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Study on Regulatory Framework for DTV White Space Utilization

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Study on Regulatory Framework for DTV White Space Utilization

Abstract

This thesis presents analysis on how and why a spectrum policy considering usability is needed for practical use of idle frequencies in digital television (DTV) band named as DTV White Space. Such DTV white space is lying in congested condition in aspect of physical condition and service content characteristics. Based on the traditional spectrum policies and a case study of DTV leading countries, an interdisciplinary approach is used to develop spectrum regulatory frameworks for introduction of new services to the public as one of approaches for efficient use of radio spectrum. In particular, the thesis suggests a need to review on DTV idle channels as public goods to balance their utilization as one of national resources. As such, rational and strategic approach is required to derive social consensus to introduce the DTV White Space through the comprehensive review. The thesis direction is focused on the DTV White Space utilization as public goods, and the policy direction has been presented in public side.

At first, a literature review was conducted to investigate the policy trends for radio spectrum policy and the new wave for enhancement of spectrum usability due to the DTV transition. Second, a survey on the present condition for the DTV White Space policy was performed to show the research motivation and efficacy through the case study on DTV leading countries such as United States (US), European Union (EU), and Japan.

Two hypotheses are implied in this thesis; the user classification and the narrow band application for the successful launching of DTV White Space service under congested idle space condition. For the verification of hypotheses, three methods are adopted such as computing, in-depth interview, and laboratory test. Such methods verify the hypotheses in terms of technology and policy aspects. Computer simulation was conducted to estimate the quantity of idle spaces for DTV White Space users based on the DTV transition channel plan at three pilot areas in Korea as an example of severe condition for using DTV idle channels.

In parallel, the in-depth interview to the experts working for the stakeholders, government, and the academic field was performed to study various opinions and presume an appropriate service content to derive social consensus. Based on the in-depth interview, the terrestrial truncated radio (TETRA) was selected as an applicable DTV White Space system. Moreover, the laboratory testing was conducted to estimate appropriate operational ranges for DTV White Space users, and to show advantage of narrowband applications in aspect of DTV disturbance by comparing a wider band system to the targeted narrow band system. Presented results were reflected as one of regulatory guidelines for DTV White Space management in the technical aspect.

The practical significance of this study is that it proposes a reference to alleviate the burden of spectrum regulator via profound understanding of the current situation in the government and stakeholders through the consideration on service contents and technical feasibility. Consequently, the radio coexistence and management directions will be on the domain of policy and technology for the introduction of new radio services in DTV band.

Keywords:

Spectrum management, Regulatory framework, DTV transition, White Space, Spectrum efficiency, Narrow band service, User classification

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For any errors or inadequacies that may remain in this work, of course, the responsibility is entirely my own.

I dedicate this thesis to
my family, my wife, Miri KIM, and my son Konwoo KIM
for their constant support and unconditional love.
I love you all dearly.

아버님 어머님 감사드립니다.
그리고 사랑합니다.

Abbreviations

3G/4G	Third Generation / Fourth Generation
ACATS	Advisory Committee on Advanced Television Service (USA)
ATSC	Advanced Television Systems Committee
AWGN	Additive White Gaussian Noise
BBC	British Broadcasting Corporation (Britain)
BER	Bit Error Rate
BS	Base Station
BT	British Telecommunications (Britain)
CDF	Cumulative Density Function
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunication Administrations (European Union)
CFR	Code of Federal Regulations (USA)
CLT	Central Limit Theorem
CR	Cognitive Radio
D/U	Desired and Undesired Signal Ratio
DMB	Digital Multimedia Broadcasting (Korea)

DMO	Direct Mode Operation
DOCR	Digital on Channel Repeater
DTV	Digital Television
DUT	Device under Test
EC	European Community (subsequently also European Union, EU)
ECC	European Communications Committee
ETRI	Electronics and Telecommunications Research Institute (Korea)
ETSI	European Telecommunications Standards Institute
EU	European Union
EV-DO	Evolution Data Only
EVM	Error Vector Magnitude
FCC	Federal Communications Commission (USA)
GA	Antenna Gain
GPS	Global Positioning System
I-Q	In-phase versus Quadrature phase
IEC	International Eletrotechnical Commission (Former ITU)
IEEE	Institute of Electrical and Electronic Engineers
ISDB-T	Integrated Services Digital Broadcasting-Terrestrial (Japan)
ISM	Industrial Scientific and Medical
ITS	Intelligent Transportation System
ITU	International Telecommunications Union
ITU-R	ITU-Radio Communications Sector

KBS	Korean Broadcasting System (Korea)
KCA	Korea Communications Agency (Korea)
KCC	Korea Communications Commission (Korea)
KISDI	Korea Information Society Development Institution (Korea)
KT	Korea Telecom (Korea)
LF	Feeder Loss
LR-WPAN	Low Rate Wireless Personal Area Network (IEEE 802.15.4)
LTE	Long Term Evolution
M2M	Machine to Machine Communication
MATV	Master TV
MIC	Ministry of Internal Affairs and Communication (Japan)
MS	Mobile Station
NAB	National Association of Broadcasters (USA)
NEMA	National Emergency Management Agency (Korea)
NTSC	National Television Standard Committee
NTSC	National Television Standards Committee (USA)
OFDM	Orthogonal Frequency-Division Multiplexing
PPDR	Public Protection and Disaster Relief
PSREC	Plumas-Sierra Rural Electric Cooperative (Britain)
RAPA	Korea Radio Promotion Association (Korea)
RF	Radio Frequency
RFID	Radio Frequency IDentification

RMS	Root Mean Square
RR	Radio Regulation by ITU
RRA	Korean Radio Research Agency (Korea)
S/N	Signal to Noise Ratio
TDMA	Time Division Multiple Access
TETRA	Trans European Trunked Radio (ETSI)
TMO	Trunked Mode Operation
TOV	Threshold of Visibility
TVWS	Television White Space
UHF	Ultra High Frequency (300 to 3,000 MHz)
USN	Ubiquitous Sensor Network
UWB	Ultra Wide Band
V+D	Voice and Data Transmission in TETRA
VHF	Very High Frequency (30 to 300 MHz)
VSB	Vestigial Sideband Modulation
Wi-Fi	Wireless Fidelity (IEEE)
WRC	World Radio Conference
WSD	White Space Device
WSDB	White Space Data Base

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Radio frequencies are limited natural resources, and its efficient usage is being required according to the increment of spectrum demand due to the advance of network and wireless technologies. In such a social circumstance, spectrum management authorities all over the world are in the process of modernizing spectrum policies and are seeking alternative spectrum management models which allow much more efficient and flexible utilization of the spectrum. Therefore, the lack of spectrum should be addressed by using the frequency sharing method and its management techniques [1].

The digital television (DTV) transition is a good example of such phenomenon which is progressing world-widely to supply the high quality TV service to the public through the advanced digital and wireless technology. This movement had started in UK, however, its neighboring European countries and US have also delivering the digitalized broadcasting services to the people through the wireless channel such as the terrestrial DTV. For instance, Netherlands had completed the DTV transition in 2006 for the first time in the world, and US followed this revolution in 2009. Recently, Japan had also terminated the analog TV service in June 24^{th}, 2011.

Some idle spaces in TV band, namely, Digital Dividend have been emerged through the TV channel rearrangement process as the one of activities for DTV transition [2]. There are countries which have already finished or being progressed DTV transition. They are planning technical and policy review on the timely spatially unused frequency in DTV band so called, DTV White Space, to use the radio spectrum more efficiently. Similarly, the DTV leading countries including Japan are expected to enhance the spectrum efficiency and the industrial promotion by introducing the DTV White Space service. Such countries are performing research for the various platforms that can be coexisting with the DTV user through the new radio technologies.

Currently, the applications of White Space applications are local centric wireless data and the communication services, and these kind services are in demand more than one DTV channel space, i.e., 6MHz or more bandwidth. It also has a possible application as a support system for the mobile broadband or wireless internet services like 3G or Wi-Fi [3, 4, 5]. Based on the pilot service results, they are planning to launch DTV White Space service within few years. Korean government also has a new plan to use timely spatially unused DTV channels through the DTV channel reassignment process for DTV transition [6].

However, they are also faced with key issue on idle spectrum usability in terms of the protection of broadcasters. The federal communications commission (FCC) in US wants to allow usage of DTV White Space under the unlicensed condition, but broadcasters are appealing their right to the court not to interrupt their service in DTV band [7, 8]. Especially in case of Korea, the wideband application will make the lower user flexibility due to a severe geographical and institutional situation. It will also be difficult to secure the sufficient spaces for DTV White Space users in current environment condition [9, 10]. Moreover, their research direction for the DTV White Space utilization is based on the technology-driven approach such that it is usually focused on the extended service of wireless internet in the commercial aspects. Therefore, it is not easy to derive the consensus with the broadcasters regarding the service collaboration for the public. There is no choice but to be constrained in the operating ranges of DTV White Space users as a secondary user status in DTV band under current situation.

The service characteristics in both contents and technology have been reflected in this thesis to derive a social consensus and enhance the DTV spectrum utilization as measures of regulatory framework on DTV White Space. First, I point out the characteristics of TV band regarding public goods to maintain a balance of their utilization as one of national. The major discussion on this part is the introduction of new wireless services in DTV band as a complementary platform to increase the spectrum efficiency. As the analysis methodology of the in-depth interview, the theory of optimal scale was applied to the DTV White Space utilization. Further, twelve experts affiliated in the related fields are targeted to the in-depth interview. The interview recipients were categorized into the following four groups; stakeholders, government, academia, and industry to give diversity and objectivity.

Second, narrowband application was applied to the computing and testing process to show the improvement of DTV spectrum usability by considering the severe condition of DTV White Spaces as a technical viewpoint. TETRA release1 was selected as a narrowband application of DTV White Space. DTV affecting range depending on TETRA operating condition was also studied. The value of EVM and S/N was used as methodology to assess the degree of DTV degradation.

This dissertation consists of seven chapters including the introduction, and the rest chapters are as follows. In Chapter 2, the DTV White Space tendency is described to investigate on the current status of DTV White Space as the research background. The Chapter 3 describes the results of expertfs opinions to presume a policy direction and extract the appropriate service. The Chapter 4 focuses on the calculation to estimate the quantity of DTV White Space in Korea as an example of severe condition, and the interference assessment is estimated through the computing process. In Chapter 5, the coexistence testing has been conducted in order to evaluate the degradation of DTV performance by the DTV White Space service. In Chapter 6, the spectrum efficiency is estimated as a measure of the direction of regulation and the results of interference testing are illustrated to show the advantage of narrow band application in terms of DTV interference. Through the above results, regulatory framework under the congested condition for DTV idle spaces is proposed, and the Chapter 7 summarizes the thesis including the future work for the DTV White Space.

1.1. Research Significance and Approach

A spectrum policy has typically induced the development of wireless technologies and their related services. The digital developed countries such as US, EU, and Japan including Korea are promoting the digitalization of telecommunications and broadcastings to cope with the improvement of spectrum utilization efficiency and the evolution of ubiquitous. Recently, the DTV White Space is being promoted by governments and Telcos in line with global trends. In addition, various technical reviews for the DTV White Space including international standardization are being conducted to be applied to the regional wireless Internet or home networking. Telcos are also considering as one of subsidiary systems for their wireless data or network services like Wi-Fi and the grid network.

1.1.1 Critical Issues for DTV White Space

The concept of the DTV White Space was emerged to use the DTV spectrum more efficiently, and most countries are reviewing the DTV White Space based on the technology-driven approach. They are usually focusing on the wide band wireless services to carry the high-speed data applications like the Video phone. In such circumstance, the DTV White Space services are heading to the commercial oriented services. In other words, it is hard to expect the narrow band applications in this particular context. Although the radio spectrum should be managed more efficiently as the one of public resources, the user status of the DTV White Space is equivalent to the 'Primary-Secondary Sharing'. In Korea, as a typical example, there are two critical issues to be addressed for successful launching of the DTV White Space services as a secondary user status in the DTV band.

- *Secure the wide DTV White Space for the high-speed data application:*
  A concern here is less efficient use of the DTV band.

- *Consensus with broadcasters as incumbent users in the DTV band:*
  A concern here is the service purpose and utilization.

First, the idle channels are affected by a spillover effect such as environmental conditions like mountainous terrain and round valley. In case of Korea, they caused a lot of the spillover, and the idle spaces in the DTV band are faced with more severe condition [9, 10]. Only few split channels may be allowable as DTV White Spaces, and it is not easy to apply the wideband services due to the interference problems.

Secondly, the DTV White Space service coverage and quality are hard to be guaranteed due to the operational limitation for the protection of broadcasters. Also, they are in the situation that the broadcasters do not want to share their service band with the secondary users due to possible service quality degradation [7, 8]. Therefore, various considerations and the related new regulatory framework are required through the reasonable hypotheses with its verifications.

1.1.2 Research Direction and Hypotheses

This study suggests approaches for the content-driven narrow band applications of the DTV White Space, and they are based on the following two hypotheses to use the DTV idle channels being placed in harsh conditions. These hypotheses reflect the regulatory framework for the DTV White Space under severe condition in aspect of technology and social environment.

1. *'Equal user condition' should be considering depending on the service contents:*
   Classification of the DTV White Space user status with two groups may contribute to the vitalization of DTV White Spaces

2. *Narrow band applications should also be introduced for a single DTV idle channel solution to derive DTV White Space and enhance the spectrum efficiency under congested condition:*
   The split idle channel spaces, i.e. 6MHz or less idle spaces, can be expected at rural or suburban areas even if DTV White Space are in severe condition.

The conflict with the stakeholders caused by the introduction of new services can be reduced if the DTV White Space is used separately according to service purposes and its radio channel conditions. Two classes, namely the 'Class One' and 'Class Two' are being considered according to the service contents and the using bandwidth. The public service with narrow band is equivalent to the 'Class One'. It can be considered as 'Calling and detection service for safety and protection' as the typical examples, and it can also be handled as the primary users depending on the situation like emergency and disaster. On the other hand, public and commercial service with wide band is equivalent to the 'Class Two'.

Figure 1.1 shows the user priorities according to the using applications at DTV band.

Figure 1.1. User priority in DTV band

1.2. Verification of Hypotheses

Technology side and a policy side are used for verification of hypotheses to approach the issue for systematically review. Regarding the technical aspect, the amount of the DTV White Space in Korea is estimated and calculated for operable range according to the DTV service coverage criteria based on minimum field strengths. With these results, the spectrum efficiency on the narrow band system is calculated according to the operational condition to show the degree of improvement at DTV White Space.

The terrestrial truncated radio (TETRA) system is applied as a narrowband application for the DTV White Space regarding the computing. The TETRA system is a set of standards developed by the European Telecommunications Standards Institute (ETSI) as a common mobile radio communications infrastructure, and it is operated around the DTV band. Therefore, it can be applied to the DTV White Spaces instantly with a little modification of the physical layer specifications including an amendment of operation regulation.

In the policy perspective, there is a need to review the direction of White Space service characteristics and its institutional improvement to introduce the new services in the DTV band. The opinions from the experts related to the stakeholders are required to understand the situations and to find the appropriate solution for the consensus issue. The in-depth interviews with the experts from the government agencies, the academia, and the industry are conducted to understand the needs for spectrum policy and extract the applicable service. In terms of the technology, the laboratory testing is examined on the DTV interference due to TETRA systems as the secondary user in DTV band.

On the basis of above researches including the pre-survey at the Chapter 1 and 2, the regulatory framework will be suggested according to their service and operating conditions. Figure 1.2 shows the conceptual idea for research approach by each field.

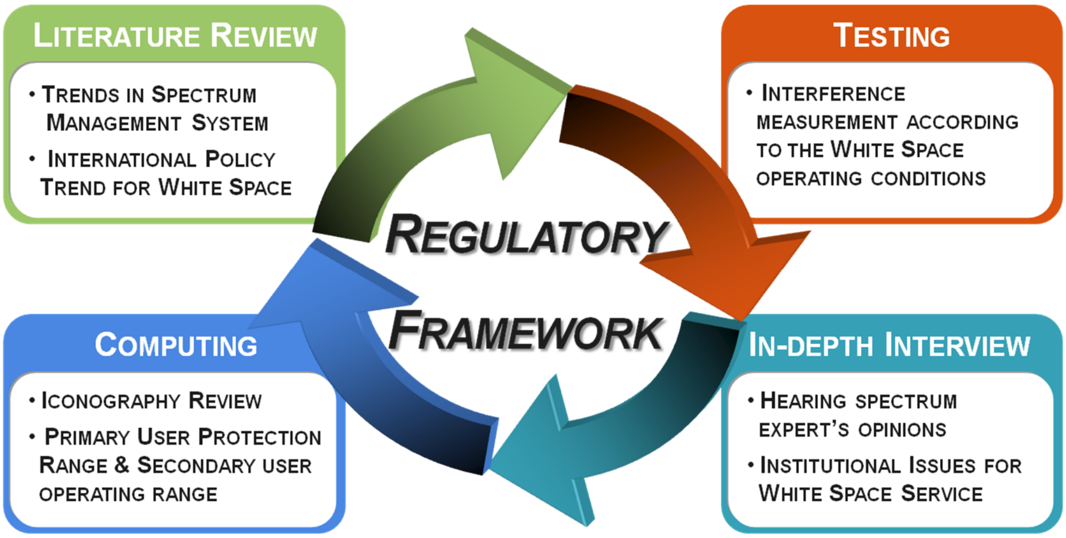


Figure 1.2. Conceptual idea for research approach

1.2.1 Computing

The computational analysis should be preceded before developing new spectrum policies according to national environment conditions because radio characteristics are quite different depending on the national environmental condition such as geographical condition, weather, and obstacles. Especially, DTV White Space users are faced with more complicated situation than other spectrum users due to existing primary users in DTV band. Therefore, the usability of DTV White Space requires for more thorough preliminary researches through the computational analysis based on reliable data like a tentative DTV channel assignment plan in Korea and an estimated DTV service coverage which is based on the recommendation of DTV propagation loss in International Telecommunication Union (ITU).

There are three subjects in this part; Estimating the quantity of the DTV White Space, deriving the interoperable range of the secondary users, and calculating the spectrum efficiencies depending on the operating conditions of the secondary users.

Firstly, an iconography review is conducted to estimate the quantity of the DTV White Space in Korea, and three pilot areas are targeted for DTV transition based on the tentative assigned DTV channels in Korea. Regarding the pilot project, Korean government conducted a review on the impact of analog TV switchover in advance and to take a measure for DTV transition by the end of December 2012. The three pilot test areas, namely Uljin, Gangjin, and Danyang, were selected in 2009 considering the geographical balance and characteristics. These areas can also represent a small and medium sized city in suburban and rural environment in Korea [11]. Based on the calculating results on DTV service area and the DTV channel plan, the DTV White Space in each pilot area can be estimated, and it is equivalent to the 'Step 1' in Figure 1.3.

To boost the DTV White Space utilization, allowing existing systems as the DTV White Space application like the local OneSeg in Japan is considered as most efficient way. Therefore, TETRA system was selected as an appropriate DTV White Space application through the iconography review and the in-depth interview, and some computational analyses were conducted to review the possibility of coexistence with the primary users. The allowable DTV protection range was examined at the status of 'Step 2' on the basis of the technical criteria.

For the 'Step 3' in Figure 1.3, the range of enhanced spectrum efficiency was estimated depending on the size of secondary user coverage on the basis of regulatory conditions to verify usability of narrow band application as the DTV White Space service.

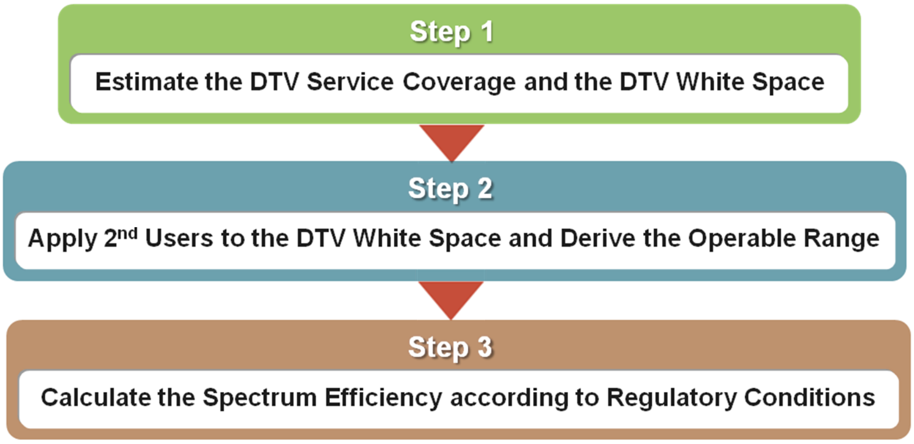


Figure 1.3. Calculating procedures for DTV White Space usability

1.2.2 In-depth Interview

The in-depth interview is conducted to hear expert opinions working in related organizations with the radio spectrum. The 12 recipients of interview were chosen with four categories; ***Stakeholders, Government, Academia***, and ***Industry field*** to give the diversity and objectivity.

There are two main purposes of the interview: Understanding the needs for spectrum policy and extracting its applicable service. It also suggests the direction of the spectrum management, the DTV White Space policy, and the way of its service vitalization. The questionnaire of in-depth interview consists of the following three parts to achieve the main objectives.

- *View of the direction of spectrum management system:*
  Current issues and appropriate spectrum management model
- *The outlook on the introduction of the DTV White Space:*
  Consideration on the environmental condition and influence on the related industries
- *DTV White Space policy for the vitalization of related industries:*
  Administrative measures and the most dominant business model

As a result of this process, policy needs in each group for the DTV White Space policy can be presumed, and it is utilized to choose a target application and to develop the regulatory framework on the DTV White Space laying in a congested condition such as in Korea. The direction of institutional improvement is also extracted to the smooth distribution and vitalization of the DTV White Space service. Figure 1.4 shows the interview recipients and its contributions to the study.

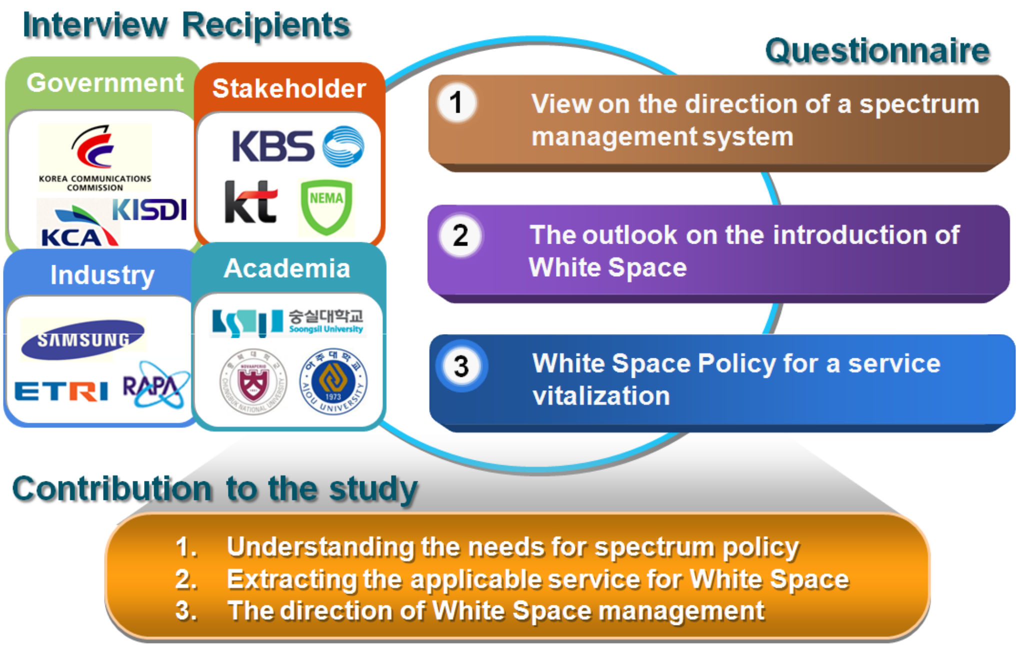


Figure 1.4. Interview recipients and contribution to the study

1.2.3 Interference Testing

The testing focuses on the interference measurement between the DTV and TETRA signals generated by the signal generators to examine the degree of influences more practically.

According to the recommendations of TETRA, it is the digital wireless communication system used 4-slot time division multiple access system (TDMA) in

25 kHz bandwidth. In addition, the nominal operating power is classified according to the operation modes, namely, the trunked mode operation (TMO) and the direct mode operation (DMO).

Under these technical conditions, the operating power levels and frequency offsets from the neighboring DTV channel are taken into account to measure the DTV interference due to the TETRA system. Moreover, based on the recommendation of the advanced television systems committee (ATSC), the signal to noise level ratio (S/N) and the error vector magnitude (EVM) are monitored to obtain the quantified results for the DTV interference [12, 13].

As for the test device configuration, two kinds of the device under test (DUT), i.e., the DTV receiver and the TETRA receiver are installed, and an additive white Gaussian noise (AWGN) generator is used to reflect a general wireless channel condition as well. This implies that the unknown and unwanted signals are always existed and they can increase the system noise level. On the contrary, a spectrum analyzer and a vector signal analyzer are configured to measure S/N and EVM. In terms of the testing procedure, the output levels of each signal generator are set to keep the difference of output power uniformly between the two systems based on the recommendation of ATSC and TETRA.

1.3. Thesis Structure

The thesis is consisted of several sub works in terms of a policy based and a technology based which are sub-classified with four stages according to the logical stream. The first stage is focused on the research objectives including literature reviews on the DTV White Space. In this stage, the computing work is also conducted to estimate the amount of DTV White Space in Korea. Then, the research direction spans in two ways to build a framework for the DTV White Space in a regulatory aspect. The in-depth interview targeted to the experts is carried out to derive the appropriate DTV White Space service models. In third stage, based on the above results, the testing is conducted to verify the hypotheses, and supporting information for a development of regulatory guidelines is presented. Finally, the fourth stage will wrap up the research and propose the regulatory framework for the DTV White Space. Each stage is conducting sequentially or independently according to the research conditions. Figure 1.5 illustrates the thesis structures.

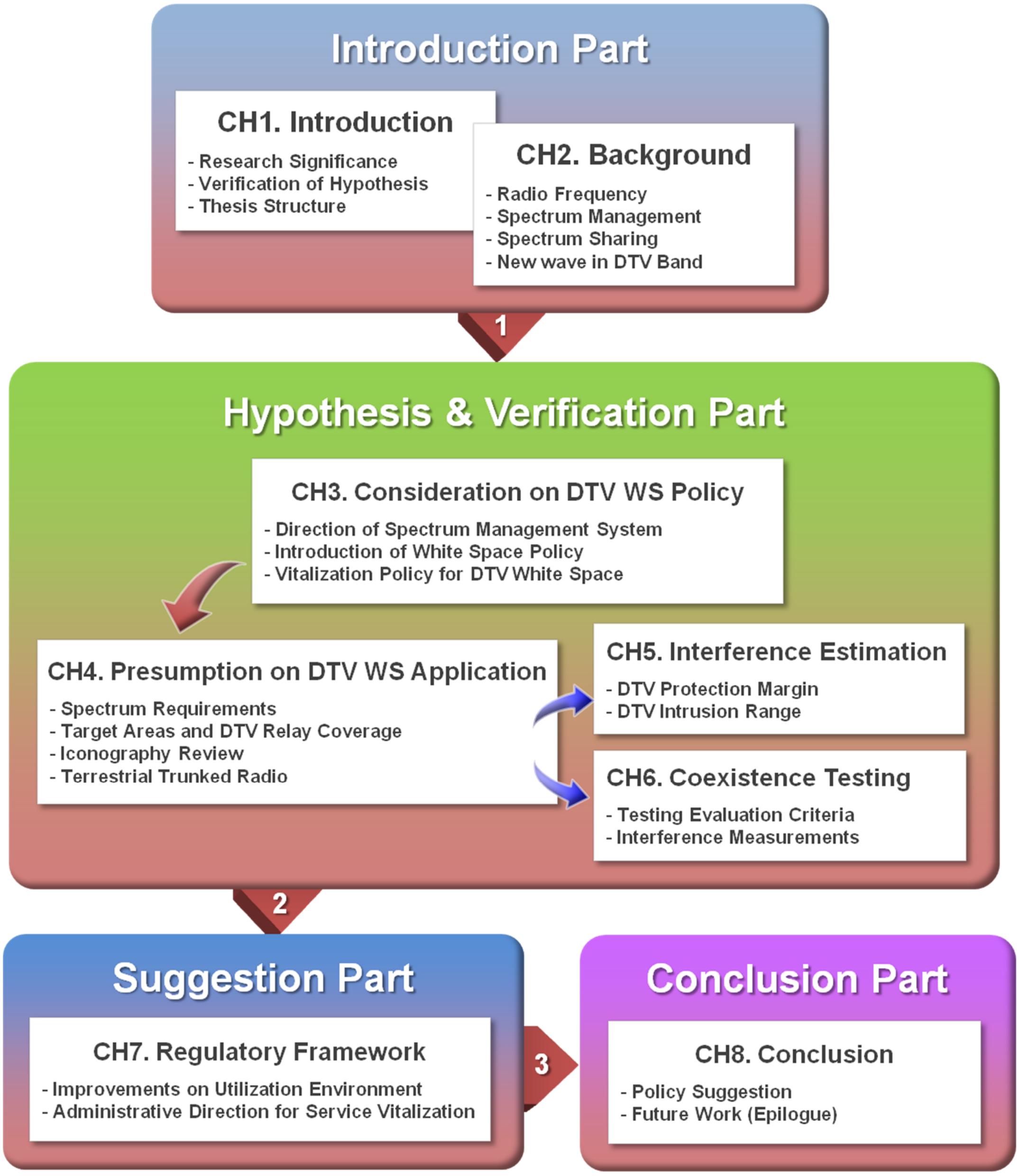


Figure 1.5. Thesis structure

Chapter 2

Background

When considering the technological point of view, the radio frequency can be said as a one of medium for signal transmission, and it is being expanded to the range of usage due to the development of radio technologies. On the other hand, efficient mange of resource is required for the public interests and industrial promotion as a one of national resources.

In this sense, there is a need to review on the movement of spectrum policy in advanced countries to set the appropriate new policy direction. In addition, the targeted service areas and technology can also be presumed through the understanding of physical characteristics on the radio frequency. The general characteristic on radio frequency was reviewed in the Chapter 2.1. In the next chapter, the policy trend and the pilot programs in US, EU, and Japan are surveyed as examples of advanced countries for the DTV White Space utilization.

2.1. Radio Frequency

The practical research on radio frequency was started by Heinrich Hertz (1857-1897) who worked for the basic phenomena of radio waves. In 1937, his name, Hertz, was adopted to the unit of frequency (Hz) to honor his accomplishments by the former ITU named as the International Electro technical Commission (IEC). They also defined the radio wave as '*Electromagnetic waves of frequencies arbitrarily lower than 3,000 GHz, propagated in space without artificial guide*' [14, 15]. In this regard, artificial guide refers to the general material to transfer radio wave such as the coaxial cable or waveguide.

On the basis of concept on the radio wave, the frequency range can be classified according to the using applications such as the satellite, broadcasting, mobile phone, and wireless internet. Further, the radio wave is affected by the geographical and weather condition due to the physical characteristics of radio wave [16, 17]. Therefore, it is necessary to understand the radio wave in physical aspects to review the spectrum utilizing strategy.

2.1.1 General Characteristics

The radio frequency can be laid in the shape of sine or cosine wave form following the time axis considering the physical characteristics. In addition, the oscillating times per second is defined to the frequency in unit of Hz, and the length of peak to peak in the wave named as the wavelength can also be marked with lambda (λ). For an example, 600 MHz means that the six billion times is oscillating per second. Figure 2.1 illustrates the conceptual definition of frequency, and the red line represents two of times of oscillation per second.

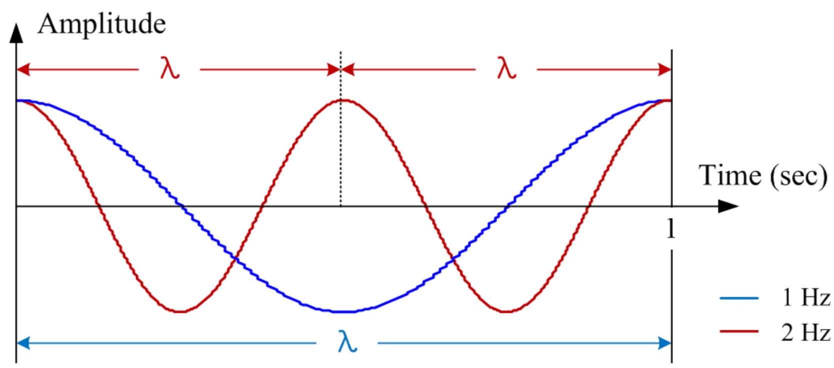


Figure 2.1. Conceptual definition of frequency and wave length

The radio frequency in free space can be expressed with the wavelength and the speed of light with the following equation.

$$f(\mathrm{Hz}) = \frac{c(\mathrm{m/sec})}{\lambda(\mathrm{m})} \tag{2.1}$$

where:

c Light speed or v_p in free space ($\approx 2.998 \times 10^8$m/sec)

v_p Phase velocity: Defined by permeability (μ) and permittivity (ϵ) of the transmitted medium

According to the above concept, the wavelength decreases more due to an inverse relationship between them. The frequency unit is used universally in the international standards and regulatory criteria rather than the wavelength. The radio communication sector in ITU (ITU-R) is classifying the range of radio frequency as the very high frequency (VHF) and the ultra-high frequency (UHF) to recognize the frequency in use easily and instantaneously [14]. Figure 2.2 shows the frequency ranges and the applications by each band in radio spectrum.

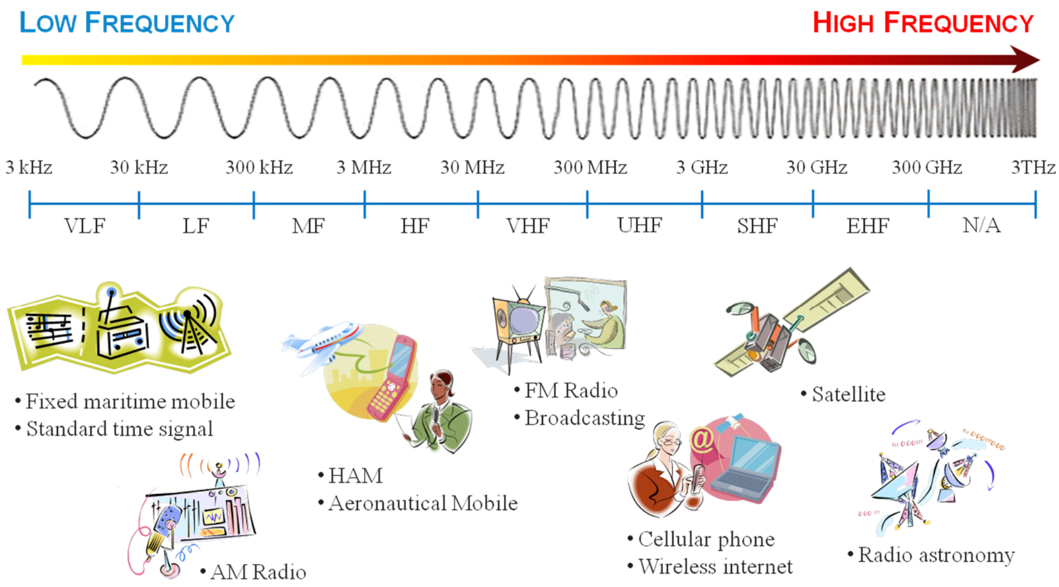


Figure 2.2. Frequency ranges and applications in radio spectrum

Regarding the propagation mechanisms, there are four ways to transmit the signal via air interface by using radio frequency in general. In addition, ITU-R describes each mechanism as one of interference phenomena on the long-term signal power losses as below.

- ***Line-of-sight***: *Straightforward propagation including small diffraction losses derived by obstacles between transceivers*
- ***Reflect***: *Change of wave front direction by obstacles which is larger than the wavelength*
- ***Diffraction***: *Change of wave front direction and pass the obstacles by irregular reflection under the non line-of-sight situation*
- ***Scattering***: *Change of wave front direction by propagation medium which is smaller than the wavelength like rain and foliage*

Figure 2.3 illustrates the propagation mechanism presented by ITU-R recommendation.

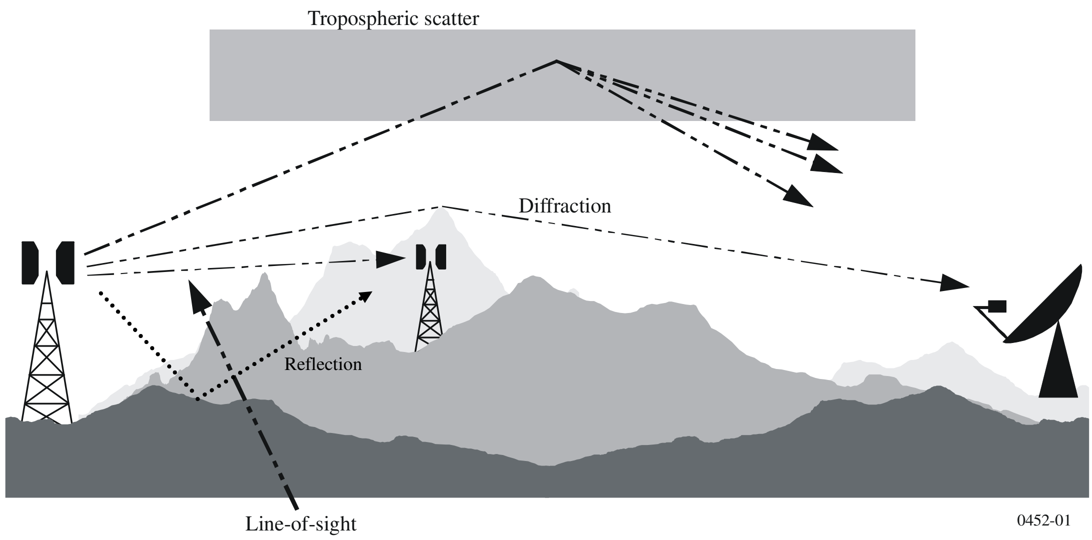


Figure 2.3. Propagation mechanism [17]

2.1.2 Path Loss

In general, the path loss occurs when transmitting the signal through the propagation materials with its own physical characteristics such as conductivity and permittivity. Especially, the propagation under air or wireless condition is expected to have additional signal losses compared to the wired condition even if it laid in free space condition.

Basically, the path loss under free space condition is defined by the power relationship between transceivers as below [16].

$$P_r(\mathrm{d}) = \frac{P_t G_t G_r \lambda_2}{(4\pi)^2 d^2} \tag{2.2}$$

where:

P_t	Transmitter radio signal power
P_r	Received radio signal power at the separated distance (d) from transmitter
G	Antenna gain of transmitter (t) or receiver (r)
λ	Wavelength of transmitted radio signal

Equation 2.2 can transform as shape of path loss in unit of deciBel like as below.

$$L(\mathrm{dB}) = 10log\frac{P_t}{P_r} = 20\log f + 20\log d - 10\log G_t - 10\log G_r - 27.55 \tag{2.3}$$

where, d and f is unit of meters (m) and megahertz (MHz). In addition, -27.55 as the constant value in this equation are derived by the wavelength relationship for light speed and radio frequency from Equation 2.1. According to this equation, the path loss will be increased by 6 dB when the value of distance or frequency is doubled.

On the basis of the path loss in free space, the estimation of path loss is estimated with empirical or deterministic approaches. The empirical estimations are based on the measurement data, and the statistical properties are used to derive estimating results. This method is easy and simple to use compared to deterministic estimation due to relatively easy consideration on parameters. Therefore, it is usually used to analyze large areas for cell planning and TV channel assignment although it is hard to expect the accurate results when comparing to the deterministic approaches.

Therefore, various empirical models are used to improve the accuracy of path loss prediction considering some additional loss factors which are depending on the environmental condition. The empirical models may be required to update the additional loss factors to reflect the current status of environmental conditions depending on the targeted areas to estimate signal path losses. This is because these models are generated by the experimental testing results at specific areas on the basis of the environmental condition on the conducted year. The Longley-Rice and ITU-R model are usually used as the predict path loss models to estimate broadcasting service boundaries at targeted area. The Longley-Rice model is utilizing by FCC reflected to the environmental condition in US. On the other hand, ITU-R model is used to estimate the path losses under various environmental conditions as one of global recommendations. In this thesis, the ITU-R model was reflected to induce general results on the DTV path losses.

Table 2.1 shows the empirical path loss models being used in general including their applicable environmental conditions [18].

Table 2.1. Empirical path loss models

Model	Target environment	Based area (year)	Target frequency
Okumura-Hata	Urban, Suburban, Rural areas on geographical terrain	Tokyo, Japan (1968)	150, 450, 900 MHz
Walfisch-Bertoni	Urban, Suburban areas impacted by rooftops and building height	City in Europe (1988)	800 to 2000 MHz
Longley-Rice	Free space over irregular terrain	New York, US (1978)	20 MHz to 10 GHz
COST-Hata	Modified Okumura-Hata	Tokyo, Japan (1991)	1500 to 2000 MHz
Lee	Urban area impacted by ground reflection & human-made structures	Philadelphia, New York (1993)	900 MHz
ITU-R P.1546	Area service over terrain	Europe, US (2009 for ver. P.1546-4)	30 to 3000 MHz

2.2. Spectrum Management

Regarding the control methods for radio spectrum, there are three typical spectrum management models; the ‘Command and Control’, the ‘Market Based’, and the ‘Commons’ [19].

As a traditional spectrum management system, Command and Control, a service carrier frequency was designated by government as a type of obtaining license. This model has been usually applied as a representative spectrum management model due to the low demands for commercial spectrum like the situation in the 1990s. There is an advantage on the interference control among radio spectrum users because radio technology and their service boundaries were already determined according to the regulatory frameworks. On the other hand, the effective use of radio spectrum is relatively hard to predict compared to other models.

According to the development of wireless technologies and the enlargement of the service market, the economic value of the spectrum was highlighted, and the market-based spectrum management system, ‘Market-Based’, was emerged to reflect to this social phenomenon and market situation. This model is generally applied to the competition situation such as the spectrum auction, and it can introduce a secondary market such as a spectrum leasing or a re-trading system, and it can derive a high usability of radio spectrum. However, this model has an issue about market failure when the government intervention is ruled out. Further, the ‘Market-Based’ is not a good condition than the ‘Commons’ in terms of the satisfaction on spectrum demand because it is the market centric system.

On the other hand, ‘Commons’ model allows multiple users within the same spectrum, and the high spectrum efficiency can also be derived through a spectrum sharing technologies depending on a time and a space. However, ‘Commons’ is difficult to guarantee a quality of the service due to the mutual interference between users which does not contain obligation to protect other users. It is also difficult to form a secondary market according to a license exempt system [19]. Table 2.2 shows a pros and cons for the three models described above.

Each model has merits and demerits, and in most countries, the spectrum regulator, i.e., government uses the above three models mutually or independently to induce their public interests and industrial promotion.

Table 2.2. Comparison of the advantages and disadvantages of spectrum management models [20]

Model	Concept	Advantage	Disadvantage
Command & Control	Spectrum distribution and allocation led by government	Easy to prevent interference issue among users	Difficult to optimal spectrum use due to lack of a reflection of market conditions
Market Based	Spectrum distribution and allocation based on the principle of the market economy	Promote efficient use of frequencies by market	Lead to market failure due to nonintervention of market
Commons	Spectrum co-use by multiple users	Quick launch and innovative use of frequency	No guarantee of service quality

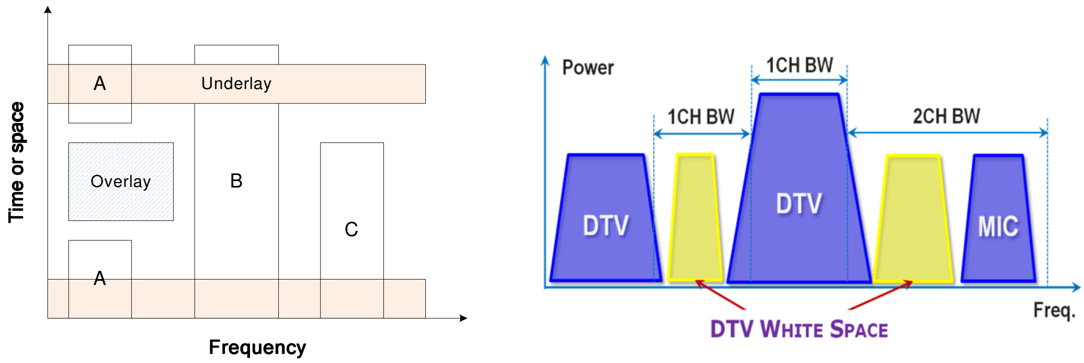
2.3. Spectrum Sharing

In general, spectrum sharing model can be classified into two ways, i.e., a user right and a sharing type. The user right can be divided into three ways as the licensed users, the unlicensed users, and the mixed users. The sharing type can be separated to the coexistence and the cooperation.

According to the above classifications, a spectrum sharing model with equal condition, namely, the 'Sharing among Equals' can coexist among unlicensed terminals within a license exempt band, and the cooperation is available when secondary users obtain a frequency use rights like a primary user or have to cope with some critical situations for the public safety [21].

However, interference avoidance technology should be guaranteed to realize spectrum sharing in different user status as the prerequisite condition. Regarding the spectrum sharing technologies, there are two kinds of methods such as the 'Underlay' and the 'Overlay', which are usually mentioned to illustrate how to share the spectrum technically.

In terms of RF application, Ultra Wide Band (UWB) system is a representative underlay system and this system is usually operating in wide band with small power: Operating level does not directly affect to the primary user. The overlay method is the other way for spectrum sharing and DTV White Space is covered by this method. It is used spatially or temporally unoccupied frequencies with a dynamic spectrum access algorithm such as CR. Figure 2.4 shows the conceptual diagrams for spectrum sharing system.



< Underlay and Overlay > < White Space: Overlay-type service >

Figure 2.4. Conceptual diagrams for spectrum sharing system

2.4. Changing of TV Channel Usage Environment

Before facing with DTV transition era, the terrestrial analog television (ATV) channels were assigned to VHF and UHF band with larger channel space when comparing to DTV channel assignment conditions, and it was caused by the mutual interference among TV channels in terms of technical aspect [12, 22].

Based on DTV technical reports, the assignment condition of DTV channel can be enhanced by digital technology related to the noise immunity such as the error correction and the noise cancellation techniques. One of the TV standards, the National Television Standards Committee (NTSC) for analog TV system and ATSC for digital TV system, recommends the channel rejection thresholds depending on the type of interfere and the degree of channel spacing based on the following table [12, 23].

Table 2.3. TV channel rejection threshold in dB

Cases	Co-Channel (dB)	Adjacent Channel (dB)	
		Lower Side	Upper Side
DTV into DTV	≥ 15	≥ -27	≥ -27
ATV into DTV	≥ 2	≥ -48	≥ -49
DTV into ATV	≥ 34	≥ -16	≥ -17
ATV into ATV	≥ 45	≥ -13	≥ -10

According the Table 2.3, ATV system requires 10dB more than DTV system when compared to the interference ratio between the systems. Especially, the most serious condition, i.e., co-channel interference ratio has about 30 dB difference between ATV and DTV. On the basis of this recommendation, DTV system can be allowed to operational margins in aspect of neighboring user accessibility, and it can also reduce TV channel reuse range due to the higher interference immunity than ATV system.

Currently, TV relays are used to cover some places where the TV signal cannot reach due to environmental condition namely shadowing zones within each service area. In terms of technical aspects, TV relays are using different channels by each to ensure the quality of service in general. When using same channel among TV relays, it is to induce the signal degradation to DTV receivers or to occur the picture superposition which is called ghost effect to ATV receivers [24]. However, such measures lead to the consumption of TV channel resources. In this situation, many new studies are underway in order to efficiently use TV band due to the advanced digital technology and DTV transition. As a part of these efforts, a new TV relay system called the Digital on Channel Repeater (DOCR) is being developed in order to use the regionally same TV channels, and it is able to be applied to the DTV transition area [25]. Through this technology, regionally single TV channel network can be realized, and it will induce efficiency use of

TV channel. In addition, more idle DTV channels are expected depending on the geo-location condition in technical aspects. Figure 2.5 shows the conceptual configuration for DOCR network.

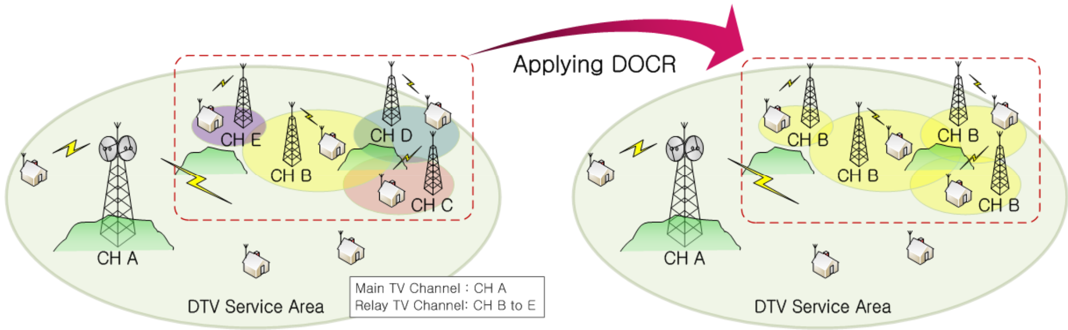


Figure 2.5. Conceptual configuration for DOCR network

Therefore, digital transition can offer new possibility for reducing the TV spectrum and expanding idle channels by significant improvements in digital technology.

2.5. New Wave in DTV Band

A spectrum policy induced the development of wireless technologies and their related services. Korea, US, EU, and Japan as the digital leading countries are promoting the spectrum policy as the improvement of spectrum utilization efficiency for the digitalization of telecommunications and broadcastings and the evolution of ubiquitous.

As a reflection of the global tendencies of terrestrial TV, many countries are planning to complete the DTV transition before and after 2012 and the DTV White Space brings a demand for a new spectrum management policy [26]. In particular, Korea and the countries that already completed the DTV transition designated the DTV White Space as DTV band are reviewing the DTV White Space as one of the DTV transition policy [27].

The US, UK, and Japan are considering the DTV White Space as the basis of an unlicensed band with small output power to introduce the DTV White Space services. They are also reviewing the related technologies and the service applications for the effective use of DTV White Space [28, 29, 30]. Figure 2.6 shows the DTV spectrum and the planned DTV White Space in major countries including Korea.

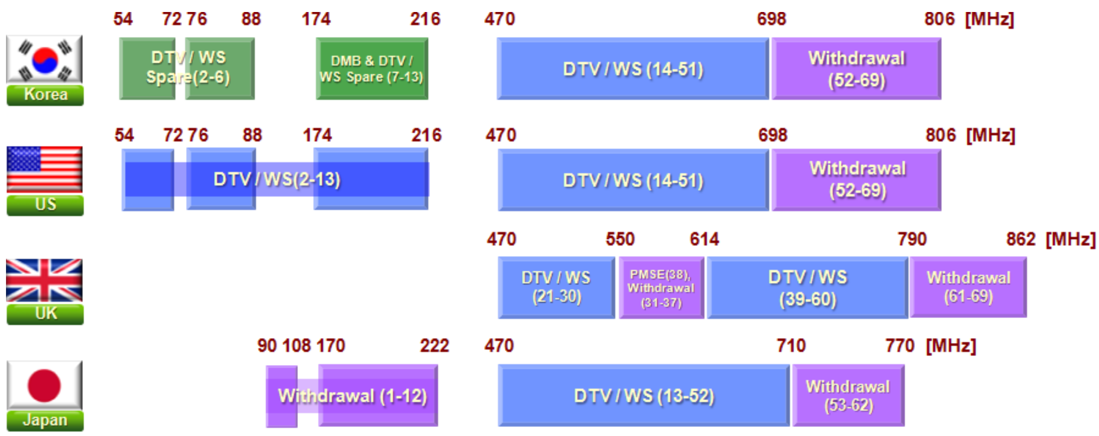


Figure 2.6. DTV spectrum and tentative White Spaces in US, UK, Japan, and Korea

The DTV pilot projects in Korea will be tested until the end of December 2012 to review the impact of digital switchover and provide systematic measures [31]. The three districts, i.e., Uljin, Gangjin, and Danyang were selected in 2009 as the DTV pilot program regions considering the geographical balance and characteristics. In 2010, these districts were shut down the analog TV following a trial basis. Jeju island was added as a DTV pilot area and completed the DTV transition in 2011 [11].

2.5.1 United States, US

The US completed the digital conversion in June 2009 and the federal communications commission (FCC) has started discussions for the introduction of White

Space since 2004. Through the 'Report and Order' in 2006 and 2008, the FCC announced to the public about the allowance condition for the DTV White Space devices. As license-exempted condition bands, the DTV White Space devices should be equipped with the White Space database connectivity, a geo-location, and a spectrum sensing functions [30]. Stakeholders on the DTV White Space like broadcasters and wireless microphone users raised the possibility of interference from the unlicensed devices to the FCC and the government asked the court to reserve judgment because it takes time to collect opinions of the introduction of White Space [7, 8].

According to the DTV transition in US, TV spectrum is composed of the VHF band and the UHF band, i.e., from the channel 2 to 51 except the channel 3 on the basis of the physical DTV Channels like shown in Figure 2.6. Especially, the channel 36 and 38 are assigned to wireless microphone channels in order to minimize a harmful interference by reflecting the opinions of broadcasters and manufacturers. Regarding the DTV White Space devices, spectrum sensing obligations required to be equipped the positioning function and the DTV White Space connectivity were abolished [32]. In addition, the FCC is planning to use the White Space as a way to encourage the development of various applications and new technologies like the 'Super Wi-Fi' [33].

2.5.2 European Union, EU

The European Union, except for already completed the digital transition countries such as Finland and Germany, agreed to carry out the digital transition by 2012, and is planning to open the digital dividend brought from the digital transition [34]. In addition, the EU decided to introduce the DTV White Space policies. Based on this consensus, the EU is planning to grant the usage flexibility to maximize social and economic interests in Europe under the protection of existing users as a prerequisite of using DTV White Space. They are expecting that the competitiveness of the EU can be improved and economics of scale can be induced through the effective use of spectrum [35].

The EU agreed to provide additional technical standards because it is highly dependent on the terrestrial broadcasting unlike the US. These standards will make the European countries cope with mutual interference due to the utilization of White Space devices and facilitate the use of DTV White Space across the Europe [36]. The European Conference of Postal and Telecommunication Administrations (CEPT) and the Radio Spectrum Policy Group (RSPG) are reviewing the DTV White Space as advance researches [37]. The CEPT has been conducting an investigation on a usable White Space channel bandwidth in each country including France and Italy [38]. The feedback was collected from stakeholders like the US in order to establish the technical requirements such as output criteria of CR devices and a hidden node margin, and to be able to use White Space devices as unlicensed one [39, 40, 41].

The UK will complete the digital transition by the end of 2012 like Korea. According to the ‘Digital Dividend Review’ published in December 2007, it is planning to allow the DTV White Space as a license exempt spectrum after the DTV transition under a prerequisite which does not cause harmful interference to DTV users [42].

According to the Figure 2.6, TV spectrum in UK is composed of the low and high parts in DTV band: from the channel 21 to 30 is a low side, and from the channel 41 to 62 is a high UHF side. It is planning to prepare access methods to the DTV White Space database and its management plan depending on the DTV channel parts by regional groups [43].

2.5.3 Japan

Japan completed the DTV transition on July 24th 2011, and the Ministry of Internal affairs and Communications (MIC) announced the usage plan on DTV White Space through the ‘MIC Action Plan for 2011’ as means of revitalization for the local communications and the future money growth [44, 45, 46].

The MIC expects the successful introduction of DTV White Space through the long-term plan in the name of DTV White Space utilization. It will focus on the case studies and the analysis of propagation environments as the first phase and develop the radio technology and amend the relevant laws and regulations as the next stage.

A special research group, namely, ‘The research team for a new vision of spectrum utilization’ was configured by the MIC in November 2009, and the operation ended in July 2010. According to the final reports of the research group, a local OneSeg service designed for the local areas was mentioned as a useful system for White Space utilization to promote the industry and revitalize the local culture. It is technically same as the 'OneSeg' system for the mobile broadcasting in Japan [3].

Recently, a special meeting, namely, 'Meeting for White Space propulsion', was held reflecting the results of the research group. After this meeting, they are planning to develop a policy measure by conducting the special district selection and evaluation, the prevention of interference from the existing systems, and the legal systems for the vitalization of related industries [47].

2.5.4 Pilot Programs for DTV White Space

The countries planning the introduction of the DTV White Space services, are conducting the pilot services for the DTV White Space, and these services target the regional areas. The US pilot services were conducted in four areas under the supervision of 'Spectrum Bridge' and 'Google'. Each area has a different theme, namely, 'Super Wi-Fi', 'Smart City', 'Smart Grid', and 'Health Care', and these services were implemented through the extended Wi-Fi technique, IEEE 802.11af [4, 48, 49, 50]. Table 2.4 shows the status of the White Space pilot services in US.

On the other hand, Ofcom conducted the computing and the radio spectrum measurements to estimate White Space targeted the London area, and it carried out the consultation on the implementing geo-location targeted stakeholders such as British Telecommunications (BT), Ericsson, and British Broadcasting Corporation (BBC) [51]. The BT conducted researches on the Cognitive Access to the DTV White Space and suggested the DTV White Space services at the international symposium based on its survey results [5]. It performed the trial test in Scotland to demonstrate the feasibility of wireless broadband to the rural communities in UK by the DTV White Spaces. Table 2.5 shows the DTV White Space service models suggested by the BT.

In Japan, the 'White Space special districts' was operated to conduct the pilot tests and to promote institutionalization in aspect of the system implementation and business development [3]. 25 special districts were chosen in various places to develop the DTV White Space usage [47]. The DTV White Space pilot services

Table 2.4. White Space pilot services in US

Region	Service Overview	Leadership
Claudville (Virginia)	"Super Wi-Fi" service: High-speed internet connectivity to business, education and community user in Claudville	Spectrum Bridge
Wilmington (North Carolina)	"Smart City" service: Broadband connectivity to the previously underserved Wilmington/New Hanover Country communities	
Plumas County (California)	"Smart Grid" service: Real-time broadband connectivity to remote substations and switchgear allowing PSREC (Plumas-Sierra Rural Electric Cooperative) system operators	Spectrum Bridge / Google
Logan (Ohio)	"Health Care" service: Wireless internet connectivity to the Hocking Valley Community Hospital campus	

are planning to implement through the localized mobile TV system, namely 'Local OneSeg', reflecting the characteristics of the special districts. Table 2.6 describes the DTV White Space pilot services in Japan.

Like the above pilot programs, most countries are expecting the vitalization of related industries through the development of DTV White Space based on the technical approaches for using the unoccupied frequencies in DTV band. The related studies have been continued steadily to satisfy the needs of radio spectrum according to the evolution of related technologies and industries. However, current applications are hard to meet the public satisfaction entirely as the one of public resources. In other words, it is rather close to the supplement systems for the current Telcos services like 3G or wireless LAN. In terms of radio resources, DTV White Space has a scarcity value due to the technical limitation and regulatory framework although it has the nature of public goods in the aspect of resource accessibility.

Table 2.5. White Space service models suggested by BT in UK

Service	Overview
Multimedia Distribution in Homes	Multiple streams of content being distributed simultaneously around the home
Broadband "from the inside-out"	Share a portion of home Wi-Fi bandwidth for outdoor public use
Rural broadband (Trials @ Scotland)	Wireless broadband provision using a combination of Wi-Fi @5GHz (point-to-point) and Wi-Fi @2.4GHz bands (point-to-multipoint)

Table 2.6. Pilot services at the White Space special districts in Japan

Service	Overview
Sightseeing & Event information	Information on sightseeing spots and events delivered to travelers
Real time advertising in formation	Real-time advertisement and price information transmitted on the shopping street
Town information	Information for the community like town information, administrative introduction, medical information, and child-nurturing support, etc. in the area
Traffic information	At transportation points such as stations, bus stops, airports, subways, and the advertisement that are appropriate for the service area

Chapter 3

Consideration on DTV White Space Policy

We may expect that the DTV White Space can be developed depending on their geographical locations through a TV channel rearrangement process as a part of DTV transition. On the other hand, it may be considered as a niche of the radio spectrum. By using these spaces, we also expect the increase of the spectrum efficiency in DTV band. In such circumstances, the leading countries of DTV transition, especially the US, the UK, and Japan, are pushing for institutional improvement and taking measures to introduce the new wireless service. However, these approaches focused on commercial aspects may have a potential issue caused by the different user status with broadcasters as a primary user in TV band.

To understand this situation objectively, the in-depth interview was conducted to achieve the research purpose, understanding the needs for the DTV White Space policy and extracting the appropriate service. It contains the direction of the spectrum management, the White Space policy, and the way of the service vitalization in public aspects. First of all, White Space policy tendency was also reviewed as the background of in-depth interview. With the results of interview, we proposed the policy guideline for the successful launch of DTV White Space service in public aspect rather than commercial aspect.

3.1. Policy tendency for DTV White Space utilization

In the US, white space as an unlicensed band was reviewed and it was decided that it should be exempt from licensing as a result. The federal communication commission (FCC), the US government agency for communications, has conducted the test twice and has established a legal basis for using the white space without obtaining a license [32]. In addition, the FCC created an international TV White Space (TVWS) fellowship and a training initiative in order to encourage white space utilization [52]. The FCC also announced a plan to build a White Space Database (WSDB) for building a political infrastructure [29]. In 2010, the FCC has assigned some channels for microphone and amended the required items for White Space devices (WSDs) based on the opinions of stakeholders [32]. FCC announced approval of first television White Spaces database and device in December 2011 [53]. Related to this, North Carolina officially launched the first commercial TV White Spaces network in January 2012 that is being operated by Spectrum Bridge, one of White Space pilot service operators [54].

Similarly, in the UK, Ofcom, a regulator for UK communications industries, discussed white space utilization in the TV band and its techniques. In 2009, they announced license exemption in TVWS [41]. Recently, Ofcom requested the opinions of stakeholders regarding WSDB operation plan [43].

In Japan, they officially started research on white space in November 2009. They will begin new wireless service using the spectrum in July 2012, although analog television (ATV) service is scheduled to be terminated by July 2011. To review and develop new services via white space, the ministry conducted a broad request for proposals for about one month, from December 11^{th} 2009 to January 12^{th}, regarding the use of white space. As a result, 103 proposals were received, and most of them were using digital signage or area OneSeg as a means of service delivery. The ministry expects positive economic effects through the enhancement of urban development and local job creation [3]. New technology like CR is planned to be reflected to WSDs after 2015 by considering the current technical limitations [28].

In such a global circumstance, Korean government is planning the DTV transition by the end of 2012, and is also expecting DTV White Space utilization. As a preliminary work for introducing White Space, they conducted the pilot test in 2011 as a shape of Super Wi-Fi at Jeju area, and they organized the special committee to examine the basic plan for DTV White Space [55]. The progress of White Space policy in each country is described in Table 3.1.

Table 3.1. Progress of White Space policy in each country

<table>
<tr><th>Year</th><th>US</th><th>UK</th><th>Japan</th><th>Korea</th></tr>
<tr><td>2008</td><td>Conduct experimental verification and prepare draft scheme</td><td></td><td></td><td></td></tr>
<tr><td>2009</td><td>Start WS pilot service at 4 areas</td><td>Start WS review</td><td>Start WS review</td><td></td></tr>
<tr><td>2010</td><td>Announce WS usage plan</td><td>Build WS testing network by BT</td><td rowspan="2">Conduct WS pilot services at 25 special districts</td><td></td></tr>
<tr><td>2011</td><td>Approve WSDB operator (Spectrum Bridge)</td><td>Consult on WSDB</td><td>Start WS review and conduct WS pilot service w/ Super Wi-Fi</td></tr>
<tr><td>2012</td><td>Launch the first commercial WS network w/ Super Wi-Fi (North Carolina) and release 3rd MO&O</td><td>Promote institutionalization on TVWS</td><td rowspan="2">Develop national-wide service with 3 types:
1. OneSeg
2. Comm. network
3. Technological usage</td><td>Conduct experimental verification for WSDs standardization and institutionalization</td></tr>
<tr><td>2013</td><td></td><td></td><td>Build WSDB</td></tr>
<tr><td>2014</td><td></td><td>Start WS commercialization</td><td>Promote institutionalization on TVWS</td><td>Start WS commercialization</td></tr>
<tr><td>2015</td><td></td><td></td><td>Start WS commercialization</td><td>Start CR based service</td></tr>
</table>

As mentioned in previous chapters, the development of White Space started for efficient use of DTV band to cope with enlargement of spectrum demands. Shown in the Table 3.1, DTV leading countries are progressing DTV White Space policy as measures for new money growth. However, it is commonly derived by Telcos and Internet Corporations to cover their insufficient wireless network resources, and these commercial based approaches may give rise to a trouble with incumbent users like the case of US and UK. The US approved the White Space database operator and the commercial network service was launched in January 2012. Recently, National Association of Broadcasters (NAB) dropped the court challenge of White Spaces in May 2012 as a result of 3^{rd} *Opinion and Order* [56, 57].

However, they also have a potential issue on TVWS utilization related to the protection of incumbent users when applying new technologies or service models. This issue may also be correspondent to the case of Japan because they started with local OneSeg service as a DTV White Space pilot program. Technically it is not a heterogeneous system when compared to the current broadcasting system named Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) [47].

3.2. In-depth Interview on DTV White Space

For the first phase for developing DTV White Space, consultation based approaches is needed rather than consumer-centric policy in order to derive consensus with primary user and relieve these ambiguous problems. The DTV environment is expected to introduce the various service models utilizing DTV White Space to follow the global trend. We benchmarked foreign countries not only to progress the DTV White Space introduction speedily but also to improve the enjoyment of media experience with the effectiveness of DTV White Space. The following questions were brought up to review the current issues and solutions more clearly.

- ***Question 1***: *Direction of spectrum management system and its future outlook*
- ***Question 2***: *Key policy for the introduction of DTV White Space and its utilization*
- ***Question 3***: *Way of Service vitalization at DTV White Space as the aspect of public goods*

In-depth interview was conducted as the main methodology to approach the problems. As pointed out by Jensen in 1991, the qualitative approach is proper when analyzing behavior on the daily experiences or special occurrences related to the social phenomena [58]. Most countries are trying to introduce new services in DTV White Space although there is no successful example of popularization of DTV white Space until now. The qualitative approaches can be appropriate solution for the DTV White Space issues when conceptualizing the results of in-depth interviews with the related experts. In addition, the invisible rules exists in all industries like the business strategies and the corporate secrets, and they can be taken into account as the critical information when conducting the structural analysis even if they have usually been treated as common sense within the industry [58]. In-depth interview with the experts engaged the related industry can be appropriate analysis methodology to get closer to our issues about the DTV White Space.

In this research, a same questionnaire was presented to the interviewee group classified according to their working places in order to extract the coincident opinions. Based on the recording on the interviews, the interview-to-text process was conducted as the first stage. Then the open coding and focused coding process were utilized sequentially as the grounded theory in order to conceptualize the text data step-by-step.

Conceptually, the coding is the one of ways to find the clues for the issues. In other words, it refers to the repeated work for the conceptualization and the analytical insights by analyzing the interview text data [59]. It is to make codes such as subentries that describe a comprehensive overview for the entire contents. This inductive coding method is named as the 'Open coding'. The core contents of the open coding can be achieved through a simplification process called as the "Focused coding". That is, the text data is conceptualized through these processes called as the "analysis of qualitative data". Table 3.2 describes the analysis process of in-depth interview as the way of qualitative approach, and Figure 3.1 shows the working process for the conceptualization.

This research conducted the in-depth interview of twelve persons categorized into the following four parts, i.e., stakeholders, government, academia, and industry, in order to secure diversity and objectivity. Three people were assigned to each group according to the work fields to avoid the bias. The questionnaire was sent to the recipient of in-depth interview by email before conducting interview in order to induce the deep and meaningful responds. Then the interview

Table 3.2. Data analysis approach process

Step	Action
1	Conduct in-depth interview with voice recording
2	Writing down contents of interview for each interviewee based on the recording data
3	Conduct 'open coding' process to extract the subentries
4	Conduct 'focused coding' process based on the results of open coding to categorize theoretically as the high-level concepts
5	Conduct intensive analysis based on the results of 'focused coding' with the high-level concepts and themes.
6	Deploy a clear logic based on the contents of in-depth interview

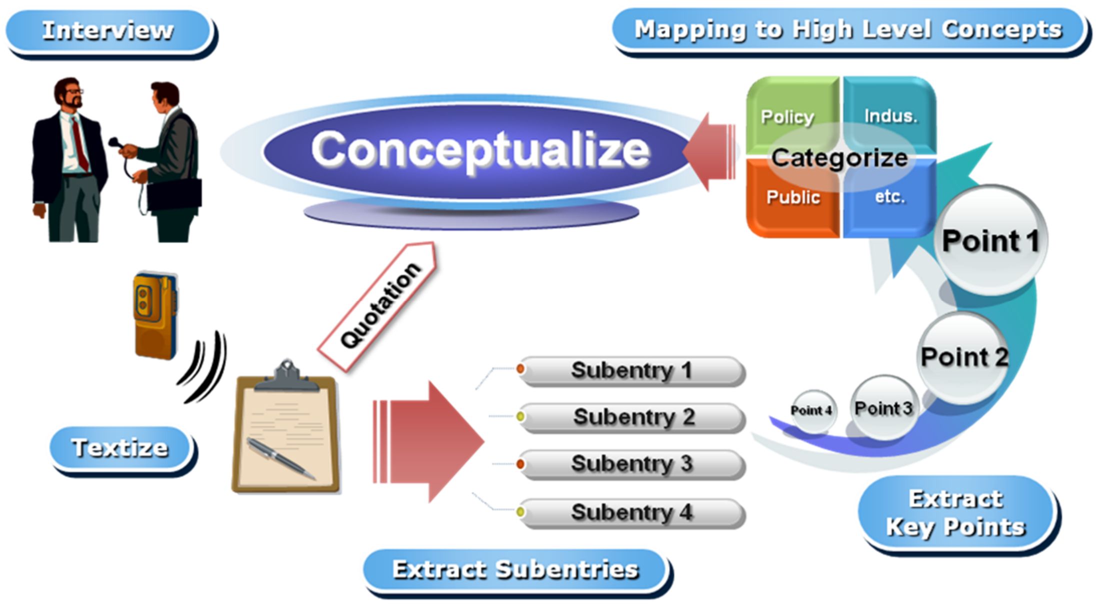


Figure 3.1. In-depth interview analyzing process

was conducted at the designated place chosen by the interviewees to give comfortable moods to them, and the interview lasted for about two hours per each person. Hearing to their opinions of the main questions was conducted to guide the main stream of the interview, and the related questions were induced in order to obtain the appropriate and expertise responses depending on the answering the main questionnaire. The interviews were recording under the consent of the interviewees as one of the coding process, and the texted files were used to analyze the interview as basic materials. Table 3.3 shows the list of interviewees and their workplace.

Table 3.3. Interviewee list*

Group	Workplace	Position
Stakeholder	Korean Broadcasting System (KBS)	Vice Director
	Korea Telecom (KT)	Director
	National Emergency Management Agency (NEMA)	General Manager
Government	Korea Communications Commission (KCC)	Director
	Korea Communications Agency (KCA)	Director
	Korea Information Society Development Institution (KISDI)	Director
Academia	Soongsil University, KCC White Space Task Force	Professor, Chairman
	Ajou University	Professor
	Chungbuk University	Professor
Industry	Samsung Electro-Mechanics	Director
	Korea Radio Promotion Association (RAPA)	Director
	Electronics and Telecommunications Research Institute (ETRI)	Director

* The name and department were omitted due to the request of interviewees

The questionnaire was designed with three groups including the view on the direction of spectrum management system, the outlook on the introduction of the DTV White Space, and the DTV White Space policy for a service vitalization. Table 3.4 shows the main questionnaire in detail.

Table 3.4. Main questionnaire

Category	Question
The view on the direction of spectrum management system	The current issues and the measure of future spectrum management?
	The most appropriate spectrum management model among the "Market based", the "Co mmand and control", and the "Commons"
	The prospects for the change of spectrum management system due to the DTV Transition
	The prospects of the relationship between the incumbent user and the expected new subscribers caused by changes in spectrum management system
The outlook on the introduction of the DTV White Space	The policy-measures needed to the introduction and use of the DTV White Space when considering the geographical and institutional situation in Korea
	The effects on the related industries through the introduction of new services in an aspect of the efficient use of spectrum resources
	The collaboration among the neighboring countries when using the DTV White Space like the case of EU
The DTV White Space policy for a service vitalization	Spectrum management measures as a key policy to activate the DTV White Space services
	The most prevailing business model as the DTV White Space service
	The necessity of introduction of policy measures in the direction of public goods
	The White Space utilization as a public service such as public information and disaster information to enhance the properties of public goods, and the management system for the service operation

3.3. Direction of Spectrum Management

The DTV White Space concept was emerged to provide the opportunity to the potential user as the unlicensed secondary user in DTV band. However, it is hard to reflect under current management model due to the different user status with incumbent users in DTV band, i.e. broadcasters. It means, in case of multi-users in the same band, they have the equal user condition among them, and it is hard to guarantee their service quality due to the mutual interference. On the other hand, DTV White Space lies on the different situation, and they have to provide security for the service of incumbent user as the primary user in DTV band. Therefore, under the scrutiny for service definition between primary user and secondary user, multilateral review is required to derive the mutual coexistence and cooperation.

3.3.1 Transition of Spectrum Management System

As reviewed at the previous chapters, the broadcasting channels are managed as a shape of government approval to prevent the mutual interference among the radio systems as a key measure of the guarantee of access rights. On the other hand, the existing use pattern of radio spectrum is managed for fixed stations in certain parts. Therefore, we can expect the idle channel due to this patterned situation, and the frequency open policy is discussed in a view of the spectrum recycling.

However, based on the results of the in-depth interview, the social mood may not be mature to discuss the possibility of the transition on the spectrum management scheme due to the introduction of the DTV White Space. That is, it is not clear about the direction of discussion on the introduction of new spectrum management system by expanding beyond the traditional model, i.e., the 'Command and Control' in aspect of using spectrum management models.

> *There is no need for who can be targeted to use the DTV White Space in aspect of spectrum policy, and it is just issued that the DTV White Space would be used in terms of the DTV spectrum policy. Regarding the utilization of DTV White Space, the experts are usually saying that the service should be limited to the restricted area and the*

low power based on the DTV White Space data due to the concern about the interference problems. - **Academia** -

It is important to draw the big picture for the DTV White Space through the pre-review on 'What policies should government consider for the DTV White Space?', 'What measures should they prepare to guarantee their services in the institutional aspect?', 'When related services can be started?', and etc. - **Stakeholder** -

Current spectrum policy should be revised. Accurate demand researches are insufficient. In the aspect of spectrum utilization, most people generally think of the spectrum as the telecommunication and broadcasting. However, the whole available frequencies have to be figured out except the current broadcasting and telecommunication bands. Therefore, the spectrum utilization should be proposed and the measures should be prepared on how to cope with the utilization in each band. - **Industry** -

In addition, the wireless data usage is exceeded anyone's expectations in terms of spectrum demand forecasting, and these changes are an early stage in life cycle in the phenomenology. It can be said that the current stage is laid in a transition period to involve the consideration of something new. Therefore, it is more difficult to discuss the future direction on the spectrum management system through recognizing the current problems.

3.3.2 Enlargement of Spectrum Sharing

Spectrum regulators usually handled their spectrum according to the 'Command and Control' model when there was no great spectrum demand for the commercial purpose prior to the 1990s. However, since the 1990 as the starting point of the expansion of the wireless communication market, the value of spectrum as an industrial aspect was emerged on the key issues for the spectrum policy. As such, the common model was introduced to reflect the enlargement of the spectrum demand. After 2000s, the spectrum management policy was faced with the advent of the digital convergence and ubiquitous era according to the evolution of the telecommunication network and their services. The new spectrum policy is a necessary condition to reflect the growing interest for radio frequencies in order to realize the economic efficiency and to secure the new spectrum resources. The changes in spectrum management system are illustrated in Figure 3.2.

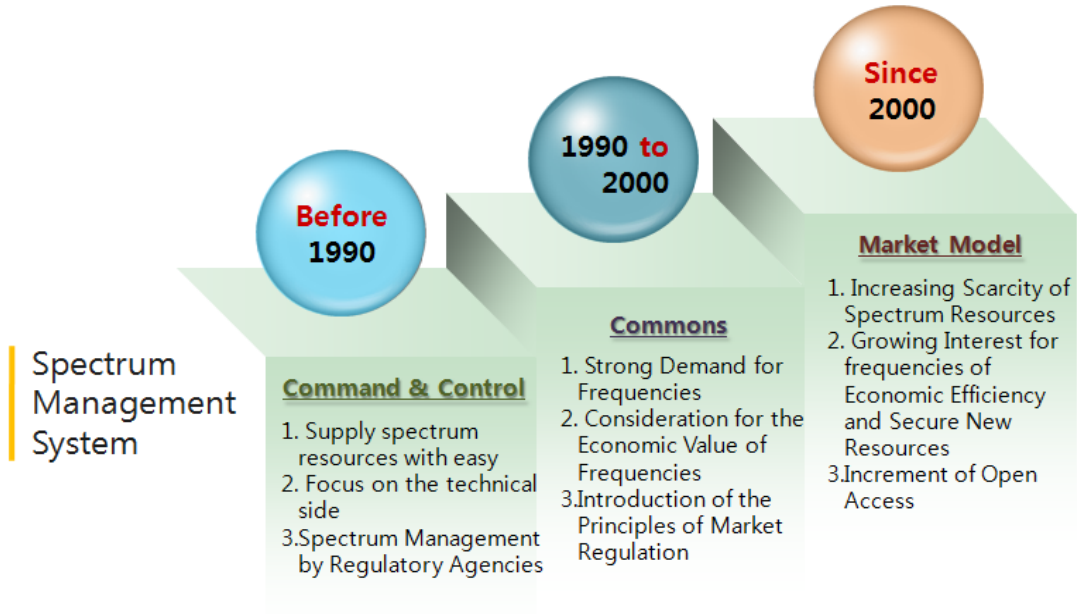


Figure 3.2. Changes in spectrum management system [19]

In case of United Kingdom (UK), they announced the spectrum management plan with three ways. The 'Command and Control' system covers around 21 percent of total radio resources, 72 percent is managed in the way of 'Market-Based' system, and the rest of them, i.e., around 7 percent is controlled through the 'Common' system [60]. The 'Command and Control' model managed by a government is applied when requiring the user separation for the reliable quality like a public, a security, and an emergency radio service. Otherwise, the high demanded spectrum like a mobile telecommunication band is handled by the 'Market-Based' model. In addition, some frequency bands led to promotion of industry through the introduction of 'Commons' model like a wide band service and the machine to machine communication (M2M). Therefore, the management systems with three ways are used separately depending on the characteristics of frequency bands and radio services to revitalize the related industries through the efficient use of spectrum resource.

The paradigm of spectrum management was shifted toward user centric due to the increment of spectrum needs, and an evolution of radio technology and telecommunication network. The development of variety management model should cope with the increasing scarcity of radio resources due to the expanding of spectrum demands and the recognition of spectrum values in terms of social economy. Figure 3.3 illustrates the paradigm shift in radio spectrum management.

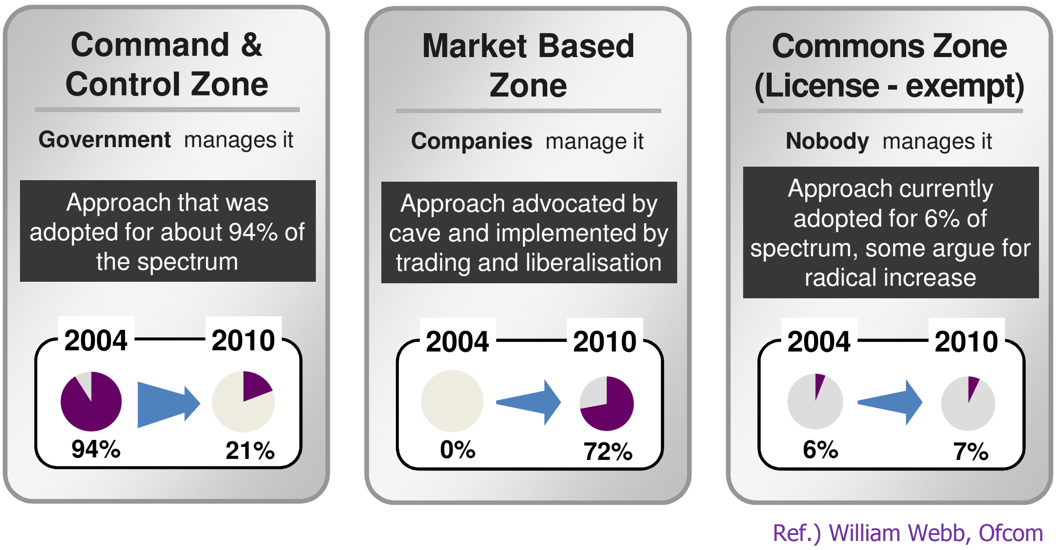


Figure 3.3. Paradigm shift in the radio spectrum management

The interest of 'Open Access' is increased continuously according to the spreading of interest for the economic efficiency and the securing of new spectrum resources like the DTV White Space [60]. However, it is difficult to choose among these three models for the DTV White Space management because it is not visualization in terms of the technical feasibility. As pointed out at the previous chapters, the DTV White Space management is progressing to various ways based on the theoretical possibilities.

It is difficult to define the direction of spectrum management system under current situation due to the unfinished technical methodology. It is important to secure the White Space at first, and the current analog frequencies in VHF band have to be considered one of the White Space utilization. - **Government** -

In Korea, the 'Command and Control' system may be reflected for a while due to the inexperience on the spectrum sharing as a form of White Space. However, the modified system based on the current 'Command and Control' system is expected in the future. - **Stakeholder** -

Although it is not easy to denote clearly when this phenomenon starts, most interviewees have the same opinions that the traditional method named the 'Command and Control' is reduced gradually, and the 'Common' based on the license exemption will expand steadily.

Some radio frequencies are used exclusively by commonplace since the 2000s as market-based, and the radio spectrum becomes scarcer under these management systems. In this situation, the lack of frequency may be deepened more and more because their using cost may be increasing according to the principle of supply and demand. Therefore, the future spectrum policy should be laid on the foundation that can compete in the innovation services through the cost-down for the infrastructures by attracting lots of companies into the market. - **Academia** -

Typically, the frequencies on 'Command and Control' system are reduced due to expanding sharing services under the name of 'Commons'. Especially, in case of the non-cellular frequencies, spectrum management scheme is expected to be in the direction of the sharing model named 'Commons' because the 'Market-Based' model is usually targeted the mobile communication services. - **Government** -

In the future, the frequencies on the 'Command and Control' system can expect transition into the 'Market-Based' according to the *output power and frequency. In other words, in case of low power applications, some frequencies will be controlled by the 'Commons' rather than the 'Market-Based'.* - **Industry** -

In the positive side of a spectrum sharing, an appeasement of exclusive rights can be expected to increase consumer benefit by saving the administration cost for the licenses. Moreover, a spectrum sharing system can prevent the monopoly among the related services, and the diversity of service contents is able to expect when the spectrum is considered the intangible public resources by preventing the privatization of spectrum resources. In the negative aspect, a sharing of spectrum resources may lead to low spectrum efficiency due to the over-utilization or the under-utilization. Thus, we can expect the improvement of spectrum efficiency through the exclusive right of spectrum utilization when granting the motivation for the profit pursuit and accelerating the innovation of related technologies [21].

3.4. Introduction of White Space Policy

3.4.1 Mixed-Sharing Model

In general, spectrum sharing model can be classified into two ways, i.e., a user right and a sharing type. The user right can be divided into three ways as the licensed users, the unlicensed users, and the mixed users. The sharing type can be separated to the coexistence and the cooperation.

According to the above classifications, a spectrum sharing model with equal condition, namely, the 'Sharing among Equals' can coexist among unlicensed terminals within a license exempt band, and the cooperation under common protocols is feasible when managed by regulator or license-holder. The 'Primary-Secondary Sharing', which shares spectrum between a primary user and secondary users, can be realized through advanced radio technologies like the CR for the secondary user terminals, and the cooperation is available when secondary users obtain a frequency use rights like a primary user or have to cope with some critical situations for the public purpose like emergencies and disasters [21].

The interviewees forecast a sharing system between the licensed users and the license exempted users under the 'Commons' scheme if being introduced the

DTV White Space services. As one of regulated industries, telecommunication operators possessing infrastructures are providing new services to the subscribers by investing lots of money. As pointed out at the previous chapters, Telcos willingness for the new business investment will fall down gradually when the entry barriers become lower for the wireless services under the name of spectrum sharing. Therefore, it may be reasonable methods that granting an exclusive right to user having infrastructures because they are protected by government control in aspect of their nature characteristics.

> *For the first phase, the shape of spectrum sharing under the license exempt condition is expected if pushing on the introduction of DTV White Space services. We can also expect higher output power when compared with other unlicensed services. Therefore, the part of their operating power levels has to be considered additionally. As one of countermeasures in next phases, we can think about the transition of user status as the license user.* - **Stakeholder** -

> *In case of Telcos as a user having the frequency rights, the spectrum sharing should be carried out through the constraint of the using power and coverage within the scope that does not infringe their service. On the other hand, the assigned frequency bands for the general purpose ensure to share as possible because there is no right to exclusive use of frequencies. The appropriate way is that exclusive bands should build the competition among users depending on the market condition. As such, the spectrum policy should be needed to induce the harmonized regulations between the license band and the license exemption band.* - **Government** -

> *Unlicensed bands only need to consider the related technology criteria without any parts of 'Commands and Control' when introducing the White Space as a shape of 'Commons'. In addition, the primary users should be managed by the technology criteria including the some parts of 'Commands and Control'.* - **Academia** -

The interference avoidance technology should be guaranteed to realize spectrum sharing in different user status as the prerequisite condition. Regarding the spectrum sharing technologies, there are two kinds of methods such as the 'Underlay' and the 'Overlay', which are usually mentioned to illustrate how to share the spectrum technically. The 'Underlay' method is to operate in a wide band with an interference power level or less like the ultra-wide band (UWB) system. The 'Overlay' method is used to find the unoccupied frequencies in time and space through a dynamic spectrum access algorithm like the CR, and it is usually referred to a key technology for the DTV White Space applications.

Currently, the radio communication sector of international telecommunication union (ITU-R) and the institute of electrical and electronics engineers (IEEE) are working on the standardization of spectrum sensing techniques including the CR technique in order to protect incumbent users in the DTV band [61].

> *In Japan, they are planning to build the data base through the 3G network, and they are also planning to provide the local area services by developing the cognitive radio technologies. In terms of service operation, the 3G network will be used to the data transfer for the sensing data, and the White Space will be used to provide the local broadcasting. In addition, the data base will include the information of the White Space stations and the frequency sensing data through the 3G network. Therefore, the White Space users can receive the information for the usable idle frequencies in their current location deliver their services through these idle frequencies. Japan is considering the overall scenarios for using DTV White Space.* - **Academia** -

However, the CR technology is in the potentially unstable status due to the hidden node problems. For these reasons, the federal communications commission (FCC) in US and Ofcom in UK demand the devices that have the cognitive function but also the geo-location or White Space database access function [29, 30]. Figure 3.4 shows the example of spectrum sharing systems depending on the sharing types and the user status.

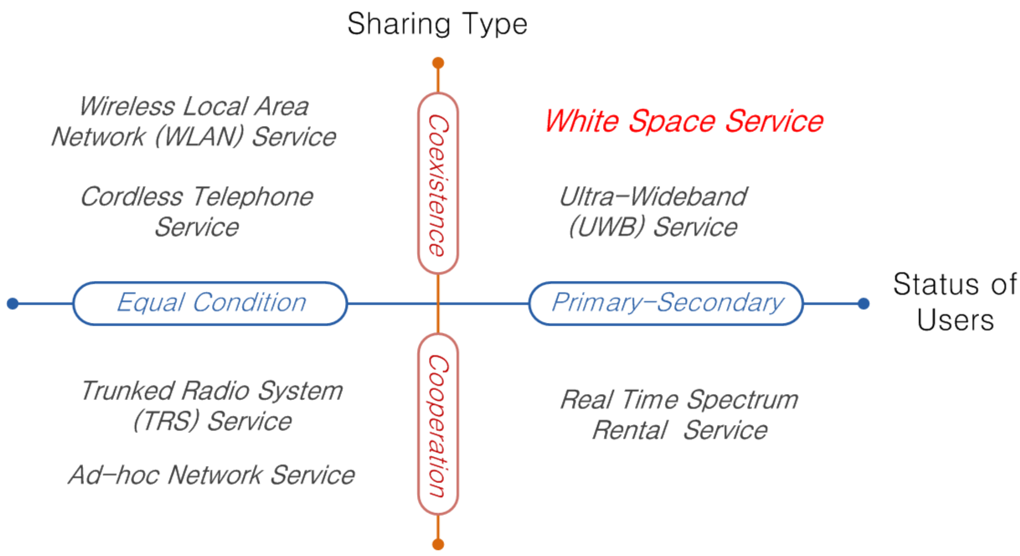


Figure 3.4. Examples of spectrum sharing system

3.4.2 Efficient Management and Allocation

The adoption of spectrum sharing system means that the radio spectrum should be managed to use the limited frequency resource efficiently in the future. The radio spectrum is considered as a key resource that led to the country's economic growth in the industrial viewpoint of mobile communication and broadcasting. Theoretically, the radio resource is infinite, but is recognized as a finite resource due to the technical economical limitation in an aspect of universal usability. In addition, the spectrum demands are concentrated under the UHF band due to the physical characteristics that can provide the service to the wide area with relatively low price, and it is also beneficial in terms of handset penetration to the public. In addition to the new service limitation, its value increases more and more [62].

Visible national resources usually take into account for being exhausted and establish measures to preserve them. On the other hand, the radio spectrum is easy to overlook its preciousness as one of limited resources due to the form of an invisible presence. The radio spectrum is managed by a spectrum regulator like the Korean Communications Commission through the 'Command and Control' mainly, and frequencies are usually assigned to users according to the using applications like the broadcasting and telecommunications. However, they are in the urgent situation to establish measures for the DTV White Space utilization to cope with exhaustion of the radio spectrum resources. They have to consider how to enhance the spectrum usability as one of invisible national resources, and the introduction of DTV White Space in aspect of new spectrum policy for the public interest.

> *The direction of spectrum control scheme should be approached in terms of national resource management. The status of frequency usage should be monitored daily in view of how to use the limited resources efficiently. Also, some regulatory measures should be introduced to mitigate regulations in order to induce the diversity of spectrum use for the whole radio spectrum.* - **Academia** -

The DTV White Space needs to be considered with the consensus issue when delivering the new services because there are already existing incumbent users in the DTV band, and it is required to allocate the spectrum according to their business characteristics. Currently, the radio spectrum is usually assigned depending on the user characteristics. There is a need for the management of the radio spectrum in aspect of service contents to use frequencies more efficiently.

> *Regarding the use of DTV White Space services, the technical using criteria on either the wide band or the narrow band can be determined by their service applications on whether the public purpose or the commercial purpose. Therefore, it is necessary to consider the direction of service applications like the local cultural heritage, the complementary system for the current mobile service, and the public protection services.* - **Government** -

> *If the government opens the door as direction of spectrum sharing among users, the radio frequencies will be available efficiently much more. It will be one of measures that can achieve the 'Green IT'. In other words, we can economize lots of energy consumption including the operating power by reducing the total number of base stations through the frequency sharing. It will also become the efficient use of radio spectrum.* - **Academia** -

In addition, a special management organization may be required in order to realize them. It should be applied for DTV White Space services but also other applications by providing the related information and guidelines as a measure of fair comparative competition between the existing operators and new entrants through the frequency database system with the investigation of complicated radio frequency status.

> *In US, spectrum management companies such as the 'Spectrum Bridge' were founded in order to use the DTV White Space efficiently. In Korea, however, there is no separated organization for a spectrum management. For the vitalization of DTV White Space, Korean government should provide the frequency information to the public, and manage and control it.* - **Academia** -

> *In Korea, they don't have a clear method for the DTV White Space management yet. However, some government affiliated agencies are considering as the DTV White Space manager. It means, raw data for the DTV White Space is managed by government, and the agencies will conduct related business as a type of trust management. Korean government will have a burden under consignment entirely to the private agencies.* - **Government** -

> *In UK, DTV White Space administrator or its user are asked their responsibilities when they do not comply the provisions controlled by Ofcom.* - **Industry** -

However, the frequency usage right is specified as the exclusive rights of frequency use based on the current spectrum law in Korea. Therefore, it is possible to face with huge resistance when forcing the direction of their spectrum sharing under the current spectrum management system. In this situation, they should be stated clearly about the possibility of frequency sharing in the future when reassigning their frequencies.

3.5. Vitalization Policy for DTV White Space

3.5.1 Multifunctional Utilization Measures of DTV White Space

As mentioned in previous chapters, the DTV leading countries and the global standard organizations are promoting the development of DTV spectrum policy to utilize and develop the DTV White Space efficiently as one of national resources, and a wireless internet and public information services are mentioned as a representative example for the DTV White Space application in general.

The Korea Communications Commission established a Task Force to develop vitalization measures for DTV White Space. There are three suggestions for the DTV White Space utilization; (1) as a subsidiary system for current mobile service, (2) as a public information application, and (3) as a local-centric application. They are reviewing the usage feasibility of DTV White Space with all respects. The first measure is to cope with the lack of current mobile system capacity due to the explosive increasing of smart phone service. It can be a way to enable for high speed data service that is difficult to expropriate the data capacity through single mobile network. Currently, 3G network service is impossible to provide the high-speed data service alone if smart phones do not support the Wi-Fi system. In addition, it is estimated that takes at least two or three years to construct the 'Long Term Evolution' (LTE) service nationally. The Wi-Fi system is considered a supplement system for the high speed data service until complete the LTE network. Also, subscribers of 3G service can use high speed data service through the general Wi-Fi networks even if they don't subscribe the data service. Dependence of Wi-Fi network is growing more than before, and Wi-Fi stations are much congested on urban areas. Other systems named as the 'Bluetooth' and the 'Zigbee' are also using the same band. In this situation, the service quality of high speed data is degraded due to the mutual interference among these systems.

> *The DTV White Spaces are considered as a new spectrum band as a solution of frequency scarcity. The technical working group in IEEE, i.e., 802.11af conducts research on standardization of DTV White Space technologies. The US is also planning to use the DTV*

White Space as high speed data service band. - **Industry** -

> *They are reviewing the usable frequencies through the idle frequencies or technical coexistence in aspect of efficient use of the radio frequency because the demand on the radio frequency is gradually increasing due to the enlargement of mobile communication market. In such situation, the review on the DTV White Space is becoming a global trend as a new growth engine of national economy through the formation of new market.* - **Government** -

The second measure is to improve the quality of public information services through the DTV White Space. The DTV White Space can be utilized as a measure of providing the lifeline information or delivering the field situation frequently if being faced with disaster situation. Disaster communications can be classified by the service contents to relieve the disaster. In case of nationwide service for simple voice and data communication, it can be provided through the current mobile applications such as the 'Terrestrial Truncated Radio' (TETRA). Meanwhile, the DTV White Space may be utilized to deliver high speed data service as measures of accurate awareness for disaster situation.

> *The DTV White Space is being reviewed as a channel for delivering high speed video in order to be sent a real disaster situation to the command center by firefighters at the scene.* - **Stakeholder** -

> *Currently, it is not easy to find the usable frequency to use for disaster and protection. Using the DTV White Space may be a solution to overcome the increasing demand and the difficult circumstance for secure of usable frequency.* - **Stakeholder** -

The third measure is to utilize as local centric services such as a local culture introduction, transportation, tourist guide, and small power broadcasting. In particular, province area is easier to find the DTV White Spaces than city area due to the low usability of radio frequencies. As such, there is an advantage to make a policy that can utilize as a specified service for local areas as one of measures for DTV White Space service vitalization. However, there is a financial issue to utilize DTV White Space as localized service. It is not a good condition to support the White Space services and their systems under current poor financial situation in each municipality when comparing metropolitan situation.

> *It is possible to utilize a type of localized service in aspect of service characteristics like local culture publicity by local government and local civic groups.* - **Academia** -

> *The White Space will have to be used within a limited range based on local areas due to a current severe condition to the DTV White Space in metropolitan. It will be applicable for regional museums, tourist guide service and public information service.* - **Industry** -

3.5.2 DTV White Space Utilization as Public Goods

The DTV White Space is laid in the unique situation due to the different user status between the DTV and the DTV White Space users. In other words, the service ranges are limited through the using licenses and protected by a government such as the spectrum regulatory authorities under current regulatory frameworks. The creation of value-added industries should be accompanied for the sustainability of service model and connect to vitalization of related industries. However, resistance for DTV White space is expected by broadcasters as incumbent users of DTV band in all of aspect for spectrum sharing conditions, i.e., the equal or primary-secondary user conditions in Figure 3.4.

> *In the era of digital convergence, broadcasters and Telcos can be placed in competition. In this circumstance, broadcasters use DTV band without frequency utilization cost. Telcos should pay lots of money to use frequencies for the frequency utilization cost. They always have complaints to government for this inequitable situation when comparing the frequency utilization condition with broadcasters.* - **Academia** -

> *It is a natural result that there is the dispute among stakeholders if they expand the spectrum usability by infringing on the rights of*

incumbent users in DTV band. Broadcasters will want institutional guarantees to receive compensation procedures and systems in a standpoint of broadcasters when taking place on the dispute between them. - **Stakeholder** -

The current direction of spectrum management is based on the technical-driven approach like a form of diaphragm, and it is usually categorized according to operator's requests and their using technologies such as 3G and broadcasting services. In reality, the DTV White Space caused by the DTV transition is laid in the situation that cannot expect to let service competition freely between the incumbent user and the new user. - **Industry** -

In the aspect of business model, service operators naturally aim to promote an economic profit through the DTV White Space service. In case of license exemption, however, it is difficult to generate revenue under the current situation that license exemption service can use for free even if an unrestricted spectrum sharing system under license exemption condition will be introduced. In this situation, the service vitalization will not be able to expect. Regional differences on ensuring the DTV White Spaces will have a significant impact on a degree of participation for the new market by the service operators, and it will lead to regional disparities.

Regional disparities are discussed as one of the most important issues at the DTV White Space Task Force. Especially, in aspect of topography condition, there are lots of mountain areas and shadowing areas in Korea, and it makes the poor condition for radio propagation. In addition, Korea is in the difficult situation to provide the DTV White Space clearly and widely due to the administrative direction on broadcasting channel management that is granted based on an administrative district. - **Academia** -

In this situation, the change of a spectrum management system is required to alleviate the deepening scarcity of spectrum resources and to improve the frequency utilization efficiency for increasing economic value. The radio regulatory authorities in each country are considering the introduction of the spectrum sharing system in time and space through the using of idle frequencies or a wideband with an extremely low operational power.

Reflecting such a social situation, the FCC in US operated the radio policy task force in 2002 to establish the long-term plan for the direction of spectrum policy, and mentioned an introduction of the 'Commons' system in the final reports of the task force [63]. Based on these reports, it continues researches on the spectrum policy to realize the spectrum sharing to cope with the formation of a secondary market [30].

Similarly, the EU clarified their attitude to the spectrum policy at the 'Framework Directive' in 2002, and stated that the effective management of the spectrum resources is required. They encourage the spectrum allocation policy and the shared use of spectrum resources based on the market and pointed out the technology and service neutrality by considering the spectrum accessibility. In addition, they emphasized the usable public frequencies as the public purpose [64].

Japan promoted an institutional improvement such as the simplification of licensing procedures for radio equipment to respond to future demand for frequencies speedily based on the spectrum open strategy. In addition, they set the fees for frequency use which was calculated in aspect of the public cost for the spectrum usage and reflected the economic value to the using frequency [65]. Moreover, they developed a new spectrum policy to cope with the increasing user data following the enlargement of user-centric wireless services like the smart phone services, and operate study groups for the efficient use of spectrum expecting the practical use of the DTV White Space [3].

As the above action plans in each country, the spectrum policy is developed in the direction to reflect the current market conditions and improves the efficiency of spectrum utilization in aspect of public goods. In terms of institutionalization, it is promoted to expand the scope of spectrum user by mitigating a right of exclusive use. Functionally, it is also promoted to realize spectrum sharing through the evolution of wireless using technologies such as CR and UWB.

Chapter 4

Presumption on DTV White Space Applications

A lot of standard organizations are developing the applicable technology to provide extended service like the current mobile communication and wireless internet services. This fact implies the current considered systems are embedded in the situation to carry huge data under the name of wide band service.

However, these approaches are only available in limited countries which have enough idle space in DTV band. This chapter is focused on technical aspect of the DTV White Space policy under severe condition on DTV White Space services. Based on the survey results of spectrum demand, the case study on Korea has been conducted to explore the possibility of applying some wireless services to DTV white spaces. Therefore, it is necessary to investigate how many idle frequencies could be generated within DTV bands after the DTV transition. The DTV channel information for DTV transition was provided by the Korean government because the DTV spectrum and channel assignment plan should be reflected to estimate DTV White Spaces in targeted areas.

4.1. Spectrum Requirements

A survey was conducted on DTV transition plan in Korea to examine the spectrum policy direction for tentatively residual frequency utilization after ATV service termination. Number of experts in the related field was targeted from

246 organizations in broadcasting and telecommunication including service operators. The survey was carried out through the cooperation of the Korea Radio Promotion Association. To facilitate the survey, a written or online process was conducted for about three months from November 2009 to January 2010. Out of 246 institutions, 113 responded to the survey, and these responses were categorized by service fields and its applications. The application and its details including requirement spectra are summarized in Table 4.1.

Table 4.1. Requirement spectra in each application [66]

Category	Application	Details, Required Spectrum (MHz)
Industrial	1. Mobile communication 2. Universal Sensor Network (USN) 3. Intelligent Transportation Systems (ITS)	• Supplemental Spectrum for 4G, 80 • Video Transmission for Monitoring, 100 • Tactical Mobile Network, 60
Broadcasting	1. Receiving environmental improvement 2. Broadcasting for next generation 3. Outdoor concerts & special events	• Fringe area solution, 30 • Relay Transmission for Mobile, 26 • Multimode Service, 108 • R&D (3DTV, UDTV, etc.), 12 • Wireless Microphone, 50
Public	1. Public Agency & Institution Communication 2. Public Protection & Disaster Relief 3. Transport & Monitoring Communication	• Regional Wireless Internet, 10 • TETRA (TRS) service, 20 • Vehicle Communication, 15 • Intelligent Transport System, 10 • Train Control, 4.4

In this result, required bandwidths depending on the services were reflected in the current wireless technologies, and applications corresponding to the bandwidths were categorized by respondents' business areas. As the results of this survey, most respondents hoped to use residual spectrum for industrial, broadcasting and public purposes. Meanwhile, some respondents had no intention of spectrum utilization for their businesses and were only observing the direction of policy for the residual spectrum [66].

Among spectrum requirements, mobile communications and broadcasting, 4G, ubiquitous sensor network (USN) and multimode service, were most in demand. These results seem to reflect international trend.

In addition to that, there were spectrum demands for a terrestrial trunked radio (TETRA) system as a public protection and disaster relief (PPDR) service and a DVB-T2 system as a mobile broadcasting service. Regarding the survey results, two kinds of applications, namely, industrial and broadcasting fields, require more than 30 MHz to provide seamless service to their subscribers. In other words, the main services such as multimode service or mobile communication service require more than 30 MHz to cover their service area. On the other hand, public services based on the respondent's answers were estimated to take less than 30 MHz including no business area in Telco or broadcasting fields such as a fringe area solution and R&D, 3DTV, UDTV, and so on. To explore the possibility of applying these required services to DTV White Spaces, it is necessary to investigate how many spectra could be generated in DTV bands after DTV transition and the DTV spectrum and channel assignment plan may also reflect as an applicable service in the DTV White Space.

Among spectrum requirements, mobile communications and broadcasting, 4G, ubiquitous sensor network (USN) and multimode service, were most in demand. These results seem to reflect international trend. Also, there were spectrum demands for a terrestrial trunked radio (TETRA) system as a public protection and disaster relief (PPDR) service and a DVB-T2 system as a mobile broadcasting service. Regarding the survey results, two kinds of applications, namely, industrial and broadcasting fields, require more than 30 MHz to provide seamless service to their subscribers. In other words, the main services such as multimode service or mobile communication service require more than 30 MHz to cover their service area. On the other hand, public services based on the respondent's answers were estimated to take less than 30 MHz including no business area in Telco or broadcasting fields such as a fringe area solution and R&D, 3DTV, UDTV, and so on. To explore the possibility of applying these required services to DTV White Spaces, it is necessary to investigate how many spectra could be generated in DTV bands after DTV transition and the DTV spectrum and channel assignment plan may also reflect as an applicable service in the DTV White Space.

4.2. Target Areas and DTV Relay Coverage

As a part of DTV transition, Korea Communications Commission (KCC) chose the pilot areas for testing the analog TV termination with the following criteria to examine the impact of DTV transition.

1. *Total number of available TV channels: More than four channels: For many broadcasters to participate the pilot test*

2. *Low spillover of analog TV signals from adjacent areas*

3. *Exception of the region which have high power TV stations: Considering lower damage to the TV service areas due to the pilot test*

Based on the above conditions, three regions, i.e., Uljin-gun, Gangjin-gun, and Danyang-gun, were selected as the demonstration areas among the eight candidates. These regions were also satisfied with the geographical balance including the above conditions [31]. In aspects of administrative factors on these regions, around 10 % has been targeted as support subjects for DTV transition because more than 70 % of total households were receiving the TV signals through alternative ways such as Cable TV, Satellite TV, and Internet protocol TVs. In addition, these areas can be represented small and medium city size under suburban and rural environmental condition in Korea. Therefore, these three pilot areas can also be reflected the regional characteristics, and these regions has been target areas for DTV White Space in this thesis. The characteristics of the pilot areas are shown in Table 4.2.

As preliminary research on the DTV White Space estimation, the propagation distances for DTV relays has been examined through computer simulations to quantitatively determine the amount of idle channels at targeted areas.

In general, the DTV transmitters are operating on high power to cover huge area. On the other hand, the DTV relays are retransmitting the DTV signal with low power to the fringe and spot areas to cover their administrative service area. Interestingly, the spillover effect is generally occurring in both systems due to the operating power and the geographical condition. Therefore, the DTV channel condition at neighboring areas should also be considered through the estimation of propagation distance depending on the operating power.

Table 4.2. Characteristics of the pilot areas

Candidate	Danyang-gun	Uljin-gun	Gangjin-gun
Area of region	780 km^2	989 km^2	500 km^2
Type of terrestrial	Round valley	Coast	Plains
Total households	14,524	23,109	18,369
Cable TV subscriber	11,730 (80.8 %)	16,837 (72.9 %)	14,102 (76.8 %)
Support objects	1,284 (8.9 %)	2,872 (12 %)	1,781 (9.7 %)

However, the DTV channel plan is mainly affected by the DTV relay because many DTV relays are usually installed to satisfy the rugged service boundary, it is also advantageous in the aspect of maintenance costs compared to DTV transmitters due to the low operating power. Therefore, this research is focused on the DTV relay, which is usually operating at less than 10 watts in Korea broadcasting environment.

For estimating the effective DTV service area, several factors were considered to a DTV relay located in suburban area with CH 40, 626 to 632 MHz such as 10 watts output power, and 850 meter altitude as a normal condition of DTV relays. According to the above assumption and the field strength curves, the correction values can be derived depending on the height of transmitting, receiving antenna and the service coverage of DTV relay which can be estimated with these values. Based on the receiver performance guidelines of Advanced Television Systems Committee, Inc. (ATSC), the threshold of visibility, i.e., -83 dBm was considered as the minimum signal level to estimate the reference value for DTV service boundary in each targeted area, by which the 15.2 dB was recommended as the threshold signal level to noise level ratio [12]. These values were applied to the propagation simulation tool managed by Korean Radio Research Agency (RRA). As a result, DTV relay has around 10 km radius as a geometrically maximum horizontal boundary including actual service areas. These results are reflected to the physical antenna conditions such as antenna gain (GA) with 4.7 dB and their feeder loss (LF) with 1 dB. Figure 4.1 shows the computing results for service

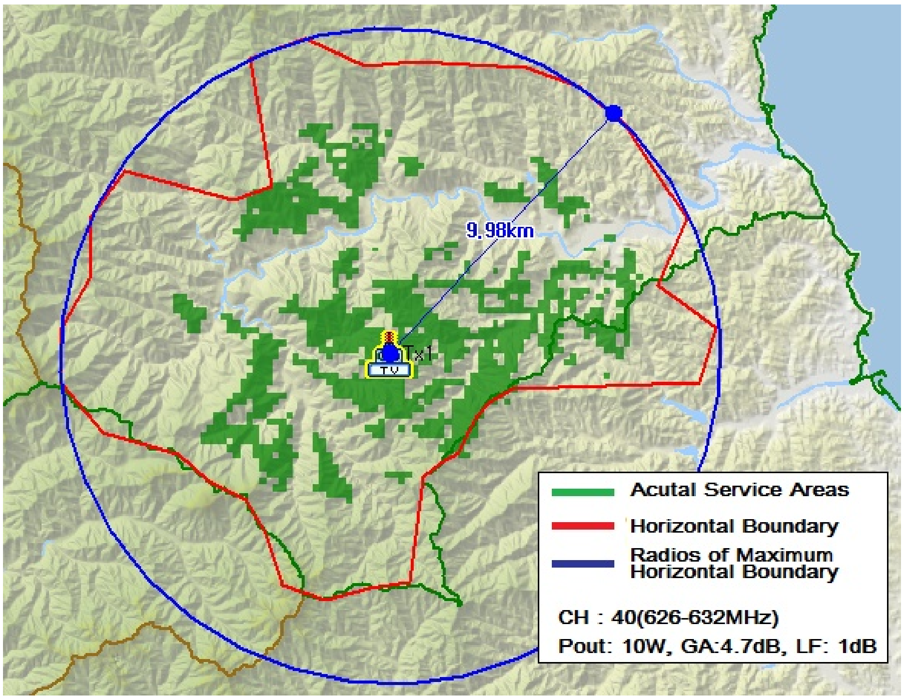


Figure 4.1. Service coverage of DTV relay (@P_{out}: 10W)

coverage of a DTV relay located at Gangwon area which is one of Korean local province with mainly covered with mountains.

4.3. Iconography Review

Based on the DTV relay coverage and the tentatively assigned DTV channels at the DTV pilot areas and their neighboring areas, the affected areas to the DTV idle channels can be assumed with three cases depending on the distance of the DTV transmitters and relays from the district boundary of the target area. Each boundary has a shape of circle and is increased by 15 km unit in radius. Moreover, the center of each boundary is placed in the same location, and the tier one represents the current broadcasting area. On the other hand, the tier two and three correspond to the affecting areas on the idle channels of the tier one as a role of spillover areas. The following three cases can be classified according to the number of affecting DTV stations in which the DTV transmitters and the

DTV relays are shown to simplify the iconography review. Figure 4.2 shows the conceptual diagrams for the iconography review.

- ***Case 1:*** *The channels of DTV transmitters and relays located at the* 1^{st} *and* 2^{nd} *tiers*

- ***Case 2:*** *Case 1 + the channels of DTV transmitters located at the* 3^{rd} *tier are additionally considered*

- ***Case 2:*** *Case 2 + the channels of DTV relays located at the* 3^{rd} *tier are additionally considered*

Based on the above assumption for affected coverage, the available bandwidth for each pilot area was estimated and is summarized in Table 4.3.

Table 4.3. Estimation of DTV idle spaces in each pilot area

Area	Case	Available BW (MHz)	Unoccupied Space, ea.		DTV Spec. vacant* (%)
			6MHz	12MHz	
Uljin	1	24	2	1	10.53
	2	24	2	1	10.53
	3	12	2	0	5.26
Danyang	1	24	4	0	10.53
	2	6	1	0	2.63
	3	0	0	0	0
Gangjin	1	54	9	0	23.68
	2	12	2	0	5.26
	3	6	0	0	2.63

*(Available Bandwidth / Total DTV Bandwidth, 228 MHz) $\times$ 100

In this result, around five percent or less of the 228 MHz DTV spectrums was only available as unoccupied spectrums in the third case where the most

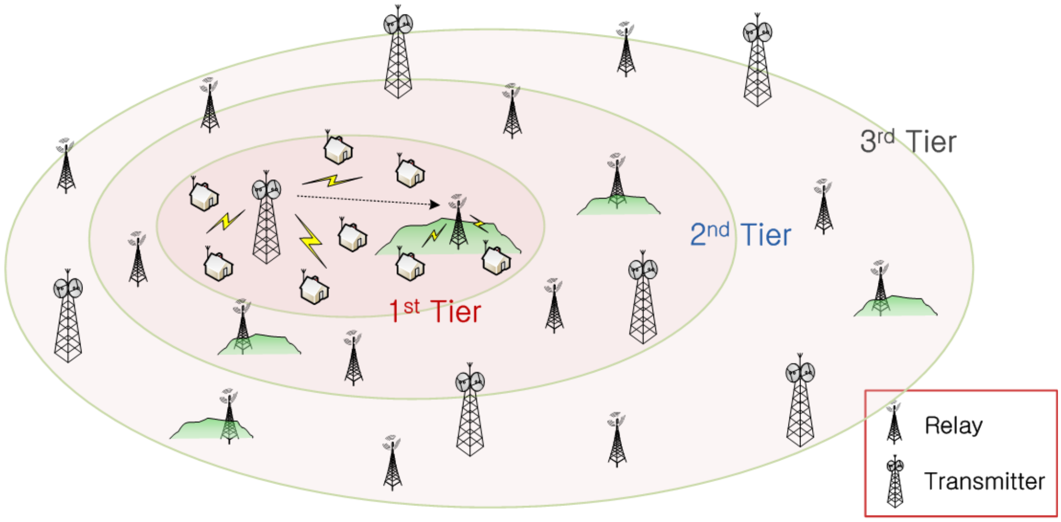


Figure 4.2. Conceptual diagrams for iconography review

severe criterion was applied. Even in the case of Danyang, there was no available spectrum as White Space. In the first and the second cases, however, to which the mitigated criteria are applied, the unoccupied spectrums were more than twice compared to that of the third case. It is natural that the unoccupied spectrums decrease as the affected area increases. However, the decreasing rate of unoccupied spectrums was regionally quite different. This means that unoccupied spectrums should be determined not only by the range of affected areas but also by the DTV conditions outside of the target area. Consequently, some DTV White Spaces can be allowed to each area, and two types of DTV White Space have been sorted like the following figure. More specifically, the sixteen idle spaces can be expected at total targeted pilot areas when considering the case one in each area as the most critical condition for DTV White Space. However, most idle spaces such as fifteen idle spaces are equivalent to the left side case, and a narrow band application can become as an appropriate solution due to the DTV White Space condition in each area. Figure 4.3 shows the result of iconography review on the DTV pilot areas in Korea.

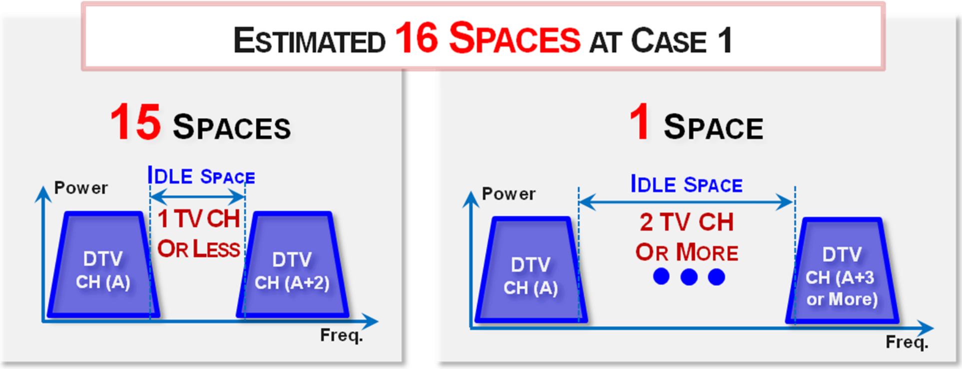


Figure 4.3. Conceptual diagrams for iconography review

4.4. Target system for Hypothesis Verification

In the technical aspects, the targeted system was selected based on the results of preliminary review such as the spectrum requirements and the estimation of DTV White Spaces to review the effect ranges of DTV users. This is due to the coexistence of the DTV White Space services. According to the results of spectrum requirement, the public services are required lower spectrum than other applications. Additionally, only few idle spaces can be expected as DTV White Space under severe environmental condition like the Korea situation.

4.4.1 Narrowband criteria and candidate systems

As a case study, I investigated a narrow band application as a targeted system satisfying the suggested policy conditions. First, the narrow band was defined preferentially and it was based on SM.1539, which is one of recommendations presented by ITU-R [67]. In this recommendation, they classify the bandwidth into three types depending on the function of necessary bandwidth for defining spurious domain boundary. It also can be described by the formulation having relationship with a lower and upper threshold value, B_L and B_U, for spurious emission bandwidth. Table 4.4 illustrates the necessary bandwidths, B_N, and frequency separation values depending on the using carrier frequency in each bandwidth type.

Table 4.4. Guideline for frequency separation values [67]

Frequency Range	Narrowband (kHz)		Normal	Wideband (MHz)	
	B_L	Separation		B_U	Separation
150 kHz < f_c < 30 MHz	4	10	2.5 B_N	0.1	1.5 B_N + 0.1
30 MHz < f_c < 1 GHz	25	62.5	2.5 B_N	10	1.5 B_N + 10
1 GHz < f_c < 3 GHz	100	250	2.5 B_N	50	1.5 B_N + 50

According to this table, 25 kHz or less bandwidth is considered as the lower threshold emission values when using 1 GHz or less as a carrier frequency, and it can correspond to the DTV band. Therefore, the values between lower threshold and normal one were reflected as the criteria of narrowband system in this thesis.

On the other hand, globally standardized systems were sorted as the candidate systems for conducting a case study to verify suggested polishes. As a precondition for the sorting, commercial or public systems in UHF band were targeted, and Table 4.5 shows the technical and service characteristics in each candidate system.

Table 4.5. Characteristics of candidate systems [68, 69, 70, 71, 72]

System	Frequency (MHz)	Service area	CH BW (kHz)	Application
RFID	433, 870, 902, etc.	Spot / Local	200	Universal product code, etc.
TETRA	470, 746, 806, etc.	Local / National	25	Policy & Fire, Transport, etc
LR-WPAN (IEEE 802.15.4)	868, 902, etc.	Spot / Local	600, 2000	Monitoring, M2M communication, etc.
Pager	319, 924, etc.	Local / National	25	Multi-purpose
Wireless Microphone	740, 928, 950, etc.	Spot / Local	200	Individual, Broadcasting, etc.

I focused on the system being operated at nearby the DTV band, 470 MHz to 698 MHz, with a narrow channel bandwidth based on the criteria in Table 4.4

for the target system. In case of Wireless Microphone, it may be allowed to the White Space as a licensed system. However, this system is hard to reflect the inherent issues for DTV White Space due to the limitation of service coverage and characteristics being used as a part of broadcasting system. In addition, the Low Rate Wireless Personal Area Network (LR-WPAN) is generally used for personal network, and needed more than 600 kHz bandwidth to carry their services. The Radio Frequency Identification (RFID) system is also usually applied to market places at small area. These systems do not satisfy the suggested policies in this thesis, narrowband system for public service. Of the two systems, I considered closer system to DTV band and TETRA was targeted to evaluate the effectiveness of suggested policies.

4.4.2 Terrestrial Truncated Radio (TETRA)

According to the previous reviews, the narrowband application for the public service was targeted, and the terrestrial truncated radio system (TETRA) was considered as an appropriate system that satisfies the above conditions such as the narrow band public service. A system like CR has some problems to be solved such as hidden node and transmit-power control [32]. Moreover it will take time for commercialization and verification in the system operation [73]. On the other hand, a conventional TETRA system could instantly use white spaces with minimal system modification, when amending the rules for them. Allowing the use of white spaces is existing system is considered to be the most efficient methods to boost DTV White Space utilization. Table 4.6 shows the current status of TETRA system related to the using frequencies and their application in each country.

In general, TETRA was designed for reliable, spectral efficient and safe voice communications and data transmission to carry out PPDR (Public Protection and Disaster Relief) service. As such ITU-R is classified in two ways, public protection (PP) and disaster relief (DR). The demand for the Global common spectrum in emergency communication has increased. However, the regional frequencies according to the Radio Regulations (RR) were only distributed at the World Radio communication Conference 2003 (WRC-2003) [75]. In WRC-2003, frequency to PPDR service was assigned as shown in Table 4.7, where Korea

Table 4.6. Current status of TETRA utilization in each country [74]

Country	Allocation	Frequencies (MHz)
France	Civilian / Private	410-430
	Emergency Services	380-400
Germany	Emergency Services	380-390, 390-395
Italy	Emergency Services / Armed Forces	380-390
	Civilian / Private	462
UK	Airwave	390.0125-394.9875, 380.0125-384.9875
	Air Radio	454, 464 or 460

and Japan are in Region III.

Table 4.7. Regional assignment frequencies (MHz) to PPDR [75]

Class	Region I (Europe & Africa)	Region II (America)	Region III (Asia & Oceania)
Lower	380~385, 390~395	N/A	406.1~430, 440~470
Upper	N/A	746~806, 806~869	806~824, 851~869
High	N/A	4940~4990	4940~4990, 5850~5925

The technical standard of TETRA release I, a set of standards developed by the European Telecommunications Standards Institute (ETSI), describes a common mobile radio communications infrastructure. In detail, the TETRA system is the digital wireless communication system using 4-slot time division multiple access (TDMA) in 25 kHz bandwidth. Each carrier provides four independent physical channels. The $\pi/4$-DQPSK modulation scheme was chosen to support a gross bit rate of 36 kbps, which means that net data rates up to 28.8 kbps can be offered to some data applications. There are two operating modes such as Trunked Mode Operation (TMO) and Direct Mode Operation (DMO) in the

TETRA standard. TMO transmitters are fixed in location and DMO transmitters move freely in space. To take these characteristics into account, the deterministic model and random model were used for comparison in calculating interference power from TMO and DMO transmitters, respectively [68]. The characteristics of each mode are summarized in Table 4.8.

Table 4.8. Characteristics of TETRA operation Mode [68]

Trunked Mode Operation (TMO)	Direct Mode Operation (DMO)
• Basic voice and data transmission (V+D) in a circuit switched mode using the network infrastructure	• Direct mobile-to-mobile communication without the support of the network infrastructure • Mobile-to-repeater communication for a communication range extension

As such, when considering the technical and service aspects, DTV White Space could be a good alternative solution as PPDR common band if resolving the issues of CR technology.

Chapter 5

Interference Estimation

As discussed in Chapter 4, the regulation criteria should be regionally set to reflect the local DTV environment when deriving an unoccupied spectrum under harsh conditions such as the case in Danyang. Therefore, the allowable DTV protection range with some no-talk regions should be examined first on the basis of the technical criteria. The DTV coverage defined in the regulations was utilized to apply to the path loss models for the derivation of the physical operating margins between the DTV users and the DTV White Space users.

5.1. DTV Protection Margin

In terms of the regulation criteria, Korea DTV coverage in the UHF band is defined as a region in which more than 41 dBV/m DTV signal is received. Meanwhile, there are two criteria of the electric field strength values on defining DTV coverage (Pt. 73 of 47 CFR) in US where the same DTV system (ATSC) is used. These criteria were determined by the date of the TV license acquisition, where the above provision will be revised at the expiration date of the license acquired at the end of 2005. Table 5.1 shows the criteria of DTV coverage in the UHF band in Korea and US.

A computing work has been conducted as theoretical analysis methodologies to derive the general results for effective area depending on the geographical conditions. Based on the criteria of DTV coverage in the regulations, the propagation distances could be determined using the empirical path loss models, ITU-R

Table 5.1. Regulatory criteria for DTV coverage in UHF Band

Category	Korea	US
Field Strength (dBμV/m)	41	41* or 48
Reference	2008-17, KCC Bulletin	§73.625, 47 CFR

* Recipient: Commercial television licensees by the end of 2004 and non-commercial television licensees by the end of 2005

P.1546, Okumura-Hata, and ETRI [76, 77]. These three types of path loss models were applied to calculate propagation distances to obtain more objective results.

ITU recommendation namely ITU-R P.1546 was used as the primary model in this thesis, and this model presented the empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage time [76, 78]. The Equation 5.1 represents the general equivalent transmission loss for the land path depending on the geometrical conditions.

$$L_d = 139.3 - E + 20\log f + C_{Env} + C_{HTx} + C_{HRx} \quad \text{(dB)} \tag{5.1}$$

where:

L_d	Equivalent transmission Loss (dB) at the distance d(km)
E	Field strength (dBμV/m) for 1 kW e.r.p
f	Carrier frequency (MHz)
C_{Env}	Correction (dB) for short urban or suburban paths
C_{HTx}	Correction (dB) for receiving antenna height (m)
C_{HRx}	Correction (dB) for transmitting antenna height (m)

In the Equation 5.1, the correction values in this equation, C_{Env}, C_{HTx}, and C_{HRx}, are reflected to the additional transmission losses and these values can be ignored when the environmental condition is in free space. The interpolation of field strength was evaluated from the field-strength curves at 600 MHz presented as a function of frequency and distance (see Appendix A: Field strength versus distance curves for a frequency of 600 MHz).

Secondly, the Korea DTV path loss model presented by Electronics and Telecommunications Research Institute (ETRI) was also used to show the reliability of path loss results for the ITU-R model [77]. The ETRI model is being used for DTV prediction in Korea as this model focuses on the DTV propagation condition by reflecting Korean testing environment. Equation 5.2 represents ETRI DTV path loss model considering Korean suburban condition.

$$L_{ETRI} = 40\log d - 10\log(G_t G_r) + 20\log(h_t h_r) + 20\log f + 142.17\text{dB} \tag{5.2}$$

where:

d	Target distance (km)
f	Carrier Frequency (MHz)
G	Antenna gain of transmitter and receiver (dB)
h	Antenna height of transmitter and receiver (m)

In terms of the Okumura-Hata model, the Hata equation is used in general to predict the field strength for mobile services in an urban environment. This model is also described in the recommendation of ITU-R to give compatible results, and the Equation 5.3 shows the Okumura-Hata model.

$$E = 69.82 - 6.16\log f + 13.82\log H_1 + a(H_2) - (44.9 - 6.55\log H_1)(\log d)^b \tag{5.3}$$

where:

E	Field strength (dBμV/m) for 1 kW e.r.p
f	Carrier Frequency (MHz)
H_1	Base station effective antenna height (30 to 200 m)
H_2	Mobile station antenna height (1 to 10 m)
$a(H_2)$	$(1.1\log f - 0.7)H_2 - (1.56\log f - 0.8)$
b	1 for $d \leqq 20$ km

b $1 + (0.14 + 0.000187f + 0.00107H_1')(\log[0.05d])^{0.8}$ for > 20 km

In each model, -114 dBm was considered as the DTV protection boundary that is designated as the DTV sensing level for DTV White Space devices in

US [30]. However, the DTV coverage is defined as the values of field strength (E, dBμV/m) such as shown in Table 5.1. Therefore, these values need to be converted to the power (P, dBm) as a function of frequency to carry out the prediction of the DTV path loss [79]. The Equation 5.4 is used to convert the field strength values to the power based values [80].

$$P(\text{dBm}) = E(\text{dB}\mu) - 130.8 + 20\log\left[\frac{615}{f_{mid}}\right] \tag{5.4}$$

where, f_{mid} is the channel mid-frequency in MHz. By using Equation 5.4, the minimum required level could be derived according to the DTV channel frequencies and the electric field strengths for DTV coverage. The targeted DTV Channels which represent the DTV band as the first and the last DTV channel, 473 MHz and 695 MHz were used respectively as fmid of each DTV channel. Corresponding calculation results are shown in Table 5.2.

Table 5.2. Power based values for DTV regulatory criteria

Physical CH No. of DTV (f_{mid})	14 (473 MHz)		51 (695 MHz)	
Field Strength, *E* (dBμV/m)	41	48	41	48
Signal Power, *P* (dBm)	-87.52	-80.52	-90.86	-83.86
Correction Factor, *CF* (dB)*	N/A	2.48	N/A	N/A

* *CF*: (Minimum Sensitivity,-83 dBm) - (Signal Power, *P)*

The maximum DTV propagation distances is calculated to derive the no-talk region based on the guidelines of the minimum sensitivity, -83 dBm, and the D/U ratio at the co-channel, 15.5 dB [12]. Based on the Table 5.2 and the empty space criteria of the FCC, the margin of the no-talk region, G_{nt} (dB), could be derived according to E and f_{mid} using the following equation, and the results are shown in Table 5.3.

$$G_{nt}(\text{dB}) = SignalPower - D/U - CF + 114 \tag{5.5}$$

The correction factor of the minimum sensitivity, *CF* (dB), was applied when the signal power is higher than the minimum sensitivity, -83 dBm. This is because no-talk regions were reflected to the undesired signal levels at the same channel, and the affected regions will be reduced when the signal power is lower than the minimum sensitivity.

Table 5.3. No-Talk margins in each frequency and regulatory criteria

Physical CH No. of DTV (f_{mid})	14 (473 MHz)		51 (695 MHz)	
Field Strength, E (dBμV/m)	41	48	41	48
G_{nt} (dB)	10.98	15.5	7.64	14.64

Based on the same margin of the no-talk region between two criteria of DTV coverage, about 4.52 to 7 dB depending on f_{mid}, can be expected for the new criterion, 48 dBμV/m, as additional margins when compared with 41 dBμV/m,. The DTV service region and the no-talk region were calculated by using the values of P (dB) and G_{nt} (dB) for the two kinds of electric field strength criteria, 41 dBμV/m and 48 dBμV/m. Figure 5.1 and Figure 5.2 illustrate the results of DTV path loss in each frequency according to the empirical path loss models.

In the calculation of the DTV path loss, DTV relays with 10 W output power was applied to reflect a normal suburban condition in each province. In addition, the propagation curves for predicting field strength at 50 % of the locations 90 % of the time, F (50, 90), was used to satisfy the FCC rules, §73.625, by using propagation curves from ITU-R P.1546-4 and the following Equation 5.6 [79].

$$F(50, 90) = F(50, 50) - [F(50, 10) - F(50, 50)] \tag{5.6}$$

Based on the results of ITU-R models, a width of 14.48 km was estimated as the no-talk region at 41 dBμV/m. In addition, a 5.2 km wide area was also expected as an extra operational margin when the criteria of DTV coverage shift to 48 dBμV/m. at 473 MHz. Similarly, 9.8 km as a no-talk region and 7.5 km as a margin was anticipated at 695 MHz. On the other hand, the results of ETRI and Okumura-Hata models were applied in the same plots to derive the comparative

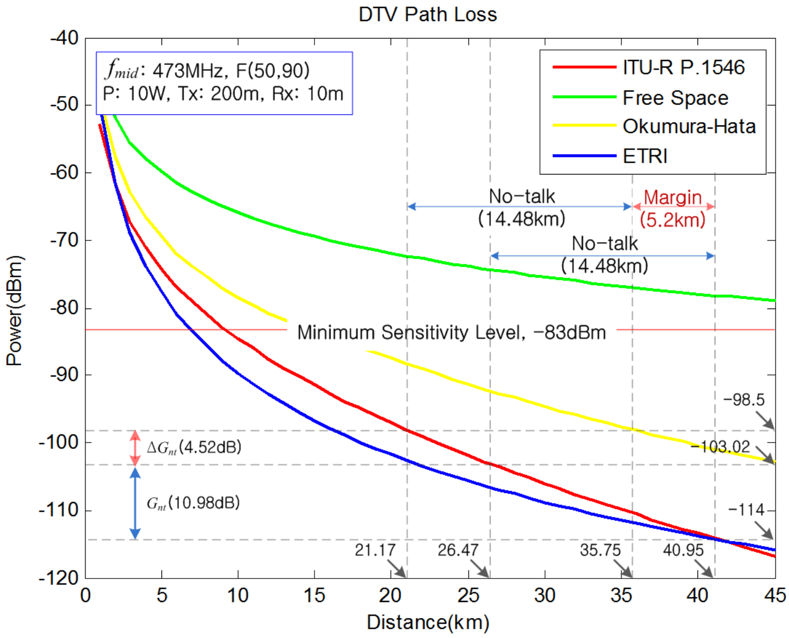


Figure 5.1. No-talk margin @ f_{mid} = 473 MHz

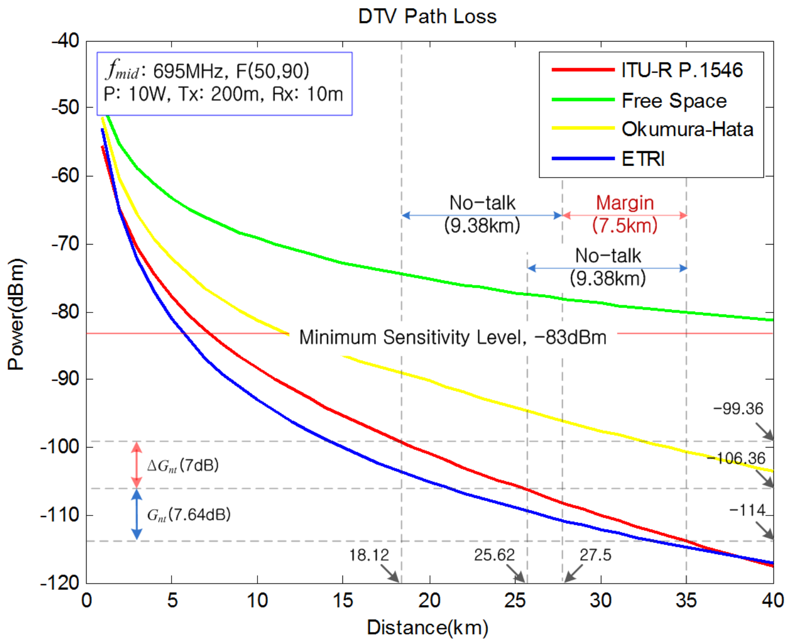


Figure 5.2. No-talk margin @ f_{mid} = 695 MHz

values of the DTV protection distance as no-talk margin to the ITU-R model in each frequency. Table 5.4 shows the calculation results for the no-talk distance and the criteria shifting margins in each model.

Table 5.4. No-talk distance and criteria shifting margin

Path Loss Model		ITU-R P.1546	ETRI	Okumura-Hata
No-Talk Distance in width	473 MHz	14.48 km	18.75 km	25.4 km
	695 MHz	9.38 km	11.82 km	16.39 km
Criteria Shifting Margin in width	473 MHz	5.2 km	5.14 km	9.01 km
	695 MHz	7.5 km	7.19 km	12.55 km

Accordingly, the ITU-R P.1546 and ETRI models show similar results when compared with the Okumura-Hata model while the results of Okumura-Hata are quite different. According to target frequencies, around 5.2 km to 7.5 km was expected as the extensible ranges for secondary service when shifting the criteria of DTV coverage.

5.2. DTV Intrusion Range

The TETRA system was discussed as one of considerable DTV White Space applications in technical and contents aspects in Chapter 4. As such the TETRA system is applied to estimate the degree of DTV intrusion range.

As the first step for the estimation of DTV intrusion range, the technical characteristics of DTV and TETRA were reviewed to calculate the amount of interference due to the coexistence of two systems. The TETRA Release 1 was reflected and utilized as one of digital wireless communication system in the world. In terms of physical conditions, it is being used to the 4-Slot TDMA technology by providing four channels within 25 kHz spectrum bandwidth, and each channel is able to transmit digital data up to 7.2 kbps. Theoretically, up to 36 kbps digital data can transmit simultaneously including some coding data. As a measure of the wireless communication, phase modulation technique is applied to transmit their digital data on air. The base station (BS) and the mobile station (MS) are separated into some power classes to control and manage their output levels by system operator. Table 5.5 shows the technical parameters of TETRA Release 1. Table 5.6 illustrates the power classes depending on the shape of transmitters, the mobile and the fixed station [68].

Table 5.5. General characteristics of TETRA release 1

Parameter	Value	
Access method	TDMA, 4 time slots/carrier	
User data rate	7.2 kbps per time slot	
Maximum data rate	28.8 kbps	
Modulation	π/4-DQPSK	π/8-DQPSK
Carrier data rate	36 kbps	54 kbps
Co-channel interference	19 dB	
Dynamic reference sensitivity level	- 106 dBm for BS, -103 dBm for MS	

Based on the above technical characteristics, it can be assumed that the TETRA system is located in the Korea DTV environment as the severe condition of DTV White Space. In addition, as stated in the previous chapter, -114 dBm was also reflected in the simulation as a criteria on the DTV intrusion boundary, which is used in US as DTV White Space sensing level. These technical criteria may be applicable because the Advanced Television Systems Committee (ATSC) is being used as the DTV standards in US and Korea [81].

In second step, following assumptions are adopted to conduct the computing simulation. First, two kinds of transmitters, TETRA base stations (BSs) and mobile stations (MSs), are being operated on DTV in the first adjacent channels as a status of interferes. Second, DTV receivers are in a cell boundary of DTV station. Third, the two kinds of boundaries, the first and the second tier and the TETRA devices are located between two boundaries (not sure about the meaning). In the third assumption, the first tier is equivalent to maximum allowable interference power, and the second tier is available for TETRA TMO

Table 5.6. Nominal power in each TETRA transmitter [68]

Base Station (BS)		Mobile Station (MS)	
Power Class	Nominal Power	Power Class	Nominal Power
1 (40 W)	46 dBm	1 (30 W)	45 dBm
2 (25 W)	44 dBm	1L (17.5 W)	42.5 dBm
3 (15 W)	42 dBm	2 (10 W)	40 dBm
4 (10 W)	40 dBm	2L (5.6 W)	37.5 dBm
5 (6.3 W)	38 dBm	3 (3 W)	35 dBm
6 (4 W)	36 dBm	3L (1.8 W)	32.5 dBm
7 (2.5 W)	34 dBm	4 (1 W)	30 dBm
8 (1.6 W)	32 dBm	4L (0.56 W)	27.5 dBm
9 (1 W)	30 dBm	N/A	
10 (0.6 W)	28 dBm		

service areas being decided by TETRA BSs which is located in the middle of two tiers. Moreover, the TETRA frequency bands for downlink communications are planned in the frequency range not to compromise the reliability and functionality of the DTV system. On the other hand, TETRA MSs for DMO services are uniformly and randomly distributed over between two tiers. The coexisting scenario between DTV and TETRA is depicted in Figure 5.3.

Based on the DTV sensing level, the protection range of the DTV service was calculated to estimate the affected range due to the TETRA devices. It is assumed that DTV relay was operating at 10 watts output power. As previously mentioned, ITU-R P.1546 was applied to calculate the DTV signal level depending on the distance from the DTV transmitter and the relay [76]. In addition, 41 dBμV/m was used as a reference of DTV coverage that is specified in Korea, and DTV signal ratio recommended by ATSC, i.e., D/U ratio, was used to define the effective signal range of DTV service depending on the frequency used [12]. For

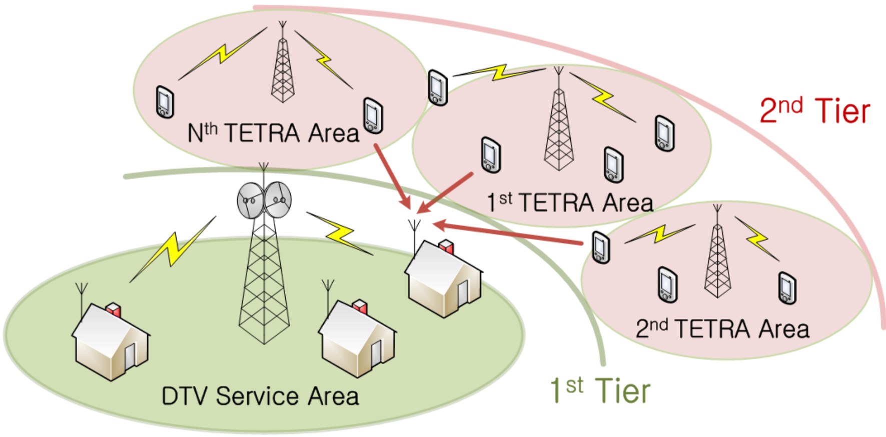


Figure 5.3. Coexisting scenario between DTV and TETRA

computational convenience, the electric field strength unit (dBμV) was converted to the signal power unit (dBm) using the Equation 5.4.

Secondly, to estimate the DTV affected ranges due to TETRA systems, some environmental conditions were assumed as below.

- *TETRA BSs are located at the center of the cells and the MSs are uniformly distributed within the cell area.*
- *The path loss is proportional to $d^{-\gamma}$, where d is a path length and path loss exponent (γ) has the value of 3.3*
- *TETRA transceivers operate on an adjacent DTV channel with a 25 kHz offset that is equivalent to channel space of the TETRA release1 system*
- *DTV is affected by TETRA transceiver leakage powers, and it is additive to the average power level from multiple interferers seen by the DTV receiver.*

On the basis of the above prerequisites, the dynamic sensitivity of the TETRA operating condition was reflected to the simulation to consider severe interference situation [82]. Total received power from the TETRA transmitters, and the total receive interference is

$$I = \sum_{j=1}^{J} \alpha_j d_j^{-\gamma} \tag{5.7}$$

where:

a_j Transmit power at the j^{th} interferer

d_j Distance between DTV receiver and j^{th} TETRA device

j Number of the TETRA devices as interfere

According to the TMO and DMO as a TETRA operation mode, the interference power in Equation 5.7 is decomposed of deterministic values of TMO and random values of DMO. Table 5.7 illustrates the simulation parameters regarding the operation condition of DTV and the TETRA devices.

Figure 5.4 describes the simulation flow to calculate interference power induced by TETRA devices.

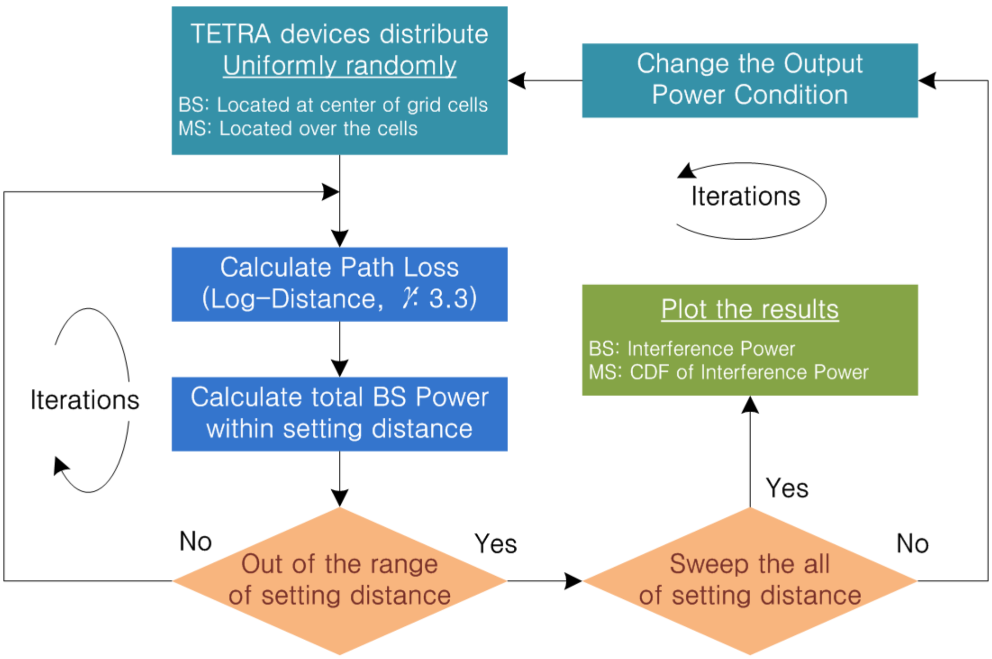


Figure 5.4. Simulation flow

Table 5.7. Simulation parameters

Parameter		Values
DTV Transmit Power		10 Watt
DTV Sensing Level		-114 dBm
Field Strength		41 dBμV/m
D/U Ratio		15.5 dB
Path Loss Exponent		3.3
TETRA Signal Offset		25 kHz
TETRA Transceiver Leakage Power		-55 dBc
Target DTV CH (Mid Freq, MHz)		CH 14 (473), CH 51 (695)
TETRA Transmit Power, Watt	Base Station	Class1 (40), Class10 (0.6)
	Mobile Station	Class1 (30), Class4L (0.56)
Dynamic Sensitivity	Base Station	-106 dBm
	Mobile Station	-103 dBm

At first, path loss and operating power of TETRA BSs are calculated according to the already defined parameters such as path loss exponent and operating power class of TMO and DMO. Second, coordinates of TETRA BSs and MSs are determined and then aggregated interference power is calculated repeatedly until the end of target distance.

After completion of such computing processes, cumulative density function (CDF) of interference power is finally calculated. In addition, the minimum distance between the TETRA MSs and the DTV receiver is assumed to be 10 m. Figure 5.5 shows the geometry for interference from TETRA MSs to DTV.

Based on the above assumption, the DTV protection margin, the distance from effective DTV signal level to DTV sensing level, was considered as the movable boundaries due to the change of the first tier in Figure 5.3. As a result,

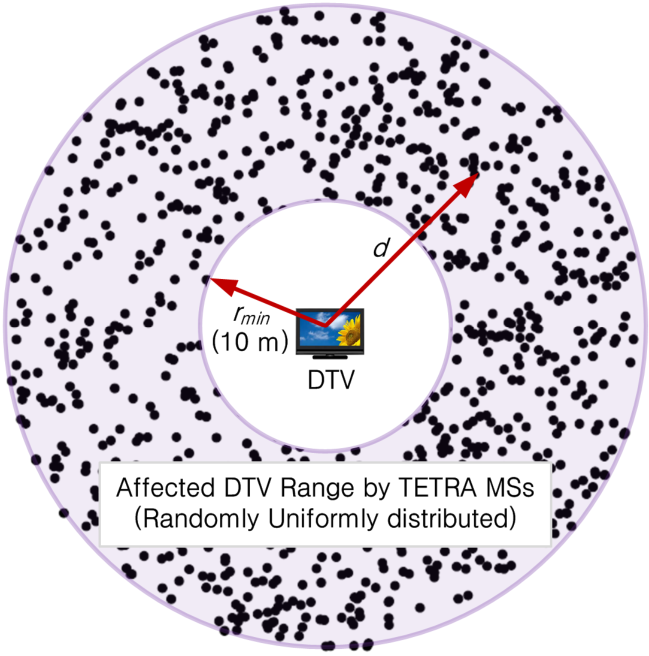


Figure 5.5. Geometries for interference from TETRA MSs to DTV

around 17.7 km at 473 MHz and 7.9 km at 695 MHz are estimated as spatial margin for the secondary users depicted in Figure 5.6.

Table 5.8 describes the computing results of the effective DTV range and the distance from the effective DTV range to DTV sensing level depending on DTV channels and operating power of the TETRA system.

As a next step, the computing on the TETRA impact range is performed from the view of a secondary user in which Table 5.7 and the equations in Chapter 5 are applied to derive the computing results. The dynamic range of TMO was conducted to estimate the disturbance of DTV user by operating TETRA as the secondary user in DTV band. Figure 5.7 shows the computing results on the DTV impact distance by TETRA TMO at 25 kHz offset. In this figure, around 0.3 km to 0.9 km is considered as the intrusive range on DTV protection area in radius due to the TETRA TMO dynamic sensitivity.

Also, the radius of Tier 1 in Figure 5.3 can be extended up to 0.9 km according to the TMO power class. The affected areas are moved up to around 2.2 km toward the DTV station, and the DTV protection areas are shrunk by the TETRA

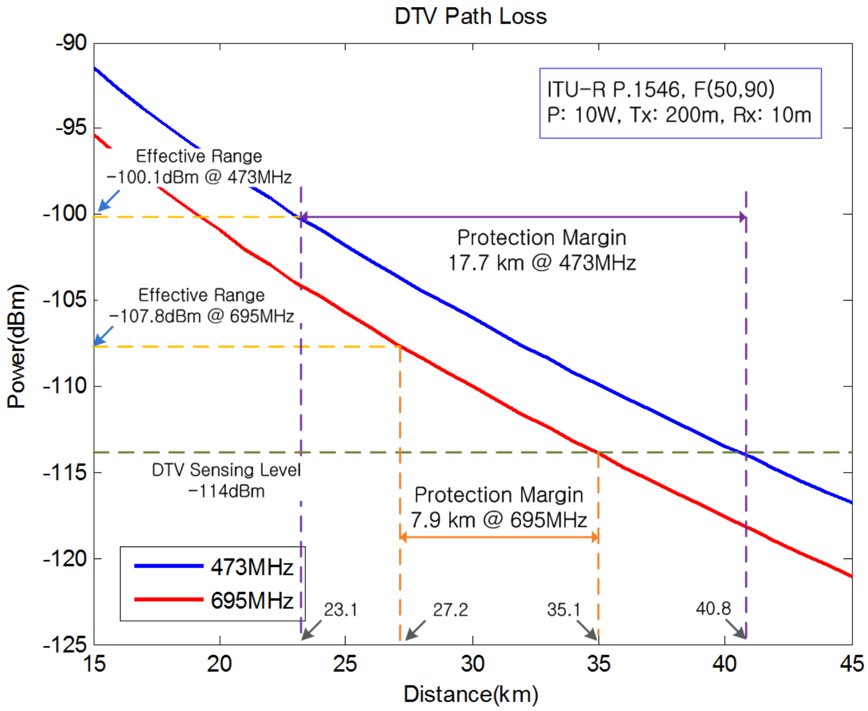


Figure 5.6. DTV protection margin in each frequency

devices operation from the edge of Tier 1. It means that the 2.2 km shrinking of Tier 1 radius is equivalent to approximately 30 % reduction of the DTV total protection margin as depicted in Figure 5.8.

The TETRA DMO is equivalent to Figure 5.5 as a precondition, and the interference possibility is estimated by cumulative density function (CDF) as an evaluation measure. Figure 5.9 illustrates the interference possibility by the TETRA MS in CDF.

It can be assessed that the possibility of interference power from the TETRA MS is less than the dynamic sensitivity level in DMO mode, and the interference probability is below 3 % in all TETRA MS power classes. Table 5.9 summarizes the computing results of impact ranges due to the TETRA in each operating mode such as TMO and DMO.

In conclusion, the TETRA system is considered to DTV White Space application as a narrow band system. Based on this assumption, the computing simulation is conducted according to the specified scenarios to estimate the in-

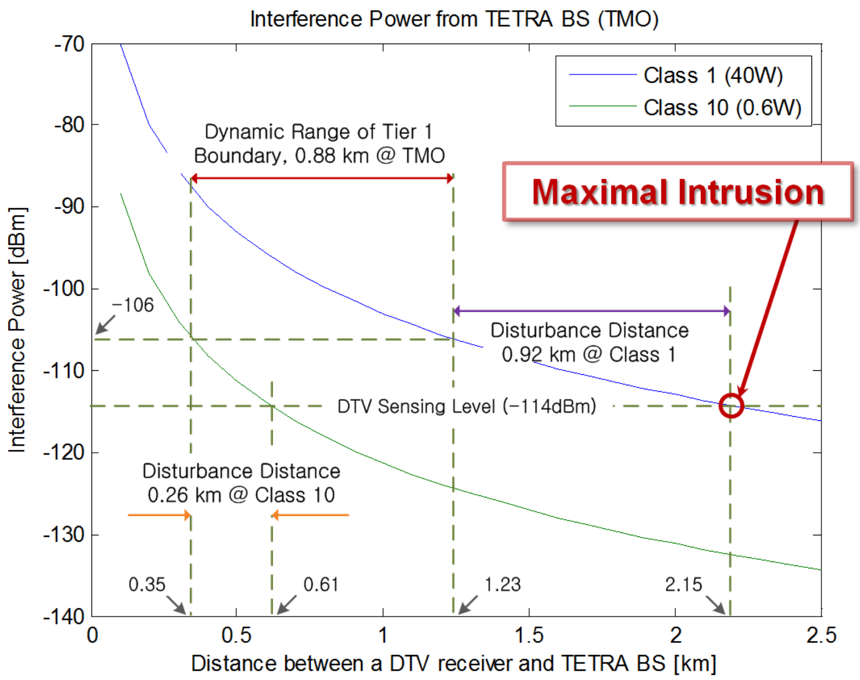


Figure 5.7. DTV impact distance by TETRA TMO (25 kHz Offset)

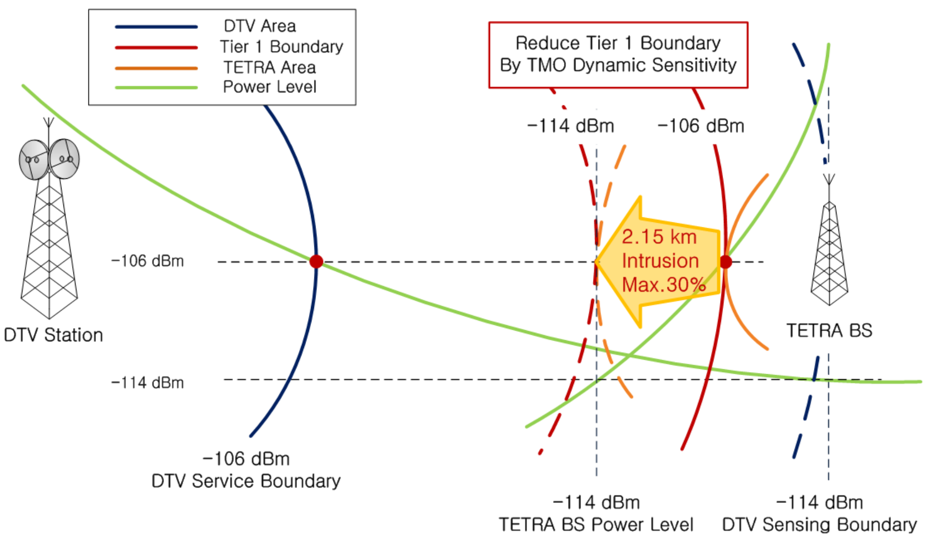


Figure 5.8. Intrusion range of DTV protection area by TETRA TMO (25 kHz Offset)

Table 5.8. Simulation parameters

Parameter		Value
Minimum Signal Power / Effective DTV Range*, dBm	CH 14	-84.55 / -100.05
	CH 51	-92.25 / -107.75
Distance from Effective DTV range to DTV Sensing Level (D)	CH 14	23.1 km ≤ D ≤ 40.8 km
	CH 51	27.2 km ≤ D ≤ 35.1 km

*Minimum Signal Power - D/U Ratio

terference power and to investigate the possibility of coexistence with DTV. The computational result indicates that the narrow band systems can be shared DTV idle space when allowing TETRA intrusion in DTV protection areas. Furthermore, the range of intrusion is theoretically smaller than wider band systems. In case of TETRA TMO mode, around 70 % DTV protection areas were remained despite the maximum interference condition. Lastly, 3 % or less of total TETRA MSs was expected to exceed the limited power at DMO mode.

Table 5.9. Impact ranges due to TETRA system

Parameter		**Value**
Disturbance Range (D_d) @ TMO	Class 1	1.23 km $\leq D_d \leq$ 2.15 km
	Class 10	0.35 km $\leq D_d \leq$ 0.61 km
Dynamic Range (D_r) of Tier 1 @ TMO		0.35 km $\leq D_r \leq$ 1.23 km
Possibility of Interference @ DMO		0.977 @ -103 dBm
Ratio of Affected DTV Area* @ TMO Class 1	CH 14	15.10 %
	CH 51	29.73 %

*(Affected DTV area) / (DTV protection area) $\times$ 100

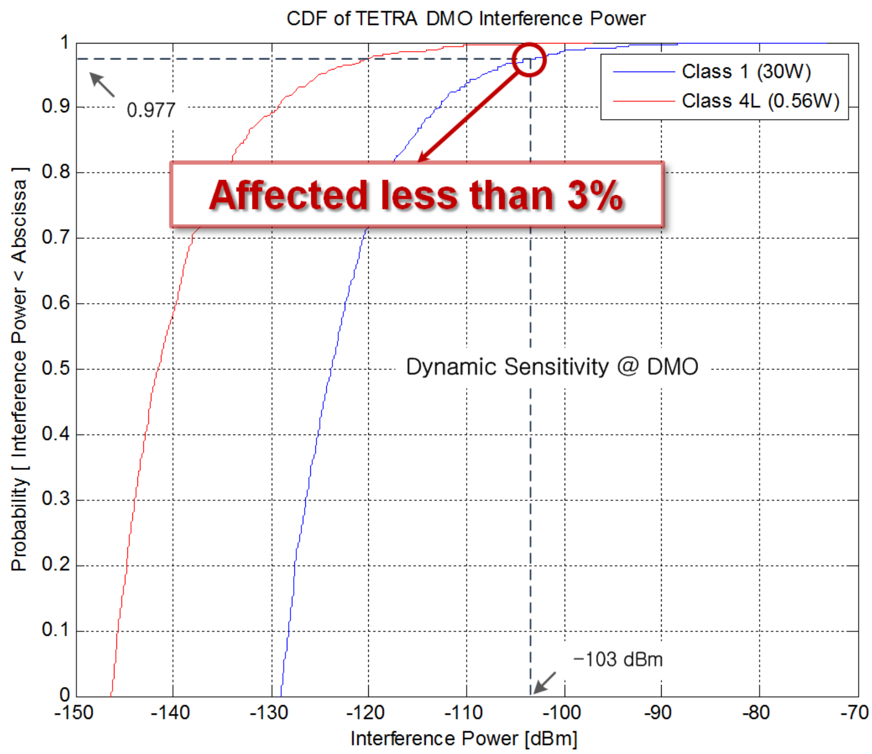


Figure 5.9. DTV interference possibilities by TETRA DMO (25 kHz Offset)

Chapter 6

Coexistence Testing

Based on the assumption of secondary user and the estimation of their physical operating margins, the coexistence testing was performed to review the degree of DTV signal degradation depending on the bandwidth of secondary users. The criteria of testing evaluation were selected according to the general characteristics of ATSC system, and the degree of DTV system degradation was examined on the basis of these criteria. To show the usability of TETRA system as a narrowband application in DTV White Space, the modified CDMA system was selected as a wideband system although the operating power conditions are modified as the lower level due the limitation of testing equipment. In summary, the advantage of narrowband applications in terms of the DTV system performance is presented.

6.1. Testing Evaluation Criteria

Two specifications called as the error vector magnitude (EVM) and the signal to noise ratio (S/N) is discussed regarding the DTV performance evaluation as the critical factors in general [13, 83]. As such, these two factors are examined in this thesis as a measure of mutual interference evaluation. Figure 6.1 shows the distorted signal between the ideal signal and the measured signal in the I-Q plane by the positional differences.

In the aspect of S/N in DTV, a small number of symbol errors per second are corrected through the extensive forward error correction within the DTV modulation. In addition, the 8-level vestigial sideband modulation (8-VSB) is

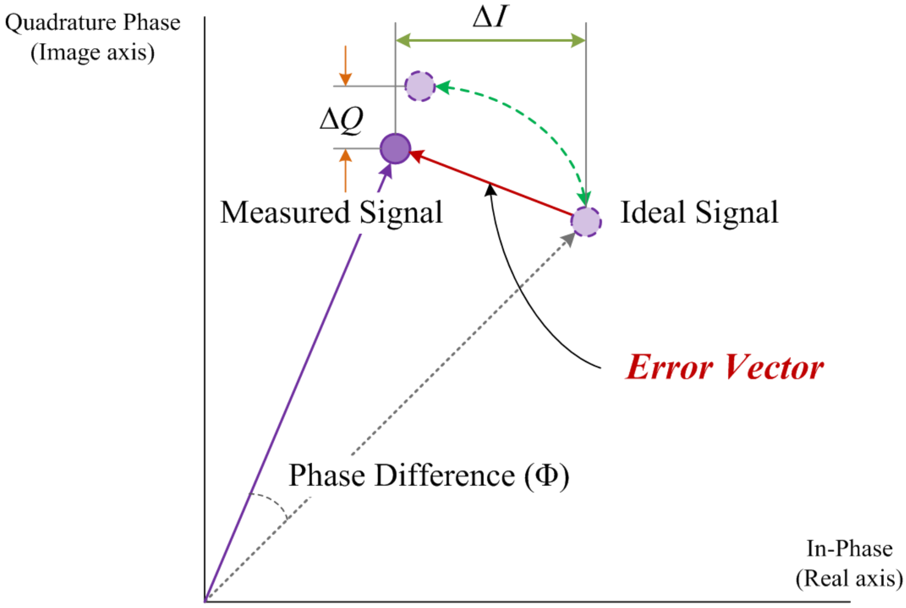


Figure 6.1. Positional differences between the ideal signal and the measured signal

being used as the DTV modulation method in ATSC DTV system. The forward error correction, however, does not work when it reaches to the system threshold due to the increment of errors. There is a chance that the digital images are damaged suddenly at that point, and corresponding information is lost totally by the cliff effect. The difference between a perfect picture and a damaged picture is less than 1 dB of S/N. Therefore, the DTV service areas or the fringe areas are determined by these small differences in S/N being caused by the cliff effect. The S/N value in an 8-VSB system is mathematically defined as the average power of ideal symbol values divided by the noise power, and it can be derived into the power based function as Equation 6.1 [13].

$$S/N = 20 \log \left(\frac{\sqrt{\frac{1}{N} \sum_{N}^{j=1} I_j^2}}{\sqrt{\frac{1}{N} \sum_{N}^{j=1} \Delta I_j^2}} \right) \quad \text{(dB)} \tag{6.1}$$

where:

I_j Symbol value in the ideal in-phase or real axis transmitted at the j^{th} interval

ΔI_j Value difference along the real axis between the ideal signal value and the measured signal value at the j^{th} interval

Like conceptualized in Figure 6.1, the noise component can be derived by calculating the differences between the ideal signal value and the measured signal value.

In the EVM, it has two meanings such as a measurement of modulator or a demodulator performance for the impairments of digital processing, the ratio of the amplitude of the root mean square (RMS) error vector to the amplitude of the largest as a percentage. Schematically, EVM is the vector difference at a given time between the transmitted signal and the measured signal. These signals can be placed in the In-phase versus the Quadrature phase (I-Q) plane, and their geographical positioning in I/Q plane can identify the signal degradation like a phase error and an I-Q imbalance. In addition, the definition of S/N is also related to the EVM for 8-VSB, and it can be defined as Equation 6.2 [13].

$$EVM = \left(\frac{\sqrt{\frac{1}{N}\sum_{N}^{j=1}(\Delta I_j^2 + \Delta Q_j^2)}}{\sqrt{I_{max}^2}} \right) \times 100 \quad (\%) \tag{6.2}$$

where:

ΔI_j Value difference along the real axis between the ideal signal value and the measured signal value at the j^{th} interval

ΔQ_j Value difference along the image axis between the ideal signal value and the measured signal value at the j^{th} interval

$I_m ax$ Distance magnitude between the ideal signal and the maximal allowable signal along the real axis in the I-Q plane

Each value, S/N and EVM, can be estimated by the above equations, and it is usually utilized as quantification measurement on the digital RF transmission errors in a different way. However, the value of EVM can be estimated by using the value of S/N under typical assumptions. In case of 8-VSB, it can be approximated to the Equation 6.3 under following assumptions: $I_{max}^2 = \pm\ 7$ and

$\Delta I_j \approx \Delta Q_j$ [13]

$$EVM \approx \left(10^{\frac{39.3 - S/N(\mathrm{dB})}{20}}\right) \quad (\%) \tag{6.3}$$

or

$$S/N \approx 39.3 - 20 \log\left[EVM(\%)\right] \quad (\mathrm{dB}) \tag{6.4}$$

It is noted that certain DTV system manufacturers are providing the plot of relationship between EVM and S/N as the Appendix C to see the DTV system performance instantaneously.

6.2. Interference Measurements

The media access conditions on DTV and TETRA were reviewed at first to build a test set and to decide testing ranges in each targeted criterion. Following the testing procedures, the TETRA interference testing were conducted as a narrowband system, and the CDMA interference testing was also performed under the same testing conditions as a relatively wider band system than TETRA. It is to compare the user accessibility in aspect of frequency offset.

6.2.1 Media Access Conditions on DTV and TETRA

Interference testing was performed based on the recommendation of standards group in each system such as the DTV system in ATSC and the TETRA system in ETSI. Among their technical criteria, the signal to noise ratio (S/N) in each system was focused on to evaluate the service performance at first. However, the DTV is considered by a situation of RF receiver, and they have laid in the affected situation of DTV service by the coexistence with other RF transmitters, i.e. TETRA system. This situation is reflected as the transmit condition and the maximal adjacent power level are considered on the TETRA system. On the other hand, the co-channel rejection thresholds are used for the evaluation on the DTV service performance.

According to the TETRA standards in ETSI, the unwanted emissions are defined as conducted emissions at frequencies or time intervals outside the allocated channel. In addition, the non-active transmit (nonact Tx) state represents a state which occurs during two timeslot durations (approximately 28 ms) before and after any active transmit. In other words, an equipment is said to be in the non-transmit (non-Tx) state whenever it is not in the active or non-active transmit state as shown in Figure 6.2 [68].

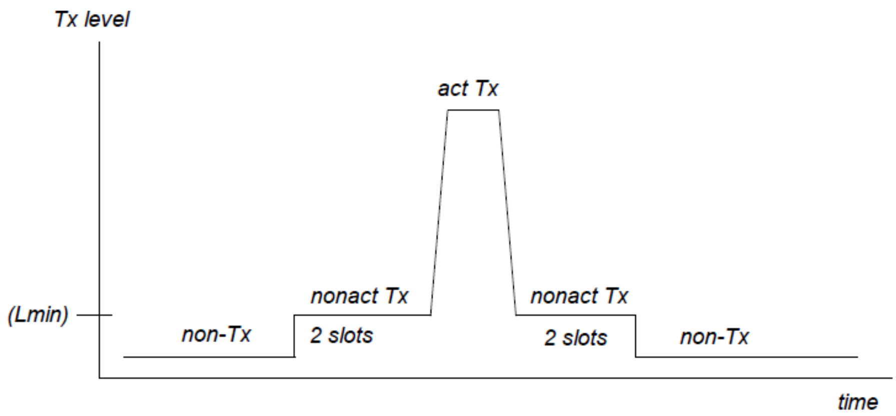


Figure 6.2. Schematic presentation of transmitter states [68]

In this situation, the level differences between the active and the non-active are defined to the maximal -70 dBc when being operated with 50 kHz offset. It also can be assumed to the signal emission status of TETRA transmitters during the testing time. Table 6.1 shows the maximal adjacent power levels according to the frequency offset and the power classes described in Table 5.6.

In the TETRA base station, the output power has to be at the nominal level in Table 5.6. In the non-active transmit state, it was applied on the specification of 'L_{min} = -40 dBc'. On the other hand, it can be of the 15 dBm level reduction of the MS output power. During the non-active transmit state, the specification 'L_{min} = -70 dBc' or 'L_{min} = -36 dBc' is applied depending on the operating condition [68].

In terms of DTV, a DTV receiver performance is usually determined by a bit error rate (BER), and $\times 10^{-6}$ is defined as the minimal value of BER for input RF signal levels to the DTV from -83 dBm to -8 dBm which is defined by the

Table 6.1. Maximal adjacent power levels in TETRA

Frequency Offset	**Maximal Level for MS in each Power Class**	
	Class 4 & 4L	**Other Classes**
25 kHz	-55 dBc	-60 dBc
50 kHz	-70 dBc	-70 dBc
75 kHz	-70 dBc	-70 dBc

FCC Advisory Committee on Advanced Television Service (ACATS) Threshold of Visibility (TOV). The values for adjacent channel and taboo channel rejection were developed based on available UHF data. According to the recommendation of ATSC, the receiver threshold levels are defined by the ratio on the desired signal verses the undesired signal level (D/U) in dB like the Equation 6.5.

$$P_{D/U}(\mathrm{dB}) = 10\log\left(\frac{P_D}{P_U}\right) \tag{6.5}$$

where:

P_D Desired signal power in Watts unit

P_U Undesired signal power in Watts unit

Table 6.2 shows the DTV co-channel rejection thresholds depending on the recommended input signal level [12].

Table 6.2. DTV co-channel rejection thresholds

Type of Interference	**Co-Channel D/U Ratio (dB)**	
	Weak Desired (-68 dBm)	**Moderate Desired (-53 dBm)**
DTV into DTV	+15.5	+15.5

Like Table 6.2, more than 15.5 dB is being required to the level difference between the desired signal and the undesired signal as the minimal endurable co-channel interference which is simply examined through the spectrum plot like Figure 6.3.

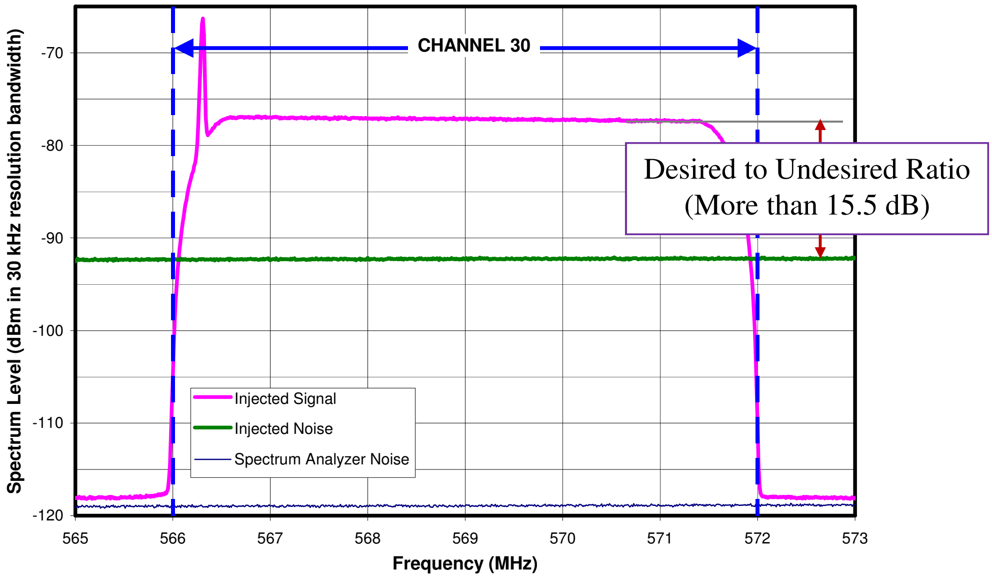


Figure 6.3. Example of DTV spectra @ CH 30 with injected noise [81]

6.2.2 DTV Interference by TETRA as a narrowband system

Based on the media access condition, the DTV interference testing was conducted to evaluate the DTV quality degradation with the values of S/N and EVM. As a part of this, TETRA was targeted as the secondary users in DTV band, and the degree of DTV signal disturbance due to coexistence of secondary user was examined according to the testing procedures.

As mentioned in previous chapters, ATSC A/74 or ITU-R BT710 is used for the evaluation of DTV receiver performance by considering the threshold of visibility (TOV, -83 dBm) and the minimum signal to noise ratio (S/N, 15.5 dB at the co-channel interference condition). However, it is noted that this approach is derived from the subjective judgments which does not allow fair comparison of the DTV performance. In general, the value of EVM is applied to the DTV transmitter as a way of system performance judgments, and it is not defined for DTV receiver evaluation. However, the system manufacturers provide the EVM value that can be covered by the S/N range of the DTV receiver, i.e. S/N = 15.5 dB, and some measurement factors are applied to the undefined parts of counterpart system due to the general characteristics on the performance reciprocity of the digital communication system. As such we used the value of EVM related to the value of S/N, and those values can be deduced from the following Equation 6.3 and 6.4.

According to the above equation, the DTV co-channel interference ratio of 15.5 dB was calculated to 15.49 % as the value of EVM for the minimum DTV protection level. The testing parameters and its ranges are described in Table 6.3.

Table 6.3. Testing parameters and ranges for TETRA system

Parameter	Value
DTV Co-channel Interference Ratio	15.5 dB or more
Equivalent Value of EVM (%)	15.49 or less
Level Difference of Output Power between DTV and TETRA TMO Class 10 @ 50 kHz Offset	41 dB* or more
Environmental Channel Effect (AWGN)	S/N: 15.5 dB or more
Secondary User (TETRA) Offset Range (kHz)	± 50 to 500, 50 spacing
Targeted DTV Channel (CH No.)	14, 33, 51
Count of Video RMS	50
No. of Repeat experiments for ea. offset	60

*[TETRA TMO Class 10 (28 dBm) - 50 kHz Offset (-70 dBc)] - DTV TOV (-83 dBm) [12, 68]

Three units of signal generators and two units of signal analyzers were used to build a testing environment. Regarding the signal generators, two units were played as a part of signal source in each system, i.e. DTV and TETRA. The other signal generator has a role of general noise in the wireless environment named as an additive white Gaussian noise (AWGN). At the opposite of the signal generators, a spectrum analyzer and a vector signal analyzer are configured to measure S/N and EVM. Figure 6.4 shows the testing equipment in each part, and Figure 6.5 illustrates the simplified testing configuration and their signal flows.

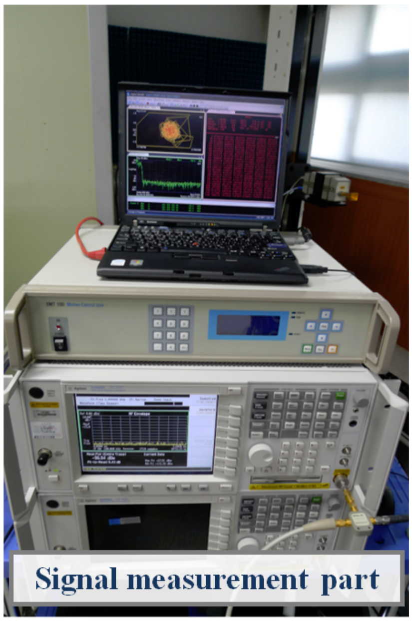


Figure 6.4. Testing equipment in each part, signal sources and measurements

Initially, we conducted the calibration before the tests in order to compensate the signal power losses due to assembly of the RF cables and combiners. The additive white Gaussian noise was added to reflect the general wireless condition as channel noise.

Further, the DTV interference testing was conducted repeatedly in each TETRA offsets to obtain statistically meaningful values as the shape of normal distribution as shown in Table 6.3. The value of each test was induced from the average on fifty times for the video RMS. The TETRA offset was tested up to ± 500 kHz considering the limitation in the performance of power spectrum ana-

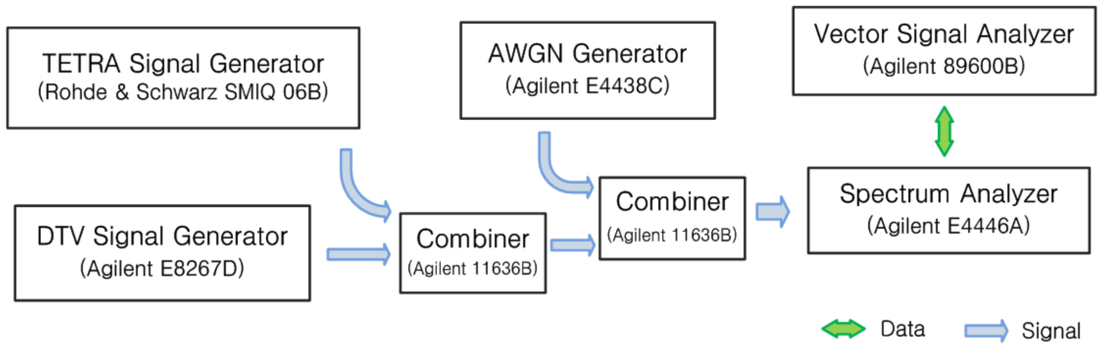


Figure 6.5. Test configuration and signal flow

lyzer, Agilent E4446A. Regarding the level difference between DTV and TETRA, we considered the value of 41 dB in order to reflect the severe condition when the DTV receiver is placed at the edge of DTV service boundary such as TOV condition, i.e. -83 dBm. Figure 6.6 illustrates the testing procedure including the iterated test flow according to the channel offset condition.

As an example of testing results, Figure 6.7 shows the results of EVM and S/N in vector signal analyzer (Agilent 89601b).

As for the analysis of EVM and S/N test result, we considered the statistical approaches to estimate the affected DTV probability due to the operating of TETRA system. According to the central limit theorem (CLT) of statistics, the testing results can be analyzed through the normal distribution assessment when the sample size is 30 or more [84]. We conducted the test 60 times for each targeted offset frequencies, and the following equation was used to calculate the error probability to evaluate the recommendation of DTV service quality according to the frequency offsets of TETRA.

$$Z = \frac{\overline{X} - \mu}{\sigma \Big/ \sqrt{n}} \tag{6.6}$$

where, $\overline{X}$ is the sample mean, and there is also a probability of '1 - α' when Z has have a value between $-Z_{\alpha/2}$ and $+Z_{\alpha/2}$. Therefore, the interference probabilities

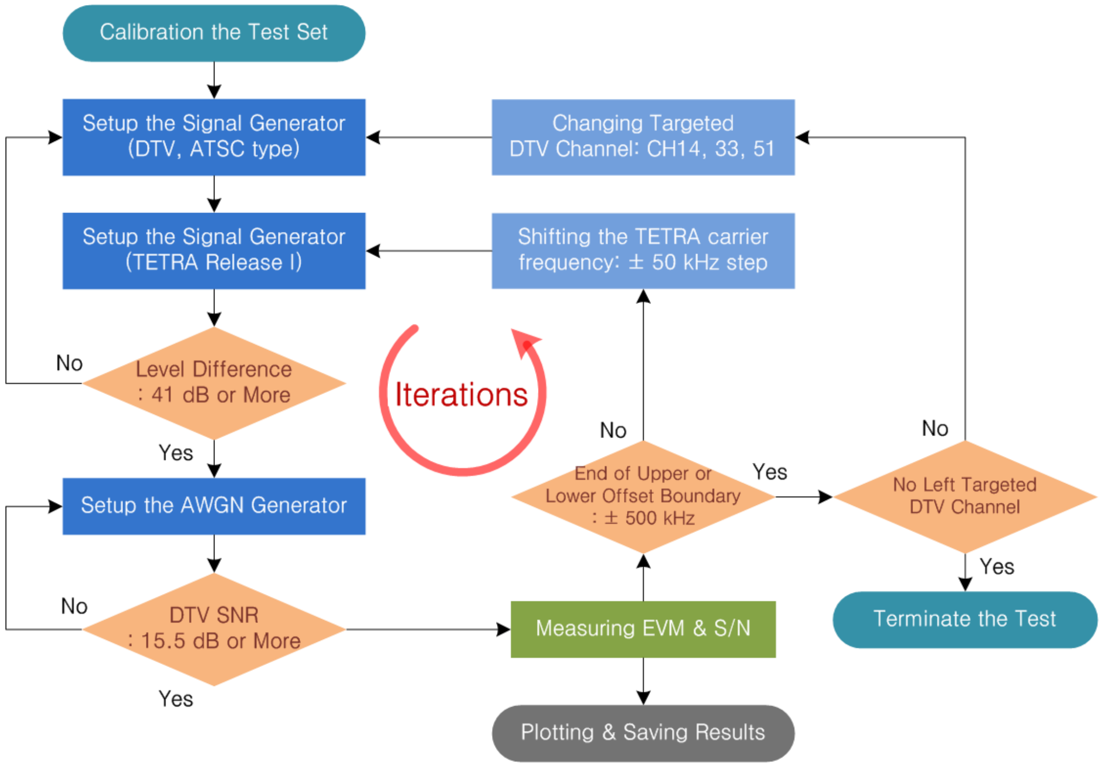


Figure 6.6. DTV interference testing flow

for each carrier offsets can be estimated from above equation.

We derived the statistical value of EVM and S/N as the critical parameters of DTV performances. The degree of DTV EVM being disturbed by TETRA can be predictable, and its values were determined according to the degree of TETRA offset frequencies. Table 6.4 and Table 6.5 shows the EVM and S/N test results according to the TETRA offset frequencies. Where, all values in the table were rounded to decimals, and the left and right side of slash represent the statistical value in each side offset.

According to the test results, the EVM was exceeded the allowable value, i.e. 15.49 % when the TETRA system operated with 400 kHz or less offset frequencies, the EVM exceeded the allowable value, 15.49 %. On the other hand, the unaffected ranges in both sides, 400 kHz or more offsets, showed relatively stable values as the statistical aspects, especially the value of standard deviation.

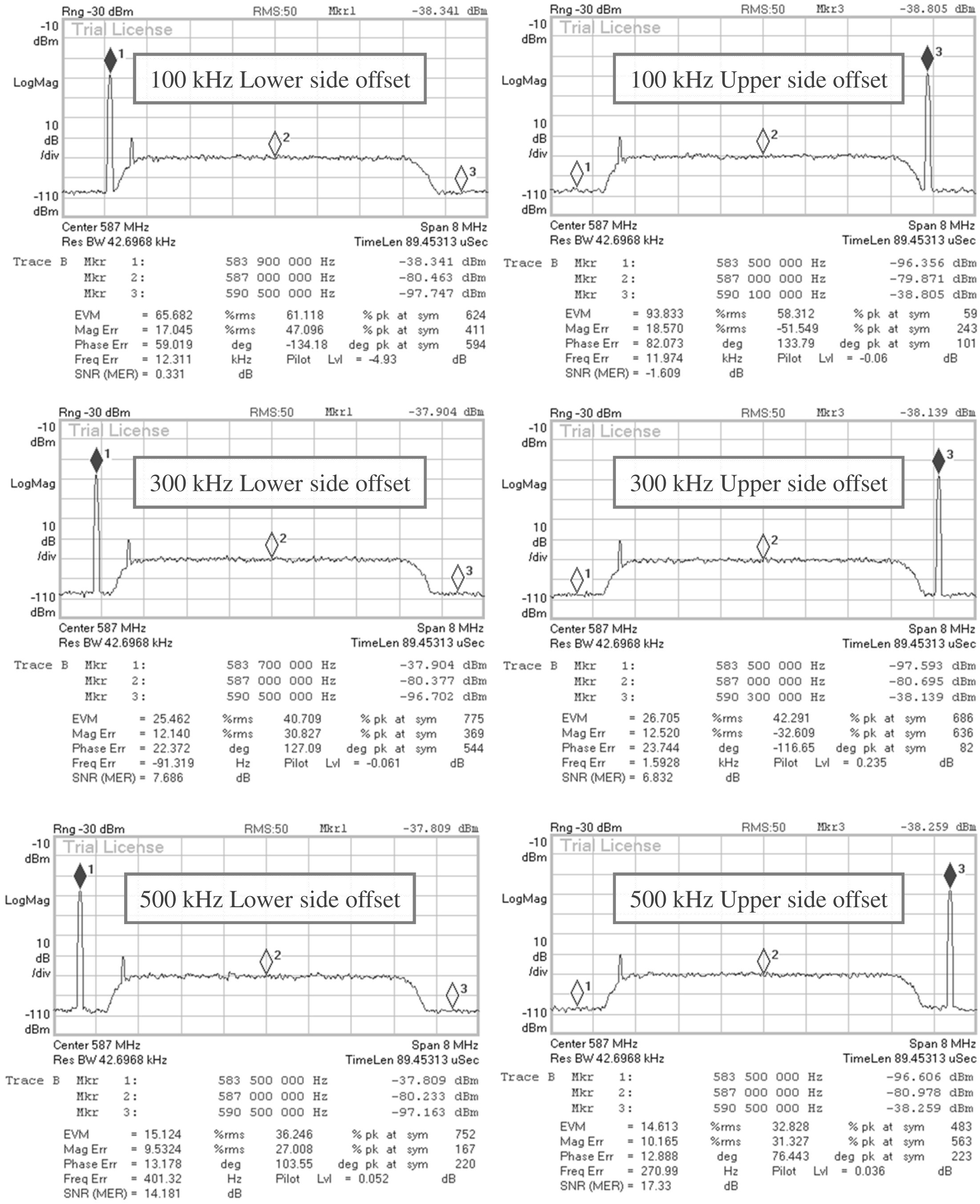


Figure 6.7. Test results on S/N and EVM by TETRA

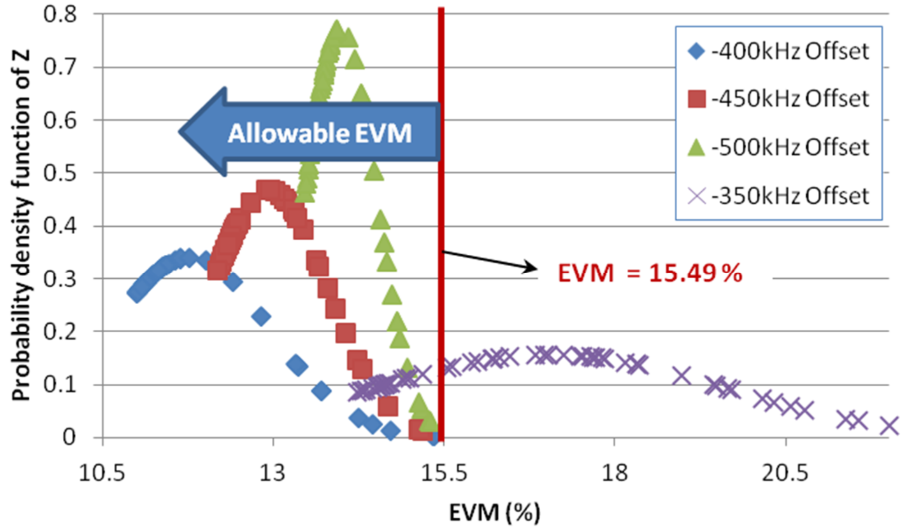
Table 6.4. EVM values according to the TETRA offset frequencies

-/+ Offset (kHz)	S.D (σ_{EVM})	Var. (σ_{EVM}^2)	Mean (μ_{EVM})	Prob. (EVM ≤ 15.49)
50	6.16 / 1.56	37.9 / 2.38	17.76 / 15.52	0.36 / 0.49
100	9.09 / 4.11	82.54 / 16.89	73.64 / 90.6	0 / 0
150	4.32 / 4.06	18.64 / 16.47	82.35 / 86.53	0 / 0
200	4.04 / 1.28	16.29 / 1.63	16.59 / 15.01	0.39 / 0.65
250	3.1 / 0.64	9.59 / 0.41	15.87 / 13.49	0.45 / 1
300	5.65 / 3.77	31.98 / 14.22	25.67 / 26.65	0.04 / 0
350	2.53 / 1.6	6.41 / 2.56	17.03 / 17.15	0.27 / 0.15
400	1.17 / 0.06	1.36 / 0	11.77 / 11.19	1 / 1
450	0.85 / 0.5	0.73 / 0.25	12.93 / 12.84	1 / 1
500	0.51 / 0.27	0.26 / 0.07	13.98 / 14.34	1 / 1

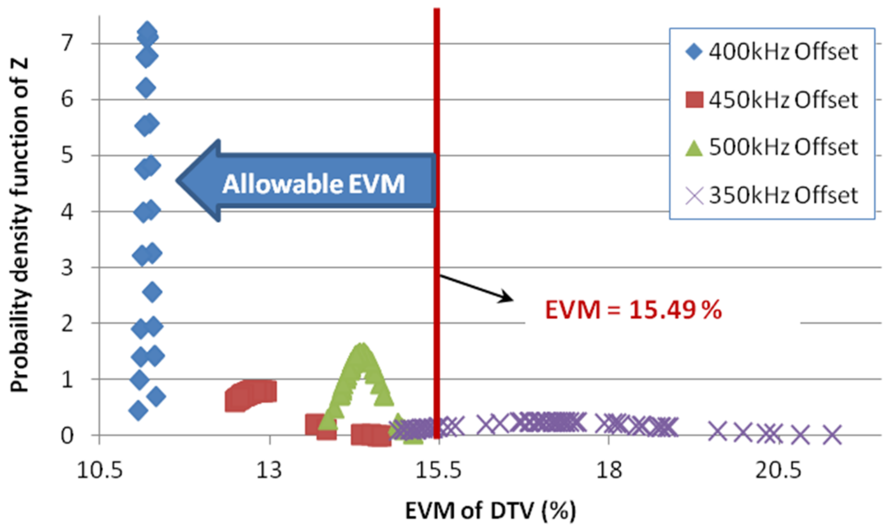
These results were verified given that the targeted offset frequencies met the criteria of S/N level, 15.5 dB. Figure 6.8 illustrates the statistic results around the unaffected offset frequencies in each side in terms of EVM.

The Appendix D and E at the end of this paper show the full results of EVM and S/N. In addition, it can be presumed that the EVM values affect more when the TETRA signals were located at the lower offset side by the test results on both sides in Figure 6.8. When considering the characteristics of ATSC physical layer, it can be a cause that the 'Lower side offset' is relatively closer to the DTV pilot frequency than the 'Upper side offset'.

The test was performed repeatedly to obtain statistically meaningful values. The test results show that the EVM values have quite differences depending on the frequency offset although the S/N values meet the regulatory criteria. Statistically, the TETRA system does not disturb DTV when it operates more than 400 kHz offset from DTV.



< Low side offset >



< Upper side offset >

Figure 6.8. DTV interference testing flow

Table 6.5. S/N values according to the TETRA offset frequencies

-/+ Offset (kHz)	S.D ($\sigma_{S/N}$)	Var. ($\sigma_{S/N}^2$)	Mean ($\mu_{S/N}$)	Prob. (S/N ≥ 15.5)
50	0.86 / 0.64	0.73 / 0.4	17.22 / 17.27	0.98 / 1
100	0.73 / 0.77	0.53 / 0.59	17.4 / 17.25	1 / 0.99
150	0.77 / 0.8	0.59 / 0.64	17.32 / 17.38	0.99 / 0.99
200	0.86 / 0.79	0.74 / 0.62	17.32 / 17.25	0.98 / 0.99
250	0.89 / 0.87	0.8 / 0.76	17.27 / 17.29	0.98 / 0.98
300	0.78 / 1.03	0.61 / 1.07	17.22 / 17.19	0.99 / 0.95
350	0.86 / 0.81	0.74 / 0.65	17.29 / 17.34	0.98 / 0.99
400	0.75 / 0.81	0.56 / 0.65	17.32 / 17.43	0.99 / 0.99
450	0.92 / 0.9	0.85 / 0.81	17.22 / 17.31	0.97 / 0.98
500	0.72 / 0.83	0.51 / 0.7	17.11 / 17.11	0.99 / 0.97

6.2.3 Comparison with a wider band application

In case of TETRA system, up to 400 kHz offset frequency is accessible at both adjacent DTV channels based on the testing results on EVM and S/N. In this situation, a review is required on the accessibility of other system to compare the degree of DTV performance degradation to the previous the TETRA interference testing results.

An appropriate system was reviewed based on the following conditions are:

- *Having 200 kHz or more channel bandwidth but a one DTV channel bandwidth (6 MHz) or less to compare clearly to the accessible range of TETRA system*
- *Being operated communication system around DTV band for commercial purpose to apply into DTV band with minimal system damage*
- *Being applicable communication system into the installed testing equipment*

without mechanical modification for giving the reliability to the comparing test results

Table 6.6 shows the status on the frequency utilization of wireless communications being used around DTV band [85].

Table 6.6. Status of frequency utilization around DTV band

System	Frequency Allocation (MHz)		Channel Bandwidth (kHz)
	Mobile Station	Fixed Station	
CDMA/1x/EV-DO	450-460	460-470	1250
CDMA/1x/EV-DO,	824-849	869-894	1250
WCDMA	824-849	869-894	5000
GSM-900, EDGE	880-915	925-960	200

Based on the above conditions and Table 6.6, the format of code division multiple access (CDMA) system was chosen as the secondary user in DTV band. In case of CDMA, it is being used for the mobile communication worldwide and it is easy to expect the system flexibility through the back of compatibility from the advanced system like the CDMA 2000 and the evaluation data only (EV-DO). In aspect of testing feasibility, the CDMA source signal was able to be generated by replacing the TETRA signal without the change of mechanical configurations in the Figure 6.5, and it was also able to grant the stability of system performance testing.

Regarding the testing condition, the general testing parameters and the procedures at the previous chapters are used, and the output powers and the carrier frequencies were modified to obtain valid results through the minimal change of testing equipment configurations [86]. As mentioned earlier, the offset conditions were conducted up to $\pm$ 500 kHz from the edge of the targeted DTV spectrum due to the performance limitation of the power spectrum analyzer (Agilent E4446A). However, the frequency offset started from 400 kHz to compare the system stability with TETRA system because the degradation of DTV performance did not happened at 400 kHz or more. Table 6.7 shows the testing parameters for comparative testing with TETRA system.

Table 6.7. Testing parameters and ranges for the testing of wider band system

Parameter	Value
DTV Co-channel Interference Ratio	15.5 dB or more
Equivalent Value of EVM (%)	15.49 or less
Level Difference of Output Power between DTV and the Secondary User (CDMA based)	Around 40 dB*
Environmental Channel Effect (AWGN)	S/N: 15.5 dB or more
Secondary User (CDMA) Offset Range (kHz)	± 400 and 500
Targeted DTV Channel (CH No.)	14, 33, 51
Count of Video RMS	50
No. of Repeat experiments for ea. offset	60

*[Secondary user output (50 mW) - 2_{nd} offset** (-60 dBc)] - TOV (-83 dBm)
**1_{st} offset: -45 dBc @ 750 kHz from $f_c, 2_{nd}$ offset: -60 dBc @ 1.98 MHz from f_c

In addition, the difference of output power between two systems was derived on the basis of the recommendation of CDMA system, and -60 dBc was applied by assuming 50 mW output powers with the secondary adjacent power ratio in DTV TOV. The value was also determined by the performance limitation of the testing equipment. Figure 6.9 shows the EVM and S/N in each offset frequency as an example of testing results, and the image was captured from the screen of vector signal analyzer, Agilent 89601b.

Based on the above assumption, the statistical values of EVM and S/N were derived to compare with the results of TETRA system. Table 6.8 and Table 6.9 show the EVM and S/N testing results according to the offset frequencies, and all values in the table were rounded to decimals. The left and right side of slash is representing to the statistical value in each side offset.

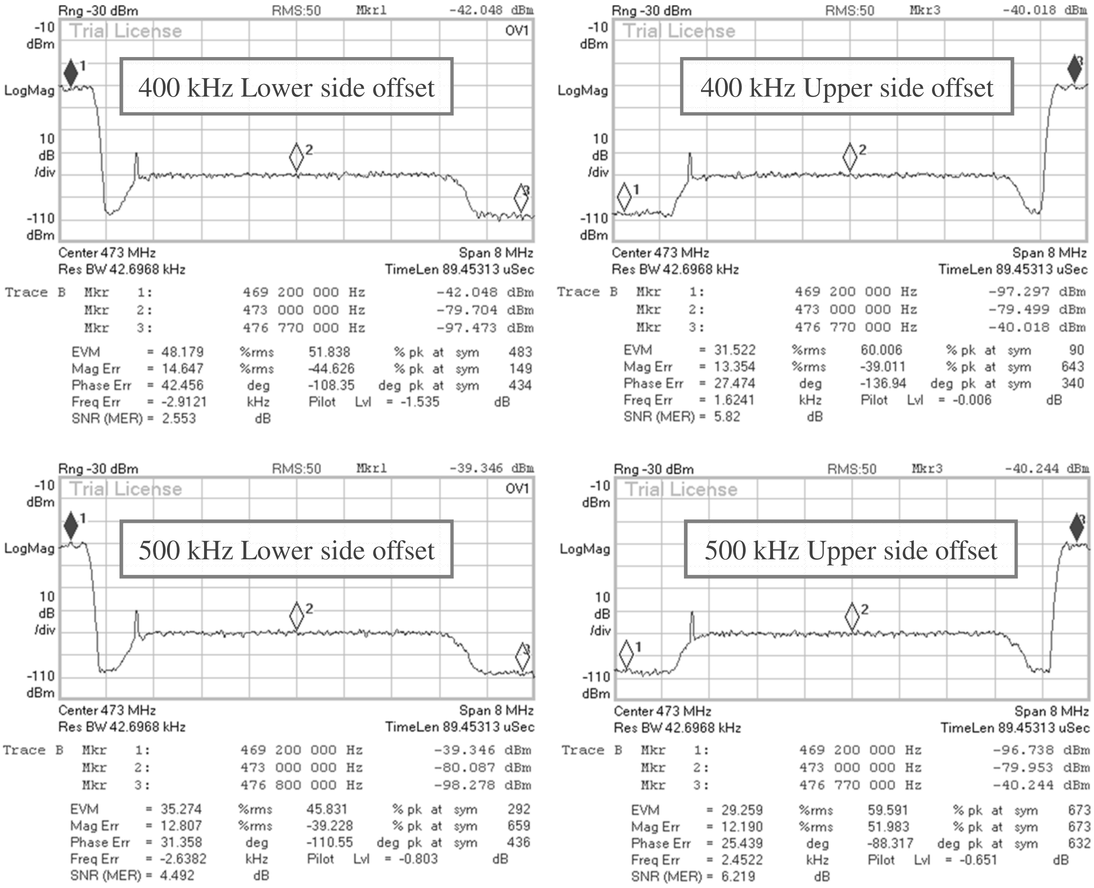
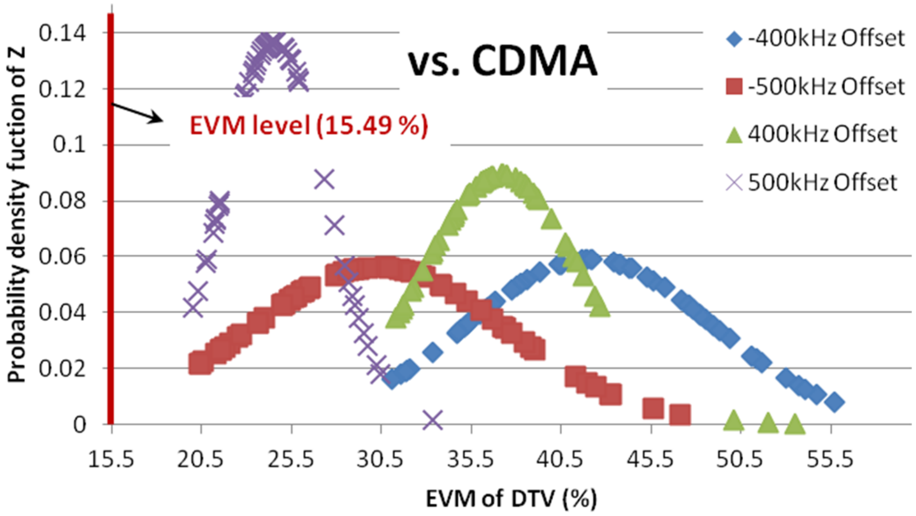


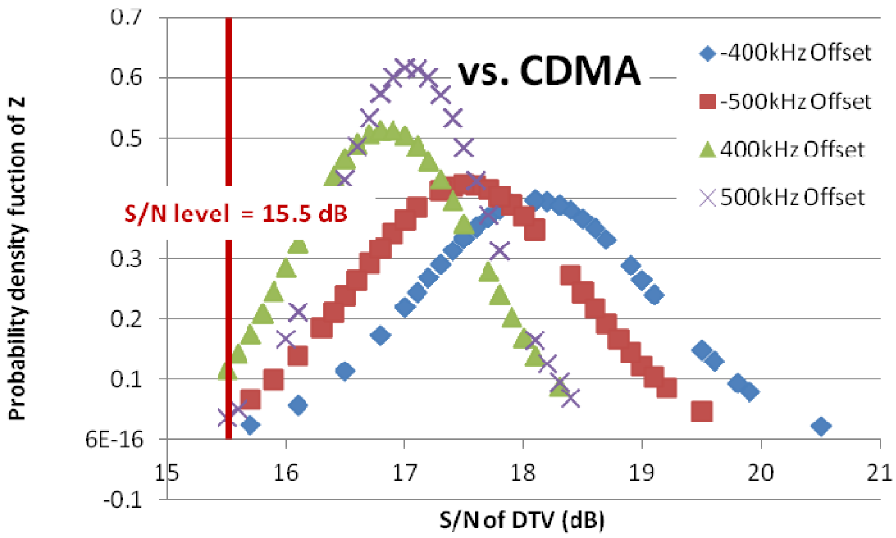
Figure 6.9. Test results on S/N and EVM by CDMA

According to the testing results, the EVM exceeded the allowable value, 15.49 %, at the all targeted offset frequencies although the targeted offset frequencies met the criteria of S/N level, 15.5 dB. Figure 6.10 illustrates the statistic results on the distributions of EVM and S/N in each offset frequency.

Similar to the results of TETRA cases, the lower side offsets affected each value than the upper side offsets when considering the degree of variation ($\sigma^2_{S/N}$) and standard deviation ($\sigma_{S/N}$). However, all EVM values for the CDMA system were similar to the conditions on 50 kHz or 100 kHz offset for the TETRA system although the testing was conducted to a quarter degree of general power classes for CDMA mobile device. Therefore, the generally being operated CDMA system



< EVM distributions in each offset frequency >



< S/N distributions in each offset frequency >

Figure 6.10. Distribution of EVM and S/N in each offset frequency

Table 6.8. EVM values according to the secondary user offset frequencies

-/+ Offset (kHz)	S.D (σ_{EVM})	Var. (σ_{EVM}^2)	Mean (μ_{EVM})	Prob. (EVM ≤ 15.49)
400	6.78 / 4.47	45.91 / 19.98	42.1 / 37.2	1 / 1
500	7.12 / 2.92	50.73 / 8.53	30.31 / 24.57	0.98 / 1

Table 6.9. S/N values according to the secondary user offset frequencies

-/+ Offset (kHz)	S.D ($\sigma_{S/N}$)	Var. ($\sigma_{S/N}^2$)	Mean ($\mu_{S/N}$)	Prob. (S/N ≥ 15.5)
400	1.0 / 0.78	1.01 / 0.6	18.09 / 16.84	1 / 0.96
500	0.94 / 0.65	0.89 / 0.42	17.51 / 17.05	0.98 / 0.99

or wider band system may be hard to apply in a single channel idle space, i.e., 6 MHz.

Chapter 7

Regulatory Framework

In this chapter, the improvements on the utilization environment and the administrative direction for the usability enhancement are discussed to propose the regulatory strategies on the manipulation of DTV White Space under technically socially severe condition. The results in chapter from three to six were utilized to explain the management direction in each subject objectively. Regarding the improvement on the utilization environment, the spectrum efficiency and the excavation of available idle channels are focused on the aspect of technical solutions by considering the narrow band application. Further, the administrative direction is suggested as one of method to enhance the spectrum usability in terms of regulatory framework. Regulatory compatibility was reviewed through the result of the case study in Korea and US because they adopt the same DTV standards, ATSC. The secondary user classification according to their service contents is proposed and the spectrum management flow is suggested as the complaining mitigation measures.

7.1. Improvements on The Using Environment

Based on the results of previous chapter, the two measures such as the enhancement of spectrum efficiency and the classification of DTV affected range can be taken into account to improve the DTV White Space utilization in technical point of view. The TETRA system is used as the DTV White Space user under the same operating condition with the previous assumption in the Chapter 5.

These methods may also be derived to the regulatory framework as one of policy directions to encourage the DTV White Space utilization.

7.1.1 Enhancement of Spectrum Efficiency

The TETRA system was selected to evaluate the spectrum efficiency as a secondary user in DTV band when considering the technical suitability. As mentioned in Chapter 4, the TETRA is a set of standards developed by the European Telecommunications Standards Institute as a common mobile radio communications infrastructure. It is generally used for the public services due to their technical characteristics. In case of the TETRA release1, 25 kHz bandwidth was used for communications with a 36 kbps data rate. There were also some power classes to control the output power levels as summarized in Table 5.6 [68].

Based on the results of Table 5.3 and Table 5.4 in Chapter 5, it was assumed that the TETRA system was operating on TMO mode and being located at the third tier in Figure 4.2 as a form of the secondary user in DTV band. Similarly, -98.5 dBm was assumed as the maximal DTV service boundary induced by the level of DTV sensitivity, i.e., -83 dBm. This is because the level difference in 15.5 dB was recommended as the desired and undesired DTV signal ratio marked as D/U by the DTV standardization group named ATSC. The DTV service areas were considered to be 21.2 km as a shape of the first tier radius in Figure 4.2. In connection with the former assumption, 63.6 km was also assumed as the equivalent values for third tier radius in Figure 4.2 which is represented as the DTV White Space service area. The spectrum efficiency has been estimated based on the pre-assumed parameters considering the regulatory criteria in Table 5.1.

For the first step of estimation of spectrum efficiency, the TETRA system was assumed as the secondary user in DTV as the result of Chapter 4. It is being operated in TMO with 0.6 Watt transmission power such as the 10^{th} power class of the TETRA base station. In addition to that, these transceivers are located in the third tier of DTV service coverage with the 50 m transmitter height and the 2 m receiver height in each. In such situation, they are being operated within the DTV band as DTV interferers. Regarding the path loss model, the ITU-R P.1546 model was used to calculate the distances to the edge of the DTV service coverage and the radius of TMO cell coverage. And, the signal level on each boundary is based on the regulatory criteria in Table 5.1. There is a 7.8 km radius at 473 MHz as TMO cell coverage considering the results of service coverage on TETRA as a secondary user in DTV band generated by the results of Chapter 5. Similarly, a 6.4 km radius was derived as the TMO cell coverage at 695 MHz. The spectrum efficiency was calculated according to the carrier frequency within the DTV band in Korea, 473 MHz to 695 MHz. Figure 7.1 illustrates the enhancement of TETRA service coverage.

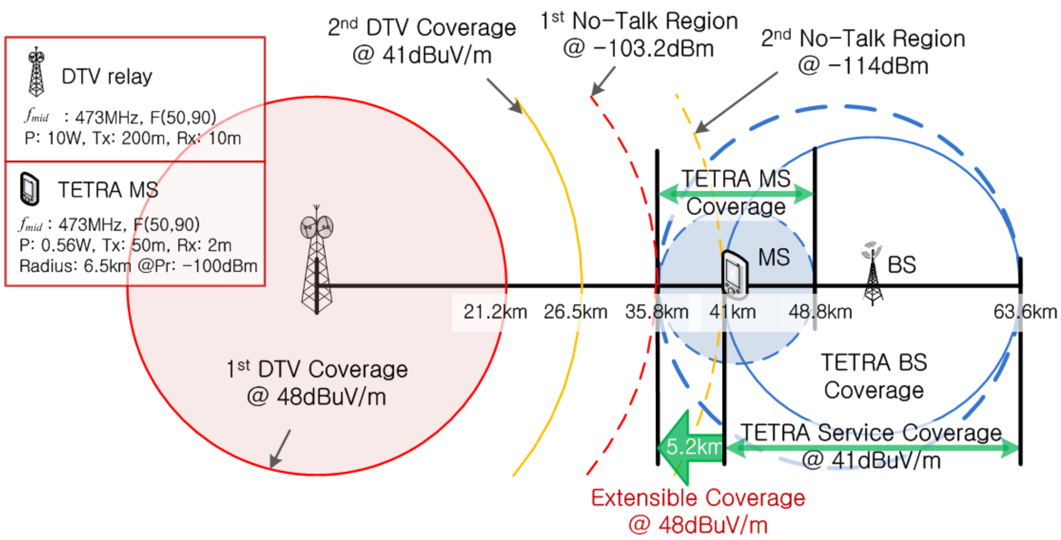


Figure 7.1. Enhancement of TETRA service boundary

In the second step, TETRA service area is assumed to be the square shape. Moreover, the maximum TETRA service area is limited by the geometric space in the simulation. Table 7.1 describes the simulation parameters.

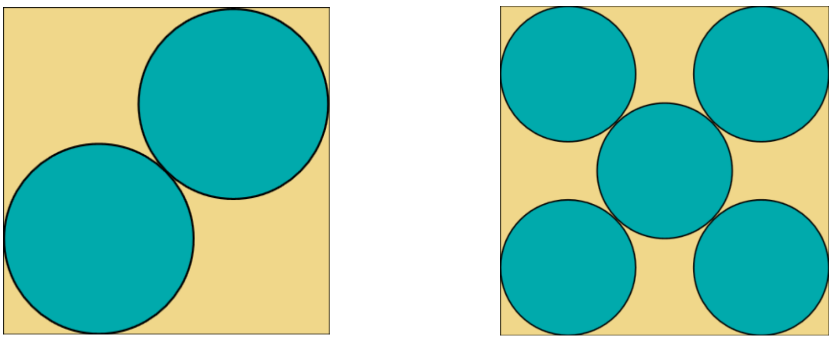
Then, the range of enhanced spectrum efficiency was considered as a measure of performance, which targeted the TETRA TMO located at the third tier in Figure 4.2. Based on the minimum TMO radius in Table 7.1, the number of TMO cell in the service area is estimated through the calculation of circle packing in a square as following equation [87].

Table 7.1. Simulation parameters for TETRA TMO

Parameter		Values
Minimum TMO Radius (R_{min})	473MHz	7.8 km
	695MHz	6.4 km
Target Distance for TETRA Service (D)	473MHz	22.6 km ≤ D ≤ 27.8 km
	695MHz	19.3 km ≤ D ≤ 26.8 km
TMO Frequency Range (f_{TMO})		473 MHz ≤ f_{TMO} ≤ 695 MHz
Transmitter Power		Power Class 10 (0.6Watt, 28dBm)
Data Rate / Bandwidth		36kbps / 25kHz

$$L = 2 + \frac{2}{d_n} \tag{7.1}$$

where the L is represented to a square size and the d_n is minimal distance between cells when n-cells have being existed in the square. Figure 7.2 shows the example of TETRA service area depending on the number of TMO cells.



$L \approx 3.414$ @ Two cells $\qquad$ $L \approx 4.828$ @ Two cells

Figure 7.2. Examples of TETRA service area and TMO cells [88]

According to the above results and the ITU recommendation named as ITU-R SM 1046, the factor of spectrum utilization efficiency can be derived as below [89].

$$SUE_{enhanced} = \frac{O_{TMO}}{B \cdot S} = \frac{\sum_{i=1}^{n} F_{TMOi}}{B \cdot S} \tag{7.2}$$

where:

O_TMO	Total occupancy in TETRA service area by all n stations
F_TMO	Total occupancy of a cell in the TETRA service area
B	TMO frequency bandwidth per channel
S	Geometric target space

The range of enhanced spectrum efficiency is derived depending on the size of target area. In this regard, Figure 7.3 illustrates the computing results on the spectrum efficiency according to the allowable TETRA service area.

In this figure, a side of the square, the TETRA service coverage varies from 10 km to 30 km, is examined to understand how the target size affects the spectrum efficiency. In addition, the steps in the Y-axis are substituted to the number of TETRA transmitters which depends on the distance of the target area and the carrier frequencies. Figure 7.3 suggests that when a side length is smaller than the minimum diameters of TMO, the transmitter could not be installed the target areas. In other words, there is no expectation of spectrum efficiency enhancement.

In case of the application of 41 dBμV/m, one transmitter is considered with the maximum within the target area regardless of the carrier frequencies. However, two TMO cells with a 7.8 km radius and four cells each with a 6.4 km radius could be expected when the field strength criteria is shifted to the new one, 48 dBμV/m. Spectrum efficiency can be enhanced with 4800 bps/Hz/m^2 at 473 MHz and 14400 bps/Hz/m^2 at 695 MHz when the spatial margins are considered by shifting the criteria of field strength from 41 dBμV/m to 48 dBμV/m.

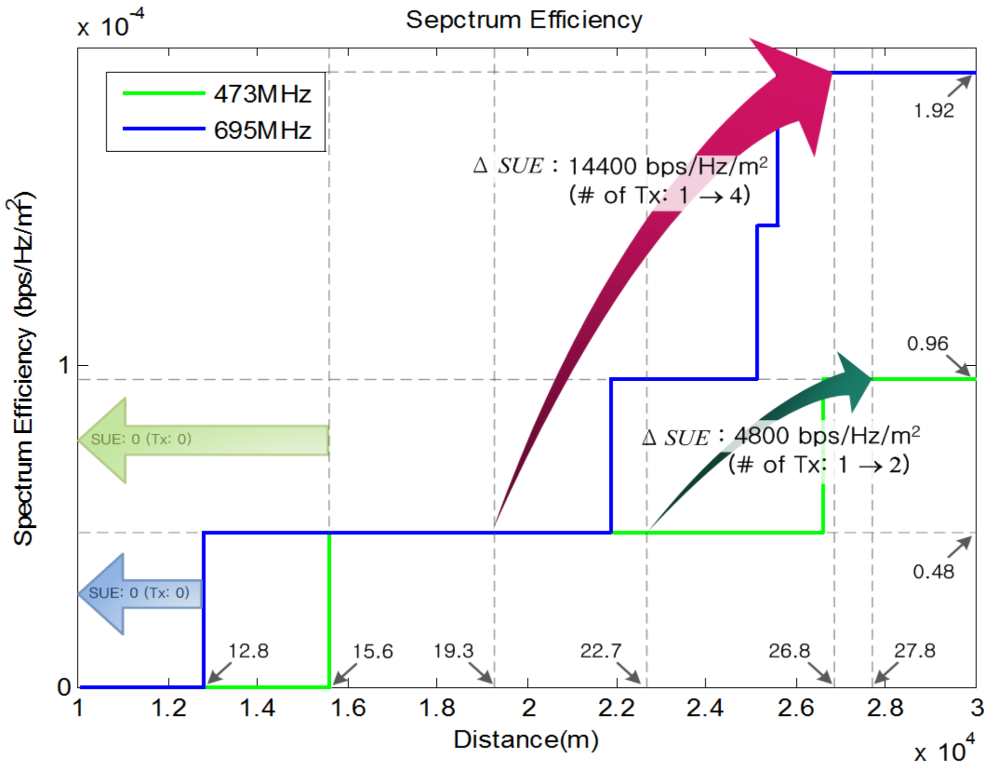


Figure 7.3. Spectrum efficiency enhancements in each frequency

7.1.2 Development on Available Space through Narrow-band Application

In the previous chapters, the influence of TETRA system as a secondary use in DTV band was calculated to follow the interference scenarios, and the interoperable range was estimated through the mutual interference testing between the DTV system and the TETRA system. Based on the results of DTV interference assessment and testing, the geographical operation margin for the secondary user is expected through the reconsideration of current technical criteria on DTV sensing area. It means that the flexibility of DTV White Space service depending on their application can be granted even if the secondary users are laid in the congested condition environmentally.

Therefore, DTV affected ranges can be estimated due to the operating of TETRA system with the TMO mode like Figure 7.4. It depicts the range of

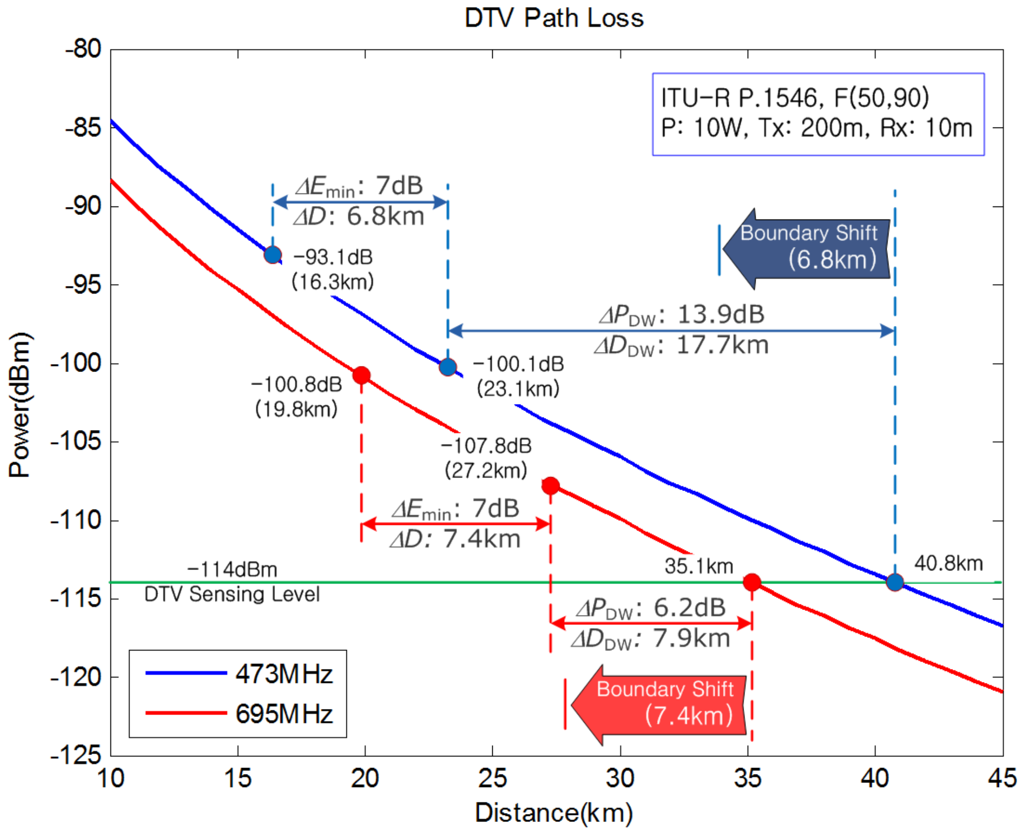


Figure 7.4. Shifting the DTV protection boundaries in each frequency

boundary shifting according to the targeted frequencies when reflecting the regulatory compatibility based on the US criteria to show the degree of affected range to the DTV protection area.

As a result, 6.8 km to 7.4 km can be considered as the extra operational margin for the DTV White Space services due to the shifting of regulatory criteria from 41 dBμV/m to 48 dBμV/m for their DTV service coverage. On the other hand, maximal 2.15 km toward to the DTV user from the DTV sensing boundary was reviewed as the intrusion range by operating of TETRA base stations (BSs). As such the intrusion range by TETRA TMO can be covered by the range of DTV regulatory compatibility, and TETRA BS is sufficient to operate at the boundary of DTV protection, i.e. -114 dBm. The MS power class meets the maximum allowable interference power level at the DTV receiver, and it may not be harmful to the DTV service. Figure 7.5 describes the DTV affected distance according to the operating power class of TETRA TMO, and it is summarized in Table 7.2 to the iconographical results of Figure 7.5 regarding the interference margin and intrusion ranges in each regulatory criterion.

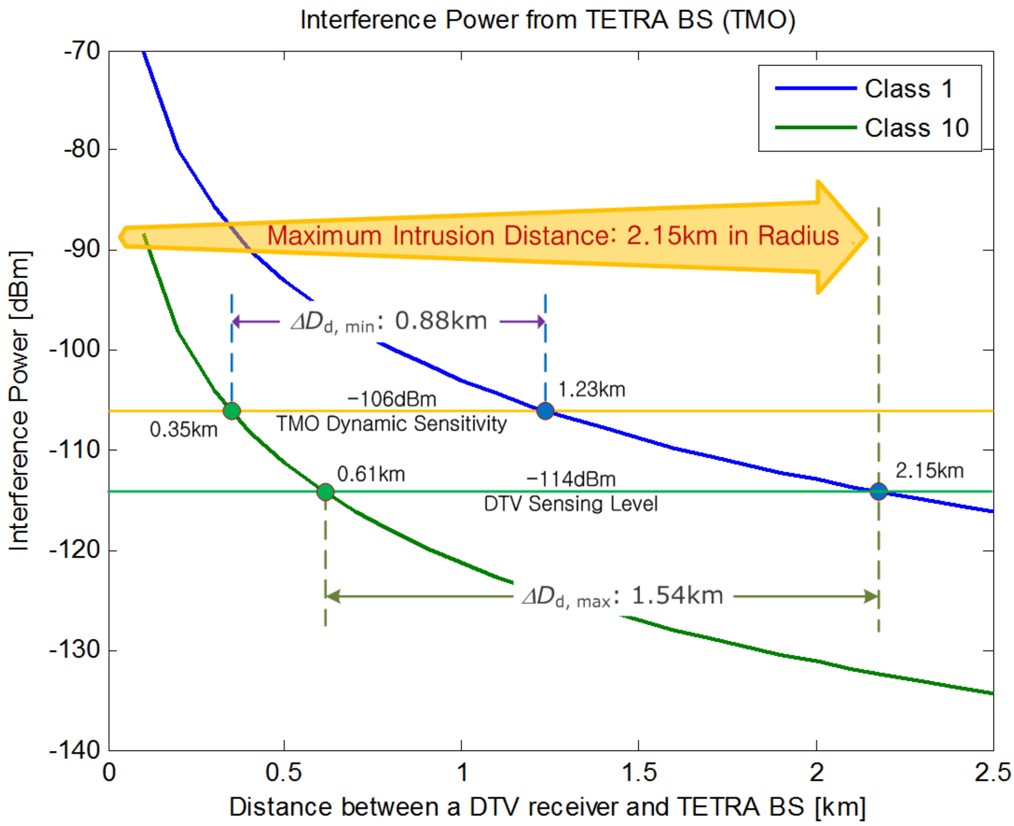


Figure 7.5. TETRA TMO intrusion distance in each operating class

However, the review on idle space excavation has to be defined according to the degree of DTV disturbance in terms of DTV performance to prepare the DTV protection measures and to derive the maximal usable spaces for the new services. The DTV interference testing targeted for the Korea DTV environment is performed as mentioned in Chapter 6 to measure an affected DTV service range by operating TETRA system as the DTV White Space application. By means

Table 7.2. Interference margin and intrusion ranges in each regulatory criterion

DTV Coverage (dBμV/m)		**41**		**48**	
Frequency (MHz)		473	695	473	695
Signal Level (dBm)*		-100.1	-107.8	-93.1	-100.8
Signal Distance (km)		23.1	27.2	16.3	19.8
Sensing Distance (km)		40.8	35.1	N/A	
Interference Margin	Distance (km)**	17.7	7.9	24.5	15.3
	Signal (dB)	13.9	6.2	20.9	13.2
Degree of Intrusion Shift (ΔD_d)		0.88 km @ -106 dBm, TMO Dynamic Range 1.54 km @ -114 dBm, DTV Sensing Level			

*DTV coverage in dBm scale - DTV D/U ratio (15.5 dB) [12, 79]
**(DTV propagation distance at -114 dBm) - (Signal level distance)

of the evaluation way, DTV signal degradation was assessed on the basis of the value of S/N and EVM.

This experiment was tested repeatedly while modifying the TETRA frequency offset to investigate the variation of S/N and EVM according to the used frequencies. The statistical approach was used as an analysis method of the testing results to quantify the degree of DTV disturbance as a value of probability.

According to the testing results, the EVM values were quite different depending on the frequency offset although the S/N values met the regulatory criteria. In terms of the EVM mean value and its standard deviation, the offset frequencies can be classified into the three; the critical, the affectable, and the allowable ranges according to the degree of DTV disturbance. The offsets fewer than 200 kHz are able to be represented as the critical range, and the offsets between 200 kHz and 400 kHz can be considered as the affectable range. On the other hand, the 400 kHz or more offsets are equivalent to the allowable ranges. Likewise, the classifications on user accessibility in aspect of technical view can also be reflected to the using priority among the DTV White Space users when required the separation among DTV White Space users as the aspect of regulation. The classification of affected range according to the offset frequencies is shown in Figure 7.6.

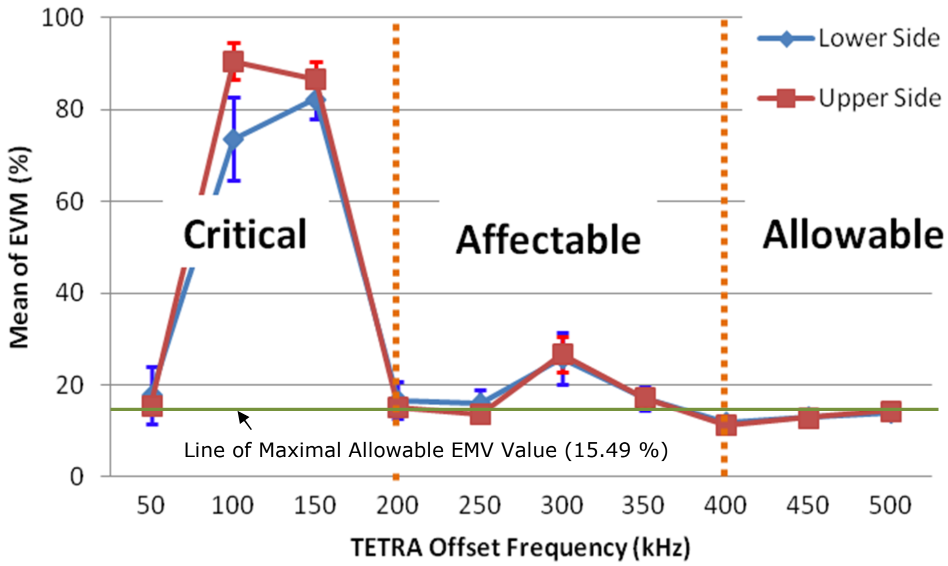


Figure 7.6. Classification of DTV affected ranges by EVM

7.2. Administrative Direction for Service Vitalization

In this thesis, the DTV White Space usability in severe condition is the main topic, and the Korea DTV environment is a good example of the severe condition on DTV White Space when considering the DTV White Space quantity and the social environment. As a methodology of DTV White Space estimation, the iconography review was examined on the basis of the tentative DTV channels at the targeted areas and their neighboring areas. The empirical path loss models were used to predict the DTV White Space based on the two regulatory criteria, i.e. 41 dBμV/m and 48 dBμV/m, and some extra margins can be expected by reconsidering the DTV service area. Also, it can lead to the enhancement of spectrum efficiency in technical aspect.

In terms of spectrum usage patterns, broadcasting service has a role of social accessibility for the public interest. It also can revolutionize as the direction of providing a sharing space on the diverse information and opinions through the media services. On the other hand, the convergence media is difficult to be represented to the public service in terms of the service cost, and it may be considered to degrade the universality of service and the participation of civil society [90]. To cope with this situation, the consideration of non-profit universal service should be reflected to the DTV White Space to minimize social gap among the TV audiences. In addition, the relief of competition among DTV spectrum users can be induced when considering the public service to the DTV idle space.

However, protection methods of incumbent user should be prepared in order not to infringe their service rights in legislative aspect as well. As such the complaining reports on incumbent users are being considered as judge criteria of regulatory criteria to define the DTV idle channels at targeted service region.

Therefore, above three considering factors should be reflected to the regulatory framework on DTV idle channels when it is faced to the congested condition depending on the service content characteristics.

7.2.1 Compatibility on Regulatory Criteria

In general, the radio spectrum is managed by the traditional way named 'Command & Control' through a spectrum regulator [1, 91]. On the other hand, a key policy of communications is to promote competition, and the pursuit of this goal is the opposite to a history of monopoly through public utility regulation [92]. In terms of broadcasters, the rights on terrestrial broadcasting services are emphasized under the name of free universal service to the public. However, DTV broadcasters do not need to have concern about the quality degradation of their mobile service due to the secondary users in DTV band. This is because some channels are prepared to mobile broadcasting service such as DMB or terrestrial broadcasting channels like OneSeg. It means that some stationary idle spectrum could be expected through the consideration on the geographical conditions of fixed stations to the regional DTV services.

In this situation, the compatibility of regulatory criteria among countries having the same broadcasting system can be reflected as the direction of environmental enhancement for secondary user as one of measures for giving flexibility to the system. Therefore, the reconsideration of regulatory criteria was reviewed through the case study on US and Korea by comparing their regulatory criteria for DTV coverage. It can be derived that the enhancement of DTV spectrum efficiency by applying the US criteria to the Korea DTV environment is available as the new regulatory paradigm.

Based on the above approaches, the management procedure for DTV idle channels can be considered as described in Figure 7.7. In this figure, the current regulatory criteria are applied to estimate the DTV idle channels as the first phase. Secondly, the compatibility of regulatory criteria is conducted when it is hard to expect idle channels for the secondary users. The regulatory criteria in US and Korea was used to explain the process of regulatory compatibility, and the values of DTV coverage, i.e. 41 dBμV/m and 48 dBμV/m are used as the compatible criteria.

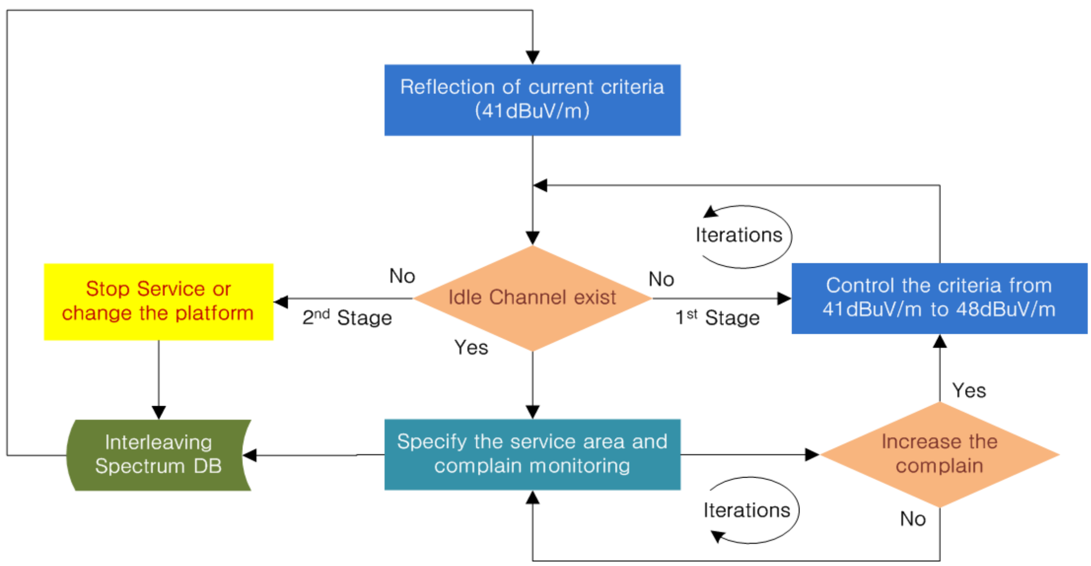


Figure 7.7. Examples on compatibility of regulatory criteria in US and Korea

7.2.2 Contents Based Classification

Based on the results of Chapter 3, the in-depth interview is focused on the White Space utilization as a part of the development of regulatory framework. Conceptually, the DTV White Space service means that it is to utilize the timely spatially unoccupied channels in DTV band, and it can be said that this is based on the provinces because the broadcasting services are being provided regionally. In this situation, it is hard to expect the national-wide service because the idle spaces are depending on the DTV channel status in each province, and the service boundary is hard to control in each DTV transmitting station due to protection of primary users by related laws.

In terms of the technical progressive in DTV band, the diversification and evolution on the service platform can lead to the expansion of information delivery. It can improve the service quality to the TV audience. However, the social inequalities and disparities could be an issue about the information gap between the top and bottom layers. This is because the new services on the DTV White Space can lead to expansion of the additional features on the TV receiver, and the multi-functional service by digital convergence can bring the deepened social structural problems. In such circumstances, increasing the utilization of idle spaces is required through the contents centric approach, and some services can be induced by the local government or non-profit organization as a measure of public interests. Specialized services reflecting the regional cultures can be expected through DTV idle channels, and it can also bring the expansion of the user scope through the market strategy like the local centric public services.

Based on the results on the in-depth interview, the interviewees presented the similar ideas regarding the DTV White Space utilization such as the public oriented services as a successful business model. Furthermore, DTV band is different from commercialized band in terms of the fact that it is being provided with content characteristics. That is, Telcos' services are aimed to corporate profit through the frequency use by license. On the other hand, the terrestrial broadcasting services are recognized as a non-profit universal service. In the same line of consciousness, the new services in DTV idle channel should also be considered as the direction on the public purpose utilization to enlarge the range of public interests.

Therefore, user classification is needed based on the providing contents to derive social consensus as a part of public interests at the first step. As an aspect for evolution of the technology and service like Super Wi-Fi user in US, technology based user classification may also be considered to induce the efficient use of radio frequency as one of public goods.

The user classification can be a good measure to reflect these matters, and higher class can be allowed to users who have public responsibilities and low impacts to primary users in technical aspects as a secondary user in DTV band. In addition, other users can be placed in a common class for technical and service diversification. Figure 7.8 illustrates the user hierarchy in DTV band according to the user qualification and their providing contents.

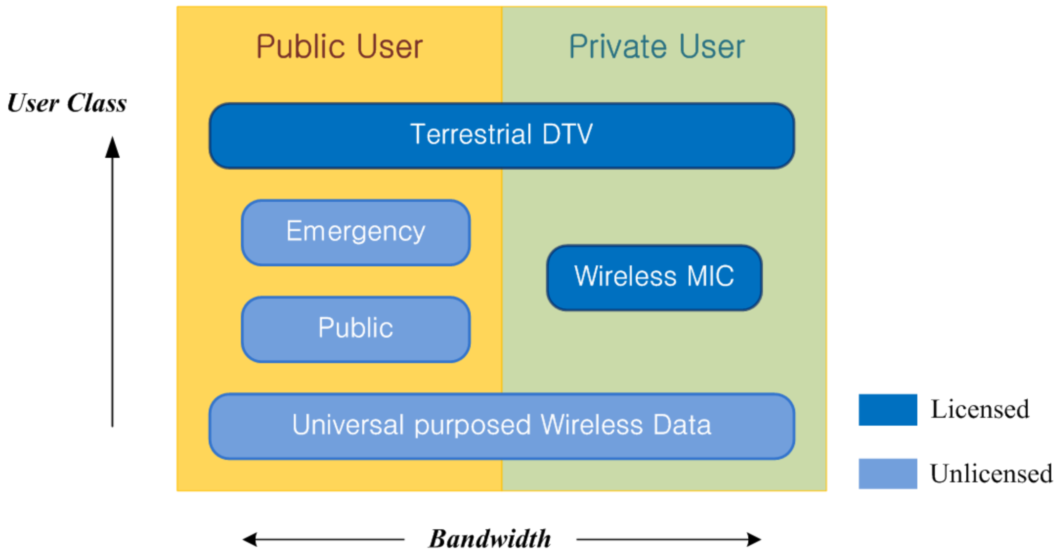


Figure 7.8. User hierarchies in DTV band

7.2.3 Complaining Mitigation

Typically, some portions of the spectrum are limited in usability to protect incumbent users based on the traditional spectrum management models named as 'Command and Control' [91, 93]. The TV spectrum is also being controlled in the same manner before emerging the new concept called as DTV White Space. Therefore, lots of complains from the broadcasters regarding the TV band can rise when just focusing the introduction of new service under the name of enhancement of TV spectrum usability. Especially, their service is emphasized by the service characteristics which is being provided to the public with free of charge, and they have a role to meet the public's right to know. In such situation, the management measures of DTV idle channels have to consider following two aspects; the enhancement of spectrum usability and the protection of incumbent user.

As shown in Table 4.1 and Table 4.3, the spectrum requirements and DTV idle channels due to the DTV transition are estimated through the user survey and the iconography review. Based on these results, three types for idle space estimation can be considered and can be applied to one type to manage the DTV idle channels depending on the geographical condition. It means that the first situation in Table 4.3 can be considered as a favorable condition to create lots of empty spaces. However, this situation is easily interrupted by primary users, broadcasters, to protect their services. On the other hand, the third situation in Table 4.3 cannot be taking into account frequency utilization efficiency because this case is equivalent to an extremely limited condition when deriving the idle channels like Danyang area. However, even in such areas, there is room for secondary users if empty space conditions could be alleviated to the second situation as described in Table 4.3. Therefore, a few bandwidths could be allowed as white spaces in the target area if some operating guidelines for mobile devices near the boundaries are given to assure the primary services. The second situation is reasonable to assume and calculate the quantity of white spaces considering two aims, namely, maintaining primary user protection and enhancing spectrum efficiency.

To achieve the second situation, it is necessary to establish a monitoring and protection scheme according to special spectrum management procedures that reflect the regional mobile device operating conditions and the complaining reports from primary users as shown in Figure 7.9.

Two specialized logical directions as shown in the flowchart in Figure 7.9 can be corresponding to the DTV idle channel management methods in terms of

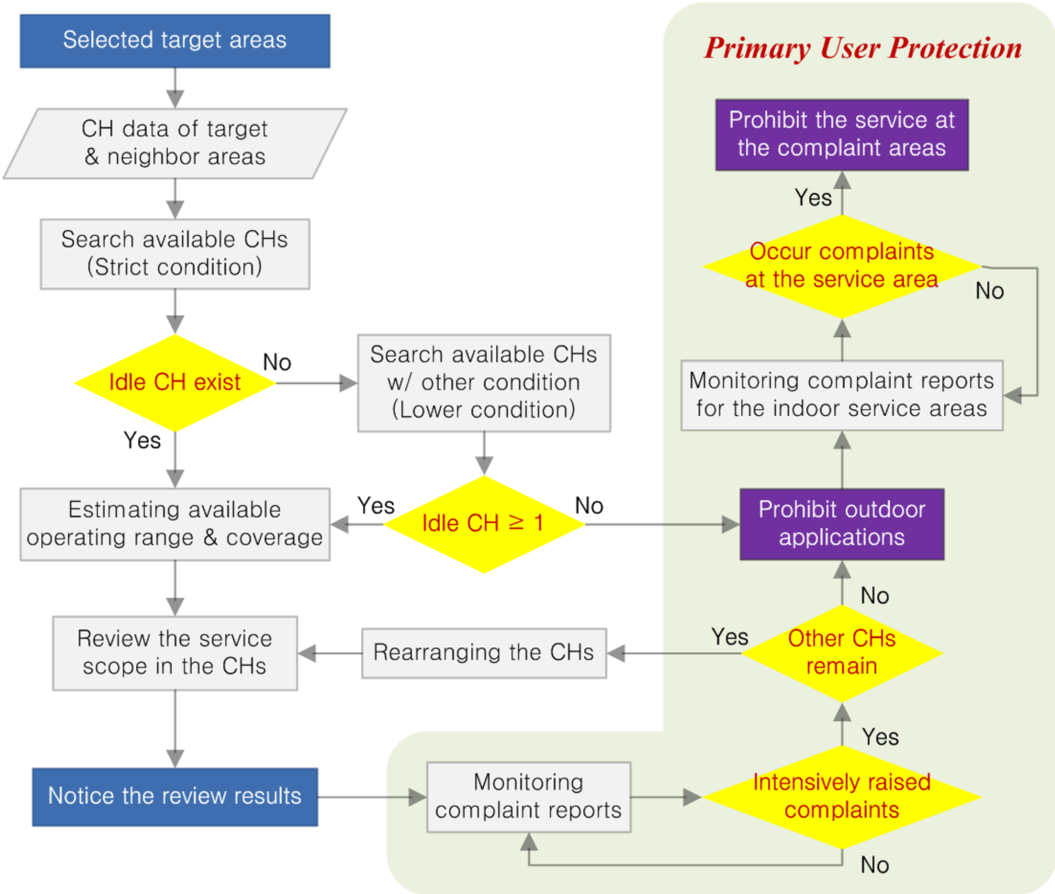


Figure 7.9. Sequential complaining managements

incumbent users in DTV band.

As shown in Figure 7.9, DTV idle channels are derived under the strict condition as for the primary users as the first phase. In case of no-idle channels due to the severe condition, the channels are reconsidered in terms of the normal condition such as the second situation in which the channel conditions are mitigated while limiting the operation scope of the second users. Further, the applications can be operated indoors only if there are no more available channels in the target areas. However, DTV White Space services including indoor case can be stopped when complaints are occurring continuously at the service targeted areas as a measure of the protection of incumbent users.

Chapter 8

Conclusion

The interest of DTV White Space is increasing due to the movement of DTV transition in each country. To cope with such global trends, DTV leading countries including Korea are preparing the introduction of DTV White Space after completing the DTV transition like US and Japan. Many research institutions and study groups are reviewing the policy direction and the service models due to the escalation of expectation on the White Space utilization. It can be said that the broadcasting band does not exist for only one purpose anymore due to the advance of radio technology by the digitalization of communication system. Therefore, convergence media services may also be enlarged by universalization of digital technology, and the transition of production and distribution mechanism can be induced as an economical direction.

As a measure of reflection on these social technical requests, this thesis presents the part of spectrum policy to encourage the DTV White Space utilization through the technical and regulatory sides. However, some complementary works are left as a future work to achieve harmony among social needs for stakeholders.

8.1. Policy Framework for DTV White Space

In Chapter 7, the environmental and regulatory conditions were pointed out as the key factors that have to be concerned to introduce the DTV White Space. As reviewed in Chapter 7, DTV White Space environment can be changed depending on the type of content and the regulatory direction. This thesis is focused on the public centric content and the deregulation on technical criteria. Especially, key ideas are suggested to the narrowband application and the regulatory compatibility among countries which adopted the same DTV standards.

Based on the review in Chapter 7, the management direction on DTV White Space can be summarized as Figure 8.1.

Each color in Figure 8.1 is representing the same status in the decision procedure as a horizontal direction, and it is also consistent with different colors according to the vertical direction. Structurally, the DTV White Space management can be divided into two ways for each direction in row and column. As the row direction, it is related to the administrative procedure on DTV White Space management, and it can be classified into two groups on the basis of the decision subject, i.e., the regulator and user. In the group of user decision, the three items are presented to make a direction of DTV White Space service. These items are derived through the contents based classification in social aspect, and the regulatory criteria compatibility in technical aspect. Initially, the range of occupied bandwidth is decided according to the service applications such as video, voice, and text. After deciding the service application, their service area is determined according to the regulatory criteria in the current country. This can be expanded to the direction of deregulation depending on the number of subscribers to ensure the right of consumers. However, it should also be permitted under the precondition of incumbent user protection, and it cannot be become the 'Class I' user due to the unstable service status when applying the deregulation criteria.

The spectrum regulator is positioned at the top of procedure in Figure 8.1 as a measure of efficient use of DTV White Space to manage the needs and complains among users. As depicted in Figure 8.1, the regulator has a charge of user classification based on the service purpose and the bandwidth. In addition to that, they can request the change of service status to the secondary user on the basis of the complaining reports, and they may also able to request termination of White Space service depending on the situation.

Complain reports should be handled based on complaints from broadcasters and TV audiences at the targeted area as shown in Figure 7.9. Nevertheless, in order to filter the contrived overreaction from opposite parties for DTV White Space services, a careful review of complaints from the audiences in the area

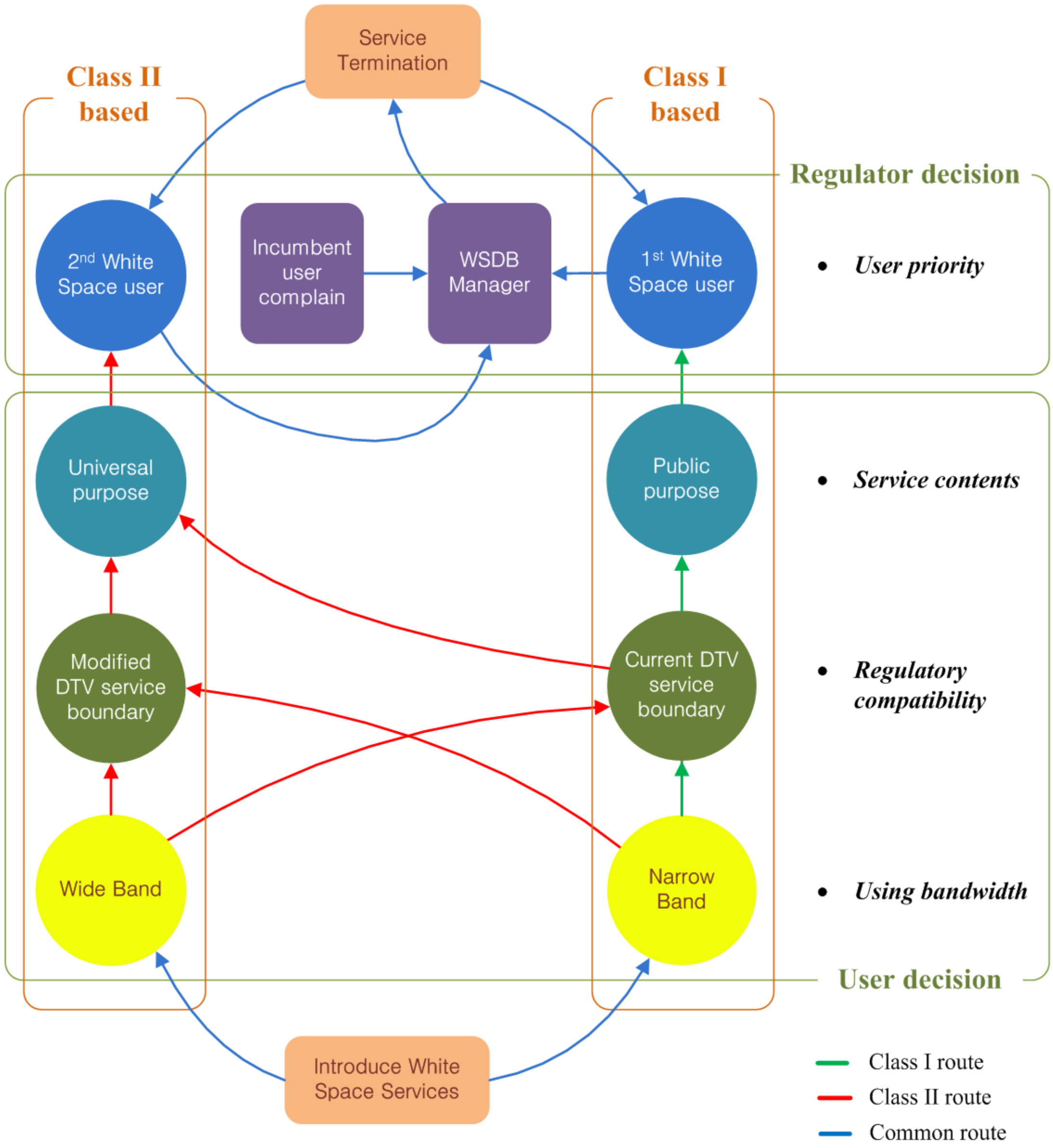


Figure 8.1. Effective management structure on DTV White Space

only where the review is requested by the broadcasters is necessary. For this, it would be appropriate to review the complaints directly from the audiences using Master Antenna TV (MATV) in the targeted area. However, it requires a systematic review to quantify the complain reports from the TV audiences because the ratings of MATV may be different by the regional economic situation and the total households as in the Table 4.2.

Therefore, interactive organic management among stakeholders is required to derive maximal usability on DTV White Space, and the cooperation among users is also needed to launch a new service successfully.

8.2. Future Work (Epilogue)

This study started from the in-depth interview. The in-depth interview was targeted to experts working in the related fields, and the purpose was to understand the prospect on the utilization of DTV idle space through the expert's opinions and to cope with the global situation that reviewing on the DTV White Space. In terms of research approach, there are significant needs in research because it was tried through the inductive analysis regarding the future direction of DTV White Space based on the current situations rather than excessive optimistic outlook. As one of the analysis results, the difference was shown for the collective awareness on the DTV White Space depending on their working group. Moreover, variety conditions and prospects were proposed to the national industrial development through the larger frame for the DTV White Space utilization. This suggestion is based on the consideration of a situation of undefined policy guideline and business directions by excluding vague expectations and differences of opinions between stakeholders.

On the other hand, this thesis has several limitations for the practical utilization on the DTV White Space policy. As first, it lacks in-depth discussion in each item by focusing the general understanding of social phenomena and prospects under the absence of a concrete policy on DTV White Space utilization. To deal with the issue, follow-up study on utilization of DTV White Space as one of public goods is required. Secondly, it does not accomplish the objective validation for the in-depth interview. It requires a critical validation on the new conceptualized theme being derived from the in-depth interview although this thesis started from the extraction of subentry on the interview contents. In other words, it is missing the analysis for the secondary implication being understood by the experts, and it did not explore the theoretical and academic discussion in depth by concentrating on the understanding of phenomena and industrial outlook. As a future research direction, more systematic quantitative research is demanded through the comprehensive research target by each business field to overcome the mentioned issues.

In terms of technical aspects, the estimation of DTV White Space was conducted based on the DTV pilot program areas in Korea and its result has been caused by the iconography review. It means that the idle spaces in DTV band are depending on the DTV channel condition in each area including their neighboring area. Meanwhile, it is hard to cover the whole cases on geographical conditions in the world. As such, the suggested model for DTV White Space utilization may be utilized at the places being expected to lots of spillover effects due to the mountainous terrain.

As a new service in DTV band, the policy measures should be developed for using the DTV White Space as commercial purpose based on the regulatory frameworks like the primary user protection. However, as the first phase on the DTV White Space development, the DTV White Space services should be oriented to the public service considering the development of frequency band and the service vitalization. In such social environment, the consideration of DTV White Space as a non-profit universal service is required to minimize gap among the TV audiences as a consumer and to prevent competition with existing services. Finally, the user-centric policy like a terminal dissemination policy is required for the service penetration.

Consequently, the DTV White Space is expected to be not only wide band services but also narrow band services as a measure of DTV idle channel utilization for increasing the DTV spectrum efficiency. Some public application like PPDR can be applied as one of narrow band solutions for White Space, and public interest and economic improvement may also be achieved by enhanced frequency efficiency. Lastly, I would like to suggest that the various service models should be reviewed for successful launch of DTV White Space, and the service necessity and objectivity should also be considered to induce social consensus.

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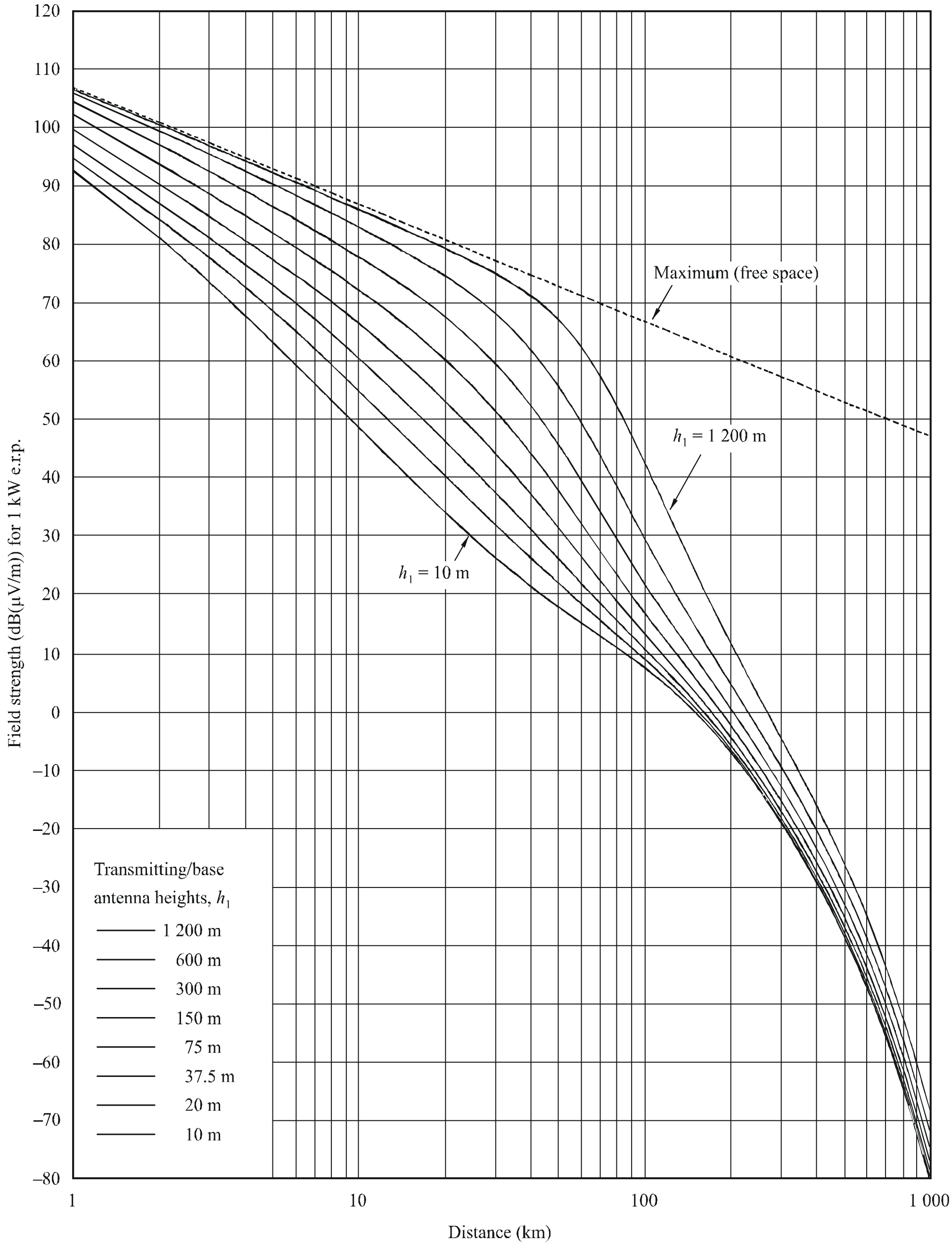
Appendix

A. Field strength vs. distance curves for 600 MHz

Below three plots were used to estimate the field strength in the range 300 MHz to 1000 MHz which is recommended by ITU-R as the path loss according to the distance of propagation in each time condition, i.e. 50 %, 10 %, and 1 % [76].

600 MHz, land path, 50% time

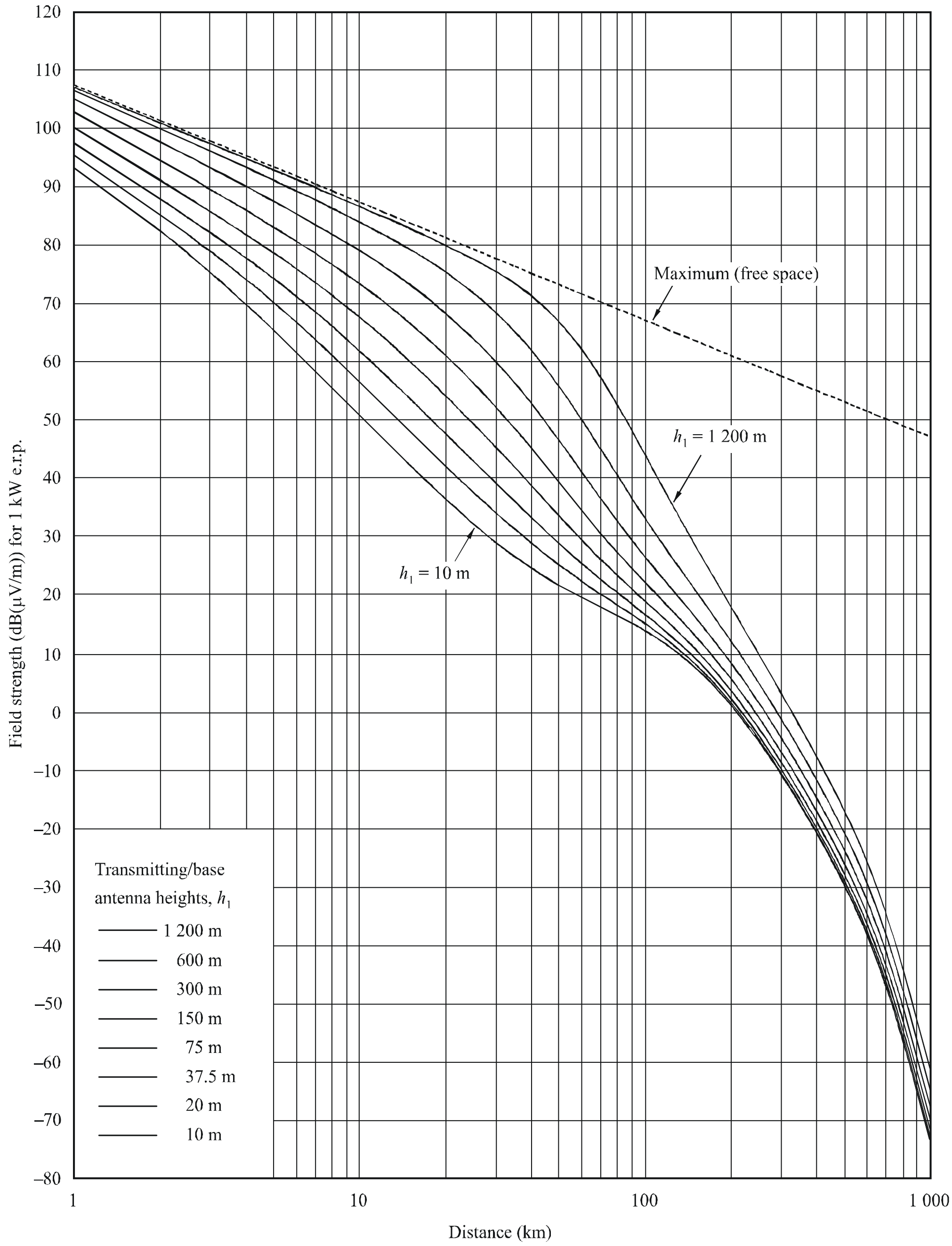


50% of locations

h_2: representative clutter height

1546-09

600 MHz, land path, 10% time

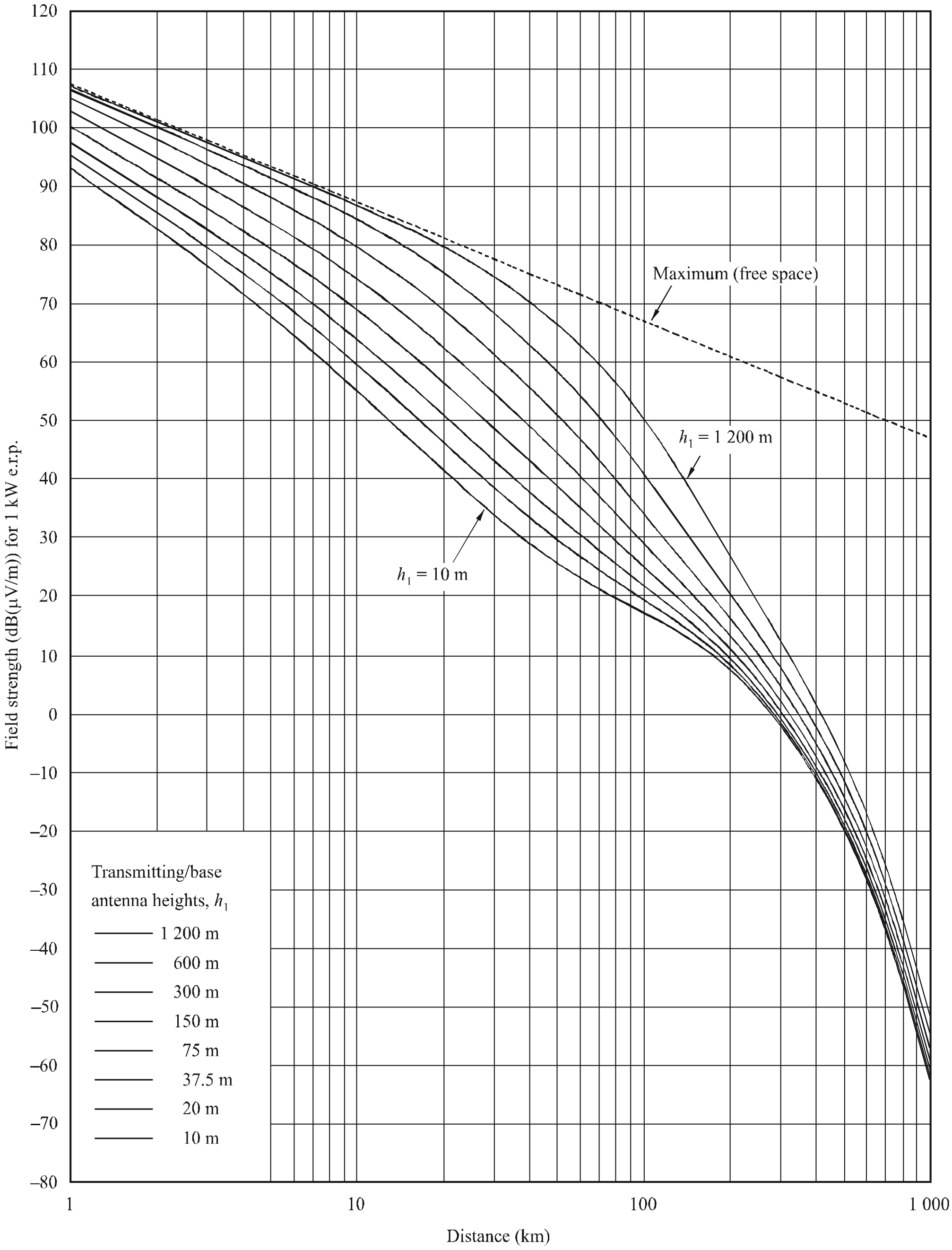


50% of locations

h_2: representative clutter height

1546-10

600 MHz, land path, 1% time



50% of locations

h_2: representative clutter height

1546-11

B. Questionnaire of In-depth Interview

B.1 View on the direction of spectrum management system

- The radio spectrum is considered an intangible national resource and its demands are increased more than before due to the evolution of radio technologies and network. In this situation, a new spectrum policy is required to cope with the frequency demands in aspect of the efficient use of radio spectrum. How do you think about the current spectrum issues and the measure of future spectrum management?

- The spectrum management system can generally be classified into three types, i.e., the 'Command and Control', the 'Market Based', and the 'Commons'. In this regard, which model do you think is the appropriate system in the convergence era among these three models? And, why do you think so?

- What do you think about the prospects for the change of spectrum management system due to the DTV transition?

- What are the prospects of the relationship between the incumbent user and the expected new subscribers caused by changes in spectrum management system?

B.2 The outlook on the introduction of the DTV White Space

- What do you think of the policy-measures required for the introduction and usage of the DTV White Space when considering the geographical and institutional situation in Korea?

- The user-centric new wireless service like a smart-phone is currently being expanded, and the user data in wireless channels is being increased more than before. In this situation, what kind of effects will the DTV White

Space policy bring up to the related industries through the introduction of new services in an aspect of the efficient use of spectrum resources?

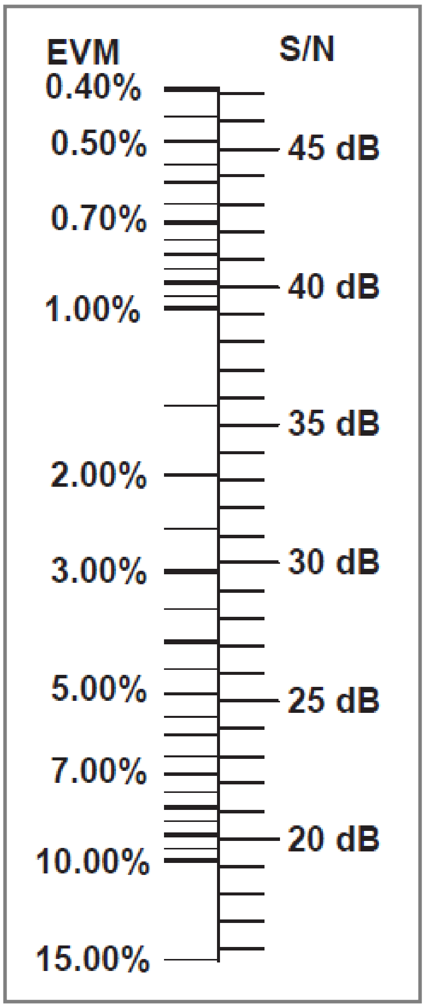
- Do you think that Korea will be able to gain advantage in competition with the standardization for the related technologies of White Space?
- European Union (EU) has concluded that the mutual cooperation should take consensus to facilitate the DTV White Space utilization among European countries, and they are also co-responding to give flexibility of services and using technologies. In Korea, what do you think that the collaboration among the neighboring countries should be considered when using the DTV White Space like the case of EU?

B.3 The DTV White Space policy for a service vitalization

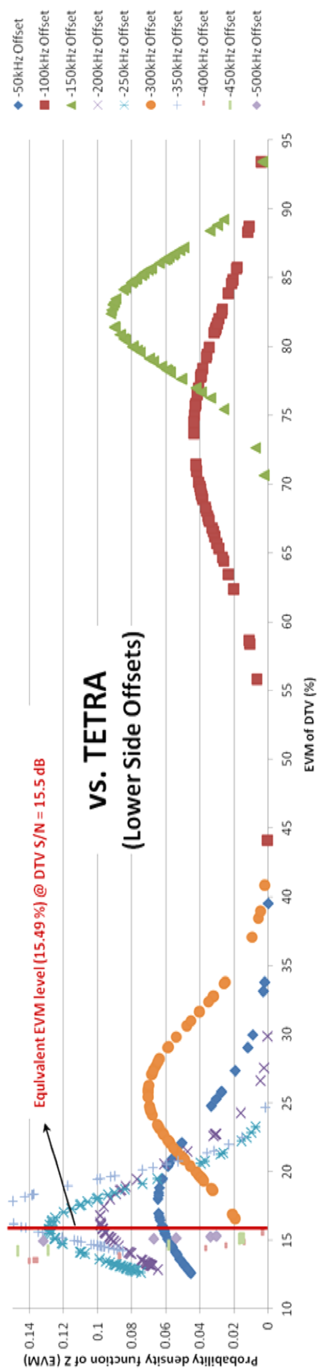
- What kind of management measures should be introduced as a key policy to activate the DTV White Space services?
- What kind of service will be the most prevailing business model on the DTV White Space?
- Currently, the wireless internet service is being discussed as the key application of the DTV White Space in aspect of the complementary system of current telecommunication services. However, it is insufficient to the measures for enhancing the properties of public goods. In this situation, what do you think about the necessity of introduction of policy measures in the direction of public goods?
- How do you think about the White Space utilization as a public service such as public information and disaster information to enhance the properties of public goods? And, what do you think about this management system for the service operation?

C. Relationship between EVM and S/N

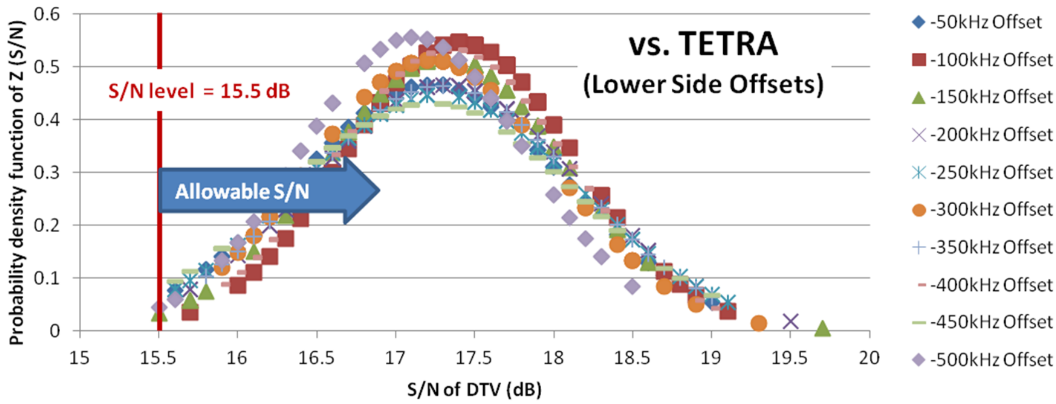
Next plot is available for the 8-VSB DTV system under the condition of $I_{max}^2 = \pm 7$ and $\Delta I_j \approx \Delta Q_j$, and it is presented by Tektronix, Inc. [13].

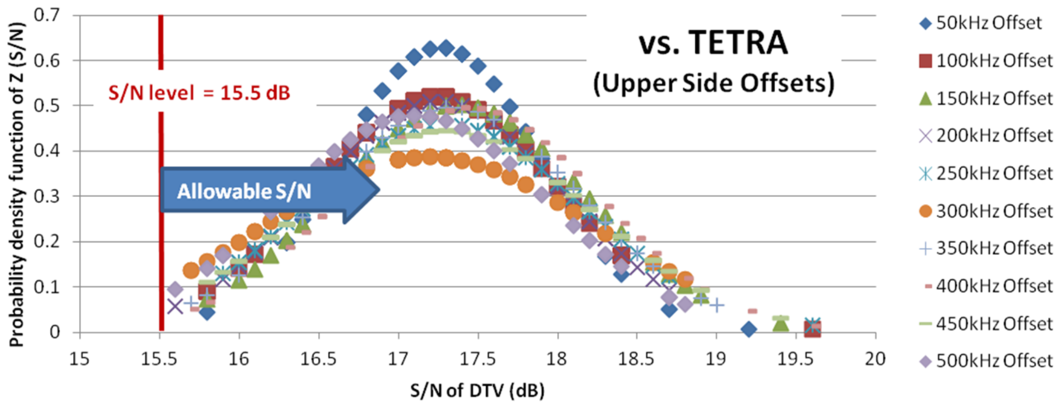


D. Distribution of EVM values for the whole testing ranges



E. Distribution of S/N values for the whole testing ranges





F. Research History

F.1 International Journal

1. Heejoong KIM, Hideki SUNAHARA, Akira KATO, "Study on Environmental Improvement for DTV White Space Utilization with Narrow Band System", *International Journal of Networks and Communications*, Vol.2, No.4, July 2012 ⇒ Corresponding to the Chapter 4, 5, and 7

2. Heejoong KIM, Hideki SUNAHARA, Akira KATO, "Study on DTV Affected Range due to Coexistence of Narrowband System for DTV White Space in Korea: Focused on TETRA Release1 as Narrowband System", *International Journal of Information Engineering* (To be published) ⇒ Corresponding to the Chapter 4, 6, and 7

3. Heejoong KIM, Seunghyeok BAEK, Ichiya NAKAMURA, Hideki SUNAHARA, "Study on Public Service Model with DTV White Space in Korea", *International Journal of Information Systems and Change Management* (In submission) ⇒ Corresponding to the Chapter 3 and 4

F.2 International Conference

1. Heejoong KIM, Hideki SUNAHARA, Akira KATO, "Comparison on DTV Affected Range by Difference of Secondary User Bandwidth in Adjacent Channel", *International Symposium on Wireless Communication System*, August 28-31 2012, Paris, France (To be presented) ⇒ Corresponding to the Chapter 6 and 7

2. Heejoong KIM, Hyungoo YOON, Hideki SUNAHARA, Akira KATO, "Study on Coexistence of a Narrow Band System with Terrestrial DTV System", *World Telecommunications Congress*, pp.1-5, March 4-7 2012, Miyazaki, Japan ⇒ Corresponding to the Chapter 5

3. Heejoong KIM, Hideki SUNAHARA, Akira KATO, "Coexistence of a TETRA System with a Terrestrial DTV System in White Spaces", *ITU Kaleidoscope*, December 12-14 2011, pp. 1-5, Cape Town, South Africa ⇒ Corresponding to the Chapter 5

4. Heejoong KIM, Hyungoo YOON, Hideki SUNAHARA, "Study on Strategy for Spectrum Efficiency Enhancement of DTV White Space in Korea", *Wireless Communications and Mobile Computing Conference*, pp.1992-6, July 4-8 2011, Istanbul, Turkey ⇒ Corresponding to the Chapter 5 and 7

5. Heejoong KIM, Jeongsam KIM, Hideki SUNAHARA, Ichiya NAKAMURA, "The Outlook on White Space Utilization Policy in Korea: Lessons from the DTV leading Countries namely the US, the UK, and Japan", *International Telecommunications Society*, June 26-28 2011, Taipei, Taiwan ⇒ Corresponding to the Chapter 4 and 7