Telecommunications Regulatory Strategies for Thailand: Analysis and Recommendations

Settapong Malisuwan, Wassana Kaewphanuekrungsi, and Nattakit Suriyakrai
National Broadcasting and Telecommunications Commission, Bangkok, Thailand
Email: {settapong.m, wassana.k, nattakit.s}@nbtc.go.th

***Abstract*—Nowadays, the application of wireless broadband has grown denser and tends to expand even more. This results in the soaring bandwidth needs to effectively support consumer demands. Besides, the growth in broadband connectivity through wireless networks has also brought about huge spectrum demands as well. As regards the soaring spectrum demands, if the regulators place importance on long-term spectrum planning through formulating the strategies and methods related to spectrum management, the country will be capable of supporting a great demand for spectrum in the future, maximizing the benefits of spectrum resources among populations as well as creating economic and social values for the country. Therefore, in order to ensure that the process will be carried out orderly, effectively, accurately, and appropriately, the related sectors should undertake some additional studies in accordance with domestic average spectrum demands to facilitate the drawing up of explicit plans that support the appropriate use of technological innovations, encourage the effective sharing of spectrum as well as shape up the policies to be more open and conform to the direction of future technological development. The objective of this paper is to introduce supportive regulatory strategies for the Thai telecom regulator. The recommendations in this paper will help the telecom regulator to foster the growth of Thai economy and serve the quality of life for the Thai society.**

***Index Terms*—Thailand, telecommunications, regulatory, strategies**

I. Introduction

The study results concerning average spectrum demands of several organizations are in the same direction. That is, the spectrum usage in mobile networks has greatly expanded affecting telecommunications industry's spectrum needs to soar rapidly. In relation to this, the study results presented in the 2012 ITU's National Wireless Broadband Master Plans for the Asia Pacific Region reveal that the estimated demands for telecommunications spectrum among countries in the Asia-Pacific region should be at least 760MHz or preferably 840MHz by 2020 [1].

According to the 2011- data traffic forecasted by the International Telecommunication Union Radio communication Sector (ITU-R) in 2006, the actual 2011-data traffic was 5 times greater than the amount estimated by the ITU-R in 2006. Furthermore, the ITU-R also forecasted that the mobile broadband traffic in 2011 will be 8 times grower during 2010-2011 [1]-[3].

Nowadays, there is only a total of 340 MHz of spectrum on the 800/900 MHz, 1800 MHz, and 2100 MHz bands available in Thailand. Therefore, to double the amount of spectrum within the duration of less than 6 years or by the end of 2020 according to the ITU's recommendations is quite practically hard-to-achieve because there are several legal restrictions regarding the negotiation urging the incumbent users to return spectrum. However, the aforementioned number forecasted by the ITU may not match Thailand's actual utilization rates due to several different internal factors. Therefore, additional studies related to domestic average spectrum demands are considered important in that the data can be used to draw up distinct future plans [4] and [5].

There are some spectrum bands which have already been used in telecommunications such as 800/900 MHz, 1800 MHz, and 2.1 GHz. Also, there are some spectrums in the 700 MHz, 2.3 GHz, and 2.6 GHz bands which have not yet been made applicable for mobile services and have had no clarity in terms of whether they can be used in such services or how long it will take the process to be complete. Therefore, it is forecasted that if the transfer of spectrum license holders cannot be undergone, the existing spectrum will possibly be inadequate for user demands [6].

Accordingly, the formulation of plans to study further demands for domestic average spectrum and the possibility of managing spectrum through different approaches apart from the exclusive-use licensing done previously, especially the shared use of spectrum (both open to group and public), provide more options fulfilling the increasing spectrum demands.

Telecommunications is one of the key infrastructures that take part in propelling the country's development in terms of economy, society, education, public health, science, national security as well as bring about social equality. If policy makers and the telecom regulator implement policies that encourage investment, competition and innovation, both the mobile sector and the wider digital economy will expand, creating prosperity, labor improvement and new entrepreneurship. Therefore, it is necessary that the spectrum demands should be taken into consideration as well. This paper aims to introduce spectrum planning and strategies for the National Broadcasting and Telecommunications Commission, the telecom regulator in Thailand.

Manuscript received October 15, 2015; revised January 17, 2016.

doi: 10.18178/joams.5.2.102-108

II. Effective Use of Spectrum

The appropriate support of technological innovation utilization will result in the effective use of spectrum that promotes telecommunications to be developed adequately for user demands. Some examples of technological innovation utilization are as follows.

A. Utilization of Mobile Network Technology along with Wi-Fi

Developers of the technology for mobile and Wi-Fi networks have commonly perceived the importance of making continual progress in technology in terms of taking the most advantage of spectrum utilization, network capacities, network data transfer speeds, user experiences, including the effective integration of technology and the remarkable revolutionary modes which correspond to one another. These affect the utilization of core technology in mobile networks such as HSPA and LTE along with Wi-Fi to attain massive global success and be able to offload partial data to the Wi-Fi networks, often called Wi-Fi Offload, to relieve as much burden placed on mobile networks as possible.

In addition, the use of small cells and femtocells which have a low output power in a large amount along with the existing macro cells to improve the efficient of the macro cells can further increase the overall network capacity in dense urban areas.

According to the study of Cisco undertaken in February 2014, it is found that 45 percent of the global mobile data traffic was offloaded through Wi-Fi and femtocells, and this particular number will be grower than the amount of major mobile data traffic by 2018 [7].

B. Utilization of Higher-Band Spectrum

Recently, the use of low-band spectrum (such as 300MHz and 3GHz) has been massive in quantity and is getting denser every day. Accordingly, the technology developers and other related sectors have begun to place importance on using higher-frequency bands because their utilization is low in density. For example, the 2.4 GHz and 5 GHz spectrum was widely used in the Wi-Fi services previously, but there has been some development undertaken to make the 60 GHz band applicable based on the 802.11ad standard. For the sake of high-speed short-range communication and satellite communication services, the use of spectrum has been expanded up to the 28 GHz band compared to previously when only the spectrum below the 12 GHz band was commonly used. There will be an increasing trend of high-band spectrum utilization due to the growing demand for higher capacities to support new technologies. Meanwhile several technologies have been developed and gain widespread use, the cost of spectrum utilization in high bands tends to be lower [6], [8] and [9].

C. TV White Space (TVWS)

"White Space", in this case, refers to the unused channels available in the terrestrial television spectrum. Normally, the terrestrial television system in each area will use some of the channels and spare white spaces to avoid interference between channels. During the past ten years, there have been some extensive studies undertaken, especially in USA, to put the white space channels into use for expanding network coverage to remote areas in particular, known as the TV White Space (TVWS) technology [10].

Generally, the Wi-Fi signal in both the 2.4GHz and 5 GHz bands can cover the area of a few square meters and can penetrate through merely two layers of wall. However, the white spaces of the spectrum band 470 – 790MHz can travel up to 10 kilometers through cultivation areas, buildings, houses, and many others. So, they can be used as media delivering wireless broadband Internet connectivity to electronic devices such as a tablet computer, cellphone, and computer through fixed or mobile base stations, using a low-cost system. Therefore, the white spaces are appropriate for providing wireless broadband Internet services in remote areas or in areas where fixed-broadband Internet services are still out of reach stemming from high wiring costs. Bases on this, the amount of truly applicable white spaces will vary among individual areas.

Though the majority of client devices are still cannot connect to the TV White Space (TVWS) directly, most of TVWS devices commonly have ports for connecting to regular Wi-Fi hubs. This enables the client devices available in current markets to be capable of accessing Internet, using the TVWS technology as a connection medium.

During the past few years, the TVWS testing has been extensively done in several regions worldwide, i.e. USA, Africa, and Asia. At the end of 2013, the UK Federal Office of Communications (OFCOM) [11], in corporation with 20 government and private organizations, underwent a 6-month TVWS technology testing. This has been considered the biggest test ever done in Europe after several immense successes have been claimed in Canada, including many other countries in Africa where the TVWS technology has been used to provide rural broadband services and as the backhaul for Wi-Fi, webcam, remote sensor, and smart grid networks.

Giant companies like Google and Microsoft have taken major part in promoting the TVWS technology, especially in the African market, to increase the number of Internet users which has already existed at only 16 percent. Owing the property of the TCWS spectrum that can travel up to 10 kilometers, it is highly suitable for providing rural broadband services in remote areas where the Internet and the electric infrastructures are still out of reach because the TVWS devices are normally designed to support solar power [12] and [13].

There have been some TVWS testing in Singapore, the Philippines, and Indonesia under the good promote of government and private organizations; both at the national and international levels. Accordingly, the expansion of wireless broadband Internet networks to Thailand's remote areas can be fulfilled if there are some studies undergone in relation to the possibilities of enabling TVWS technology.

D. Utilization of Other Technologies

There are a large number of technologies developed to enhance in spectrum utilization efficiency, both over the licensed and public spectrum. This includes the Ultra-wideband and Spread Spectrum (UWS) that spreads the signal over a wide-spectrum range using a very low output power so that the incumbent or primary users can share the spectrum with secondary users of UWB without causing interference. Therefore, it is suitable for short-range transmission and indoor purposes accordingly.

The software-defined Radio (SDR) is a radio communication system where the signal processing software has been typically implemented in general hardware and the technology can be adjusted to support various wireless protocols (such as GSM, WCDMA, HSPA, LTE, Wi-Fi, etc.). With the appropriate software utilization, this kind of technology is convertible depending on spectrum and interference. It is normally used with the Cognitive Radio (CR) that is capable of understanding and learning from previous operations and will adjust its own behaviors, according to unused channels and the amount of interfering signals, through adjusting the receiving and transmitting techniques appropriately at all time [14] and [15].

III. Spectrum Strategy: The Shared Use of Spectrum

The spectrum regulators worldwide have placed emphasis mainly on the allocation of spectrum through providing "exclusive use" to allow particular license holders to have full control over the use of spectrum bands, driving network operators to acquire the utmost confidence in operating businesses. However, this approach is not exactly the best policy because there is inadequate spectrum available for the soaring demands, especially when the appropriate spectrum bands have already been allocated. Therefore, the study of possibilities enabling the shared use of spectrum through providing Licensed Shared Access and allocating the public spectrum which does not require further licenses has to be undertaken in response to the fast growing technology that increases the enormous spectrum demands.

The spectrum is, as a real, the resource that can be shared among users if there is some technology making the shared access possible without any interference, although the same spectrum band, area, or time of usage is being shared. This includes providing the allocation mechanism that enables the shared use of spectrum to yield the maximum efficiency. For example, Licensed Shared Access (LSA) is introduced to regulate the use of spectrum that is held by non-mobile incumbent users, has a low utilization rate, and is unable to shift its function for other purposes in the near future. Accordingly, the LSA users are allowed to use the entire or partial spectrum in the same band as same as the authorized incumbent users under exclusive licenses who may appear in the form of government or private organizations. This depends on the regulations on the shared use of spectrum and the right to use spectrum where the quality control can be carried out.

Initially, Qualcomm and Nokia suggested the regulatory method known as the Authorized Shared Access or ASA which aims at promoting the use of some spectrum bands which are not being used by primary users at a particular time and location for the sake of International Mobile Telecommunications (IMT), whereas the primary users can still make use of that particular bands us usual and be able to make plans for utilization forecasting. Later on, the ASA concept had been expanded by the Radio Spectrum Policy Group and finally gave rise to the LSA. However, the ASA and LSA are both considered based on the same basic concept [16]-[18].

Figure 1. Example showing the utilization of 2.3 -2.4 GHz spectrum band in specific in Thailand.

A remarkable example marks the occasional use of spectrum held by government or military organizations during some time intervals or in some locations. This is shown by Fig. 1 illustrating the utilization of the 2.3–2.4 GHz spectrum is applicable only in limited boundary shown by the shaded areas. Therefore, there are some possibilities of providing LSA users with licenses that enable them to put the common spectrum bands on services to support user demands in other areas. The given rights will subject to the quantity and quality of the spectrum available, under the regulations on shared use of spectrum. By other means, some restrictions can be enforced to allow incumbents to be capable of using the allocated spectrum only during the time interval specified and permit the licensed LSA users to use the particular spectrum during different time intervals.

The structures and privileges pertaining to the license issued by this particular mean are not a far cry from those of the exclusive licenses, but the right to use spectrum is more open to allow both the incumbent users and licensed LSA users to use the same spectrum. The non-mobile utilization in limited areas of incumbent users benefits the LSA licensees to be capable of forecasting, claiming their distinct rights to use the spectrum, and manipulating the system to allow the effective shared use of spectrum. This

particular licensing approach subjects to the negotiation conducted among three sectors: Primary users, secondary users, and regulators. It is composed of general agreements on the shared use of spectrum in terms of authorized areas and technical utilization as well as the conditions required in case the users are in need of moving out of any spectrum bands. The shared use of spectrum according to the LSA concept is currently under the process of consecutive development undergone by several organizations; both in Europe for the 2.3-2.4 GHz band and in U.S. for the 3.5 GHz band, etc. Fig. 2 shows the structure on spectrum allocation on the basis of LSA.

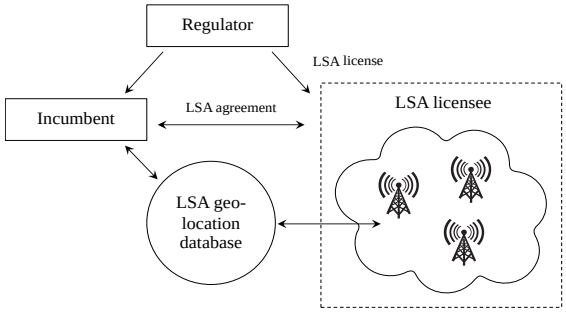

Figure 2. The structure on spectrum allocation on the basis of LSA [18].

TABLE I. LSA LICENSING-RELATED SECTORS

Related Sectors	Processes of Generating Motivations to Follow the Method of LSA
Spectrum Regulators	The motivation for spectrum regulators is that the manipulation of spectrum based on the LSA method will help the regulators be capable of responding to the demands for public and commercial services. Under the condition where the transmission of data using mobile devices take a quantum leap in its growth, the growth of spectrum utilization then gets higher consequently. The use of LSA in spectrum management will be considered one of the strategic tools that the regulators can consider a choice providing mobile telephone network providers with access to spectrum during appropriate time, in case the incumbent users have never made the maximum use of the spectrum for a long time.
Incumbent Users	The incumbent users will be under the protection of spectrum usage rights, in the same way that the LSA users are eligible to access and make use of the spectrum that is not using by incumbent users. Accordingly, the incumbent users may view that the management of spectrum on the basis of LSA is a method contributing to cost reduction through allowing the authorized LSA users to use the spectrum. Moreover, the incumbent users also have rights to forecast and regulate the use of spectrum in a long run, and may gain payments from LSA users, based on the aforementioned method.
Future LSA Users	At the first stage, the LSA users must have an understanding of when and where the spectrum is unused throughout the period of spectrum license to ensure that they can use the spectrum in a particular location or at a particular time. This can facilitate them the considerations for investment decision-making. Furthermore, there should be some clarity and legal certainty in terms of regulations on the shared use of spectrum which will promote permission requests on the predictable basis. This will benefit the business forecast and assurance of service quality which will strengthen the motivation on device and networks of LSA users.

The LSA licensing-related sectors can be categorized into several major groups, i.e. spectrum regulators, incumbent users, and future LSA users. The motivations that may promote the aforementioned related sectors to follow the method of LSA can be as above Table I.

Utilization of the spectrum that has not been used at its maximum capacity in wireless broadband services will benefit the country in terms of economy. According to the studies of SFC Associates Ltd. conducted among EU countries, it is found that the increasing shared use of spectrum in 200 – 400 MHz band for wireless broadband services will result the EU in gaining economic benefits of several tens of billions of euros by 2020. Moreover, it also provides the certified operators on the basis of LSA, known as LSA users, with immediate access to the spectrum without the need for allocation made by spectrum regulators. This is considered a method responding to the leapfrog growth in spectrum utilization [19].

According to the study of Plum Consulting (December 2013) which revealed and published the economic benefits of LSA in the 2.3 GHz in Europe, it is found that to free up spectrum for other uses requires the operating cost of around 50 million euros and another amount of administrative costs, whereas the benefit gained through reducing infrastructure expenses is as high as 12,000 million euros. For example, the implementation of LSA in the 2.3 GHz band will bring about economic benefits of the value up to 86,000 million euros in Europe while the implementation of LSA in the 3.5 GHz band will bring about economic benefits of the value up to 260,000 dollars in USA [20].

However, the Mobile Network Operators (MNOs) can expand their service capacities through utilizing the spectrum unused by incumbents in the area with high demand density for data services. This can be carried out without further investments in infrastructures because the operators can use the ones that have already existed, resulting in lower service prices. Similarly, the study of GSMA also points out that the shared use of spectrum on the basis of LSA can give rise to the economic benefits from making use of the spectrum that has been currently non-beneficial. This can be done through using shared spectrum and saving costs of investments in the shared spectrum among operators [21].

The allocation of spectrum on the basis of LSA is considered a way to make efficient use of spectrum. It may be appropriate for applying to the spectrum already utilized by the government sectors. Consequently, it should be flexible enough for the incumbent licensees to be capable of improving their own networks as well as should enable both the incumbent licensees and certified LSA users to use the spectrum and adjust themselves to technological changes in conformity with the spectrum usage rights acquired.

In addition, the use of TV White Space technology (TVWS) is also an example of spectrum sharing between terrestrial television and wireless broadband service providers or the users who directly use the spectrum in the TVWS band. There is a possibility that the shared use of spectrum along with this particular technology may be

considered the integration between the licensing of a model called Licensed Shared Access for wireless broadband providers and the liberalization of spectrum usage in the form of Unlicensed Spectrum, as long as the standard for related TVWS devices are guaranteed by regulators [22].

IV. Recommendations on Telecommunications Regulations

The analytical result of this research reveals that the Thai regulator can carry out the process of regulating spectrum utilization through implementing the Licensed Shared Access or LSA for the 2.3GHz band to promote the use of the particular band in mobile broadband services. However, the 2.3GHz spectrum band has already been occupied by incumbent users of telecommunications and radio telecommunications. Moreover, the Thai telecom regulator should focus on the allocation of digital dividend spectrum in mobile services. Therefore, in order to carry out the process, the related sectors should take their primary functions into consideration and make improvement on the overall spectrum use as follows:

1) Improve the overall process of spectrum usage. Based on this, the regulators make announcements on improving the overall spectrum usage and propose law revision requests to make clear that the auction revenue and funds can be used as the compensation for the transfer of spectrum usage. Furthermore, there should be some propositions regarding the consideration criteria for LSA to handle the situation where the spectrum is authorized to be used for telecommunications specifically in the locations where interference doesn't occur. This includes the proposition of technical conditions to prevent interference.
2) Regarding the 2.3 GHz spectrum, the related sectors should suggest some methods determining the usage proportion of the 2300 – 2370 MHz spectrum at around 70 MHz in telecommunications and the usage proportion of the 2370 – 2400 MHz spectrum at around 30 MHz in radio services. However, there have been some users of the spectrum band from various sectors, including telecommunications, national security divisions, and other radio telecommunications-related sectors. Therefore, the methods of using spectrum in telecommunications should be carried out based on the following method of relocating spectrum users as shown in Table II.

The implementation of the Licensed Shared Access (LSA) technique to boost the broadband spectrum usage efficiency should give priority to the 2.3 GHz spectrum due to the high possibility of being successful in issuing licenses soon. This can be done through negotiating with TOT Public Co. Ltd or license holders to impose conditions and scopes of spectrum usage to prevent interference. As a matter of fact, this particular spectrum can be used for the 4G LTE technology and will greatly benefit the country. In relation to this, the legal workflow stages are suggested in Table III.

TABLE II. The Methods of Using 2.3GHz Spectrum

Usage	Spectrum holder	Operation method
Telecommunications	TOT Public Company Limited	Since the expiration date of the 2.3 GHz spectrum usage right of TOT Public Co., Ltd is not specified, the subcommittee to examine matters relating to spectrum allocation, utilization, and necessities for spectrum usage in telecommunications have agreed to claim the end of spectrum usage period based on the telecommunications license type 3 which is going to expire by 2020. Therefore, the method of negotiation that urges TOT Public Co., Ltd to return partial spectrum voluntarily within 2017-2020 is approved to be implemented accordingly. Anyway, TOT Public Co.,Ltd is allowed to improve technologies in the leftover spectrum to motivate negotiations.
	National security divisions	There is the necessity of using special gadgets to enhance national security. Therefore, the action plan for the improvement of spectrum usage in national security divisions should be imposed through moving the operations from the 2300 – 2370 MHz band to the 2370 – 2400 MHz band before the end of 2020.
Radio telecommunications	Other sectors	For the annually authorized use of some spectrum in radio telecommunications where the fixed-link operations are movable, such operations should be relocated to other bands determined for fixed-services by 2017 – 2020. This can be undertaken through issuing public announcements in relation to improving the 2.3 GHz spectrum.
Radio telecommunications	PTTEP and some parts of PTT	The spectrum usage of PTTEP and some parts of PTT in the gulf of Thailand exerts no impact on the authorization of spectrum usage in telecommunications. Therefore, such usage is allowed to be carried on specifically in the gulf of Thailand.

TABLE III. Workflow Stages of Legalizing the Licensing of Spectrum in the 2.3 GHz Band on the Basis of Licensed Shared Spectrum (LSA)

Stage	Workflow	Duration
1	The telecom regulator (NBTC) has analyzed the possibility of LSA implementation in the 2.3 GHz band along with the pros and cons of spectrum usage authorization on the basis of LSA, specifically in this particular case.	2 months
2	Submit the analytical results to the telecommunications committee for approval and assign the NBTC to grant the cabinet permission for having TOT Public Co.,Ltd disclose the information on using the 2.3 GHz spectrum and implement the LSA technique.	1 month
3	The NBTC makes the procedures legalized and fair so that TOT Public Co.,Ltd remains accessible to the 2.3 GHz spectrum on the basis of license conditions. Then, the NBTC carries on the process to come up with spectrum auctions in this particular band within 1 year.	8 months
4	The NBTC issues licenses and make assessment.	1 month

3) Since the licensing of spectrum usage in the mobile broadband range is the key to propelling socio-economic benefits, the priorities over spectrum assignment through auctions should be sorted into short-term and long-term strategies as shown in Table IV.

TABLE IV. STRATEGIES FOR SPECTRUM ASSIGNMENT AND USAGE BASED ON TIME INTERVALS

Strategies for spectrum allocation	Time interval	Spectrum band and usage
Short-term strategy	2015 - 2017	4G LTE technology using the 2.3 GHz spectrum, under the conditions on spectrum sharing through LSA techniques
Long-term strategy	2018 – 2022	The 700 MHz spectrum according to the APT band plan, using the Digital Dividend technology The 1800 MHz spectrum where the concession agreement between CAT and DTAC has expired

4) The public sector should impose distinct policies concerning the allocation of exact digital dividend in telecommunications. Regarding to this, the most appropriate digital dividend for Thailand is APT700 in 698 – 806 MHz band. In order to bring about the largest economy of scale in conformity to the usage in the APT and telecommunications, authorized regulators should allocate the APT700 spectrum (698–806 MHz) mainly for International Mobile Telecommunications (IMT) to enable operators and other related business sectors to draw up plans for the most effective use of spectrum in conformity with international practice guidance.

Therefore, the 700 MHz digital dividend should be used in mobile telecommunications to bring about congruence in the APT, especially among bordering neighbors. In order to reduce the problems regarding interference in such locations, there must be some actions taken as follows.

- To finish switching from analogue to digital broadcast television within the duration of 5 years (from 2015 – 2020), the Office of the National Broadcasting and Telecommunications Commission (CAT) should draw up plans for analogue switch-off (ASO) during 2015. Also, the framework for analogue switch-off should be completely established by 2020 according to the agreement made among ASEAN countries.
- Improve the use of 470 – 510 MHz spectrum and conduct negotiations to find a method for moving as many incumbent users as possible to other parts of the spectrum within the duration of 5 years in response to the increasingly widespread digital television broadcasting. The process of removing incumbent users from the spectrum requires remedy measures, finance measures, other related incentives as well as the revision of legal provisions, rules, and related regulations. This includes the process of negotiations among neighboring countries to come up with agreements on spectrum usage on the border with the need for ATP cooperation, leading to the assignment of the 700 MHz digital dividend for telecommunications services.

V. CONCLUSION

In Thailand, telecommunications is one of the key infrastructures that take part in propelling the country's development in terms of economy, society, education, public health, science, national security as well as bring about social equality. It is obvious that the emphasis on bringing about the digital economy and economic growth is based on telecommunications network infrastructures with extensive coverage and high-quality. In this paper, the analyses and recommendations on the spectrum allocation method as well as the continual promotion of investments in data communication and telecommunications carrying out by researchers are considered important factors stimulating the growth in the country's overall economy and eventually taking part in narrowing social gaps. These contribute to the significant first step toward the leapfrog sustainable growth in the country's economy and society, especially for Thailand.

REFERENCES

[1] International Telecommunications Union, *Guideline for the Preparation of National Wireless Broad and Masterplans for the Asia Pacific Region*, October, 2012.

[2] ITU, "Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-advanced," *Report ITU-R 2078*, 2006.

[3] ITU, "Assessment of the global mobile broadband deployments and forecasts for international mobile telecommunications," *Report ITU-R M. 2243*. 2011.

[4] NBTC, "Order of national broadcasting and telecommunications commission," *Subject of Spectrum Management Masterplan*, 2012.

[5] NBTC, *Detail Investigation Report of Spectrum Assignment or Spectrum Utilization, Need of Holding Spectrum and the Legal Right of the Concession or Mobile Service Convention*, 2013.

[6] FCC, "Mobile broadband: The benefits of additional spectrum," *FCC Staff Technical Paper*, October 2010.

[7] Cisco, "Cisco visual networking index: Global mobile data traffic forecast update, 2013-2018," February 5, 2014.

[8] OFCOM, "Future demand for mobile broadband spectrum and consideration of potential candidate bands," March 18, 2013.

[9] OFCOM, "Spectrum management strategy: OFCOM's approach to and priorities for spectrum management over the next ten years," Oct 2, 2013.

[10] OFCOM. (September 2014). TV White Spaces Pilot. [Online]. Available: http://stakeholders.ofcom.org.uk/spectrum/tv-white-spaces/white-spaces-pilot/2014

[11] OFCOM. The General Authorization Regime. [Online]. Available: http://stakeholders.ofcom.org.uk/telecoms/ga-scheme/

[12] (November, 2013). Google, Google Africa Blog. Google in Sub-Saharan Africa: news, stories and thoughts. [Online]. Available: http://google-africa.blogspot.com/2013/11/trial-in-cape-town-shows-that-tv-white.html

[13] (May 2014). Microsoft, Microsoft Research. Pilot and demonstration. [Online]. Available: http://research.microsoft.com/en-us/projects/spectrum/pilots.aspx

[14] M. Cave, C. Doyle, and W. Webb, *Essentials of Modern Spectrum Management*, Cambridge: University Press, 2007.

[15] Markets and Markets. (2012). Heterogeneous Networks (HetNets): Small Cells & Carrier WiFi Market-Global Advancements. Technology Roadmaps. Market Forecasts & Analysis (2013-2018). [Online]. Available: http://www.marketsandmarkets.com.

[16] B. Coleman and M. H. Giulia, "Spectrum sharing: Taxonomy and economics," *Coleman Bazelon Giulia McHenry*, February 2014.
[17] GSMA Public Policy Position, "ASA (Authorized Shared Access) and LSA (Licensed Shared Access)," February 2013.
[18] Ericsson, "Spectrum sharing," October 2013.
[19] European Parliament, "Establishing a multiannual radio spectrum policy programme," European Parliament. Decision No. 243/2012/EU of the European Parliament and of the Council, March 14, 2013.
[20] Plum consulting, "The economic benefit of LSA in 2.3GHz in Europe," December 2013.
[21] GSMA, "Licensed Shared Access (LAS) and Authorized Shared Access (ASA)," February 2013.
[22] T. Richard, "The economic significance of license-exempt spectrum to the future of the Internet," 2012.

Settapong Malisuwan was born on 24th March 1966 in Bangkok, Thailand. He was awarded full scholarship from Thai government for PhD in electrical engineering (telecommunications), specializing in mobile communication systems from Florida Atlantic University (State University System of Florida), Boca Raton in 2000. He received his MSc in electrical engineering in mobile communications system from George Washington University in 1996 and was awarded First Class Honors, Gold Medal Award and Outstanding Cadet Award by the university. Additionally, he also achieved MSc in electrical engineering in telecommunication engineering from Georgia Institute of Technology in 1992. He is currently the Vice Chairman and Board Commissioner of National Broadcasting and Telecommunications Regulator in Bangkok, Thailand. He was awarded The "Science Towards the Excellence in 2013" by The Senate Standing Committee on Science, Technology, Communications and Telecommunications. His research interests are in electromagnetics, efficient spectrum management and Telecommunications policy and management.

Wassana Kaewphanuekrungsi was born 1st February 1979, Bangkok, Thailand. She received her B.S. in Statistics from Chulalongkorn University, Thailand, 2000, and M.S. in Technology Management from Thammasat University, Thailand, 2006. She joined National Broadcasting and Telecommunication Commission (NBTC) as Assistance to Vice Chairman of NBTC in December 2011, which is responsible in the field of telecommunications planning and microstrip antenna design. Previously in 2010, she worked for as senior system analyst at Bangkok Insurance (Public) Co., Ltd. Her research interests are in information technology, telecommunication technology, wireless communication, antenna design and spectrum management.

Nattakit Suriyakrai was born in Khonkhaen, Thailand on 22nd March, 1987. He received his Bachelor of Liberal Arts in Japanese Language from Thammasat University in 2010. He has been working as an Assistant to Vice Chairman in National Broadcasting and Telecommunications, Bangkok, Thailand since November 2012. His research interests are in technology management and spectrum management.