other public interests, and fair and free competition, including encouraging the public to participate in the management of public mass communication. A country typically has a regulatory authority. Such an authority is denoted by law, i.e., administrator, national regulatory authority, or regulator.

In terms of economics, spectrum is a scare resource and limited by its frequency band, time, and place. The spectrum can be used for different purposes or services. The different services of spectrum make it similar to other goods that follow supply and demand. Demand for spectrum is created by the users, and supply of spectrum is provided by the regulator. A particular aspect of spectrum, from an economic point of view, is that it is non-excludable, non-depletable, and subject to congestion problems. It therefore has some properties that are similar to public goods, although it is not purely public goods, as will be explained below.

1.3 How is spectrum managed?

With regard to the propagation of spectrum, there are three levels of spectrum management: allocation, allotment, and assignment. Allocation[1] and allotment[2] are designed at international level, while assignment is the responsibility of national agencies. Management at international level is by the International Telecommunication Union (ITU), a United Nations specialized agency, through issuing Radio Regulations (RR) via the World Radiocommunication Conference (WRC) to harmonize the allocation of frequency bands with radiocommunication services.

Harmonization can also be regional. Active regional organizations are the Asia Pacific Telecommunity (APT), the European Conference of Postal and Telecommunications Administrations (CEPT), the Inter-American Telecommunication Commission (CITEL), the African Group, and the Arabic Group. They help to consolidate and compromise different ideas within and across regions.

The national assignment[3] and the modes of assignment vary by country. Spectrum may be assigned by an administrator, national regulatory authority (NRA), or relevant ministry, depending on the laws of the country. Before the spectrum is assigned, the NRA normally checks the availability of spectrum, existing users, related regulations (national and international), and suitable technical characteristics imposed on the use of spectrum and radiocommunication equipment.

All obligations imposed by the authority must comply with the ITU RR, however, to avoid harmful interference between countries and maintain priority on claims on using this spectrum. Within their territory, the regulators have the right to manage the spectrum by their own authority but not to interfere with neighboring countries. They set up coordination and cooperation with neighboring countries to help manage interference.

1.4 What is spectrum assignment?

Spectrum assignment policy is limited to wireless or radiocommunication in 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, beside 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 (Radiocommunication Bureau, 2005).

Spectrum management policy is a subset of telecommunications policy. Telecommunications policy includes technical, economic, and social aspects. It overlaps the natural sciences (technic) and social science (economics and society). Telecommunications policy often, but not always, deals with 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.

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[1] *Allocation* (of a frequency band)*:* Entry in the Table of Frequency Allocations of a given frequency band for the purpose of being used by one or more terrestrial or space *radiocommunication services* or the *radio astronomy service* under specified conditions. This term shall also be applied to the frequency band concerned. (International Telecommunication Union – Radio Regulations 2008)

[2] *Allotment* (of a radio frequency or radio frequency channel)*:* Entry of a designated frequency channel in an agreed plan, adopted by a competent conference, for use by one or more administrations for a terrestrial or space *radiocommunication service* in one or more identified countries or geographical areas and under specified conditions. (International Telecommunication Union – Radio Regulations 2008)

[3] *Assignment* (of a radio frequency or radio frequency channel)*:* Authorization given by an administration for a radio *station* to use a radio frequency or radio frequency channel under specified conditions. (International Telecommunication Union – Radio Regulations 2008)

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

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 below.

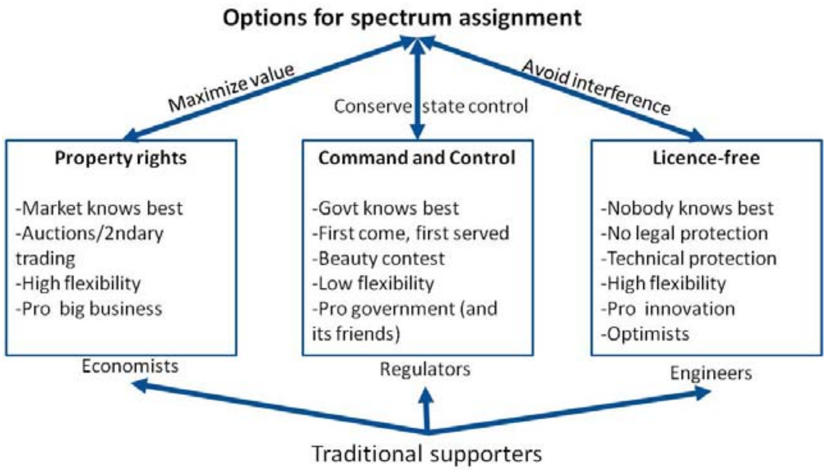

Figure 1. Options for spectrum assignment [4]

Historically, spectrum has been assigned by a command-and-control approach, an administrative approach in which the competent authority, mostly 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 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.

[4] Source: Geiss (2004)

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 so far. After BT had 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 among 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 - 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). Table 1 shows four categories of goods.

Table 1. Categories of goods[5]

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

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 form 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).

1.5 Spectrum commons

The exclusive right to use frequency granted by a regulator, with a command-and-control or market-based approach, transforms spectrum into private goods. The regulator therefore limits the use of

[5] Source: Kiser and Ostrom (1982, p. 198), Table 7.1

frequency to licensees who can access the frequency. In the command-and-control approach, the regulator holds all the rights to the use of the frequency. The regulator has full control over licensees, creating inflexibility in terms of changing to new technology. Under the market-based approach, the regulator allows licensees to transfer frequency to other parties by a market mechanism that will be discussed in terms of the institution of spectrum commons and the bundle of rights to use frequency in Chapter 2. The market mechanism may also raise an unexpected auction fee and affect long-term investment.

On the other hand, the non-exclusive right to use frequency unlicensed can be treated as common-pool goods. In this situation, no one has an exclusive right to use frequency. Everyone can use the same frequency under some constraints. Nevertheless, services under spectrum commons cannot claim protection, because spectrum commons is open to anyone with any application, under the given limitations. For example, in the use of a Wi-Fi hotspot in a conference room, anyone who has a Wi-Fi device can access the Wi-Fi hotspot for conference material. It is hard to prohibit or exclude other participants from accessing the Wi-Fi hotspot. When the use of the Wi-Fi reaches its maximum capacity, however, there is no more access to the Wi-Fi hotspot, because all of the frequencies are occupied.

In the Radiocommunication Act of Thailand, no one can use any radiocommunication device without permission from the regulator. For example, prior to 1996, there was no use of Wireless Local Area Networks (WLANs) in Thailand, because the regulator did not authorize the use of WLANs. In 1996, the regulator granted authorization of WLANs with relevant radiocommunication licences. The use of WLANs in Thailand began in a limited area, because it required relevant radiocommunication licences. Once the WLAN was included in the portable computer and mobile phone chipset, mass production of WLAN devices rendered the price of WLAN devices cheaper. The use of WLAN devices then increased. The regulator realized that relevant radiocommunication licences limited the use of WLANs. In 2004, the regulator declared that the use of radiocommunication devices in the 2400-2500 MHz band with power up to 100 milliwatts (equivalent isotropibcally radiated power, e.i.r.p.) was exempted from all radiocommunication licences.

Here, the regulator assigns specific frequency as spectrum commons, also known as unlicensed band, collective use or license-exempted. Regulators impose constraints on devices in terms of power limitation, frequency, and necessary technical specification to avoid harmful interference.

Most short-range devices (SRDs) use the industrial, scientific, and medical (ISM) applications band, but not all applications become widely used. The phenomenon of the expansion of Wi-Fi devices is growing around the world, with examples such as the laptop, personal device accessories (PDAs), mobile phones, and printers. Moreover, there is ongoing growth in Wi-Fi-enabled devices, which will reach almost 300 million in 2010, according to forecasts by Celine (2008). Figure 2, obtained from Celine (2008), shows the growth in Wi-Fi-enabled devices.

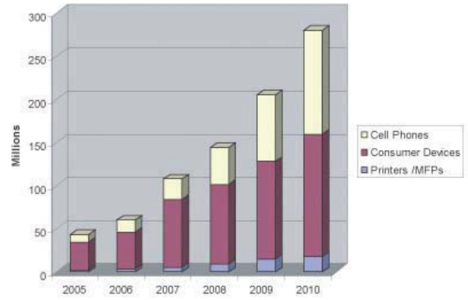

Figure 2. Wi-Fi-enabled, application-specific devices shipment forecast[6]

In general, spectrum commons has its advantages and disadvantages. Spectrum commons has many advantages compared with other approaches, including lowering the entry barrier for new entrants, lowering the administration cost, increasing social benefit, creating innovation, and stimulating demand. Spectrum commons also has several disadvantages, however, e.g., irreversibility of frequency, overuse, and difficulty estimating demand.

The value of spectrum commons can help regulators determine the optimal time to implement spectrum commons. The concept of the benefit and cost analysis helps find the value of spectrum commons. The projection of benefits and costs in the future predicts the value of spectrum commons in the future and discounts it to the current value of spectrum commons.

1.6 Motivation

The traditional command-and-control approach is inefficient because it is inflexible and unable to cope with emerging technologies. The market-based approach limits the number of frequency users to those who pay most. The characteristic of the exclusive right to use frequency limits the number of people who can access the frequency. Spectrum commons grants a non-exclusive right to use frequency however. This increases the number of people who can access the frequency.

In Thailand, most frequency assignments use a command-and-control approach, which is inefficient in terms of the frequency licensee distribution. Most frequency licensees are government agencies or state-owned enterprises. It is interesting to explore the Thai case, because the development of spectrum commons policy involves two separate processes: an authorization of the use of radiocommunication devices and an exemption of relevant radiocommunication licensed or unlicensed.

An exploration of the spectrum management institution provides a starting point for understanding the current situation in Thailand. The history of spectrum management in Thailand is explored to provide an understanding of the development of spectrum assignment. Three worlds of action, a property rights regime and natural resource concepts help to explain the interaction between stakeholders. An understanding of the current situation in Thailand offers potential for frequency assignment for spectrum commons.

[6] Source: Celine (2008)

The investigation into the public consultation of the Radio Spectrum Policy Group (RSPG) in 2008 helps to understand the situation of spectrum commons in European countries. The advantages and disadvantages of spectrum commons are reflected in the stakeholder's interest. It is a European example that will be adjusted for use in Thailand, in terms of a suitable time to implement spectrum commons.

The indicator of spectrum commons implementation is the valuation of the spectrum commons. The benefit and cost analysis is the concept to measure the valuation of the spectrum commons. Moreover, the example valuation of spectrum commons in the UK in 2006 provides a practical procedure to measure spectrum commons.

To measure the value of spectrum commons in Thailand, the adjusted framework and method will be applied to suitable and available information. The output from the valuation of spectrum commons will provide important information for the regulator on whether to license or unlicense a specific frequency band.

1.7 Aim and research question

The purpose of this licentiate thesis is to examine the spectrum commons approach to spectrum assignment. The examined case is Thailand. The main research question is: **"What are the consequences of using spectrum commons for frequency assignment in Thailand?"**

The research problem is divided into three parts: conceptual, empirical, and analytical. The conceptual part deals with the right to use frequency and examines the framework associated with spectrum commons. The empirical part gathers information from history of spectrum management in Thailand and public consultation on spectrum commons in the context of European countries to explore the type of spectrum commons in Thailand and the advantages and disadvantages of spectrum commons. The analytical part uses the benefit and cost analysis concept on spectrum commons in Thailand.

In its approach to the main research question: "What are the consequences of using spectrum commons for spectrum assignment in Thailand?" the thesis addresses five research sub-questions; see Table 2.

Table 2. Research question

Main research question	**What are the consequences of using spectrum commons for spectrum assignment in Thailand?**
RQ.1	*What is a suitable framework for analyzing different types of spectrum commons?*
RQ.2	*What type of spectrum commons has been used in Thailand?*
RQ.3	*What are the advantages and disadvantages of spectrum commons in general?*
RQ.4	*How can the benefits and costs of spectrum commons be measured?*
RQ.5	*What are the implications of implementing spectrum commons in Thailand?*

RQ.1 looks at finding a framework to analyze different types of spectrum commons. Kiser and Ostrom (1982), and Field (1992) provide the three worlds of action as a framework to analyze spectrum commons. The five rights of the property regime by Schlager and Ostrom (1992) are also adopted in

order to find the interaction between the layer of the decision-maker and the right to use frequency. The comparison between property rights regimes and natural resources in the Maine lobster industry (Schlager & Ostrom, 1992) addresses the right to use frequency.

RQ.2 looks at the use of the framework developed in RQ.1 to understand the institution of spectrum commons and its application to Thailand so far. The exploration of the history of spectrum assignment also helps the understanding of spectrum commons and the right to use frequency in Thailand. These are important premises for identifying possibilities for implementing spectrum commons.

RQ.3 looks at the advantages and disadvantages of spectrum commons from the public consultation of the Radio Spectrum Policy Group (RSPG) in November 2008 in the European Union to obtain the current thoughts of stakeholders that built up a general understanding regarding the use of spectrum commons.

RQ.4 is the benefit and cost analysis of the spectrum commons concept from Campbell and Brown (2003), Indepen (2006), and Sweet et al. (2002) to build a framework that can be used to measure spectrum commons in Thailand. Campbell and Brown (2003) provide the framework of the benefit and cost analysis in terms of the undertaken project. The framework applies mostly to whether a company intends to undertake a specific project. The comparison between the current values of whether to undertake the project provides the decision-makers with important information. The values without undertaking the project are obtained from the same allocation resources for alternative uses. Indepen (2006) provides a practical method to measure the unlicensed application in the United Kingdom in 2006, based on the ten most important applications among a hundred applications of unlicensed devices. Sweet et al. (2002) provide the valuation of the spectrum using the engineering value – cost saving in the infrastructure of the network operator.

RQ.5 covers the implications of implementing spectrum commons in Thailand.

The five research questions are intended to contribute to increased understanding of using spectrum commons and to the effectiveness of using spectrum commons in Thailand.

The scope of this thesis focuses on understanding the institution of spectrum assignment, including the decision-maker and decision situation – the institutional arrangement, events, and community – in order to find possibilities for implementing spectrum commons for spectrum assignment in practical ways in Thailand. It also covers the advantages and disadvantages of implementing spectrum commons in the context of Europe. This thesis also has an economic perspective on the value of the spectrum. By using the concept of the benefit and cost analysis, the value of spectrum commons has been identified as important information for the regulator to decide whether to license or unlicense the specified frequency band.

1.8 Structure of thesis

The licentiate consists of seven chapters, starting with the Introduction in Chapter 1, which includes the background, and research question of this research. Chapter 2 provides spectrum management from both the ITU and the rights to use frequency from academic papers, addressing a suitable framework for spectrum commons in RQ.1. Chapter 3 deals with the methodology of the thesis. Chapter 4 presents the development of spectrum management in Thailand, corresponding to RQ.2. Chapter 5 is about the advantages and disadvantages of spectrum commons, corresponding to RQ.3. Chapter 6 concerns the benefit and cost analysis concept, corresponding to RQ.4. Chapter 7 addresses the findings, corresponding to RQ.5, and the conclusion of this thesis.

Chapter 2 Spectrum management: Perspective from practice and literature

This chapter addresses a suitable framework for analyzing the spectrum commons and elaborates on the first research question. Exploring the perspective from the ITU and relevant literature, in practice, helps to address the appropriate framework for understanding spectrum commons.

Background

Electromagnetic waves consisting of electric and magnetic components were first explained by James Clerk Maxwell in the 19th century. Their dualistic properties relating to light and particle motion were discovered in the early 20th century, when such waves also began to be used for communication. Radio waves are now also referred to as frequency, radio frequency, radio spectrum, or simply spectrum. This thesis only discusses the wave properties of frequency and wavelength.

An important characteristic of spectrum is that higher frequencies reach shorter distances but have larger carrying capacity. Once frequency is transmitted, it will propagate until its power has dissipated. Physical boundaries cannot stop spectrum at the border of a country. Spectrum management activities have therefore been performed internationally by the United Nations agency ITU.

2.1 Spectrum management by the ITU[7]

The ITU uses the RR as a tool to manage spectrum internationally. The RR is revised every three to four years by WRC. The current RR is RR 2008, which was revised by WRC2007. RR 2008 defines the usable frequency up to 3,000 GHz and divides the uses of frequency into services. There are about 40 services in RR 2008, including terrestrial and space services such as broadcasting, mobile, satellite, maritime, aeronautical, fixed, and earth exploration services. Each service can be shared as primary and secondary services. The primary service uses the capital letter and secondary service uses the lower case letter in the Table of Frequency Allocation in Article 5, RR. Moreover, the secondary service must not cause harmful interference to the primary service and cannot claim protection from harmful interference by the primary service and other secondary service[8].

The RR also divides the world into regions. The regions are defined by lines A, B, and C. Region 1 covers all the European and African countries, Region 2 covers North and South America, and Region 3 covers Asia and Australasia. For example, Sweden is in Region 1, the USA is in Region 2, and Thailand is in Region 3. The regions in RR 2008 are shown in Figure 3.

Reuse of frequency has an indirect relationship with coverage area. A large coverage area has low reuse of frequency, and a small coverage area has high reuse of frequency.

[7] This section is based on the ITU handbook of spectrum management 2005, but it is written in the author's own words.
[8] 5.23-5.32, Article 5, Radio Regulations (2008).

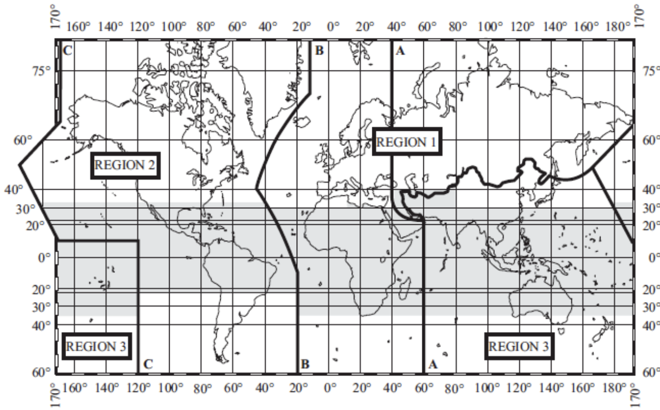

Figure 3. Regions in Radio Regulations 2008[9]

The frequencies are divided into ranges or bands. A wavelength equals its speed of propagation (normally that of light) divided by its frequency ($\lambda = c/f$). Each range of frequency has its own propagation characteristics, as in cases like sea-surface communication, stratospheric scattering, and long-range communication. Table 3 shows the propagation in different frequency bands.

Table 3. Radio frequency propagation[10]

Band	Frequency	Range	Uses	Bandwidth	Interference
VLF	3-30 kHz	1000s of km	Long-range radio navigation	Very narrow	Widespread
LF	30-300 kHz	1000s of km	Same as VLF strategic communications	Very narrow	Widespread
MF	0.3-3 MHz	2000-3000 km	Same as VLF strategic communications	Moderate	Widespread
HF	3-30 MHz	up to 1000 km	Global broadcast and Point–to-Point	Wide	Widespread
VHF	30-300 MHz	200-300 km	Broadcast, PCS, Mobile, Wan	Very wide	Confined
UHF	0.3-3 GHz	< 100 km	Broadcast, PCS, Mobile, Wan	Very wide	Confined
SHF	3-30 GHz	Ranges from 30 km to 2000 km	Broadcast, PCS, Mobile, Wan, Satellite Communication	Very wide up to 1 GHz	Confined
EHF	30-300 GHz	Ranges from 20 km to 2000 km	Microcell, Point-to-Point, PCS, and Satellite, (Personal Communication Services: PCS)	Very wide up to 10 GHz	Confined

[9] Information obtained from 5.2-5.9, Article 5, Radio Regulations (2008)
[10] Table obtained from http://www.ictregulationtoolkit.org/en/Section.2658.html

Spectrum-reusable characteristics vary with service, frequency, location, time, and transmitter power. The following section explains the Table of Frequency Allocation in RR 2008 and represents the allocation of frequency.

Table 4. Example of table of frequency allocation

410-460 MHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
420-430	FIXED MOBILE except aeronautical mobile Radiolocation 5.269 5.270 5.271	
...	...	
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	**432-438** RADIOLOCATION Amateur Earth exploration-satellite (active) 5.279A 5.271 5.276 5.277 5.278 5.279 5.281 5.282	

Table 4 shows the frequency allocation in the 410-460 MHz band. It consists of sub-bands 420-430 and 432-438 MHz. The 420-430 MHz band is worldwide allocation, i.e., the same allocation for all three regions. There are two primary services, indicated by capital letters: fixed and mobile except for aeronautical mobile. There is a secondary service indicated by a lower case letter: radiolocation. There are three footnotes for all the services: 5.269, 5.270, and 5.271.

In the other band, 432-438 MHz, frequency is divided into two sections. The first section is on the left, with frequency uses only in Region 1. There are two primary services: amateur and radio location. There is a secondary service: earth exploration-satellite (active) and it has 5.279A as a specific footnote. There are eight footnotes for all the services, e.g., 5.138 and 5.271. The second section is on the right, with frequency uses in Regions 2 and 3. There is one primary service: radiolocation. There are two secondary services: amateur and earth exploration-satellite (active). Only earth exploration-satellite (active) has 5.279A as a specific footnote. There are seven footnotes for all the services, e.g., 5.138 and 5.271.

Furthermore, the RR works as an international treaty that all ITU Member States are obliged to follow. It is essential to understand the Table of Frequency Allocation in the RR to implement the correct spectrum assignment.

Allocation and allotment are assigned by the ITU, but spectrum is assigned by the NRAs. Besides allocation and allotment, the ITU also regulates by adding footnotes to encourage the use of spectrum commons and improve the efficiency of frequency usage.

2.2 Functional responsibilities and requirements for spectrum management

The handbook, National Spectrum Management (2005), also provides functional responsibilities and requirements of spectrum management, as follows;

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;

i) National liaison and consultation; and

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

Spectrum management planning and regulations

The spectrum management organization should take the advancement of technology as well as the social, economic, and political realties into the development of the implementation plans, regulation, and policies. The Table of Frequency Allocation is the output of the planning and policy-making effort, which reflects 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 the public and government interest and how to share the spectrum.

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, 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 are 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 are 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, if it does not cause harmful interference and protection is not required. Reasons to follow the ITU table are 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 license 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 licenses, 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.

License 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 license, 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, help 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 the 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.

To conclude this section, the ITU provides the overall functional responsibility and requirements for spectrum management organizations, ranging from planning, assignment, monitoring, enforcement, and the supporting unit. The next section concentrates on the rights to use frequency in each spectrum assignment approach, including command-and-control, market-based and spectrum commons, which can be divided into three levels: constitutional choice, collective choice, and operational level.

2.3 The rights to use frequency

As mention in Section 1.4, Chapter 1, an overview of spectrum assignment is given, including three typical approaches: command-and-control, market-based, and spectrum commons. Each approach has a different set of rights – the particular actions that are authorized (V. Ostrom, 1976) – to use the frequency, depending on the rules that refer to the prescriptions that create authorizations (Schlager & Ostrom, 1992).

The adoption of three economic institutions: the operational, institutional, and constitutional level from Field (1992), or the three worlds of action by Kiser and Ostrom (1982): the operational,

collective choice, and constitutional choice level of action, are considered below as a framework to address spectrum commons. Kiser and Ostrom (1982) provide the metatheoretical framework to explain the relationship 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 are 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). In other words, this framework explains phenomena attributed by the aggregation of individual actions that an individual decides to take or strategies (plans of action) based on situations and the individual. The situation depends on rules, events, and community. This framework also captures the dynamic situation by feedback from the phenomena that influence the community, situation, and individuals.

Five working parts of the institutional structure

There are 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. The figure shows the interactions, which are explained below:

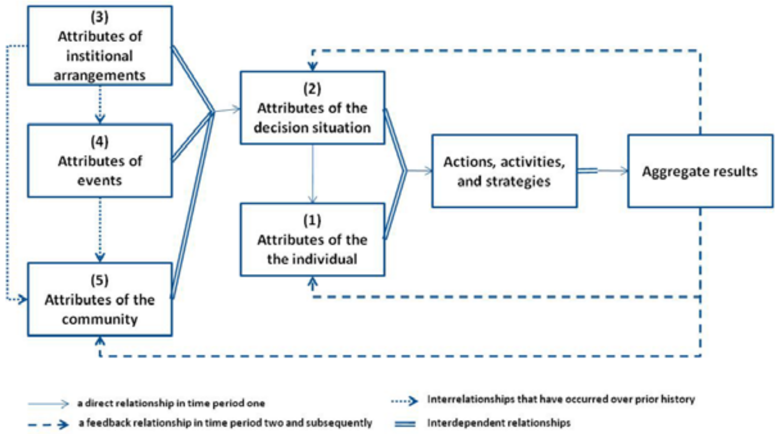

Figure 4. The working parts of an institutional analysis[11]

Attributes of an individual or decision-maker

When an individual wants to take an action or strategy, he or she must know the consequence 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 bounce and use a groundstroke: the outcome of the action is different. In order to predict actions, a minimum of the following assumptions must be made: the level of information about decision situations, the valuation of potential outcomes, the alternative actions within the situation, and the process of calculation to act from alternative actions or strategies.

[11] Source: Kiser and Ostrom (1982, p. 187) Figure 7.1

Attributes of decision situations

The decision situation is determined from interdependent relationships. Relationships depend on more than one input from institutional arrangements, events, and the community. If the environment changes during the game, e.g., a new ball or racket, the decision situations change and influence the player's actions and strategies.

Institutional arrangement

An institutional arrangement is a set of rules to: 1) allow entry and exit conditions for participation; 2) determine allowable actions and outcome from interaction; 3) distribute authority among positions; 4) aggregate joint action; 5) provide procedural rules in complex situation; and 6) identify information constraints.

In order to implement rules, they should be enforced in parallel, depending on the attributes of the community.

The types of rule mentioned above are: 1) boundary rules, 2) scope rules, 3) position and authority rules, 4) aggregation rules, 5) procedural rules, and 6) information rules.

The rules of World Cup football provide an example of institution arrangements, as follows:

1) Boundary rules: which teams can enter the tournament, i.e., qualifying rounds for countries on continents and number of teams on each continent;

2) Scope rules: the size of the football field, ball, and goal area that allow actions and outcomes, and the number of players, the number of player changes, and the number of faults;

3) Position and authority rules: the rights and duties assigned to players, referees, linemen, and coaches;

4) Aggregation rules: how to score, wins, and losses;

5) Procedural rules: how teams proceed through the tournament competition in the first round, second round, third round, quarterfinal, semi-final, and final; and

6) Information rules: how information about the tournament rules, the opponent's strategies, and other matters are conveyed to players.

Attributes of events (public and private goods)

There are four attributes of events 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. An individual consumes separable consumption goods, while more than one individual consume joint consumption goods. Joint consumption goods are defined as public goods that are non-subtractable, while separable consumption goods are private goods.

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 individual can consume with exclusion.

Measurement is the degree of packaging and unitization. Public goods are hard to package and unitize, while private goods are easy to package and unitize. The calculation of private goods is more precise than of public goods.

The degree of choice indicates the consumers' choices 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.

V. Ostrom and E. 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, night clubs, telephone service, cable TV, electric power, and libraries, have a low cost of exclusion and low level of subtractability. Common-pool resources, i.e., 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.

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.

The community

The community includes all stakeholders that directly or indirectly affect the decision situation. The attributes of the community comprise levels of common understanding, common agreement, and distribution of resources.

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

With a common understanding of the rules, real actions must be evaluated. If community members obey the rules, allowable actions, and outcomes, the need for rules 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 on the market or in the community. If resources are distributed equally, a competitive environment arises. Otherwise, oligopoly or monopoly may occur.

Three worlds of action and three levels of analysis

Five working parts explain the relationships of individuals (decision-makers), the decision situation, the institutional arrangement, the events, and the community, as mentioned in Figure 4. The aggregated result not only influences or feeds back to the institutional arrangement in the same world of actions, but also influences the next world of actions. Kiser and Ostrom (1982) suggest that there are three worlds of action: constitutional choice, collective choice, and operational world. The top level is the constitutional choice world. The middle level is the collective choice world. The low level is the operational world. The following figure shows the interaction of the three worlds of action over time.

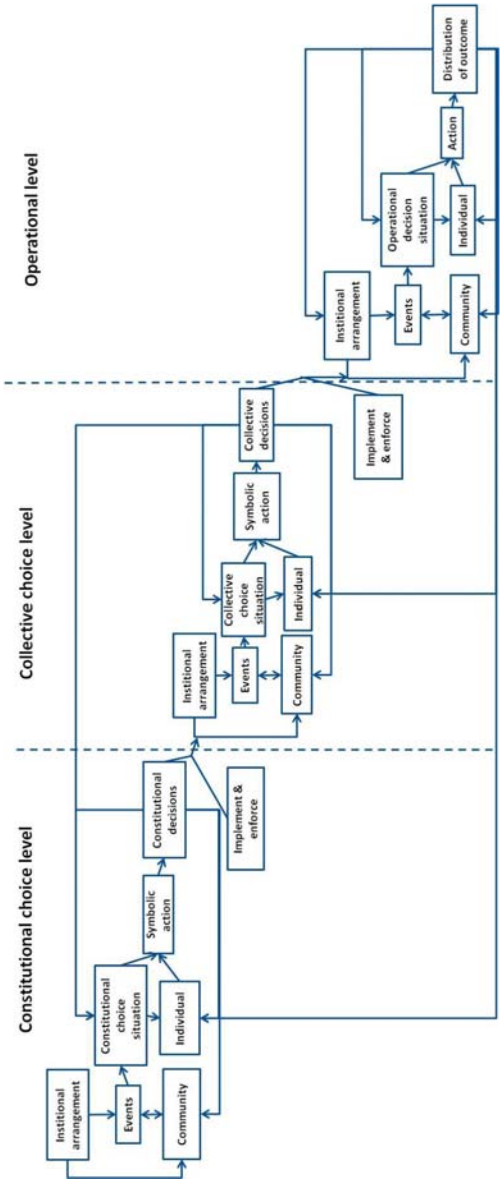

Figure 5. Three levels of institutional analysis[12]

[12] Source: Kiser and Ostrom (1982, p. 207), Figure 7.2

The constitutional choice level also comprises five working parts, with additional feedback from the aggregate result from the collective choice level. At this top level, the decision-maker makes a high-level decision in terms of constitution, e.g., constitution, law, or regulation. This decision is given to the collective choice level.

The collective choice level also comprises five working parts, with additional feedback from the aggregate result from the operational level. At this middle level, the decision-maker makes the operational rule, such as determining, enforcing, continuing, or changing the actions authorized by the constitutional rules from the constitutional choice level.

The operational level also comprises five working parts with the feedback from the aggregate result from its level. At this low level, the actions or strategies of individuals happen according to determined rules from the above level.

Constitutional decisions establish rules as institutional arrangements and their enforcement for the collective choice level. Collective decisions establish institutional arrangements and their enforcement for individual action at an operational level.

As a constitutional decision-maker, 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 join tournaments.

An example of the Maine lobster industry

The three levels of action are applied to the Maine lobster industry by Schlager and Ostrom (1992). The purpose is to explain a conceptual scheme to distinguish a bundle of property rights from the authorized user, proprietor, claimant, and owner of the Maine lobster industry.

The Maine lobster industry comprises the fishing ground, state authority, and fishermen. The fishing ground is the area in the sea that contains the scare resource, in this case, the lobster. There are two types of fishing ground. First, inland, it is the sea associated with the harbor. Second, the open water ground, the sea that is outside the inland area. The state authority is the State of Maine, the community owner. The fishing ground is a common property resource or common pool resource. Fishermen are people who fish in the fishing ground.

There are two types of property rights: *de jure* and *de facto*. *De jure* rights are given by law or regulation and are formal and legalized. *De facto* rights originate from resource users who manage their resources among themselves as *de jure* rights.

Moreover, there are five rights for common pool resources: access, withdrawal, management, exclusion, and alienation. At an operational level, there are access and withdrawal rights. At the collective choice level, there are management, exclusion, and alienation rights. The following table shows the summary of rights at each level.

Table 5. Property rights of common-pool resources[13]

Level of action / Economic	Rights
Constitutional	-
Collective choice / Institutional	Management, Exclusion, Alienation
Operational	Access, Withdrawal

[13] Source: Kiser and Ostrom (1982, pp. 250-251)

Schlager and Ostrom (1992) provide the definition for each right. Access right is the right to enter a defined physical property. Withdrawal right is the right to obtain the products of a resource (e.g., lobster in the fishing ground). Management right is the right to regulate internal use patterns and transform the resource by making improvements. Exclusion right is the right to determine who will have an access right and how that right may be transferred. Alienation right is the right to sell or lease either or both of the above collective choice rights (Schlager & Ostrom, 1992, pp. 250-251).

The State of Maine issues the right to fish, including access and withdrawal rights for authorized users, as *de jure rights* and leaves other rights for the community to decide as *de facto* rights.

Authorized users are fishermen who have rights to access the fishing ground, access right, and obtain lobsters from the fishing ground, withdrawal right, as day-to-day activities. At operational level, fishermen go to the fishing ground and use the fishing equipment at a particular location specified by the claimant in a collective choice.

The claimants determine management rights in terms of which fishing equipment is allowed or prohibited. Where fishermen can fish is set for authorized users at the operational level. This management right is not given by the State of Maine. The claimant has a management right as a *de facto* right.

The proprietor has an exclusion right for who can fish in the fishing ground. This exclusion right is not given by the State of Maine. The proprietor has an exclusion as a *de facto* right.

If, however, no one intends to use the fishing ground, the exclusion right is not practicable. The difference between claimant and proprietor disappears.

Owners have all the rights to use the resource, including an alienation right to rent, lease, sell, or transfer their right to others. In the Maine lobster industry, the State of Maine owns the fishing ground, and fishermen cannot sell or lease their fishing ground. Thus, a *de jure* and a *de facto* right of alienation are not different, because the fishermen do not have an alienation right. A summary of the bundles of rights is shown in the following table.

Table 6. Bundles of rights associated with position[14]

Position / Rights	Owner	Proprietor	Claimant	Authorized User
Access and withdrawal	x	x	x	x
Management	x	x	x	
Exclusion	x	x		
Alienation	x			

Schlager and Ostrom (1992) also refer to the study of the Maine lobster industry by Acheson (1975), Grossinger (1975), and Wilson (1977). The State of Maine has owned the fishing ground since the establishment of the state. It is a *de jure* right. The fishermen have to obtain a license to fish in the fishing ground.

Prior to 1920, the fishing ground was separate from the owners of the harbor along the coast. The fishermen in the harbor determined who could enter the fishing ground, and how, when, and where to fish. The fishermen obtained the management and exclusion rights as *de facto* rights. The fishermen cannot lease, sell, or transfer the right, however, because the alienation right is owned by the State of Maine.

[14] Source: Schlager and Ostrom (1992, p. 252), Table 1

Enforcement within the fishing ground was also down to the fishermen. The sanction for persons violating the communal rules was gear destruction. The fishermen used wooden traps on the sea floor and tied up buoys. If anyone violated the communal rules, the rope was cut. The cutting rope represents the exclusion right to determine who can access the fishing ground.

After 1920, new technology emerged. Motors were installed on boats instead of buoys. Fishermen could harvest lobster in a large area all year long. The traditional wooden trap and buoys could only operate in summer. The fishermen who installed the motors gained more benefit from fishing lobster both inland and on the open water. The traditional inland fishermen could only fish on inland fishing ground.

The new motor technology changed the mode of how to fish. The enforcement of exclusion turned into a lobster war between the inland and open water fishermen. The *de facto* rights for management and exclusion became blurred and were reduced to *de jure* rights – only access and withdrawal rights. In order to solve the problem, the inland and open water fishermen agreed to have a mixture of traditional wooden trap and buoys, and motors. Moreover, the separation between the fishing grounds allowed traditional communal rules, such as cutting the rope, as exclusion rights – *de facto* right and did not allow enforcement, free access as an authorized user – *de jure* right was established.

The enforcement of communal rules that remain in the fishing ground helps fishermen limit the harvest. This exclusion right has encouraged fishermen to invest in institutional arrangements. Fishing grounds that have no communal rules, however, harvest all year long without a limit. Thus, over-harvesting represents as tragedy of commons. Wilson (1977) also reports that controlled fishing gains average 22,929 USD per year, with fishermen in uncontrolled fishing grounds gaining on average 16,449 USD per year.

The Maine lobster industry example proposes property rights for decision-makers, ranging from authorized users, claimants, proprietors, and owners, to understand better the bundle of rights at different institutional levels. Exploring the institution and decision-makers interaction helps to understand the bundle of rights (access, withdrawal, management, exclusion, and alienation right) in a property rights regime.

The economic institution: constitution, institution, and operation, therefore provides a decision-making context. Moreover, the bundle of rights in the property regime also clarifies the differences between decision-making positions.

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. Moreover, the property rights regime from the Maine lobster industry provides the bundle rights to resources, especially the common pool resources.

An analysis of decision-maker at each level of spectrum management reveals the relevant stakeholders shown in the following table.

Table 7. Level of action and stakeholders

Stakeholders	Level of action / Economic institution
Administrator / Regulator / Authority	Constitutional choice
Operator / Provider / Standard Setting Organization	Collective choice / Institutional
User	Operational choice

Constitutional choice level

A high level of regulation conducted directly will influence the collective choice level. In radiocommunication, the constitutional level starts from 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).

The following sample is at constitutional level and includes the allocation of spectrum commons and relevant recommendations, which have been to allocate the spectrum commons frequencies that have been decided to the ITU-RR 2008. There are two main footnotes i.e. 5.138 and 5.150 allocated for industrial, scientific, and medical (ISM) applications. The use of ISM applications is according to ITU-RR No. 1.15. These applications are used to generate and use radio-frequency energy locally for ISM, domestic, or similar purposes, excluding applications in the field of telecommunications. Short-range radiocommunication devices in this band must accept harmful interference (SM.1538-2, 2006) however.

SM.1538-2 (2006) also provides a definition for short-range radio communication devices (SRDs), covering radio transmitters that provide either unidirectional or bidirectional use with low capacity, causing interference with other radio equipment.

Examples of short-range device applications are telecommand, telemetry, voice and video, equipment for detecting avalanche victims, broadband radio local area networks (RLANs), railway applications, road transport, and traffic telematics (RTTTs) equipment for detecting movement and for alerts, alarms, model control, inductive applications, radio microphones, RF identification (RFID) systems, ultra-low power active medical implants (ULP-AMI), wireless audio applications, and RF- (radar) level gauges (SM.1538-2, 2006).

Footnotes 5.138 and 5.150 contain five and seven sub-bands, respectively. In 5.138, there are 6,765-6,795 kHz, 433.05-434.79 MHz in Region 1, 61-61.5 GHz, 122-123 GHz, and 244-246 GHz. These bands are designated for ISM applications. The use of these frequency bands for ISM applications is subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services may be affected. In applying this provision, administrations shall have due regard for the latest relevant ITU-R Recommendations.

In 5.150, there are 13,553-13,567 kHz, 26,957-27,283 kHz, 40.66-40.70 MHz and 902-928 MHz, and in Region 2, 2,400-2,500 MHz, 5,725-5,875 MHz, and 24-24.25 GHz. These bands are also designated for ISM applications. Radiocommunication services operating within these bands must accept harmful interference that may be caused by these applications. The ISM equipment operating in these bands is subject to the provisions of No. 15.13.

A summary of ISM frequencies and the main applications is shown in the following table.

Table 8. Frequencies of ISM bands 5.138 and 5.150[15]

Frequency	Footnote	Bandwidth	Region 1	Region 2	Regions 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 – Eurobalizing
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		✓		Cordless telephone
2,400-2,500 MHz	5.150	100 MHz	✓	✓	✓	WLAN
5,725-5,875 MHz	5.150	150 MHz	✓	✓	✓	WLAN
61-61.5 GHz	5.138	0.5 GHz	✓	✓	✓	Millimeter-wave radar
122-123 GHz	5.138	1 GHz	✓	✓	✓	Non-generic SRDs
244-246 GHz	5.138	2 GHz	✓	✓	✓	Non-generic SRDs

Note: 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.

SM.1538-2 (2006) also suggests the other six bands commonly used for SRDs. These 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. The use of these bands is subject to specific regulation, such as the 402-405 MHz band used for ultra-low, power-active medical implants subject to Recommendation ITU-R RS.1346, the 5,795-5,805 MHz bands, and the 5,805-5,815 MHz band used for transport information and control systems subject to Recommendation ITU-R M.1453.

The use of SRDs depends on national administration regulations. In general, SRDs cannot claim protection from other radio communication services, although some NRAs specify protection due to the nature of the application. SRDs are used on a worldwide basis. The technical and operating parameters, and the spectrum requirement are also found in SM.1538-2 (2006). The SDR regulations should not be more restrictive than necessary.

As in every country, in order to adopt ITU regulations, Thailand puts these footnotes into the National Frequency Allocation. The following table is an example of the Thailand Table of Frequency Allocation in the 2,400-2,500 MHz band.

[15] Source: Radio Regulation (2008), Articles No. 5.138 and 5.150

Table 9. Example of Thailand's Table of Frequency Allocation[16]

Allocation to services		
Thailand		Remark
2,300-2,450	FIXED T17 T21 MOBILE RADIOLOCATION Amateur S5.150 S5.282 S5.396	
2,450-2,483.5	FIXED T21 MOBILE RADIOLOCATION S5.150	
2,483.5-2,500	FIXED T22 MOBILE MOBILE-SATELLITE (space-to-Earth) RADIOLOCATION Radiodetermination-satellite (space-to-Earth) S5.398 S5.150 S5.402	

Countries should also specify domestic regulations for the use of these footnotes. For example, in the USA, the Federal Communication Commission (FCC) specifies rules in Part 15 of the Communication Act. In the European Conference of Postal and Telecommunications Administrations (CEPT), countries adopt recommendation CEPT/ERC/REC 70-03 "Relating to the use of short-range devices (SRD)" for use in these footnotes. In Thailand, the National Telecommunications Commission (NTC) issues the National Telecommunications Commission Regulation of Exemption of Radiocommunication Licences (2007c) for use by short-range devices. Most of these regulations specify the frequency, power limitation, and necessary technical specification for use by these footnotes. The following table shows an example of the technical specification by the FCC and CEPT.

Table 10. CEPT power level[17]

Maximum power level	Frequency bands
100 mW[(1)]	2,400-2,483.5 MHz (for RLANs only) 17.1-17.3 GHz 24.00-24.25 GHz 61.0-61.5 GHz 122-123 GHz 244-246 GHz

(1) 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).

Table 11. FCC general limits for any intentional transmitter[18]

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

16 Source: http://www.ntc.or.th/index.php?option=com_content&task=view&id=3368&Itemid=191 (accessed on May 26, 2010)
17 Source: SM.1538-2 (2006, p. 9) Table 3
18 Source: SM.1538-2 (2006, p. 9) Table 4

The ITU regulations and the national regulation are both at the constitutional level, providing a broad guideline for collective-choice or the institutional level.

Collective choice or institutional 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, i.e., 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. The 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. PAN can connect mobile phones, faxes, printers, computers, laptops, GPS receivers, video recorders, and cameras.

At the 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 which devices can access their network.

Operational level

At this level, the users have choices 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.

After understanding the three worlds of action from the decision-maker at each level: constitutional choice, collective choice, and operational levels, the following discussion considers the right to use frequency. It is related to the right to use the frequency from relevant literature.

The difference between market-based approach (which assignee has property rights over the spectrum) and spectrum commons approach is explained by Benkler (2006). Benkler explains these two schemes as "I can buy an easement from my neighbor to reach a nearby river, or I can walk around her property using the public road that makes up our transportation commons."

According to the observations by Hardin (1968), spectrum commons allows use of the resource until it is overused or overpopulated, i.e., the tragedy of the commons. Hardin (1968) also suggested that this problem cannot be solved by technical means, except by implementing the concept: "freedom is the recognition of necessity." This means that there should be constraints to control resource use. This reflects the basic characteristic of spectrum commons, i.e., unlimited access to resources but with constraints. The proposal of eight design principles by E. Ostrom (1990) is another way of solving the tragedy of commons. There is an opposing view from Heller (1998), however, of an underused resource with multiple owners with exclusive rights, as a new property right defined by the government. Heller (1998) also suggested managing this underused resource by concentrating on the content of a property bundle rather than on the clarification of rights.

If frequency (or spectrum) is regarded as property, there are two main kinds of property: public and private. Heller (1999) defined the boundaries of private property that lie between the commons and the anti-commons. The public also claimed property when the property could physically be monopolized by private persons, and the properties themselves were most valuable when used by indefinite and unlimited numbers of persons (Rose, 1986). In terms of property, the spectrum commons have no exclusivity, alienation, or management (Wang, 2009). Another idea by Werbach (2004) regards "Supercommons." It has open entry and open boundaries, a white space which encouraged different business models to use spectrum with impermissible interference. The concept of Supercommons is hard to implement and goes far beyond the spectrum commons.

Another interesting concept by Faulhaber (2006), and Faulhaber and Farber (2002) proposed a mix of market- and commons-based regimes to meet future needs. E. Noam (1995) and (1998) suggests a similar mix with full openness to entry for all users and a dynamic access fee payment, which is automatic by a clearing house. The access fee depends on the demand and supply conditions at the time of access. This idea is opposed by Brennan (1998) and Hazlett (1998) who argue that it would take a long time to prove the open-access concept and that the mechanism would duplicate the efficiencies of the market and make the spectrum resource under-utilized.

The practical discussion on how to implement spectrum commons is also interesting. Benkler (1998) proposes a model based on non-owned components and an information infrastructure based on unlicensed wireless devices, such as commons, and suggests that the computer hardware and software market is necessary to operate in an unlicensed environment that will drive the innovation and deployment of the infrastructure. Werbach (2003) suggests that regulators should make more unlicensed spectrum available through a dedicated open-access band with low-power underlay and opportunistic sharing to overcome spectrum scarcity. Lehr and Crowcroft (2005) provide a concept to manage spectrum commons by implementing an appropriate protocol that includes liquidity and is decentralized/distributed, adaptive, and flexible. Peha (2005) suggests that a licensing scheme works better with a QoS requirement and that an unlicensed one works better for a wireless connection between a computer and cable modems.

Bundle of rights to use frequency

The example of the Maine lobster industry provides an understanding of property rights regimes, including access, withdrawal, management, exclusion, and alienation rights such as authorized users, claimants, proprietors, and owners.

Considering the right to use 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 phones. The phone connects to the base station via a selected frequency. The selected frequency is occupied by users. 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 the management and exclusion right to define how, when, where,

and who can access the frequency. For example, when the 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 7, stakeholders are divided into the three levels. Applying the idea from Table 6, the bundle of rights of each stakeholder reveals the rights to use frequency shown in Table 12.

Table 12. Bundles 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

At the 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, the frequency assignment by 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 by 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 the collective choice or institutional level, the management and the exclusion right 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 the operational level, the access and withdrawal right 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 13 shows the rights to use frequency and the regulated level.

Table 13. 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

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. Assignee has inflexibility 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 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.

In conclusion, the economic institution or level of action, and the property rights regime from the Maine lobster industry provide a starting point for the discussion. The economic institution or level of action has three levels: constitutional, institutional or collective choice, and operational levels that define and divide the decision-making positions. The property rights regime explains the bundle of rights, including access, withdrawal, management, exclusion, and alienation rights. The economic institution and property rights regime both explain the Maine lobster industry, for which the common pool resource is the fishing ground.

In the Maine lobster industry, the decision-making positions are authorized user, claimant, and proprietor and owner. Property rights vary from access and withdrawal, management and exclusion to alienation right.

By analogy, frequency is a scarce resource similar to the fishing ground. The economic institution comprises the stakeholder at each level. The authority, administrator, or regulator is at the constitutional choice level that provides the law and regulations. The operators, providers, or standard setting organizations are at the collective choice level. They provide network rules, namely, how, when, and where to use the frequency, and determine who can use the frequency. The user is at the operational level, which follows the rules from the collective choice level.

The bundled rights to use frequency can also be divided into five rights, as mention in the property rights regime in the Maine lobster industry. These are access, withdrawal, management, exclusion, and alienation rights. The access and withdrawal rights to use 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 the transceivers combine access and withdrawal rights to use the frequency at the same time.

At the 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 specified username and password.

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

At the 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 on which the alienation right is decentralized. If the regulator holds the alienation right, the approach iscommand-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 right 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.

2.4 Summary

This chapter addresses a suitable framework, derived from the three worlds of action and property rights regime, to understand the institution of spectrum commons. The analysis of the decision-maker and decision situation at each level helps us to understand the interaction between stakeholders. The property rights regime provides the right to use frequency from the study of the Maine lobster industry. These findings address a suitable framework for analyzing different types of spectrum commons (RQ.1).

Chapter 3 Methodology

The discussion of method considers specific methods that concern the type of data and the data collection method, research design, method of data analysis, and methodology. This thesis uses mostly non-numeric data and archival research design. It also uses deductive and inductive approaches.

3.1 Type of data and data collection method

In this thesis, the problem is on the conceptual level of telecommunications policy. Suitable data should contain the rationale and clearly describe the interactions between the regulator and other stakeholders involved in considering spectrum commons in the Thai context. Non-numeric data may be appropriate, because numeric data may not elaborate on the institution of spectrum commons, especially, the way it is. Moreover, it is hard to quantify policy matters in terms of numeric data. The conceptual part of the thesis relates to policy decisions by exploring the available documents containing policy decision-making.

In order to use documents as data in this thesis, Flick (2009) provides guidelines on how to select suitable documents with criteria: authenticity (primary or secondary data), credibility (official or personal), representativeness (typical or non-typical), and meaning (clarity of text).

The authenticity of documents depends on the source of the data. If the data come from a primary data source and they are documented by a first witness, then the authenticity is high. If the data come from a secondary data source and they are documented from primary data, the authenticity of the document is medium or low. The level of credibility of a document depends on the type of document. If the data are from an official document, the credibility is high. If the data are from a personal document, the credibility is low. The degree of representativeness is measured by the type of document. If the document was drawn up for a specific purpose, the representativeness is non-typical. If the document was drawn up for a general purpose, the representativeness is typical. The level of meaning of the document depends on the clarity of the document. For example, primary data should be clearer than secondary data. These concepts are applied to this thesis and through each research questions as shown below.

Research question 1 – What is a suitable framework for analyzing different types of spectrum commons? The primary source is obtained from Kiser and Ostrom (1982) and Schlager and Ostrom (1992). The three levels of action by Kiser and Ostrom (1982) also contribute to a metatheoretical framework that explains the relationship between an institutional arrangement and individuals in terms of transformation of rules for individual behavior. The article by Schlager and Ostrom (1992) explains the conceptual scheme to distinguish a bundle of property rights from the view of the decision-makers. These two main pieces of literature help to explain and describe the institution of spectrum commons. They are original works intended to generalize the framework for many fields and typical representativeness.

Research question 2 – What type of spectrum commons has been used in Thailand? The necessary document includes the history of the institution and how it developed. The research presented here is original and unique and is based on personal archival research. The primary data come from the minutes and summary of minutes of the National Frequency Management Board, the archive of the International Telecommunication Union in part of Thailand (Siam), the history of the Post and Telegraph Department (PTD) at its 100-year anniversary (1983), the regulations including the Radiotelegraph Convention, the Radiotelegraph Act, the Radiocommunication Act, Sound and

Broadcasting, the Ministerial Regulations, the National Telecommunications Commission Regulations, the Constitution of Thailand, the Act of Establishment of the National Broadcasting Commission and the National Telecommunications Commission, the Telecommunication Business Act, and the PTD's Regulations. Additional interviews were conducted with people who helped to find the right documents and confirm the requested incidents.

The number of the WLAN devices collected from the PTD is the old archive of type approval of radiocommunication devices. There was a manual count, item by item, of all radiocommunication devices that were submitted for the type approval process. Each record of a type-approved radiocommunication device was from the PTD's official issue by issue. Each issue can contain one item or a thousand items, depending on the applicant's requirement. The record of type-approved radiocommunication devices was made manually and was contained in several big logbooks. First, only the 2,400-2,500 MHz band was filtered from the whole logbook, from 1996 to 2004, item by item. This involved a large amount of work. The second filtering from all the radiocommunication devices operating in the 2,400-2,500 MHz band was done by counting only WLAN devices. It includes the access point, portable unit, circuit board, and PCMCIA or USB module that enables the creation of an access point. The data exclude the Wi-Fi module in the mobile phone. The result of the second filtering was put into an Excel file for the database.

The number of the WLAN collected from the Customs Department of Thailand has been available from 2001 to now. The item code of the WLAN has been requested by formal letter from the Customs Department via the Customs Customer Service. After obtaining the item code, the manual count from the online database at the Customs Department was done month by month in order to construct the Excel file as a database.

The history of spectrum management in Thailand is an original work that collects the important events from the above-mentioned sources. Exploring the laws and regulations, double-checking the minutes of board meetings, and interviewing the relevant persons help to confirm the crucial moment of history of spectrum management in Thailand.

Research question 3 – What are the advantages and disadvantages of spectrum commons in general? The primary and secondary data come from literature, including Cave (2007), Chaduc and Pogorel (2008), Mark and Williams (2007), Tonge and Vries (2007), and from the public consultations of the Radio Spectrum Policy Group on "Aspect of a European Approach to Collective Use of Spectrum" posted on June 10, 2008 and closed on September 29, 2008. There are nine respondents, including the ARD-ZDF, Deutsche Telecom/T-Mobile, the EICTA, GSMA Europe, Metil Telecom consultants, Microsoft, Telefónica, PWMS Manufacturer Group, and Delft University of Technology. The result of this public consultation was posted on November 19, 2008.

Data from the public consultation contain the advantages and disadvantages of spectrum commons in European countries. Finding important dimensions for the public in Europe may also be relevant to other countries. The literature also helps to categorize the most important issues associated with the consideration of spectrum commons and the consequences of applying it.

Research question 4 – How can the benefits and costs of spectrum commons be measured? The data come from the work by Campbell and Brown (2003) and provide a benefit and cost analysis with and without a project for the decision-maker. If the decision-maker undertakes the project, how much of the scarce resource will be allocated to this project and what the value of the project will be. If the decision-maker does not undertake the project, the same amount of the scare resource can be allocated to alternative uses.

Data also come from the study of Indepen (2006). This work provides details on the use of a benefit and cost analysis for spectrum assignment and, within this, exploits the consequences of applying spectrum commons. Indepen (2006) is measuring the valuation of unlicensed applications in the UK from 2006 to 2026.

The view of using the engineering value from Sweet et al. (2002) also provides the valuation of spectrum as a cost saving in the infrastructure of the network operator.

These three pieces of literature indicate practical ways of measuring the benefits, costs, and consequences of spectrum commons. Practical possibilities of introducing spectrum commons in Thailand will be discussed and a similar approach considered and applied to Thailand.

Research question 5 – What are the implications of implementing spectrum commons in Thailand? The information comes from the results of the four previous research questions. Combining these provides suggestions and implications for implementing spectrum commons in Thailand and describes the consequences and expected outcomes of certain implementation strategies.

To conclude this section, the primary data from the International Telecommunication Union, the Post and Telegraph Department, and the National Telecommunications Commission provide a high degree of authenticity. Moreover, most of the information comes from official documents from the International Telecommunication Union, the Post and Telegraph Department, and the National Telecommunications Commission. It has a high level of credibility. The representativeness of the documents depends on the purpose of creating them. The purpose may have been general (typical) or specific (non-typical). In this thesis, the documents are specific. The representativeness of this thesis is also mainly non-typical. Furthermore, the meaning of the document is measured by the clarity of the document. It is reflected in the level of understanding of the document that communicated the message from authors.

3.2 Research design

The main research strategy is archival analysis, including history, content analysis, and literature critique (Lee, 1999; Miles & Huberman, 1994). In order to fulfill the research questions, data will be gathered from the archive of the Thai regulator, including the regulations and the minutes of meetings, and relevant literature, including journals and books.

The first research question provides a suitable framework for analyzing different types of spectrum commons. Analyzing the conceptual analysis of the three levels of action model by Kiser and Ostrom (1982), and the property rights regime and natural resources by Schlager and Ostrom (1992) provides a metatheoretical framework. This framework addresses the relationship between the institutional arrangement, the individual, and the bundle of property rights regime. The benefit of discriminating between the three levels of actions includes important data on the relationship between the constitutional choice, collective choice, and operational levels. This describes the relationship between the decision-maker and the decision situation for each of the levels. This interaction helps to describe the institution that needs to be considered in this thesis. The bundle of property rights regime addresses the rights that are relevant to the resources and stakeholders. This helps to describe the right to use frequency.

The second research question uses the framework from the first research question to understand the institution of spectrum commons in Thailand. The thesis uses the deductive approach of two theories: the property rights regime and three levels of action and applies them to the rights to use frequency of

spectrum commons in Thailand. The possible forms of spectrum commons in Thailand are induced from the rights to use frequency of spectrum commons, indicating three forms of spectrum commons, including public commons, private commons, and unlicensed.

The third research question uses relevant literature (Cave (2007), Chaduc and Pogorel (2008), Mark and Williams (2007), and Tonge and Vries (2007)) and the Radio Spectrum Policy Group's (RSPG) public consultation on aspects of the European Approach to "Collective Use of Spectrum," 2008, as sources of data to analyze many aspects of the advantages and disadvantages of spectrum commons, including the relevant stakeholders' viewpoint and summing up the framework to analyze a suitable time to implement spectrum commons. The method of data analysis is document analysis, especially content and hermeneutics analysis. The methodology has been adopted by Bryman and Bell (2007) and has been used successfully to analyze information generated from the social factor, as stakeholders in public consultations on spectrum commons.

The fourth research question deals with conceptual benefit and cost analysis (Campbell & Brown, 2003; Indepen, 2006; Sweet, et al., 2002). This shows how the overall concept of valuating spectrum commons is applicable. Using the existing framework, the thesis uses the deductive approach of benefit and cost analysis. In the case of Thailand, however the adjusted framework can be treated as constructive.

The fifth research question uses the output from the previous research questions to indicate the impact of spectrum commons applied to the case of Thailand.

3.3 Approach

The three levels of action by Kiser and Ostrom (1982), and the property rights regime and natural resources by Schalger and Ostrom (1992) use the existing theory in the first research question. Moreover, the concept can be applied to analyze the institution of spectrum commons in Thailand with a deductive approach. Furthermore, the empirical results from the history of spectrum commons are used to induce the type of spectrum commons in Thailand.

The advantages and disadvantages of spectrum commons have been drawn from the public consultation of the Radio Spectrum Policy Group on spectrum commons in European countries in 2008. The research into each contribution by nine respondents from academia, manufacturers, end-users, operators, and consultants has been investigated in order to categorize the common view or idea of spectrum commons in consultation. Moreover, the Radio Spectrum Policy Group has also summarized the main ideas and responded to the public consultation in a final report. The final report and relevant literature have been explored to create a point of discussion on the view of advantages and disadvantages of spectrum commons and further issues to be considered when implementing spectrum commons. The output of a discussion on advantages and disadvantages induced from public consultation and relevant literature is categorized by stakeholders.

Furthermore, the concept of the benefit and cost analysis from Campbell and Brown (2003), Indepen (2006), and Sweet et al. (2002) is used for the valuation of spectrum commons in Thailand by a deductive approach from this literature and a constructive approach to Thailand.

The methodology of the thesis is therefore both deductive and inductive. It is deductive because the right to use frequency and the valuation of spectrum commons are deduced from existing theory, including three layers of action, the property rights regime and natural resources, and a benefit and cost analysis. It is inductive because the type of spectrum commons, and the advantages and disadvantages are induced from the history of spectrum commons in Thailand and a public consultation in Europe. The possible forms of spectrum commons in Thailand are induced from the rights to use frequency.

3.4 Summary

The type of data used in this thesis consists of documents (non-numeric) collected from the International Telecommunication Union, the National Telecommunications Commission, and the Post and Telegraph Department, as well as academic literature, which has a high degree of authenticity and credibility. The thesis uses documents as data for the data collection method.

This thesis uses archival analysis for data analysis, including history, content analysis, and literature critique. Non-numeric data and archival analysis are both used in the qualitative method.

The methodology of this thesis is both deductive and inductive, as it uses existing theories: layers of action, property rights regime and natural resources, and a benefit and cost analysis to deduce the results. The type of spectrum commons, and the advantages and disadvantages of spectrum commons are induced the from author’s perspective.

Finally, the thesis uses mixed methods, with quantitative methods as the primary method and archival research design as the qualitative method, which uses deductive methodology, archival analysis, and non-numeric data as document.

Chapter 4 The history of spectrum assignment in Thailand[19]

This chapter elaborates on the second research question: What type of spectrum commons has been used in Thailand? From the understanding of the framework for the right to use frequency and the interaction by the stakeholder in frequency management activities in Chapter 2, the concepts provide a framework to explore the history of spectrum management in Thailand. This chapter provides a chronological account of how spectrum assignment, especially spectrum commons, developed in Thailand with regard to the regulated level of the decision-maker for spectrum assignment.

4.1 The context of examining the history of spectrum management in Thailand

By understanding the history of spectrum assignment in Thailand, the development of right to use frequency originates from the regulator for command-and-control approach with full rights to use frequency as exclusive right to use frequency. On the other hand, the spectrum commons is also developed with two stages: authorization and unlicensed.

In Thailand, telecommunications developed from wireline to wireless communication: from telegraph, telephone over a 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, especially 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 according to the international treaty (The International Telegraph Convention (1906) and (1912)). Most of the users were government agencies. There was otherwise little usage and low demand, so there was no congestion of the use of radiocommunication.

After the Radio Act was enacted, all radiocommunication activities were prohibited, except with authorization granted by the authority in terms of radiocommunication licences. The authority was the 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 allocation. Thus, on March 26, 1974, the National Frequency Management Board (NFMB) was established to determine the national technical standard, and control, assign, and register frequency, examine the standard of radiocommunication devices, create an efficient procedure, 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 acted as the approval board before the PTD issued radiocommunication licences. The NFMB operated until 2002, while the PTD was transferred to the Ministry of Information and Communication Technology.

On October 1, 2004, the National Telecommunications Commission (NTC) was established, and the PTD was dissolved by law to become the Office of the NTC on January 1, 2005. A new era of

[19] This chapter is a revision of Ard-paru (2010).

telecommunication with an independent regulator, the NTC, was founded in order to change the authorization process into a licensing process. Not only the technical aspects, but also social and economic aspects were included in the licensing process.

The development of spectrum assignment started from command-and-control, though the spectrum commons (unlicensed devices) initiated by the NFMB delegated some authorities to the PTD and issued the Ministerial Regulation for Exemption of Radiocommunication Licences. The use of a market-based approach for frequency assignment was mentioned at the NFMB. Unfortunately, it was not a success.

4.2 No Radio Act[20]

At the initial stage, before the establishment of the Radio Act, decision-making for frequency assignment belonged to His Majesty the King of Thailand, according to the monarchy system before December 10, 1932. His Majesty the King transferred the authority to a government agency to provide radiocommunication services. Without domestic regulations, His Majesty the King used the international treaty, the International Telegraph Convention, as an institutional arrangement. The use of frequency during this period was infrequent. The radiocommunication service was primarily a wireline replacement, i.e., a radiotelegraph service. The radiotelegraph was used within the government agency and extended to the general public at a later stage.

The first attempt to build a telegraph infrastructure was made during the reign of King Rama X in 1869 by English telegraph technicians. It failed to meet the deadline however. In 1875, the Thai government's Ministry of Defence built the first telegraph infrastructure from Bangkok to Samuth Pragran, with a range of 45 kilometers. Moreover, the first telephone using the telegraph infrastructure was established between Bangkok and Samuth Pragran to report on boat traffic at the seafront. At the early stage, communication was limited to within government agencies. The general public had telegraph service provided on July 16, 1883. The building of a telegraph infrastructure with zinc-coated iron wires was extended through the main provinces in Thailand and connected to those of neighboring countries.

On August 4, 1883, the Post Department and the Telegraph Department were established. On April 21, 1883, however, Siam (now Thailand) filed an application for membership of the International Telegraph Union (which changed its name to International Telecommunication Union, ITU, in 1932), and this obliged Thailand to adopt its conventions and constitution.

In 1886, the Ministry of Defence transferred the telephone and its related tasks to the Telegraph Department to provide telephone service for the general public.

On July 19, 1898, the Post Department and the Telegraph Department merged to form the Post and Telegraph Department (PTD) under the Ministry of Interior and provided mainly postal and telegraph services.

In April 1903, the first attempt to use radiotelegraph communication took place between Koh Sri Chang, Chol Buri and Phu Khao Thong, Wat Sa Ket, and Bangkok and it was granted by the Ministry of Interior. It failed however.

[20] This section is mainly based on the Post and Telegraph Department (1983), the registration letter of May 29 (1883), and the International Telegraph Convention (1906) and (1912).

In 1906, Thailand participated in the First Radiotelegraph Conference and signed the radiotelegraph convention in Berlin, Germany. In 1907, the first successful radiotelegraph communication in Thailand was conducted by the Army and the Navy.

In 1912, Thailand participated in the Second Radiotelegraph Conference, London, which revised the First Radiotelegraph Convention to strengthen measures relating to the improvement of safety at sea by means of radiotelegraphy, after the tragedy of the Titanic. Thailand also adopted the word "radio" for use in Thailand and translated it into the Thai language in 1914.

To summarize this period, radiotelegraphy as radiocommunication was only used in government agencies and was strongly restricted. The use of the radiotelegraph was adopted at the International Radiotelegraph Conventions in both Berlin and London in 1906 and 1912, respectively, however. Frequency assignment was made by the authority, using the international treaty as guidance on a first-come first, served basis. The use of radiotelegraphy was limited for the general public, because of the lack of equipment and supporting regulations.

A summary of significant events is shown in following table.

Table 14. Period before the Radio Act

Time	Event
1875	The first telegraph infrastructure from Bangkok to Samuth Pragran was built.
1883	The first telegraph service for the public was launched.
1883	Siam became an ITU member. The Post Department and the Telegraph Department were founded.
1898	The Post and Telegraph Department was founded.
1906	Thailand signed the first radiotelegraph convention in Berlin, Germany.
1907	The first radiotelegraph communication in Thailand was established.
1912	Thailand signed the Second Radiotelegraph Convention in London, UK.
1914	Thailand adopted "radio" for use in the Thai language.

4.3 The Radio Act –command-and-control[21]

At this stage, His Majesty the King delegated his authority to the government agency, as stated in the Radio Act. The decision-maker for frequency assignment changed from time to time depending on the amendments to the Radio Act. The Radio Act empowered the PTD as the decision-maker. The PTD also endorsed the international treaties, such as the International Radiotelegraph Convention, as domestic regulations. The use of radiocommunication was prohibited, unless the users obtained approval from the authority. The use of radiocommunication services was highly regulated by the authority in terms of the conditions of use and inflexibility in terms of change. Only government agencies were allowed to access frequency. The government agency still provided radiocommunication service directly to the general public. The government agency had the role of administrator and operator at the same time.

The Radio Act in Thailand was enacted on April 28, 1914, in the Radiotelegraph Act. The Act empowered the PTD, under the Ministry of Transport, to control the use of telephony over radiotelegraphy on ships on the Thai seas, ashore, and inland in Thailand. The use of radiotelegraphy endorsed the International Radiotelegraph Convention, London, 1912, as a necessary regulation. All

[21] This section is mainly based on the Post and Telegraph Department (1983), the Radiotelegraph Act (1914, 1919, 1921 and 1930), the Radiocommunication Act (1935, 1938, 1940, 1942, 1948 and 1954), the Radiocommunication Act (1955, 1961, and 1992), and the Sound and Broadcasting Act (1955, 1978 and 1987).

radio stations had to be approved by the Minister of Transport prior to installation, except for use by the Army and the Navy. The use of radiotelegraphy on commercial ships was only for distress and safety. The second amendment of the Radiotelegraph Act was in 1921 in order to allow ships on Thai seas, including the Koh Si Chang area, to use radiotelegraph communication temporarily with approval of the Minister of Transport. On September 14, 1930, the third amendment of the Radiotelegraph Act was enacted in order to decentralize power from the government to the Minister of Commerce and Transport to allow the general public to have radiotelegraph receivers, including trading, possessing, using, and installing licenses.

During World War I (WWI), all uses of radiotelegraph communication within Thai territory were prohibited, while Thailand declared a neutral position on August 17, 1914 until May 22, 1919, when cancellation of the prohibition on the use of radiotelegraph communication was enacted because Thailand joined the Allies in WWI. Radiotelegraphy on board Allied and neutral ships could be operated over Thai territory.

In 1927, the Navy transferred two radiotelegraph stations, Sa La Daeng and Songkhla, to the PTD. Fifty radiotelegraph stations were also built in provinces and districts throughout Thailand.

In the same year, the Minister of the Ministry of Commerce and Transport conducted a pilot broadcasting station and arranged a national radiocommunication meeting in Thailand in order to allocate frequency between the PTD, under the Ministry of Commerce and Transport; the Ministry of Navy; the Ministry of Army; and the Department of Aircraft.

On January 15, 1928, international radiotelegraphy was conducted by the PTD with a 20,000-watt vacuum tube transmitter and high frequency (HF) between Bangkok and Berlin.

On February 15, 1930, a permanent broadcasting-sound station was established at Phayathai Palace (Radio Bangkok at Phayathai) with 2,500 watts of transmitting power, 350-meter wavelength or 826.44 kHz, 41-meter wavelength or short wave radio, and a 40-meter antenna tower. The call signs[22] of this station were HSP1 and HSP2.

In 1930, the PTD established two aeronautical radio stations at Phisanulok and Don Muang to facilitate aeronautical activity, including weather news broadcasting, and direction and location finding. In 1934, the PTD established three additional aeronautical radio stations at Nakhon Ratchasima, Udon Thani, and Surat Thani. In 1938, the PTD established the last aeronautical radio station at Koh Samui. In 1940, the PTD established the radio beacon station north of Don Muang for navigation systems and transferred all aeronautical activities to the Department of Civil Aviation and Aerothai Company Limited in 1948.

On February 1, 1935, a new Radiocommunication Act was enacted to replace the Radiotelegraph Act in order to update the regulation and cope with the change of technology in radiocommunication. The Act empowered the PTD, the Ministry of Commerce, to control the use of broadcasting receivers, including trading, importing, possessing, using, making licences, and the use of radio stations on board ships and aircraft. The majority of this Act related to broadcasting service. There were five amendments to this Act in 1938, 1940, 1942, 1948, and 1954. In 1938, additional power was given to the Prime Minister, apart from the Minister of the Ministry of Commerce. In 1940, the definition of repair was included in the licence. In 1942, there was an extension to the date line from March 31 to

[22] The call sign is the identifier of the radiocommunication station that supplies a territory or geographic area. All stations open to international public correspondence, all amateur stations, and other stations that are capable of causing harmful interference beyond the boundaries of the territory or the geographical area in which they are located shall have call signs from the international series allocated to its administration, as given in the Table of Allocation of International Call Sign Series in Appendix **42** (Nos.19.28A and 29 -RR2008).

December 31, and a change in responsibility for the Minister of Transport. In 1948, additional power was given to the Minister of Transport to issue special licenses for safety for civil aviation. In 1954, a legal person was added by the Cabinet approval, for exemption from the Radiocommunication Act in order to promote broadcasting service in Thailand.

On April 1, 1939, the PTD transferred the broadcasting activities to the Public Relations Department.

In 1945, during World War II, the power plant in Bangkok was bombed, so the Minister of Transport requested that the PTD prepare a spare broadcasting transmitter for temporary use and experimental purposes. It was named HS1PN. On June 5, 1946, the HS1PN extended its frequencies to 4755, 7022, 920, and 5955 kHz.

On February 8, 1955, two important acts were enacted: first, the new Radiocommunication Act and, second, the Sound and Television Broadcasting Act.

The Radiocommunication Act of 1955 revoked all previous acts regarding radiocommunication and prohibited the use of radiocommunication equipment, the operation of radios, and the reception of international news for commercial purposes except with authorization granted by officials. According to this Act, the licences were for making, importing, possessing, using, exporting, and installing. Moreover, the radio operator and international news reception for commercial purpose licence was also included. This Act empowered the Minister of Transport to authorize the aeronautical radio stations and empowered the PTD to control and assign frequency to stations. The Act limited the use of frequency to the PTD, the Public Relations Department[23], the Ministry of Defence, and other specified government agencies in the Ministerial Regulations. There were two amendments to the Act, in 1961 and 1992. In the 1961 amendment, permission was granted to all government agencies to use radiocommunication equipment. In the 1992 amendment, further additions were made: a new trading licence, the empowerment of the PTD to authorize the installation of radio stations, and the empowerment of the Minister of Transport to exempt radiocommunication licences for some services and charge the licensee a frequency usage fee.

The Sound and Television Broadcasting Act 1955 allowed the general public to use broadcasting receivers with a one-time registration for the lifetime of the receiver, and separated the Broadcasting Act from the Radiocommunication Act. This Act prohibited transmission of sound and television broadcasting services, as well as making, possessing, importing, exporting, and trading receivers of sound and television broadcasting, and using radiocommunication equipment, except with authorization granted by officials or specified in the Ministerial Regulations. The licences according to this act were for transmitting sound or a television broadcasting service, making, possessing, importing, exporting, and trading. This act empowered the Prime Minister and appointed the Public Relations Department to administer the act. The act was not enforced, however, for the Public Relations Department, the PTD, the Ministry of Defence, and other specified government agencies in the Ministerial Regulations. Thus, the Act controlled only the use of sound and television broadcasting receivers. Transmitters of sound and television broadcasting fell under the Radiocommunication Act and its amendments. There were three amendments, in 1959, 1978 and 1987. In the 1959 amendment, permission was given for the general public to possess, import, export, and trade sound and broadcasting receivers without related licences. In the 1978 amendment, there was a revision of licence fees according to the current economic situation. In the 1987 amendment, there was an addition of media in sound and television broadcasting services including cable TV.

[23] The Public Relations Department is the government broadcasting agency with both regulator and operator roles.

On June 24, 1955, a television broadcasting station was established at Pang Khun Prom Palace with the National Television System Committee (NTSC) system of Radio Corporation of America (RCA) from the USA. It used Channel 4 for this station. On June 14, 1959, the second television broadcasting station was established and used Channel 7 with NTSC system.

To summarize this period, both the Radiocommunication and Broadcasting Acts were developed. With regard to the Radiocommunication Act, there were three acts, including the Radiotelegraph Act 1914, the Radiocommunication Act 1935, and the Radiocommunication Act 1955. The purpose of the Radio Act is to cover the areas that wireline communication cannot reach in the initial stage. The need for distress and safety communication at sea and in the air also makes the implementation of radiocommunication mandatory. The first radiocommunication was ship-to-shore, which developed into aeronautical radio stations for aircraft and grew into the mass communication of the sound and television broadcasting service. With regard to the Sound and Television Broadcasting Act, only the use of broadcasting receivers and content management was controlled, leaving the installation of transmitting stations to the Radiocommunication Act. The majority of radiocommunication usage only occurred in the government agencies. The priority was national security, distress and safety at sea and in the air, followed by broadcasting.

A summary of significant events is shown in following table.

Table 15. Period of Radio Act

Time	Event
1914	First radio act – the Radiotelegraph Act
1928	First international radiotelegraph – Bangkok and Berlin
1930	First permanent sound broadcasting station – Phayathai Palace Two aeronautical radio stations – Phisanulok and Don Muang
1935	The Radiocommunication Act enacted
1955	The Radiocommunication Act and the Sound and Television Broadcasting Act were enacted. The first television broadcasting station – Channel 4 Pang Khun Prom Palace

4.4 The National Frequency Management Board –command-and-control[24]

After the government delegated decision-making for frequency assignment to the PTD via the Radio Act, the government decided to change its positions on the telecommunication industry. The government decided to separate the role from a solely integrated government agency, including the decision-maker for frequency assignment, and provide service to the general public, to have separate functions: a decision-maker for frequency assignment and providers. The decision-maker was the PTD, which had its responsibilities reduced to frequency management only. Government-established state enterprises were to provide service to the general public, such as Telephone Organization of Thailand (TOT) and the Communication Authority of Thailand (CAT).

All of the frequency assignees were government agencies and state enterprises however. The Radio Act only empowered the PTD as decision-maker for frequency assignment. There was much political intervention by government agencies. Using cabinet approval, the government therefore set up the NFMB to decide on frequency assignment over the PTD. The authority centralized the regulated level however.

[24] This section is mainly based on the Post and Telegraph Department (1983), minutes of the meeting of the National Frequency Management Board (1974 - 2000), and a summary of minutes of the meeting of the National Frequency Management Board (2001).

The Radiocommunication Act and the Sound and Television Broadcasting Act were enacted on February 8, 1955. These acts empowered the PTD and the Public Relations Department to control the use of frequency of radiocommunication stations and issue sound and television broadcasting licences, respectively. No technical characteristic were imposed on the use of such radiocommunication stations however. Moreover, these two acts did not encroach on government agencies, which had control over radiocommunication stations. Thus, the Thai government received experts from the United States Operations Mission (USOM) to investigate and report with recommendations to the Thai government.

In the USOM report of 1966, there was a crucial recommendation to set up a radio regulatory office at the same level as the department[25] in order to determine the technical specifications of radiocommunication devices, assign frequency, register the use of frequency to the ITU, enforce the regulations, solve interference problems, monitor the use of frequency, and research and develop radiocommunication services. This office could be under any government agency.

On October 24, 1967, the Cabinet agreed not to implement the radio regulatory office and to set up the Frequency Management Board instead. Most of the work of this board concentrated on broadcasting, especially drafting its governmental broadcasting regulations.

On February 8, 1972, the government agreed to set up the National Frequency Management Board (1972), after a suggestion by the Ministry of Defence, in order to strengthen the PTD in terms of staff and instruments. The National Frequency Management Board (1972) supported the creation of the radio regulatory office inside the PTD. The radio regulatory office was succeeded in 1973 and called the Frequency Management Bureau. The Frequency Management Bureau has the same rank as the division within the PTD. After that, the National Frequency Management Board (1972) was dissolved.

Until March 26, 1974, the Thai cabinet approved and ordered the Ministry of Transport to establish the NFMB by the Ministry Order of 78/1974 on April 19, 1974, to examine and coordinate radiocommunication activities before licenses were granted by the PTD.

In the beginning, the NFMB comprised representatives from the Security Council, the Military Communication Department, the PTD, the Prime Minister's Office, the Ministry of Internal Affairs, the Office of the National Economics and the Social Development Board, and the Budget Bureau, and was chaired by the Minister of Transport. In 1991, two specialists were added to the NFMB.

The NFMB had responsibility for determining the national technical standard, and control, assign, and register frequency, examine the standard of radiocommunication devices, create efficient procedures, evaluate the radiocommunication stations, and coordinate all radiocommunication users.

The NFMB convened meetings from 1974 to 1979 and from 1982 to 2002[26]. The NFMB met on a monthly basis. The total number of meetings was 164. The total number of issues considered was 2,003. The number and issues of the meetings are shown in Table 16. The NFMB worked as the approval board for all the radiocommunication activities in Thailand and had the PTD to work as the secretary of the NFMB to implement board decisions.

[25] In Thailand, the bureaucracy of government comprises the ministries. Each ministry has several departments under supervision. Each department has several divisions under supervision. Each division has several sections under supervision.
[26] From 1980 to 1982, the Director General of the PTD dissolved the NFMB using direct power from the Radio Act of 1955, but strong political intervention re-established the NFMB.

Table 16. National Frequency Management Board meetings

Year	1974	1975	1976	1977	1978	1979	1982	1983	1984	1985	1986	1987	1988	1989
Times	9	5	5	11	13	8	7	5	11	10	10	11	9	6
Issues	26	76	63	106	190	143	68	64	112	100	112	164	152	119
Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Total**
Times	5	6	5	5	5	3	2	4	2	2	2	2	1	**164**
Issues	132	90	53	48	41	30	14	36	23	16	10	11	4	**2045**

The NFMB gave guidelines or procedures for frequency management of several services, including broadcasting service, fixed service or microwave link, land mobile service, satellite service, and low-power devices. The highlights were the guidelines of amateur radio service, the sound and television broadcasting plan, the citizen band for the general public, the fixed microwave link plan, the trunk radio plan, the National Table Frequency Allocation 1999, etc.

The NFMB drafted the National Frequency Management Regulation, which came into force on January 9, 1975. This regulation was under the Office of the Prime Minister and signed by the Prime Minister, but the Minister of Transport was the person in charge.

The National Frequency Management Regulation of 1975 empowered the NFMB to authorize all radiocommunication stations before they could obtain radiocommunication licences from the PTD. There were five sections in this regulation. Section 1 – Radiocommunication Station: all radiocommunication stations belonged to the government agency or to private sectors that had contracts with government agencies. Section 2 – Transmitting Power: no transmitters should operate over the given limit. Section 3 – Antennas and propagation: all antennas should use the given specification. Section 4 – Frequency assignment: only assigned frequencies should be operated and followed under the Radio Regulations and ITU Recommendations. Section 5 – Others: all transferred radiocommunication stations should be approved by the NFMB prior to transfer.

From 1974 to 1979, the NFMB had several important issues ranging from drafting the relevant regulation to assigning frequency to specific users. The majority of licensees are government agencies (national security and civil service) such as the military, the police, and the Royal Bureau, the Ministry of Public Health, the Department of Provincial Administration, the Royal Forest Department, and the Princess Mother's Medical Volunteer Foundation. The private companies that had contracts with a government agency, such as mining, road construction, sugar factories, were the second group of licensees. The objective of frequency assignment during this period ranged from national security and national interest to specific uses by private companies. The majority of uses or services of frequency assignment was fixed service and land mobile service. Fixed service included fixed link point-to-point and point-to-multipoint. Land mobile service included walkie-talkie and trunk radio. The NFMB used the first come, first served basis for frequency assignment.

From 1982 to 2002, the second period after the re-establishment of the NFMB, due to the strong political intervention, the NFMB still used the first come, first served basis. The most important frequency assignment by the NFMB was the frequency assignment to TOT and CAT for cellular service, especially the concession under both TOT and CAT.

In the sixth meeting of the NFMB in 1989, the NFMB assigned the frequency of the 900 MHz band for cellular service to TOT. TOT has Advanced Info Service PLC (AIS) as a concessionaire. The AIS uses GSM 900 for its service.

In the first and third meetings of the NFMB in 1990, the NFMB assigned the frequency of 1800 MHz for cellular service to CAT. CAT has Total Access Communication PLC (DTAC) as a concessionaire. The DTAC uses GSM1800 for its service.

On November 4, 1997, the NFMB issued guidelines on frequency assignment to provide clear criteria and transparent processes. There were four sections in this regulation. Section 1 gave the characteristics of the frequency assignees, which were the government agencies, state enterprises, or private sectors that had contracts with government agencies. Section 2 covered the assignment criteria including 1) the purpose of frequency usage, 2) efficient use of frequency, 3) block allocation for flexibility of users, 4) National Frequency Allocation Table, Radio Regulations, and ITU-R Recommendation, 5) primary and secondary service, 6) neighboring country, 7) the duration of frequency assignment was five years, and 8) auction possibility. Section 3 dealt with the right of frequency assignees that cannot be transferred to others, partially or wholly, before NFMB approval. Section 4 was ex-post regulation after frequency assignment, including 1) utilization report after one year, 2) recall of unused frequency after two years, 3) enforcement for the missed use of frequency assignment, 4) compensation to the existing assignees if there has been harmful interference, 5) partial recall if frequency utilization was inefficient, and 6) the right to change the frequency assignment, if necessary.

On February 20, 1998, at the first meeting of the NFMB, the NFMB approved a frequency transfer within the CAT concession (now CAT Telecom PLC). CAT proposed the transfer of 1710-1722.6/1805-1817.6 MHz to Wireless Communication Service Company Limited (now True Move) and 1747.9-1760.5/1842.9-1855.5 MHz to Digital Phone Company Limited (now belongs to the AIS), additionally from the DTAC, which was the existing concessionaire on 1800 MHz of CAT. The NFMB approved CAT's proposal to limit the duration of frequency transfer to that of CAT-DTAC's contract. The whole process was conducted from January 31, 1997 to February 20, 1998.

The frequency transfer reflected the property right of frequency, which gives ownership or individual right to use. The whole frequency transfer process was with the NFMB via the command-and-control approach however.

The main purpose of establishing the NFMB was to reduce political intervention by government agencies, because the Radio Act 1955 did not enforce it[27]. Thus, there was much political intervention in the PTD. The emergence of the NFMB acted as a buffer for the PTD. From 1980 to 1982, the Director General of the PTD dissolved the NFMB using the direct power of the Radio Act of 1955, but strong political intervention re-established it.

On October 11, 1997, the Constitution 1997 of Thailand was enacted. Article 40 gave guidelines to an independent agency to regulate frequency as a national resource. This constitution did not affect the working of the NFMB until the Act on Establishment of the National Broadcasting Commission (NBC) and the National Telecommunications Commission (NTC) were enacted on March 7, 2000. There was a provision in Article 80 that prohibited additional frequency assignment and business licenses, so the NFMB could not assign new frequency. The NTC was ultimately formed on October 1, 2004. During almost four years, from March 7, 2000 to October 1, 2004, there were no new frequency assignments or business licences for telecommunication or broadcasting service. Furthermore, the NBC could not be established because of the extremely strong political intervention.

[27] The Post and Telegraph Department, the Public Relations Department, the Ministry of Defence, and other government agencies in Ministerial Regulations shall not be enforced under the Radio Act 1955. This means that these government agencies do not require a radiocommunication licence. Prior authorization from the NFMB shall be sought however.

On October 1, 2002, the PTD was transferred to the Ministry of Information and Communications Technology and the PTD proposed the continuation of the NFMB, but the Ministry of Information and Communications Technology dissolved it.

On November 16, 2002, the Telecommunications Business Act was enacted and it removed all monopoly rights from the government agencies or state enterprises, including TOT and CAT, which monopolized domestic and international telecommunication services, respectively, by revoking the Telegraph and Telephone Act of 1934 and 1974.The opposite situation arose, however, because there was no regulator NTC to exercise the power of this act. The existing operator under the state-owned enterprises became stronger because it faced no new entrants or regulator.

During the period of the NFMB, all radiocommunication services were monopolized by government agencies or the private sector that had contracts with government agencies. In the beginning, the general public was only allowed to use low-power devices, which will be discussed in Section 4.6, first with relevant licences and then unlicensed. The frequency assignment used the command-and-control approach on a first come, first served basis. At this stage, the technical aspects in terms of harmful interference were the main concern of the assignment process.

To summarize this section, the NFMB was set up to separate the roles of the PTD. Before the NFMB, the PTD had sole authority as administrator, regulator, and operator of frequency assignment in Thailand. After the NFMB, the PTD only had an administrator and operator role. The NFMB had the regulator role instead.

The NFMB used command-and-control on a first come, first served basis for frequency assignment. Until the end of 1997, the NFMB set the broad scope of a market-based approach for auction, if necessary, and allowed the transfer of the right to use frequency to other parties after NFMB approval. The frequency transfer showed that the NFMB frequency assignment guidelines of 1997 gave property rights to frequency. Unfortunately, there were no auctions during the NFMB period.

A summary of significant events is shown in following table.

Table 17. Period of National Frequency Management Board

Time	Event
1955	The Radiocommunication Act and the Sound and Television Broadcasting Act enacted
1972	The first National Frequency Management Board is dissolved
1974	The National Frequency Management Board (NFMB) founded by ministry order
1975	The National Frequency Management Regulation came into force
1997	The first guidelines for frequency assignment came into force The Constitution of Thailand enacted
2000	The Act on Establishment of the NBC and NTC – Article 80 enacted
2002	The PTD transferred to the Ministry of Information and Communication Technology The Telecommunications Business Act enacted The NFMB dissolved

4.5 The National Telecommunications Commission[28]

After the separation of the decision-maker for frequency assignment from the providers during the NFMB period, the decision-maker was still under the direct control of the government. The Constitution of 1997 initiated an independent regulatory agency to regulate the use of frequency as national interest. The constitution changed the decision-maker to an independent agency. Consequently, the relevant acts and regulations changed the old scheme of authorization or permission to have a licensing scheme that allowed all qualified parties to obtain frequency. The authority still held highly regulated power imposed on radiocommunication use however. The telecommunication industry comprised an independent agency, a provider (state enterprise and private entity), and users.

The NTC was established on October 1, 2004, after a long delay of almost four years from the Act on Establishment of the NBC and NTC was enacted in 2000, and three years after the Telecommunication Business Act was enacted in 2001. The PTD was dissolved by law and transferred to the Office of the NTC on January 1, 2005.

The Act on Establishment of the NBC and NTC 2000 separated the role of authority for frequency assignment. The NTC comprised seven commissioners acting in the regulator role. The office of the NTC acts as the secretary office of the NTC. The MICT acts as administrator on behalf of the Thai government in international activities.

For almost six years, the NTC issued regulations to change the scheme of authorization of frequency, which was monopolized by government agencies, state enterprises, or private sectors that had contracts with government agencies, into a licensing scheme for all parties, including both government and non-government organizations in order to optimize the benefits of frequency, which is a national resource, at all levels (local, regional, and national).

The NTC issued almost 112 regulations, which were published in the *Royal Gazette*[29] from October 1, 2004 to March 30, 2010, to ensure the transition from the monopoly to a liberalized market. There are two NTC sets of regulations concerning the frequency assignment published in the *Royal Gazette*, but one regulation on frequency assignment was never published.

The NTC regulations that were not published concerned the interim provision on frequency assignment on January 7, 2005 and were not published in the *Royal Gazette*. There were three phases: short, medium, and long term. The short term ran from January 7 to March 31, 2005, and did not allow new assignment except for national security and disaster relief. The medium term ran from April 1 to July 31, 2005, and allowed new assignment, if necessary, apart from national security, disaster relief, and international treaty or state contract. The long term was after July 31, 2005, and was subjected to the NTC regulation of the frequency assignment criterion.

The NTC regulation of the frequency assignment criterion that was published in the *Royal Gazette* on September 28, 2005, consisted of ten sections. Section 1 revokes the NFMB guidelines for frequency assignment from 1997. Section 2 is the definition of non-commercial and commercial use. Section 3 states the purposes of frequency assignment. Section 4 concerns necessary frequency assignment, including government agencies, one-year renewal of commercial and non-commercial use, the urgency

[28] This section is mainly based on the Act of Establishment of the National Broadcasting Commission and the National Telecommunications Commission (2000), the National Telecommunications Commission Regulation of interim provision of frequency assignment (2005d), the National Telecommunications Commission Regulation of frequency assignment criterion (2005b), the National Telecommunications Commission Regulation of frequency assignment for experiment with temporary use (2005c), and the National Telecommunications Commission Regulation of frequency transfer (2007a).

[29] The regulations published in the *Royal Gazette* came into force. No one has the right to claim that he/she/it does not know the regulations.

of non-commercial use, and harmful interference to existing services. Section 5 gives the frequency assignment criteria including characteristics of frequency assignees, technical characteristics, social impact, financial aspects, and compatibilities with the Telecommunications Master Plan and Frequency Master Plan. Section 6 is the process of application. Section 7 states the frequency usage fees according to the Ministry of Information and Communication Technology Regulation on March 10, 2003. Section 8 gives the right for the NTC to exempt this regulation. Section 9 is the enforcement date. Section 10 deals with the cancellation of all regulations that conflict with this regulation.

The second NTC regulation of frequency assignment that was published in the *Royal Gazette* on November 17, 2005, concerned experimenting with temporary use and was intended to facilitate the development of new technology. Currently, there are 18 licensees to test the WiMax technology. Each licensee had to pay a frequency usage fee and had 90 days for experimenting.

The NTC regulations on September 28 and November 17, 2005, do not mention the right of frequency assignees, which had been mentioned in the NFMB guidelines for frequency assignment in 1997. Article 53 of the Act of Establishment of the NBC and the NTC in 2000, however, clearly states that the frequency licence is an individual right that cannot be transferred prior to NTC approval. On July 31, 2007, the NTC issued the regulation according to Article 53 as the guidance and process for frequency transfer.

The frequency transfer was addressed in 2007, however, by the NTC regulation on frequency transfer in 2007 and provided the process and details of frequency transfer, including the rights of transferor and transferee, and the frequency transfer fee. Moreover, this regulation provided the concepts of frequency sharing, frequency substitution, and refarming. After the licensees obtained the frequency assignments from the NTC, they had to proceed as stated in the NTC regulation of frequency transfer if they wanted to transfer the frequency to other parties.

The highlight of the frequency transfer was the transfer of 1900 MHz between the TOT Public Limited Company and CAT Telecom Public Limited Company. Both companies are state-owned and incumbents in the telecommunications market. The process began on October 22, 2008, and finished at the NTC meeting on March 13, 2009. The frequency transfer fee – five percent of the frequency value – was 262 million baht (around 8 million USD).

This frequency transfer showed the property right of frequency, especially the exclusive right to use the frequency – an individual right. The mechanism is by the command-and-control approach, which followed the NTC regulation of frequency transfer in 2007.

Four new NTC[30] commissioners were appointed on February 18, 2010. The NTC has introduced a market-based approach – an auction for 3G frequency in the 2 GHz band. The process of the 3G auction was ended by the Supreme Administrative Court Order on September 23, 2010.

To summarize this section, the NTC issues regulations to change the authorization scheme to a licensing scheme in order to shift from a command-and-control economy to a market economy. Frequency transfer that represents the property right of frequency can also be carried out by the NTC, by both a command-and-control and a market-based approach.

A summary of significant events is shown in following table.

[30] The NTC comprises seven commissioners – one chairman and six commissioners. The term of the NTC is six years. In the first three years, three commissioners had to withdraw. In this case, one commissioner resigned before withdrawing. There are therefore four new commissioners of the NTC.

Table 18. Period of the National Telecommunications Commission

Time	Event
1997	The Constitution of Thailand enacted – Article 40 gave birth to the independent regulator
2000	The Act on Establishment of the NBC and NTC – Article 80
2002	The Telecommunications Business Act enacted
2004	The National Telecommunications Commission (NTC) founded
2005	NTC frequency assignment criterion came into force
2007	NTC frequency transfer came into force
2009	1900 MHz frequency transfer – TOT and CAT telecom
2010	Four new NTC commissioners appointed 3G auction ended by the Supreme Administrative Court Order on September 23, 2010

4.6 Self-regulated – spectrum commons[31]

The exclusive right to use frequency was awarded to the frequency assignees to ensure there was no harmful interference in the use of radiocommunication services. The new technology developments made the use of exclusivity of frequency unnecessary however. The non-exclusive use of frequency was initiated in the low-power devices, especially in the ISM band. The users shared the frequency with others and accepted the interference from the other users or devices. The constraints of such uses included the specified frequency and power limitations.

The NFMB fist attempted to delegate the 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. The users had to obtain authorization from the PTD. The use of low-power devices still require the relevant radiocommunication licences however. The PTD realized the benefit of 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 manufacturer or importers. The NTC also allowed the Internet service provider to use the spectrum commons. The stakeholders were extended to the service provider as well.

In Thailand, there are two separate steps for unlicensed devices. First, 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. Second, when the use of these devices increases over time, the authority may consider exempting the related licences imposed on the

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

use of these devices to reduce the burden for the general public by issuing a regulation to exempt the related licenses 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 time of no regulation – without the Radio Act – there was no use of radiocommunication devices for the general public except by government agencies. With the Radio Act enacted, all radiocommunication usages were prohibited except the authorization granted by PTD since 1914. On March 26, 1974, the cabinet approved for 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 service in the 26.92-27.23 MHz band in limited areas. The power of the transmitters must 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, in 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 the anti-theft device in cars and motorcycles for the general public.

In 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 up to one watt. The UHF transceiver was the walkie-talkie application service.

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

In 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) transceivers, cordless telephones, wireless microphones, wireless remote controls, such as small plane remote controls, anti-theft devices, garage door openers, and radiocommunication devices in the industrial science service that were not used for communication purposes such as microwave ovens.

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

Additional low-power devices introduced in 1986

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

After the NFMB delegated authorization of all radiocommunication devices with power up to one watt, the PTD allowed the use of transceivers in medical instruments with power 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 licenses was different because the power to waive licences belonged to the Ministry of Transport, which had to issue the Ministerial Regulations according to the Radio Act of 1955 and its amendment.

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 the exemption of radiocommunication licences to the Ministry of Transport to issue the Ministerial Regulations. There were lengthy procedures from drafting to announcement however. First, the PTD drafted the Ministerial Regulations. Second, the draft of the Ministerial Regulations was sent to the Council of State in order to check the format and content and send it back to the PTD for revision. Third, the draft of the Ministerial Regulations included revision by the Council of State to be sent to the Ministry of Transport for consideration and signing. Fourth, 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 licence 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 of 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. There were: 1) wireless microphones with power up to 10 milliwatts in the 33-50, 88-108, 165-210, and 470-490 MHz bands and with power up to 30 milliwatts in the 902-960 MHz band; 2) wireless telephones with power up to 10 milliwatts in the 1.6-1.8, 30-50, and 54-74 MHz bands; 3) radio-control models with power up to 100 milliwatts in the 26.964-27.405 MHz band; 4) long-range radio control with power up to 100 milliwatts in the 26.964-27.405 MHz band and with power up to 10 milliwatts in the 300-500 MHz band; 5) transceivers of the citizen band with power up to 100 milliwatts in the 26.964-27.405 MHz band, and warning devices with power up to 10 milliwatts in the 300-500 MHz band; 6) transceivers in medical instruments with power 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 the new applications.

On October 15, 1996, the PTD allowed the general public to use radiocommunication devices in the 2400-2500 MHz band with Effected Radiated Power (E.R.P.) up to 100 milliwatts for indoor use only. These devices had to hold either the possessing, using or installing radiocommunication licences. 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 up to 10 milliwatts in the 1900-1906 MHz band and they could be used with DECT and PHS technology with slight modification of frequency arrangements.

Ministerial Regulation No. 30

On January 17, 2001, Ministerial Regulation No. 30 was published and Section 3 of the 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 2400-2500 MHz band by deleting “of indoor use only.” The limitation of power, the related radiocommunication licences, and the type approval remained imposed however.

Change in Ministerial Regulation [2004]

There was a change in the format of the Ministerial Regulations that called on the substance of the regulation. The 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 of 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, importing, exporting, and trading of radiocommunication licences. Section 3 exempted the possession, use, and exporting of radiocommunication licences. Section 4 exempted the possession, importing, exporting, and trading of radiocommunication licences for cellular telephone, radio paging, and radiocommunication devices in Global Mobile Personal Communication by Satellite (GMPCS), which had been type-approved by the PTD. Section 5 exempted importing and exporting of radiocommunication licences for cellular telephone, 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 radio that already had licences and been transferred. Thus, the transferees did not require the possession and use of radiocommunication licences. The operation of amateur radio required the amateur radio certificate separately, 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. First, 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). Second, the Ministerial Regulation of 2004 added five items in Section 2. These were 8) the receiver in radio navigation service, radio navigation satellite service, radio location service and radio location satellite service, 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.) up to 10 milliwatts, 10) devices in the band lower than 135 kHz with E.I.R.P. up to 150 milliwatts, 11) devices in the 13.533-13.567 MHz band with E.I.R.P. up to 5 milliwatts, and 12) devices in the 2400-2500 MHz band with E.I.R.P. 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[32]. The procedure to publish 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 the 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 Procedure 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 application, 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 Licences was published, adapting the Ministerial Regulation for the Exemption of Radiocommunication Licences in 2004 and indicating which radiocommunication licences were and were not exempted.

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 Radiocommunication Licences in

[32] 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.

2004. The differences are: 1) the deletion of the wireless microphone in the 902-960 MHz band, which is the same band as cellular phone (GSM 900 MHz); 2) the deletion of wireless telephone in the 54-74 MHz band, because the technology is obsolete; 3) open applications in the 26.965-27.405 MHz band with power up to 100 milliwatts; 4) open applications in the 30-50 MHz band with power up to 10 milliwatts; 5) open applications in the 300-500 MHz band with power up to 10 milliwatts; 6) receivers in the meteorological aid service, meteorological satellite service, Earth exploration-satellite service, standard frequency and time signal service, standard frequency and time signal satellite service, space research service, radio astronomy service, and safety service. Section 3 has the exemption of possessing, using and exporting radiocommunication licences but still holds the making, importing, and trading 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 importing and exporting of radiocommunication licences for radiocommunication devices for experiment and research and is also used by the 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 5150-5350 MHz band with E.I.R.P. up to 200 milliwatts for indoor use only, and in the 5470-5725 and 5725-5850 MHz bands with E.I.R.P. 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). The suppliers must certify that the equipment has technical specifications according to the NTC Regulation, as a Supplier’s Declaration of Conformity.

Remarks on collected data on WLAN in Thailand

Before this time, there were three regulations regarding the type approval test by the Post Telegraph Department. On July 21, 1992, the PTD imposed the regulation of a type approval test for amateur radio equipment, because there was much illegal equipment in use in amateur radio service that could be tuned to other frequency bands. On December 7, 1995, the PTD revised the regulation of 1992, and on April 7, 1998, it extended the type approval test to other services, including land mobile, maritime mobile, and aeronautical mobile service. On June 7, 2001, the PTD revised the regulation of 1995 to accept test reports from accredited test laboratories other than the PTD.

In 1996, the PTD allowed the use of WLAN in Thailand with the relevant radiocommunication licences including the type approved for radiocommunication devices. The number of WLANs on type approval, possessing and importing licences are available in the archive of the PTD and the NTC FMS database. They are not publicly available on the website however. The manual access to the PTD has been conducted to gather the information from 1996 up to 2004. After the Ministerial Regulation of the Exemption of Radiocommunication Licences – the Ministry of Information and Communication Technology came into force; the information regarding the unlicensed devices at the PTD was not collected.

Fortunately, the Customs Department has an online database on the importation of radiocommunication devices, including WLAN routers. The information is available from 2001.

Figures 6 and 7 show the number of WLAN routers that were type-approved by the PTD from 1996 to 2004 and the imported number of WLAN routers by the Customs Department from 2001 to 2010.

The number of WLAN routers in Figure 6 depicts the gradual growth of the use of WLANs in Thailand from 1996 to 2000. At that time, WLANs were used little and in a limited area. The increased growth in WLANs occurred from 2000 to 2004, in parallel with the big demand from warehouse management in big supply distribution.

The number of WLANs collected from the PTD was a subset of the number of WLANs collected from the Customs Department. The PTD's number had been collected since 1996 and ceased in 2004, however, after unlicensed regulations came into force (Figure 6). The Customs Department's number is available from 2001 to now (Figure 7). Figures 6 and 7 show the number of WLANs at two important points. The first point is after 1996 (the first time that WLAN was allowed to be used in Thailand). The second point is after 2004 (after the unlicensed regulations came into force). In order to compare the two stages of implementing unlicensed regulation – before and after – the growth of WLAN routers can be observed from Figures 6 and 7.

The number of WLAN routers in Figure 7 addresses the continued growth since 2001. The big growth started after the Ministerial Regulation of the Exemption of Radiocommunication Licences in 2004. This growth was in parallel with the event of WLAN being put into in the chipset of the smart phone and laptop. Mass production may also reach economy of scale, rendering the low price of the Wi-Fi chipset.

Figures 6 and 7 display differences in the number of WLAN routers before and after the implementation of unlicensed regulations in Thailand. This unlicensed regulation is one of many factors that encouraged wide use of WLAN routers in Thailand.

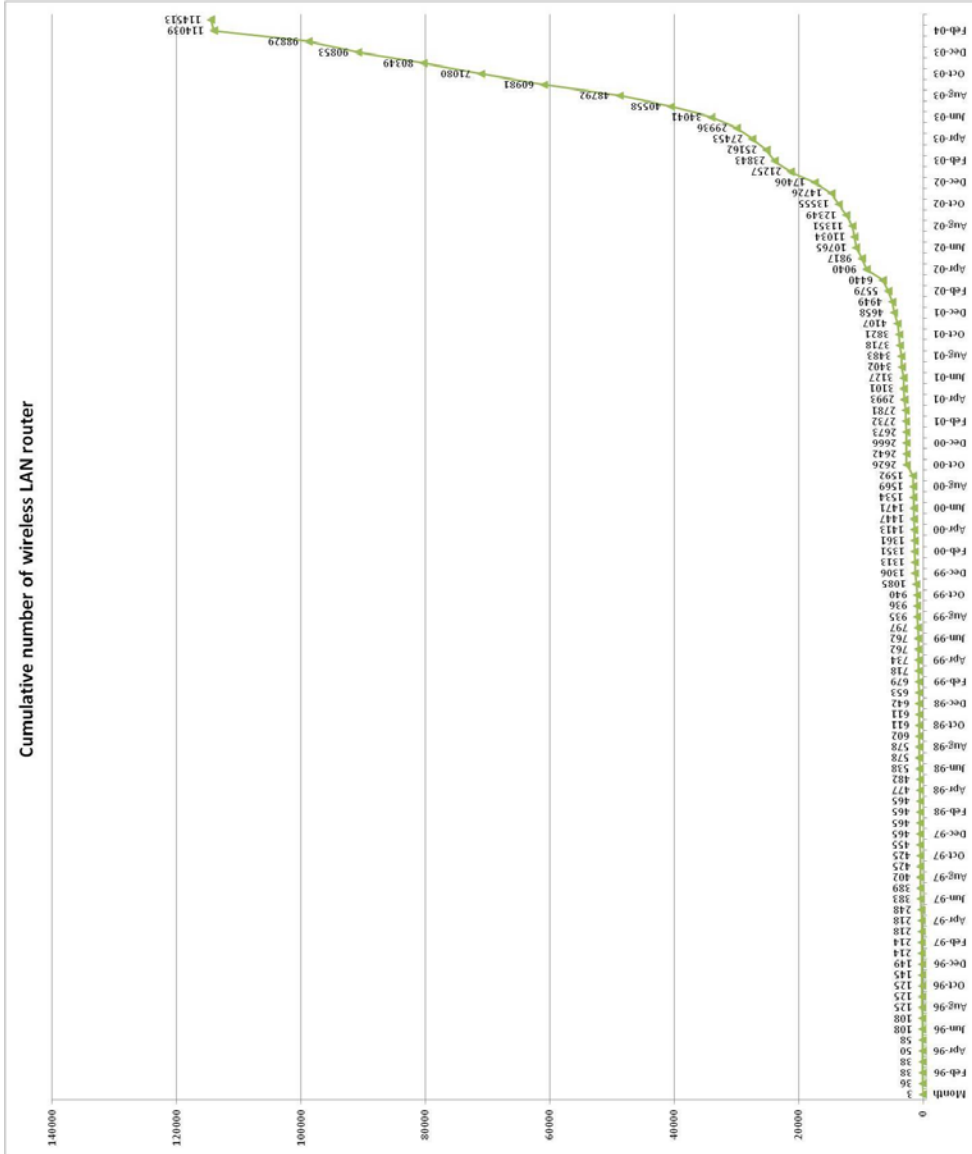

Figure 6. Number of WLAN routers 1996-2004[33]

[33] Source: Post and Telegraph Department, Thailand

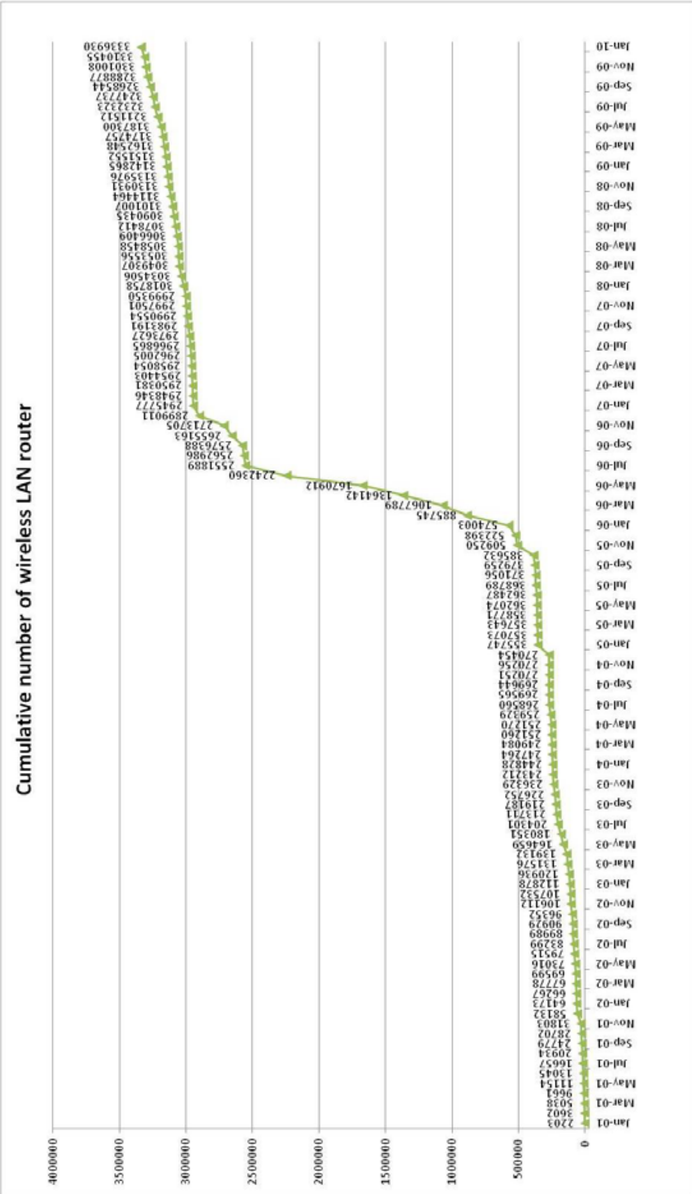

Figure 7. Number of WLAN routers 2001-2010[34]

[34] Source: Customs Department, Thailand

Summary

To summarize this period, after the NFMB delegated power to the PTD, development of short-range devices was gradually introduced. It 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.

A summary of significant events is shown in the following table.

Table 19. Period of self-regulated spectrum commons

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 the Citizen Band (26.96-27.23 MHz) transceivers, cordless telephones, wireless microphones, wireless remote controls, such as small 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

4.7 Discussion

In Thailand, the development of spectrum assignment has several roles. There are four important roles related to spectrum assignment: administrator, regulator, secretary office[35], and operator. Figure 8 shows the different actors in each period and the role of the actors.

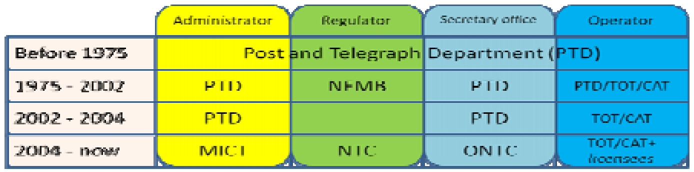

Figure 8. Role of actors in spectrum assignment in Thailand

[35] The Secretary Office is the secretary unit of the regulator. The secretary office works as the administrative unit of regulators.

Figure 8 shows the actors, including the administrator, regulator, secretary, and operator. The administrator represents the Thai government as the Thai delegate to international activities, such as international conferences, conventions, treaties, negotiations, and cooperation. The regulator acts as the national authority to assign frequency and issue the relevant regulations. The secretary works as the regulator's office and does all the administrative works for the regulator. The operator provides the services to the end-users after obtaining the frequency from the regulator.

Before 1975, the Radio Act had been enacted since 1914 and it gave sole authority to the PTD to assign frequency to users. At same time, the PTD acted as the administrator, regulator, and operator.

The NFMB was founded in 1975 by cabinet approval. The NFMB's role is as regulator to separate the authority from the PTD. The NFMB worked as regulator to assign frequency to users until 2002 and it was dissolved by the Ministry of Information and Communication Technology. The PTD was transferred under the Ministry of Information and Communication Technology in 2002.

After the Act on Establishment of the National Broadcasting Commission (NBC) and the National Telecommunications Commission (NTC) was enacted in 2000, the NTC was founded in 2004. During 2002-2004, there was no regulator to assign new frequency to users, according to the provision of the Act on Establishment of the NBC and NTC 2000. There was uncertainty in the Thai telecommunication industry.

The NTC was founded in 2004. The NBC was never founded however. So far, the NTC has only acted as regulator to assign frequency in telecom matters. The NTC does not have full authority to form the Joint committee between the NTC and the NBC to approve the National Table Allocation or National Master Plan. The reason of the Supreme Administrative Court on September 23, 2010, was not to provide the NTC with any right to pursue the 3G auction until the establishment of the National Broadcasting and Telecommunications Commission.

Table 20 presents Thailand's frequency assignment profile and the development of frequency assignment.

Table 20. Thailand's frequency assignment profile

Country / Issue	Thailand
Type of economy	Command–and-control economy (beginning) and becoming a market economy
Frequency transfer (alienation right)	The NFMB in 1998 The NTC in 2009
Auction	The NFMB initiated in 1997 The NTC attempted in 2010
Spectrum commons	Authorization since 1974 and unlicensed since 2004

In order to elaborate on Table 20, Table 7 in Chapter 2 provides the stakeholders at each level of actions. At the constitutional choice level, there is an administrator and a regulator. At the collective choice level, there are operators. At the operational level, there are users.

At constitutional level, the decision-makers range from His Majesty the King or an authority appointed by the King during the monarchy period to the authority appointed by the Radio Act and the government. At constitutional level, the decision-maker produces rules and regulations to govern the

use of frequency. The decision-maker changes from time to time, starting from His Majesty the King, the authority appointed by the King, the authority appointed by the Radio Act, and the authority appointed by the Cabinet to the independent regulatory agency.

At the collective choice or institutional level, the operator or provider appears in terms of state enterprises as 100% owned by the Ministry of Finance. State enterprises, at the collective choice level, follow the rules and regulation from the constitutional level and create their own rules as network rules for users at operational level to follow. In Thailand, the state enterprises can have a private company as a partner to provide service to users.

During the authorization period, before the NTC, only state enterprises and their private companies can obtain frequency to provide telecommunication service to the general public, until the NTC changes to a licensing scheme to allow all qualified entities to obtain the frequency. At the collective choice level, there were therefore only state enterprises at the initial stage and many more private companies after the NTC period.

At the operational level, users always follow rules from both the operators at the collective choice level and the regulator at the constitutional choice level.

In Thailand, the rights to frequency use – access, withdrawal, management, exclusion, and alienation – vary by the regulated level and position in the telecommunication industry.

Before the Radio Act, all rights to frequency use belonged to the authority – His Majesty the King. There was a high degree of regulation because only the government agency could access frequency that was strictly controlled by His Majesty the King or an authority appointed by the King. The use of frequency had followed international treaties such as the International Radiotelegraph Convention.

Through the Radio Act, all rights to frequency use belonged to the stated authority: the PTD. Regulation was high because the PTD imposed conditions on the use of radiocommunication devices in terms of the installation of a radiocommunication station to provide the exclusive right to use frequency without interference. Conditions on use, including frequency, duration, area, and technical characteristic are rights to access, withdrawal, management, and exclusion. The alienation right belongs to the authority however.

After the NFMB was set up with Cabinet approval, the decision-maker of the frequency assignment changed from the PTD to the NFMB. Moreover, the NFMB exercised the alienation right (frequency-transfer of DTAC in 1998) and initiated auction of frequency in 1997. There was no case for holding auctions at that time however. The regulation was therefore slightly reduced because of the auction initiative to use the market mechanism to assign frequency.

In 2004, the NTC changed the authorization scheme to a licensing scheme and opened the telecommunication industry to qualified entities. The decision-maker for frequency assignment changed to the NTC. Regulation remains at a high level, however, according to the conditions imposed on the use of radiocommunication devices. In 2009, the NTC approved the frequency-transfer between TOT and CAT, in the case of the 1900 MHz band. This event reflects that the NTC holds the alienation right of frequency. The licensees have access, withdrawal, management, and exclusion rights. Now, the NTC aims to hold a 3G auction by 2010 but be ceased by the Supreme Administrative Court Order. Therefore, the degree of regulation may change due to the use of a market mechanism – an auction to assign frequency. The alienation right will be passed on to the winner during the auction.

While regulations from the regulator give exclusive rights to use frequency without harmful interference, a degree of self-regulated or spectrum commons allows for a non-exclusive right to use frequency. No one owns frequency. Everyone has to share frequency. In order to avoid harmful interference, the regulator assigns specific frequency, power limitation, and application as constraints. In Thailand, the spectrum commons as an unlicensed device was stated in 2004. The Thai experience shows that two steps are required for the spectrum commons approach, however: authorization of the use of spectrum commons and the exemption of radiocommunication licences allowing open access.

Moreover, the regulated level of network for spectrum commons is provided by the Internet service provider type 1 according to the NTC Regulation of Criteria and Procedure for Internet Service Licence Application (2005). The providers have the ability to manage Wi-Fi hotspots for their service.

Furthermore, spectrum commons can be divided into three groups, depending on the level of management rights: public commons, private commons, and unlicensed. If there is someone – a service provider or state agency – to manage access to the frequency, it is private commons or public commons, respectively. An example of private or public commons is access to the Internet via a Wi-Fi hotspot provided by the Wi-Fi operator or state agency to manage the frequency to access the Internet.

An example of unlicensed use is access to the Internet via a wireless router or Wi-Fi at home or in the office. Importantly, users do not pay for frequency access via a wireless router or Wi-Fi, but have to connect to the Internet by other means.

4.8 Summary

To summarize this chapter, the discussion on Thailand's history confirms the rights to use frequency in Table 13 in Chapter 2, provided the exclusive right to use frequency by using a command-and-control and market-based approach. The level of regulation depends on the alienation right the regulator delegates to the assignee. Spectrum commons is a non-exclusive right to use frequency and can be divided into three types: public commons, private commons, and unlicensed, responding to RQ.2.

Chapter 5 Advantages and disadvantages of spectrum commons in Europe[36]

This chapter elaborates on the third research question: What are the advantages and disadvantages of spectrum commons? The chapter reflects on the advantages and disadvantages of spectrum commons from the author's perspective by blending the perspectives of stakeholders in the consultation with relevant literature.

The views of different stakeholders in European countries provide issues to be considered when implementing spectrum commons. The chapter starts by collecting views of stakeholders in the public consultation[37] of the Radio Spectrum Policy Group (RSPG) on commons on the "Aspect of a European Approach to Collective Use of Spectrum." There are nine respondents including the ARD-ZDF, Deutsche Telecom/T-Mobile, the EICTA, GSMA Europe, Metil Telecom consultants, Microsoft, Telefónica, PWMS Manufacturer Group, and the Delft University of Technology. These contributions, together with the results of the RSPG public consultation, provide input data for this chapter.

The main literature comes from Cave (2007), Chaduc and Pogorel (2008), Mark and Williams (2007), and Tonge and Vries (2007). They provide additional ideas in parallel with the RSPG consultation. These include suggestions for discussion on the appropriate time to implement a frequency, choosing a suitable frequency and an amount, and the technical aspects.

5.1 Examining literature and consultation

This section discusses the views of Cave (2007), Chaduc and Pogorel (2008), Mark and Williams (2007), Tonge and Vries (2007), and the RSPG public consultation in November 2008 in terms of the advantages and disadvantage of spectrum commons. Finding similarities and differences in the examined data motivates the identification of issues for spectrum commons. Table 21 summarizes the main advantages and disadvantages commonly recognized by the different input data.

Table 21. Advantages and disadvantages of using spectrum commons

Advantages	Disadvantages
Irreversibility	Reduce the barrier to entry
Lack of innovation if sharing with licensed services	Lower administrative cost
No legal right to complain of interference	Greater social benefit
Congestion and limited quality of service	Create innovation and stimulate demand for new service
	Suitable for small user and low-density area

These advantages and disadvantages of spectrum commons are discussed in more detail in the following paragraphs.

[36] This chapter is a revision of Ard-paru and Bohlin (2009).
[37] The public consultation on the draft RSPG opinion on "Aspect of a European Approach to Collective Use of Spectrum" was posted on June 10, 2008, and closed on September 29, 2008. The results of this public consultation was posted on November 19, 2008 (RSPG, 2008).

5.2 Disadvantages of using spectrum commons

Irreversibility
Once the regulator or administrator assigns a frequency band with certain conditions for licensed exemption or unlicensed spectrum, anyone can use the band as a public good. An example is Wi-Fi devices. Most laptops include a Wi-Fi chip set, and the Wi-Fi access point can be used anywhere from the home to public areas such as airports, train stations, and universities. Wi-Fi hot spots are also located in hotels and department stores.

If the regulator regained frequency and refarmed it for other users or services, it would be more difficult, because the equipment could be everywhere, and it would take a long time to clear this band. If, for example, the 2400-2500 MHz band, which is already used for Wi-Fi, Bluetooth, and other short-range devices, were considered for refarming for new services, i.e., a cellular mobile network. All these devices would have to stop transmission to ensure a new service would not receive interference.

Lack of innovation when sharing licensed services
Normally, when regulators assign frequency to licensees, an appropriate constraint is imposed, such as the technical specification of transmitters and receivers, the height of the transmitting station, the modulation type, and the level of transmitter power. After that, the regulator sometimes identifies spectrum commons to share with the licensed services. The regulator places more constrains on spectrum commons to ensure that use will not interfere with licensed services. Sharing obstructs innovative applications, because new applications are limited to prior constraints. It is more likely that an extension of spectrum commons of less than 30 GHz will reduce sharing between licensed services.

Solutions to interference between licensed services and spectrum commons are available by implementing an appropriate framework that addresses distance, level of power, part of spectrum, type of usage, and technology (especially cognitive technology) constraints.

No legal right to complain about interference
In general, after the regulator grants a specific frequency band to the spectrum commons for public use. All applications can be used with constraints. Users cannot complain when interference occurs. This means that users must bear their own risk when using equipment under spectrum commons.

For example, many people use a Bluetooth earphone to communicate on their mobile phone. When capacity is fully occupied, the mobile phone cannot connect to the Bluetooth earphones because there are no vacant channels. The more users there are, the more congestion there will be. Another example is garage door openers. If the neighbor has the same model, when the device is pressed, the nearby garage door will open.

Congestion and limited quality of service
The use of devices under spectrum commons is generally limited in terms of the service area, because they are low-power devices. A common problem of congestion usually happens when all users use their applications at the same time. The quality of service will vary from high, when few people use the service at the same time, to poor quality of service when there is heavy concurrent usage. For instance, at the beginning of the ITS conference in Japan, a few participants logged on to the Wi-Fi network and the system worked smoothly. When all the participants tried to access the Wi-Fi network, however, they system became overloaded and collapsed.

The use of spectrum commons in the band below 30 GHz with other services may create congestion of the existing spectrum use and cause poorer quality of service.

On the other hand, quality of service can be improved by combining licensed services and spectrum commons, which may improve the utilization of spectrum (make it more efficient) by introducing cognitive devices in the guard band or interleaving channels – spacing between the transmitting or receiving channel. The development of a relevant standard of spectrum commons will also reduce congestion and improve the quality of service through improved spectrum efficiency.

5.3 Advantages of using spectrum commons

Reducing barriers to entry
When regulators assign frequency under spectrum commons, the frequency can be used equally. There is no license or frequency usage fee (unlicensed). Users only pay for their devices. This is a crucial advantage of spectrum commons. Moreover, new entrants or players can enter the market more easily and launch services to compete with incumbent operators. This means that the barrier to entry is reduced. The market under spectrum commons will have many more providers and applications.

Furthermore, after the regulator announces a specific frequency band with certain constraints, the manufacturer who produces the equipment will have certainty over the introduction of its new products to the market. This announcement will reduce the manufacturing risk of creating the equipment. If the specific frequency band can be used in other countries – regional or worldwide – the manufacture will have an economy of scale to produce the devices more cheaply. For example, the price of Wi-Fi products has fallen dramatically.

Lower administrative costs
Under spectrum commons, the regulator only defines the frequency band, amount of bandwidth, and usage constraints (in terms of standardization of the equipment).

In contrast, if the regulator uses the command-and-control or market-based approaches for frequency assignment, the regulator must define property rights, coordinate existing users, and settle disputes. Thus, administration costs under spectrum commons are lower.

Greater social benefit
Society benefits from the use of spectrum under spectrum commons in many ways. First, without paying spectrum access or usage fees, the operators will enter the market more readily. After the regulator assigns the band, under spectrum commons, manufacturers have certainty of producing equipment. Moreover, if the band is regional or worldwide, manufacturers are able to provide cheaper devices to the market.

Furthermore, these devices will be circulated globally, i.e., GSM mobile phone roaming. Besides this, the compatible standards eliminate harmful interference. If, however, the devices cannot be used globally, global circulation will not occur. For example, the low-power FM micro transmitter and the ultra-wide band equipment (UWB) are widely used in the USA but are illegal in the EU.

Innovation and stimulating demand for new services
Rapid adoption of and demand for new applications increase under spectrum commons. This new demand drives innovators that create products. Competition innovation under spectrum commons will lead to new applications.

To make this happen, regulators should remove all unnecessary constraints and only maintain rules for safety and prioritized services. Restrictions on spectrum commons should be more flexible, generic, and only be applied to broad categories of devices.

Suitability for smaller users and low-density areas
Spectrum commons is suitable for use by small users. More users create more congestion. Furthermore, pilot projects under spectrum commons for the new frequency should be in low-density areas to avoid harmful interference to existing neighborhood services.

Developments in wireless technology – cognitive radio, software define radio, and smart antenna – will improve sharing between existing services however.

5.4 Examining advantages and disadvantages

The discussion on the advantages and disadvantages of spectrum commons is categorized into a SWOT analysis and the results are interpreted for major stakeholders, according to their interest.

Table 22. SWOT analysis of advantages and disadvantages of using spectrum commons

Strength - create innovation	**Weakness** - congestion and limited quality of service
Opportunity - reduce barrier to entry - lower administrative cost - greater social benefit - stimulate demand	**Threat** - irreversibility - lack of innovation when sharing with licensed services

Spectrum commons has a major strength in encouraging innovators to create, because spectrum commons allows the space to be shared by all technologies, services, and applications. This strength creates an ideal test bed for innovative activity.

Furthermore, spectrum commons creates certainty for manufacturers and stimulates user demand. Once manufacturers have certainty[38], they will develop and supply devices to the market more readily. From the newcomers' viewpoints, spectrum commons reduces barriers to entry (licensed or access fee). Spectrum commons offers end-users more choices. Moreover, if the market is competitive, users will have access to better and cheaper devices. Spectrum commons also lowers the costs of administration and regulation. The regulator has to set the standard of the devices in terms of *ex ante* regulation. The standard of devices could be just the frequency, maximum power, and the general safety standard.

When spectrum is already assigned to public use, it is harder to refarm[39]. For instance, if the regulator wants to refarm the 2.4 GHz band – the Wi-Fi band – the regulator has to recall all devices. Another threat of spectrum commons is lack of innovation while sharing with a licensed service. As spectrum commons and licensed services have constrained the use of devices to avoid interference, they also provide less opportunity to develop their spectrum use. Fortunately, this threat, congestion, and the limited quality of service can be solved by new technology and relevant standards, including software-defined radio and cognitive radio.

From the SWOT analysis, it is apparent that spectrum commons has more strengths than weaknesses. Most threats can be solved by the development of new technology and relevant standards. There are some risks, however, concerning the maturity of new technology that the regulator should consider.

[38] The manufacturer and the innovator could be the same person.
[39] Refarming of spectrum is the process of recalling spectrum from existing services or users and re-assigning it to new services or users.

When the objective of spectrum use is safety and prioritized services, spectrum commons is not the appropriate solution. If there is no specific objective, however, spectrum commons should be selected. Furthermore, if the objective of spectrum assignment is to encourage innovation and stimulate new demand, spectrum commons may be appropriate.

5.5 Issues for spectrum commons implementation

Suitable time
A possible indicator is the assessment of costs and benefits to find the net benefit of spectrum commons. A comparison of economic value between spectrum assignment approaches and economic value could possibly be measured from auction.

Suitable frequency
Existing users have paid for spectrum and do not want to share, but newcomers will want frequency band.

Possible frequencies for spectrum commons are the remaining bands from the transition to Digital Television (white space in the US), the interleave channel in TV broadcasting (broadband wireless access), and the vacant frequency above 40 GHz.

Suitable frequencies for spectrum commons have minimum use, are vacant or expected to be vacant in the future, or are inefficient or under-utilized. They will depend on the different situations, from country to country, which have no single solution for this topic.

Amount of frequency
The top-down approach determines the overall bandwidth required for spectrum commons across the frequency band. For example, if mostly low-power devices are used, the estimation of the amount of frequency for low-power device usage in the next ten years will be measured. After that, the regulator must identify the frequency and release it for spectrum commons. It will then review spectrum commons use periodically.

In the bottom-up approach (band-by-band basis), the regulator selects the frequency band that is determined to be the most likely use of band under spectrum commons and licensed. Next, the regulator estimates the economic value of the use of that band under spectrum commons and licensed. The regulator selects the approach that maximizes economic value. If it is spectrum commons, the regulator should determine the restrictions to be applied.

Technical aspects
After the selection of frequency and amount of spectrum under spectrum commons, the technical specification for devices should be imposed. In order to control the use of spectrum commons, the technical standardization of the devices set by the regulator depends on the assigned frequency. Furthermore, the greater the risk of interference, the more restrictions on usage should be imposed.

The implementation of band segmentation can also mean multiple classes of spectrum commons applications. The low level of power of UWB devices means that they can be used across the entire frequency band.

Spectrum commons has many advantages, including the creation of an innovative environment and no spectrum usage fee because of the non-exclusive right to use frequency, lower administrative and social costs. The main disadvantages is irreversibility. To implement the spectrum commons scheme,

the regulator should use a benefit and cost analysis as an indicator of the potential net social benefit of the introduction of a spectrum commons scheme.

5.6 Interpreting the results of the main stakeholders and discussion

Figure 8 provides a synthesis of the stakeholders' view based on close readings of the stakeholders' consultation document by the ARD-ZDF, Deutsche Telecom/T-Mobile, the EICTA, GSMA Europe, Metil Telecom consultants, Microsoft, Telefónica, PWMS Manufacturer Group, and Delft University of Technology, and the final report from the RSPG consultation.

The interpretations are made by examining stakeholders as decision-makers, the decision situation according to Figure 4 in Chapter 2, and the level of actions according to Table 7 in Chapter 2.

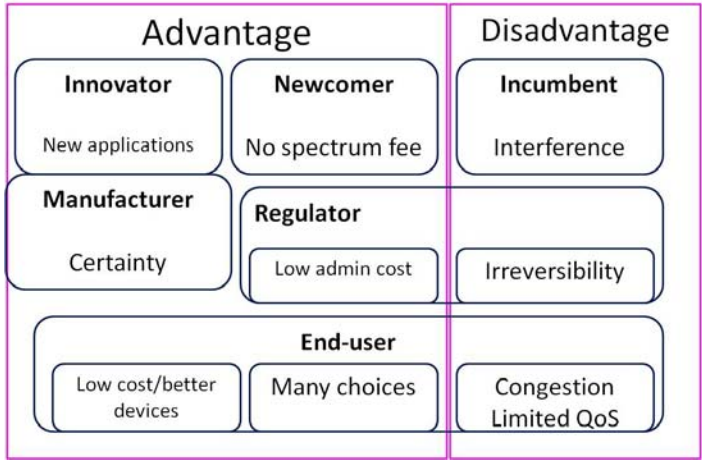

Figure 9. Stakeholders of spectrum commons

At the constitutional choice level, the decision-maker is the regulator. The decision situation comprises the institution arrangement, events, and the community. At this level, the regulator has an international agreement as the institution arrangement, such as the Radio Regulations as an international treaty. The feedback from the event is also a characteristic of spectrum commons. Spectrum commons has a non-exclusive right to use frequency. Spectrum commons therefore has a high cost of exclusion and is highly subtractable, like common-pool goods such as the fishing ground in the Maine lobster industry. The community is the common understanding of the international regulation.

The regulator provides the law and regulations for spectrum commons. The regulator has the advantage of low administrative costs to manage spectrum commons compared with other spectrum assignment approaches. Spectrum commons has the disadvantage of irreversibility however.

At the collective choice level, the decision-makers are manufacturers, innovators, incumbents, and newcomers. They use law and regulations of spectrum commons from the regulator as an institutional arrangement to create their own rules for users at the operational level. These rules, namely network rules, are standards for devices for manufacturers and innovators, and network management for incumbents (existing operators) and newcomers (new operators).

If the regulations are technology and service neutrality, innovators can create new applications. If the regulator allocates frequency worldwide, the manufacturer gains economies of scale from mass production. The price of the device then becomes cheaper.

The operator or provider will also set up the access rules for users to access frequency. This could be via a username/password. The access rule determines who qualifies to access the network.

The event is the characteristic of spectrum commons that is similar to the constitutional choice level. The community is the common understanding of the national law and regulations from the regulator.

Manufacturers have the certainty to produce spectrum commons devices as an advantage. Innovators have the potential to create any applications under spectrum commons that are specified by the frequency and power limitation as advantages. Newcomers have low-cost entry to the market, because spectrum commons is on a non-exclusive use basis. No one owns the spectrum or pays a spectrum fee, which are advantages. The incumbents worry about interference from sharing spectrum commons with their existing service, which are disadvantages.

At the operational level, the decision-maker is the end-user. The end-user has to use the devices according to the rules set at the collective choice level for spectrum commons. The institution arrangement is a network rule from the collective choice level. The event is the characteristic of spectrum commons that is similar at the constitutional choice level. The community is the common understanding of network rules including how to use the devices.

The end-users have many choices of devices and application as advantages. Spectrum commons have the potential to create competition among devices, applications, and operators. This competition provides cheaper prices, better devices, as advantages. Unlimited use of spectrum commons devices may, however, create congestion and limit the quality of the service, which are disadvantages.

5.7 Summary

This chapter discussed the advantages and disadvantages of spectrum commons corresponding to the third research question.

Advantages of spectrum commons include a lower entry barrier and improved administration costs, the creation of innovation, and the stimulation of demand. On the other hand, a disadvantage of this approach is irreversibility after spectrum assignment. This problem can be solved by the development of new technology and relevant standards of devices. A SWOT analysis also shows that spectrum commons has more strengths and opportunities than weaknesses and threats. The riskiness of the new technology should be taken into account however.

Finally, it is difficult for the regulator to select an appropriate frequency. A benefit and cost analysis will be used to compare the economic value of spectrum usage under spectrum commons with other approaches. The result will be information to help regulators select the spectrum assignment approaches. The challenge of the activity for the regulator is to balance the benefit of spectrum usage for all users.

Chapter 6 Conceptual benefit and cost analysis

The chapter addresses the fourth research question: How can the benefits and costs of spectrum commons be measured? The purpose is to measure the benefits and costs of spectrum commons to find its value.

The value of spectrum commons depends on its applications. The applications of spectrum commons are mostly short-range devices. Short-range devices have many applications and frequencies. For example, the Wi-Fi routers can operate at both the 2.4 and 5.7 GHz band. The Bluetooth wireless headset operates at 2.4 GHz. If the regulator provides the technology and service neutrality for spectrum commons regulations, there will be great potential for many new applications to emerge. Thus, the applications of spectrum commons have been identified, in the first place, to value spectrum commons.

The value of spectrum commons can be viewed from different perspectives. From the perspective of firms that use spectrum commons for their businesses, the value of spectrum commons derives from the financial benefits and costs at firm level. From the perspective of the national economy, however, the value of spectrum commons derives from economic benefits and costs. The financial benefit and cost analysis at firm level is therefore part of the economic benefit and cost analysis. The value of spectrum commons to the national economy will be important information for the regulator to decide whether to license or unlicense spectrum.

This chapter elaborates on the benefit and cost analysis at the conceptual level. The concepts are benefit and cost analysis (Campbell & Brown, 2003), valuation of unlicensed applications (Indepen, 2006), and engineering value (Sweet, et al., 2002). A possible framework for valuation of spectrum commons in Thailand is provided at the end.

6.1 Benefit and cost analysis

Campbell and Brown (2003) provide a benefit and cost analysis to appraise the project: with and without projects. If the decision-maker undertakes the project, there is a need to know how much of the scarce resource will be allocated to it and what the value of the project will be. If the decision-maker does not undertake the project, the same amount of scare resource can be allocated to alternative uses.

Campbell and Brown (2003) also provide a conceptual scheme view for appraisal of the project. Figure 10 provides both a firm and whole economy (social) point of view.

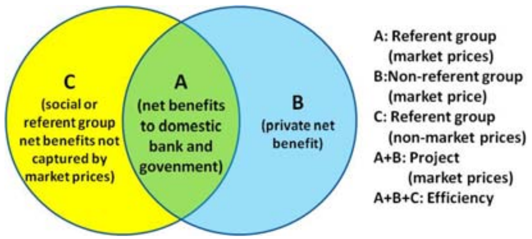

Figure 10. Relationship between the project and the private, efficiency, and reference group net benefits[40]

[40] Source: Campbell and Brown (2003, p. 7), Figure 1.3

Figure 10 shows the overlap between circle A+B (project) and circle A+C (social or referent group[41]) from the appraisal of the project. The A+B area represents the project benefit and cost analysis at the firm level (financial benefit and cost analysis). This A+B area can be obtained from the value of the project at private market prices. The B area represents the private benefit and cost analysis for the firm by subtracting tax, interest, and debt from the project. The A+B+C area represents the efficiency benefit and cost analysis that is used to shadow prices instead of market prices[42]. The A+C area represents the benefit and cost analysis of the referent or social group. The A+C area can be obtained directly from the value of all members in society. Alternatively, the analyst can obtain the whole A+B+C and subtract B.

With regard to suitable information for the regulator to license or unlicense spectrum, the efficiency benefit and cost analysis will be selected. The process should begin with the financial benefit and cost analysis at the firm level and, as far as possible, the added value of all members in society.

To appraise the project (implementing spectrum commons), the benefits are measured as revenues from the project. The costs are measured as all the expenses. Forecasts are made for both the revenues and the costs through the duration of the project. For simplicity, the demand forecast may be set to be the same for the whole project. After identifying all the benefits and costs, the calculation of the net present value (NPV) of the project is made by using an appropriate discount rate. The discount rate is calculated from the Weighted Average Cost of Capital (WACC) of the firm. A positive NPV throughout the project duration indicates a profitable project. The value of spectrum commons is represented by the net present value of the project.

Moreover, the value of all the members in society should be identified as the stakeholders. The details of finding the value of all the stakeholders should be further investigated.

6.2 Valuation of unlicensed applications

Indepen (2006) provides details of the benefit and cost analysis: how the valuation of unlicensed applications can be measured in the UK from 2006 to 2026. There are a number of unlicensed applications in the UK. It is hard to project all applications however. Ten unlicensed applications were selected: road user charging in the 5.8 GHz band; automotive short-range radar in the 24, 77/79 GHz band; blood glucose sensor in the 401-406, 600, and 1400 MHz bands; RFID in the retail market in the 860-960 MHz band; public access Wi-Fi in the 2.4 and 5 GHz bands; home data networking, especially home entertainment, in the 2.4 and 5 GHz bands; wireless building automation in the 2.4 and 5 GHz bands; fixed wireless link in the higher 70 GHz band; telemetry in the utilities in several bands; and wireless home alarms in several bands. These applications are the most important unlicensed application in the UK. Table 23 shows the value of spectrum commons of ten unlicensed applications.

Table 23. Spectrum value of unlicensed applications in the United Kingdom[43]

Application*	Value in 2026 (£m)*	Frequency (GHz)*	Relevant to Thailand
road user charging	53	5.8	similar use, initial phase
automotive short-range radar	1776	24, 77/79	76-77 radar 24-79 not used
blood glucose sensor	0	0.4	less use

[41] The referent group is defined as a group of individuals deemed by the decision-maker to be relevant in the relatively narrow interpretation in the context of the social benefit and cost analysis (Campbell & Brown, 2003, p. 6).
[42] In certain instances, the accounting prices can replace the shadow price (Campbell & Brown (2003), Chapters 5 and 12).
[43] (*) Source: Indepen (2006, p. 53) Figure 6.2

Application*	Value in 2026 (£m)*	Frequency (GHz)*	Relevant to Thailand
RFID in retail market	2478	0.860-0.960	warehouse register board
public access Wi-Fi	5270	2.4	similar use and continued growth
home data networking	395	2.4	similar use and continued growth
wireless building automation	96	2.4	pilot project
fixed wireless link	50	70	not used
telemetry in the utilities	600	0.4	not used
wireless home alarms	143	0.9+0.4	not used

As mentioned in Section 1.6, most of the frequency assignments use a command-and-control approach that is inefficient in terms of the frequency licensee's distribution. Most frequency licensees are government agencies or state-owned enterprises. The development of a spectrum commons policy in Thailand has two separated processes: authorization of the use of radio communication devices and exemption of relevant radiocommunication licences or unlicensed.

The unlicensed regulation was imposed in 2004. The application in the 2400-2500 MHz band, especially WLAN, was authorized for use in 1996 with the relevant radiocommunication licences. Until 2004, the 2400-2500 MHz band was open for any applications with power up to 100 milliwatts (e.i.r.p.). The consequent growth in the number of WLANs from the Customs Department is displayed in Figure 7.

From Table 23, the biggest value unlicensed application in the UK is public access Wi-Fi. It is used in the 2.4 GHz band. In the study by Indepen (2006), there are three applications in the 2.4 GHz band, i.e., public access Wi-Fi, home networking, and wireless building automation. Wireless building automation is not widely implemented in Thailand. Public access Wi-Fi and home networking are interesting to explore however.

The framework of Indepen (2006) is shown in the following figure.

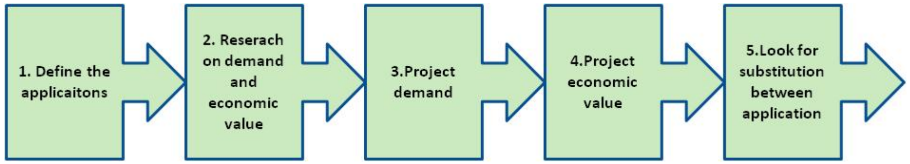

Figure 11. Approach to projecting the economic value of license-exempt applications[44]

First, the framework begins by defining the application to provide a definition of an application that makes unambiguous projections of economic value. Second, research into the demand for and economic value of the application helps analysts understand the application, the technical characteristics of the application, the demand for the application, and the sources of economic value from the application.

Third, by making demand projections, analysts project future application demand, which reflects market demand, excluding any congestion and cross-application interference. Future demand projections involve four tasks: 1) defining the basic measure of demand for public access Wi-Fi and home networking using the volume of traffic and number of households with wireless access, respectively; 2) constructing demand scenarios, i.e., low, medium, high, reflecting the range of likely

[44] Source: Indepen (2006, p. 2), Figure S1

outcomes and associated probabilities of each scenario; 3) considering the drivers of demand and constructing a basic demand model; and 4) using a spreadsheet to generate high, medium, and low demand projections.

Fourth, the economic value from the demand projection of future cost and benefit estimates is obtained. There are three projections reflecting high, medium, and low demand scenarios. Fifth, looking for the substitution effect to avoid over-estimating the economic value of an application. For example, the Wimax will be the substitution service for public Wi-Fi hotspots to provide access to the Internet. Indepen (2006) selected 10 out of 100 unlicensed applications, however, and given that, there is no substitution effect of the study.

Indepen (2006) provides the number of access point per square kilometer subject to the empirical test and assumptions, i.e., 8.7 and 19.5 per square kilometer outdoors and indoors (public access Wi-Fi). The number of access points is the output of the interference testing scenario at 50 test points. Moreover, the maximum volume of the capacity that an access point can handle is also assumed. During a busy hour, the access point activity ratio is 30%, the workable carrier is 11 Mbps, and the interference protection of the test point is 90%, and three non-overlapping channels at 2.4 GHz are assumed. The maximum handling volume is 87,000 and 39,000 Mbytes/square kilometer indoors and outdoors during a busy hour, respectively. The population penetration can be used to calculate the traffic volume per year including dense areas, urban areas, and rural areas.

6.3 Engineering value

Sweet et al. (2002) provide the concept of valuation of the spectrum by using the engineering value. The engineering value is determined by the cost saving in the infrastructure of the operators' network, obtained when the additional spectrum is used (Sweet, et al., 2002). This is one way to value B stated in Section 6.1.

Wireless communication can replace wire communication. For example, the copper wire telephone line from the local exchange to the customer premises can be replaced by the wireless local loop. The cost saving from implementing a wireless connection instead of a wire connection is the value of the spectrum.

In the other case, the use of WLAN or Wi-Fi in the office replaces the LAN connection to all personal computers. The cost saving for wiring the LAN connection is the value of the Wi-Fi or spectrum commons.

The value of spectrum commons depends on its application and operating frequencies. For example, Internet access from xDSL, cable modem, Fiber to the X (FTTx) (home, building, and curb, etc.), and mobile telephone networks can be replaced by spectrum commons via Wi-Fi or WiMax (if the regulator allows WiMax as spectrum commons). The value of spectrum commons depends on which part of the network is replaced as a cost saving. At the least, the copper wire local loop to the customer premises can be replaced by a Wi-Fi hotspot. The WiMax can also be replaced by FTTx in rural areas.

The cost savings are all relevant costs, including investment, installation, operation, and maintenance costs. The engineering value is the cost saving that can be used as the value of spectrum commons.

6.4 Outline of the valuation of spectrum commons for Thailand

In Thailand, spectrum commons has been implemented since 2004, according to the Ministerial Regulation of the Ministry of Transport No. 24 (1993), and the updated regulation of spectrum commons is the National Telecommunications Commission Regulation of Exemption of Radiocommunication Licences (2007c). The regulator did not account for the valuation of spectrum commons when selecting a specified frequency for unlicensed devices.

The process originates from importers or operators who want to market low-power devices. They send applications to import devices to the regulator for import radiocommunication licences. The regulator checks with the existing regulation, including the National Table Frequency Allocation, ITU regulations, and recommendations. The regulators check the technical specifications of the devices: frequency, power limitation, application, and standard to ensure there is no harmful interference with the existing services. After that, the regulators grant the authorization and the import radiocommunication licence. The authorization includes the relevant radiocommunication licences. If regulators want to facilitate the use of devices and deregulate them, they should support unlicensed regulation. Once devices are unlicensed, all relevant radiocommunication licences are exempted.

The case of WLAN

In Thailand, the PTD allowed WLAN use in 1996 under the PTD regulation and users had to obtain relevant radiocommunication licences. At the time, the use of WLAN was limited to indoor use only. In 2003, the PTD amended the regulation to allow both indoor and outdoor use with relevant radiocommunication licences.

The WLAN devices became unlicensed in 2004 in terms of the Ministerial Regulation of Exemption of Radiocommunication Licences, the Ministry of Information and Communication Technology including WLAN in the 2400-2500 MHz band. Moreover, the NTC has granted licensed Wi-Fi hotspots to the Internet service providers since 2005. In 2007, the NTC updated the unlicensed regulation and allowed 5150-5350/5470-5725/5725-5850 MHz for WLAN.

Two scenarios for spectrum commons in Thailand

In Thailand, Wi-Fi devices co-locate with a fixed microwave link in the 2.4 GHz band. Wi-Fi devices operate with low-power output of 100 milliwatts (e.i.r.p.). The fixed microwave link operates at higher power output, however, for example, output power of 3 watts and antenna gain of 17 dBi. The Wi-Fi devices can operate with a fixed microwave link without causing harmful interference.

From the case of Thailand, spectrum commons can be implemented into two scenarios. The first scenario, as mentioned above, is co-location with an existing service. The second scenario is the trade-off between licensed and unlicensed for new frequency.

Co-location with existing services

In Thailand, the decision-makers or regulators must decide whether to implement spectrum commons with the existing services. If the regulator decides to allow spectrum commons to be co-located with existing services, the value of frequency use can be obtained from both existing services (Z) and spectrum commons (X), in the case of implementing spectrum commons and the externality of spectrum commons in terms of social benefit (Y). On the other hand, the value of frequency use can only be obtained from existing service in the case of not implementing spectrum commons. The value of implementing spectrum commons can be obtained directly from the value of the frequency use of spectrum commons and its externality. Figure 12 depicts the value of spectrum commons and whether it should be implemented.

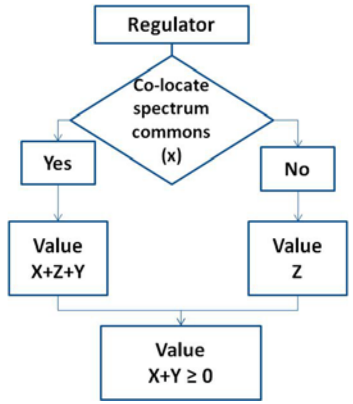

Figure 12. Value of spectrum commons (co-location with existing service)

The spectrum commons can be co-located with existing service. The value of spectrum commons can be derived directly from the spectrum commons itself and its externality.

Trade-off between licensed and unlicensed for new frequency allocation

If the regulator has to trade off between licensed and unlicensed application, the value of the spectrum has to be determined for both licensed and unlicensed. The value of licensed spectrum can be obtained from the financial benefit and cost analysis at firm level. On the other hand, the value of spectrum commons can be determined from an efficiency benefit and cost analysis at the economy level. The value of spectrum commons has been obtained from the financial benefit and cost analysis of its applications and the benefit of all the members of society.

The regulator has to take the value of licensed and unlicensed spectrum into consideration. The regulator selects the higher value of the spectrum. Figure 13 describes the trade-off between licensed and unlicensed spectrum.

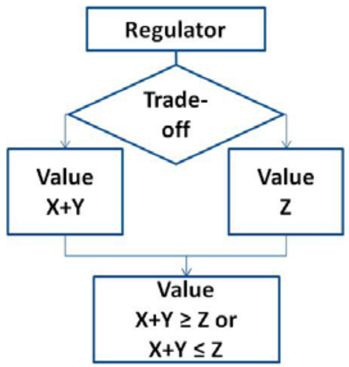

Figure 13. Value of frequency in the case of trade-off between licensed and unlicensed spectrum

This helps to reflect the decision-maker's choices to implement spectrum commons co-located or trade-off options.

Suggestion for a valuation of spectrum commons in Thailand

Spectrum commons was introduced into Thailand in 1993, according to the Ministerial Regulation of Ministry of Transport No. 24. At the time, only technical aspects had been taken into account, especially the harmful interference with other services or applications. The specific usage, frequencies, and power limitation have been addressed by the regulation. Until 2004, the Ministerial Regulation of the Ministry of Information and Communications Technology of the Exemption of Radiocommunication Licences, the unlicensed application had been more service and technology neutrality. Only specified frequency and power limitation remains in the regulation.

The regulator does not take the valuation of spectrum commons in Thailand into account as important information on whether to allow usage of unlicensed applications. There are many unlicensed applications in any frequency band in Thailand. The focus on the operating application and frequency band should be identified. This thesis provides an initial suggestion to value spectrum commons.

From the value of unlicensed applications from Indepen (2006) in Table 23, the highest value is public Wi-Fi that operates in the 2.4 GHz band. In the 2.4 GHz band, Thailand has allowed WLAN to be used since 1996 and unlicensed since 2004. It is interesting to explore WLAN, because there are two timelines: 1996-2004 and after 2004. Moreover, the Internet service provider has been able to use Wi-Fi to provide hotspots for Internet access since 2005. The use of the 2.4 GHz band for Wi-Fi in Thailand also increases from time to time.

At the initial stage, the operating frequency is identified as the 2.4 GHz band in this thesis. The application of unlicensed applications is Wi-Fi routers that can be used as public Wi-Fi hotspots and home Wi-Fi routers.

The important stakeholders that are relevant to Wi-Fi routers have also been identified. At the constitutional choice level, it is the regulator (NTC). At the collective choice level, there are manufacturers, importers, dealers, retailers, Wi-Fi operators, Internet service providers, and telecom operators. At the operational level, it is the end-users.

The stakeholders are the public Wi-Fi operator and the end-users. Table 24 shows the possible benefits and costs of the public Wi-Fi operator and end-users (home data networking). The Wi-Fi operator will use public Wi-Fi access as its project, as B in Section 6.1. The end-users use the Wi-Fi router at home as the benefit of the referent group, as C in Section 6.1.

Table 24. Benefit and cost of public access Wi-Fi and home data networking

Public Wi-Fi operator		Home data networking	
Benefit	**Cost**	**Benefit**	**Cost**
Revenue	Wireless router installation+maintenance	Wiring cost reduction	Wireless router
Wiring cost reduction	Internet connection fee	Increased flexibility	
Licence exemption	ISP licensed fee	Licence exemption	

Public Wi-Fi operator

Revenue: The Wi-Fi operators receive income by charging the users in several packages, pre-paid and post-paid service. The possible packages are charged per volume or duration of usage. The stream of income can be forecast from the user demand deriving from the network capacity utilization.

The forecast of demand is from 2010 to 2030. The volume of traffic varied from area to area. The three types of population density are business, urban, and rural area. The assumption of high, medium, and low demand can be applied. The portion, as a percentage of the maximum volume of traffic, can be adjusted as 100%, 85%, and 20%, respectively. The business, urban, and rural area can be calculated as a percentage of the overall area such as 3%, 6%, and 91%, respectively. These two assumptions are obtained from an NTC project in 2010 on comprehensive spectrum valuation wireless performance and demand assessment for the Kingdom of Thailand: towards and optimized spectrum master plan.

The demand forecast for public access Wi-Fi can be captured as a portion of Internet traffic. The interpolation of the growth of that traffic can infer demand for public access Wi-Fi from 2010 to 2030 as a top-down approach.

Cost saving: The Wi-Fi connection can be replaced with a traditional local loop such as copper wire. The Wi-Fi as an access medium can save the cost for wiring the local loop to customer premises or line rental from a telecom operator. The local loop in Thailand is copper wired. Moreover, the Wi-Fi connection can provide higher bandwidth than xDSL and in areas without any wired network.

Licence exemption: The Wi-Fi operators are exempted from paying for importation, installation, and using Wi-Fi routers, because of the unlicensed regulation. Moreover, the frequency usage fee is exempted.

Cost: The public Wi-Fi operators have to pay for the Wi-Fi router and installation cost – a one-time charge. Moreover, they have to pay the maintenance cost after implementation to the end of business. The cost of connection from the public Wi-Fi router to the Internet gateway is the operating cost. The ISP license is the administrative cost payable yearly.

Home data networking

Cost saving: The Wi-Fi connection can replace the wire inside the home. The Wi-Fi as an access medium can save the cost of wiring cable to customer devices such as LAN connection, printer, speakers, and home entertainment.

Other benefit: The flexibility of the customer to move around the home will be the added as a consumer surplus.

Licence exemption: The end-users are exempted from paying for installation, and using Wi-Fi routers because of the unlicensed regulation. Moreover, the frequency usage fee is exempted.

Cost: The users have to pay for their Wi-Fi routers once.

The number of Wi-Fi routers at home can be calculated from the number of households with a wireless router, which can be obtained from the number of xDSL subscribers. Most providers offer wireless routers to new subscriber for free or at a deductible price. A portion of the growth of xDSL will be used to project the demand for home data networking.

6.5 Summary

The conceptual benefit and cost analysis provides the framework for valuing the project (implementing spectrum commons) at the first and the whole economy level. The financial benefit and cost analysis is used to find the value at firm level, which is one part of the economic benefits and costs in the whole economy. The engineering value can also be used to value the cost reduction at firm level. The study of the valuation of unlicensed application in the United Kingdom provides the practical procedures to find the valuation of unlicensed application.

The suggestion of a valuation of spectrum commons has been identified in the public access Wi-Fi and Wi-Fi routers at home as the initial stage. The possible benefits and costs of Wi-Fi operators and home data networking are specified in Table 24, responding to RQ.4.

Chapter 7 Findings and future research

The purpose of this licentiate thesis is to examine the spectrum commons approach to spectrum assignment. The examined case is Thailand. The main research question is: **"What are the consequences of using spectrum commons for frequency assignment in Thailand?"**

To approach the main research question – What are the consequences of using spectrum commons for spectrum assignment in Thailand? – this thesis addresses five research questions:

RQ.1 *What is a suitable framework for analyzing different types of spectrum commons?*

RQ.2 *What type of spectrum commons has been used in Thailand?*

RQ.3 *What are the advantages and disadvantages of spectrum commons in general?*

RQ.4 *How can benefits and costs of spectrum commons be measured?*

RQ.5 *What are the implications of implementing spectrum commons in Thailand?*

RQ.1 looks at finding a framework to analyze different types of spectrum commons. Three economic institutions from Kiser and Ostrom (1982) and Field (1992) are adopted. The five rights of the property regime by Schlager and Ostrom (1992) is also adopted in this thesis to find the interaction between the layer of the decision-maker and the right to use frequency. The comparison between property rights regimes and natural resources in the Maine lobster industry addresses the right to use frequency.

RQ.2 looks at the use of the framework developed in RQ.1 to understand the institution of spectrum commons and its application to Thailand. The exploration of the history of spectrum assignment also helps the understanding of spectrum commons and the right to use frequency in Thailand.

RQ.3 looks at the advantages and disadvantages of spectrum commons from the public consultation of the Radio Spectrum Policy Group (RSPG) in November 2008 in the European Union to obtain the current thoughts of stakeholders regarding the use of spectrum commons.

RQ.4 is the benefit and cost analysis of the spectrum commons concept from Campbell and Brown (2003), Indepen (2006), and Sweet et al. (2002) as the framework to measure spectrum commons in Thailand. Campbell and Brown (2003) provide the framework of the benefit and cost analysis in terms of the undertaken project or not. The comparison between the current values of whether to undertake the project or not provides the decision-maker with important information. The values without undertaking project measures are obtained from the same allocation resource to alternative uses. Indepen (2006) provides a practical method to measure the unlicensed application in the United Kingdom in 2006. Indepen (2006) selected the ten most important applications among a hundred applications of unlicensed devices. Sweet et al. (2002) provide the valuation of the spectrum using the engineering value – cost saving in the infrastructure of the network operator. The adjusted framework of Campbell and Brown (2003), Indepen (2006), and Sweet et al. (2002) addresses how to value spectrum commons in Thailand. The finding is a framework to evaluate spectrum commons in Thailand in terms of the benefit and cost analysis.

RQ.5 covers the implications of implementing spectrum commons in Thailand.

The five research questions are intended to contribute to increased understanding of using spectrum commons and contribute to the effectiveness of using spectrum commons in Thailand. The summary of these findings are as follows:

1) The economic institution or three worlds of action provide three layers of analysis: constitutional choice, collective choice, and operational level. This framework provides an understanding of the decision-maker and the decision situation within and between layers. Moreover, the property rights regime and natural resource of the Main lobster industry provides the right to use frequency: access, withdrawal, management, exclusion, and alienation rights.

2) The frameworks from RQ.1 provide rights to use frequency in Thailand. Three types of spectrum commons have been used in Thailand: public commons, private commons, and unlicensed. The spectrum commons has non-exclusive right to use frequency. The regulated level of the network provides the different types of spectrum commons. If the state agency manages the network, it is public commons. If the private entities manage the network, it is private commons. If the end-users manage the network by themselves, it is unlicensed. The thesis provides an overview of the spectrum assignment institution in Thailand.

3) The advantages of spectrum commons are lowering barriers to entry for newcomers, lowering the administration costs for the regulator, creating innovation for the innovator, and stimulating demand. The disadvantage of spectrum commons is irreversibility after spectrum assignment.

4) The benefit and cost analysis provides the framework to value the spectrum. The 2.4 GHz band is the specified frequency for the spectrum commons. The applications of the 2.4 GHz bands are public Wi-Fi operators and home data networking. The valuation of spectrum commons can be used as important information for regulators to decide whether to license or unlicense spectrum.

5) The spectrum commons has potential to increase spectrum usage more efficiently by allowing spectrum commons to be co-located with existing services.

The research problem is divided into three parts: conceptual, empirical, and analytical parts. The conceptual part deals with the right to use frequency and examines the framework associated with spectrum commons. The empirical part gathers from history and public consultation to explore the type of spectrum commons in Thailand and the advantages and disadvantages of spectrum commons from the public consultation on spectrum commons in the context of European countries. The analytical part is to use the benefit and cost analysis concept on spectrum commons in Thailand.

7.1 Findings

RQ.1 What is a suitable framework for analyzing different types of spectrum commons?

The economics institution and three worlds of action from Schlager and Ostrom (1992) provide the level of analysis for the decision-maker and decision situation. The property rights regime and natural resource in the Maine lobster industry from Kiser and Ostrom (1982) also provides the right to use the common pool resource. These two concepts provide a framework to analyze the right to use frequency in Thailand. The chronology of events of spectrum management in Thailand provides evidence of the rights to frequency use. The result is provided in Table 25.

Table 25. Bundles of rights associated with telecommunication stakeholders (cf. Table 12)

Rights \ Stakeholders	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

The market-based approach has all the rights to use frequency, including access and withdrawal, management, exclusion, and alienation rights (i.e., selling or leasing frequency). Command-and-control does not have an alienation right however. The command-and-control and market-based approaches both grant the exclusive right to use frequency to licensees. Spectrum commons does not have an exclusive right to use frequency however. There are two types of users in spectrum commons, i.e., general and advanced users. These users have access and withdrawal rights because of the characteristics of transceivers. The transceivers are specified to access and use the frequency at the same time. Only the advanced users have the additional exclusion right to determine who can use their network by setting passwords or encryption code.

RQ.2 What type of spectrum commons has been used in Thailand?

The type of spectrum commons that has been used in Thailand is addressed. Using the category of the right to use frequency from Table 25 provides the regulated level of the regulator. Moreover, the exclusivity of using frequency provides exclusive and non-exclusive use in order to separate the spectrum commons from the command-and-control and market-based approach. The type of spectrum commons is provided in Table 26.

Table 26. The rights to use frequency (cf. Table 13)

Regulated level \ Property right	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

There are three types of spectrum commons, i.e., public commons, private commons, and unlicensed. Regulators delegate some rights to licensees to manage their network. These represent the regulated level. If the state agency is in charge of network management, it is called public commons. For example, the local municipalities have their Wi-Fi network for their community. If the private entities manage their network for commercial service, it is called private commons, such as the public Wi-Fi hotspots in hotels, airports, department stores, etc. If the end-users have to manage by themselves, it is called unlicensed.

The history and development of the spectrum management institution in Thailand also provides an original work that narrates important events concerning spectrum management, especially spectrum commons in Thailand. There are two steps to implementing spectrum commons in Thailand: 1) the authorization of the use of devices and 2) the exemption of relevant radiocommunication licences.

RQ.3 What are the advantages and disadvantages of spectrum commons in general?

The advantages and disadvantages of spectrum commons are provided from the analysis of public consultation in Europe by the RSPG and relevant literature. Figure 14 shows the advantages and disadvantages of spectrum commons with the relevant stakeholders.

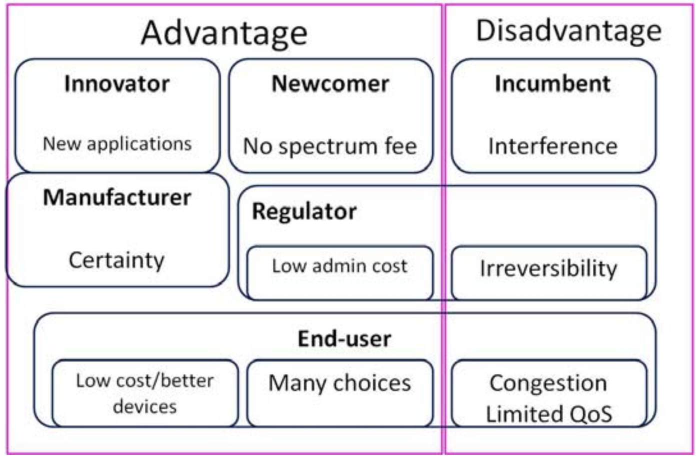

Figure 14. Stakeholder of spectrum commons (cf. Figure 9)

Advantages of spectrum commons include lowering barriers to entry, lowering the administration costs, creating innovation, and stimulating demand. On the other hand, the main disadvantage of spectrum commons is irreversibility after spectrum assignment. To determine the net benefit of spectrum commons, a comparison of the advantages and disadvantages is required. Most disadvantages can be solved by the development of new technology and a relevant standard of devices, except irreversibility, once the spectrum commons has been assigned to public use.

RQ.4 How can the benefits and costs of spectrum commons be measured?

The concept of the benefit and cost analysis for the appraisal project to undertake or not is the outline to value the spectrum commons. The efficiency benefit and cost analysis captures the financial benefits and costs at firm level plus the value or benefits and costs of all members in society from implementing the spectrum commons. The cost saving from the engineering value contributes to the value of spectrum commons as benefits for both the firm and society.

The procedure to measure the benefits and costs of spectrum commons begins with the identification of the operating frequency and application of spectrum commons. The stakeholders of specified applications of spectrum commons have been explored. The limitation of stakeholders at the initial stage should be considered in order to limit the scope of valuation of spectrum commons. The categories of benefits and costs of the application of spectrum commons have been identified. Data collection from the identified benefits and costs should be pursued in order to calculate the value of spectrum commons.

In this thesis, the 2.4 GHz band has been identified as the operating frequency. The public Wi-Fi routers and home data working (home Wi-Fi routers) are the target of the valuation of the spectrum commons. The possible benefits of the public Wi-Fi operator are revenue, cost saving from wiring, and license exemption. The possible costs of the public Wi-Fi operator are wireless routers, installation and maintenance costs, Internet connection, and the ISP license fee. The possible benefits of home data networking are cost savings form wiring, licence exemption, and increasing flexibility. The possible cost is the wireless router.

RQ.5 What are the implications of implementing spectrum commons in Thailand?

The frameworks in Chapter 2 and RQ.1 (three worlds of action, and property rights regime and natural resource) provide the analysis of exclusive and non-exclusive right to use frequency. The exclusive use of frequency by a command-and-control or market-based approach has limited the use of spectrum to the assignees or winning bidders. They sometimes do not occupy the spectrum. The framework of non-exclusive use of frequency is introduced in spectrum commons, while no one owns the frequency or has an exclusive right to use frequency. Users must share frequency and accept interference. The non-exclusivity increases the number of users and the efficiency until the maximum capacity is reached.

Moreover, three types of spectrum commons have been used in Thailand in Chapter 4 or RQ.2 (public commons, private commons, and unlicensed). They provide the current status of spectrum commons in Thailand. These three types also appear in other countries that have a similar situation.

Regulators should use these findings for further consideration of using spectrum commons to increase spectrum efficiency in terms of utilization of frequency and distribution of frequency users.

The public consultation of RSPG in November 2008 in Chapter 5 or RQ.3 provides the advantages and disadvantages in a European context. Most of the spectrum commons frequency is worldwide allocation however. The stakeholders are also most probably the same. The findings of advantages and disadvantages at high level should not be different. There may be a slight deviation in the local context.

Regulators should conduct a similar public consultation to identify the advantages and disadvantages of spectrum commons in their context to adjust to their environment.

The regulator may consider adding spectrum commons to other frequency bands, impose power limitation, and specify frequency as necessary constraints. These constraints have a high potential to attract innovation. The market will select services and applications freely under the constraint to respond to demand. The low entry barrier makes spectrum easier to access and encourages competition in the market. The end-user will have better quality of service and lower prices.

The benefit and cost analysis to value spectrum commons in Chapter 6 or RQ.4 provides the framework to measure the value of spectrum commons. The result of the valuation of spectrum commons depends on the availability of data collection and varies from country to country.

Regulators should use the value of spectrum commons as important information on whether to license or unlicense spectrum. The value of spectrum will reflect the best utilization of spectrum. Greater use of spectrum commons of frequency assignment will increase spectrum efficiency in terms of the number of frequency users and the spectrum utilization.

The regulator should consider the loss of the frequency usage fee through non-exclusive right as income loss. On the other hand, the operator and end-users gain the benefit of not paying the frequency usage fee. The benefits to society may be greater than the lost income of the regulator.

7.2 Generalizability: Can spectrum commons be applied in other countries?

Learning to use spectrum commons in Thailand provides information to regulators in other countries that have a similar use of spectrum in the same or other regions. The use of the ISM band in footnotes 5.138 and 5.150 is the starting point to considering the use of spectrum commons in their countries. The worldwide frequency allocation will support the use of spectrum commons in terms of the available standard and devices.

The benefit and cost analysis offers the valuation of spectrum commons as an indicator for the regulator to decide whether to license or unlicense spectrum. The value of spectrum commons depends on the number of applications. This study of the valuation of spectrum commons may serve as an example to considering the use spectrum commons in other countries.

The RSPG public consultation in the European countries provides the perspective of relevant stakeholders. The context can be generalized if the behavior of stakeholders is similar to other contexts, such as the behavior of incumbents, manufacturers, end-users, and regulators in Thailand. There may be some extent of similarity. The public consultation in Thailand will help adjust and form a precise perspective on spectrum commons in the Thai context however.

7.3 Future research

The possible outcome of implementing spectrum commons in Thailand can be measured in terms of the valuation of spectrum commons from the perspective of the regulator. The valuation of spectrum commons provides important information on whether to license or unlicense spectrum. The other possible outcomes for implementing spectrum commons should be investigated further for other stakeholders, applications, and frequencies. The suggestion in this thesis is limited to public access Wi-Fi and home Wi-Fi routers in the 2.4 GHz band. There are only two stakeholders in this thesis, i.e., public Wi-Fi operators and end-users. The possible extensions of other frequencies, such as WiMax or other stakeholders such as manufacturers or innovators, should be considered in future research.

Further exploration of spectrum commons theory may be a possibility for future research. A deeper, metatheoretical exploration of spectrum commons would be possible to gain a deeper understanding of spectrum commons theory.

Deeper or wider exploration of the social benefits of spectrum commons should be considered as future research to find the contribution of spectrum commons to other areas in society. For example: Could spectrum commons contribute to the wealth of a country? Could spectrum commons improve the overall efficiency of spectrum? Could spectrum commons help to improve society?

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List of abbreviation

AIS	Advanced Info Service Public Company Limited
APT	Asia Pacific Telecommunity
ARD-ZDF	ARD-Verbindungsbüro and ZDF-Europabüro
BT	BT Public Company Limited
CAT	Communication Authority of Thailand
CCTV	Closed Circuit Television
CEPT	European Conference of Postal and Telecommunications
CISPR	Special Committee of the International Electrotechnical Commission for Interference
CITEL	Inter-American Telecommunication Commission
DSL	Digital Subscriber Line
DTAC	Total Access Communication Public Company Limited
EHF	Extra High Frequency
EICTA	European Information & Communications Technology Industry Association
E.I.R.P.	Equivalent Isotropically Radiated Power
FCC	Federal Communication Commission
FTTx	Fiber to the X
GHz	Gigahertz
GMPCS	Global Mobile Personal Communication by Satellite
GPS	Global Positioning System
GSMA	GSM Association
HF	High Frequency
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiocommunication
kHz	Kilohertz
LAN	Local Area Network
LF	Low Frequency
MAC	Medium Access Control
MF	Medium Frequency
MHz	Megahertz
MICT	Ministry of Information and Communications Technology
MoT	Ministry of Transport

mW	Milliwatt
NBC	National Broadcasting Commission
NFMB	National Frequency Management Board
NPV	Net Present Value
NRA	National Regulatory Authority
NTSC	National Television System Committee
NTC	National Telecommunications Commission
O2	Telefónica O2 UK Limited
ONTC	Office of the National Telecommunications Commission
PAN	Personal Area Network
PCMCIA	**P**ersonal **C**omputer **M**emory **C**ard **I**nternational **A**ssociation
PCS	Personal Communication Services
PDA	Personal Device Accessories
PHY	Physical layer
PTD	Post and Telegraph Department
PWMS	Professional Wireless Microphones Systems
QoS	Quality of Service
RCA	Radio Corporation of America
RF	Radio Frequency
RFID	Radio Frequency Identification
RLAN	Radio Local Area Network
RQ	Research question
RR	Radio Regulations
RSPG	Radio Spectrum Policy Group
RTTTs	Railway applications, road Transport and Traffic Telematics
SHF	Super High Frequency
SIM	Subscriber Identity Module
SoD	Supplier’s Declaration of Conformity
SRD	Short-Range Device
SWOT	Strength Weakness Opportunity Threat
TOT	Telephone Organization of Thailand
True Move	Truemove Company Limited
UHF	Ultra High Frequency
ULP-AMI	Ultra Low Power Active Medical Implant
USB	Universal Serial Bus
USOM	United States Operations Mission
UWB	Ultra Wide Band

VLF	Very Low Frequency
VHF	Very High Frequency
WACC	Weighted Average Cost of Capital
Wi-Fi	Wide Fidelity
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMO	World Meteorological Organization
WRC	World Radiocommunication Conference
WWI	World War I
2G	Second Generation mobile telephone
3G	Third Generation mobile telephone