Spectrum Management Policy Framework For Digital Dividend in Sri Lanka

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Abstract

Digital terrestrial television enables the transmission of multiple channels in the same spectrum used for the transmission of a single analog channel. Thus the switchover from analog to digital terrestrial television known as the analogue shut off, releases the spectrum for the use of other services. This is known as the Digital Dividend. Although Sri Lanka is the first to introduce most of the latest cellular technologies in South Asia, the allocation of the spectrum for these technologies are adhoc operator request based instead of with clear objectives and spectrum management plans. The objectives of this thesis are to analyse the procedures followed by other countries for analog to digital TV switchover and to propose a spectrum policy framework for the digital dividend in Sri Lanka.

In this paper, spectrum policy changes in other countries are analyzed, especially the movement from an administrative approach to a market driven approach. Furthermore, the analog shut off implemented in other countries and the impact to the key stakeholders (subscribers, broadcasters and government) are assessed, along with the benefits of digital dividend for Sri Lanka.

A key finding of the analysis is the success of the analog shut off is achieved from a push pull strategy; push from the government and authorities by providing concessions, imposing rules and regulations and pull from the customer by enticing them with new content on free to air basis. The timing of the implementation has a major impact on the technology to be selected and it is recommended to form a independent consortium with both state and private sector companies (three to four companies) to facilitate the digital TV infrastructure to make optimal use of the spectrum and to reduce the cost. "Auction" is identified as the optimal method for spectrum allocation and the released spectrum can be used to increase the cellular communications (VoLTE, VoNR) and internet penetration, especially in the rural areas.

Keywords:
Digital Dividend, Spectrum Management, Digital Television, Analog Shut Off, Auction.

Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Signature　　　　　　　　Date

The above candidate has carried out research for the Masters thesis under my supervision.

Signature of the supervisor　　　　　　　　Date

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Chapter 1

Introduction

1.1 Digital Dividend Overview

Digital dividend is the release of the spectrum due to the analog shut off, or due to transition from analog terrestrial television broadcasting to digital terrestrial television broadcasting [1]. Digital terrestrial television offers better picture, sound quality and facilitates mobile reception as opposed to analog terrestrial television. Most importantly, digital television broadcasters can transmit multiple channels on the same spectrum used up by a single analog channel, thereby releasing the spectrum for other uses [2]. Based on this distinct advantage, switch over from analog to digital terrestrial television is implemented and underway in many countries such as, Australia, US, Europe, Singapore, India, Hong Kong Japan etc. [1].

The mobile industry could intensely accelerate the rollout of broadband communications and enhance coverage if 100MHz or 25% of the spectrum utilized by analog television broadcasting (470MHz to 862MHz) can be reassigned to mobile services [3]. To provide a broader mobile coverage, fewer network infrastructure is needed due to the better signal propagation with low frequencies. This could be an ideal means to provide mobile coverage to rural areas at a minimal cost [3].

A balanced and well planned spectrum reassignment between the ICT industries, mobile broadband and broadcasting, in accordance to the countries development goals will ensure that the nation earns the full economic and social advantages of the digital dividend.

1.2 Current Sri Lankan Scenario – Television Broadcast and Cellular Mobiles

1.2.1 Television Broadcast in Sri Lanka

- On the 13th of April 1979 a television network was launched in Sri Lanka for the very first time. Sri Lanka's first terrestrial television channel was ITN which was under Independent Television Network Limited. This was acquired by the government on 05th June 1979. Sri Lanka Rupavahini Corporation was established in 1982 and ITN was brought under the same act, Sri Lanka Rupavahini Act of 1982 [1]

- Private television networks establishment was permitted by Sri Lankan government in 1992. This made significant changes in the television broadcasting. Subsequently, the Maharaja Television Network was launched [1]

- Since then, over the time, several broadcasting networks have been launched using public frequencies. In 1997, Swarnawahini, a private company was established which functions currently by the same brand name. Derana, a company with multiple broadcasting platforms as printed media, radio and television came in to action in 2005. In 2008, IPTV service was launched by Sri Lanka Telecom who is the national telecommunications provider in Sri Lanka [1]

- To date there are 20 analog broadcasters and 05 DTH satellite broadcasting operators in Sri Lanka [1]

1.2.2 Digital Terrestrial Television

In addition to the analog terrestrial television, Channel 44 and 50 (658 MHz & 706 MHz) have been issued to Dialog Axiata PLC to launch Digital Terrestrial Television [4].

Rupavahini digital test transmission commenced in 2012 from Kokavil for Northern province using DVB-T2 and ISDB-T from Colombo in 2014. In 2014, Sri Lankan government initiated the discussions of terrestrial television broadcasting digitization. The plan was to adopt Integrated Service Digital Broadcasting-Terrestrial (ISDB-T) standard offered by Japan with a plan of analog shut off in western province by 2017. The project progressed very slowly and eventually became standstill.

Sri Lankan government reinitiated the digitization of terrestrial television broadcasting in 2021 and has been decided to introduce ISDB-T Technology to suit the country, subsequent to a feasibility study conducted by the Japan International Cooperation Agency (JICA)

1.2.3 Cellular Mobile

Figure 1.1: Cellular Mobile Evolution in Sri Lanka
Source: Author

- Cellular Mobile Service in Sri Lanka began in 1989 with the first generation (1G) analog network operated in 900MHz band with Total Access Communication System (TACS) standard
- In early 1990, Advanced Mobile Phone System (AMPS) standard based analog cellular service was introduced in 800MHz band
- It was in the second generation that digital transmission was introduced via a wireless link. In mid 1990s Global System for Mobile Communication (GSM) came in to action to mitigate the capacity restrictions in analog systems. The first spectrum allocated in the 900MHz band for GSM. Low date rates (9.6kbps) and voice services were offered by 2G mobile network and General Packet Radio Services (GPRS) which is 2.5G could cater data rates up to 15kbps. This was sufficient to meet the market demand at the time
- To full fill the demand for the high data rates, in early 2000, the third generation (3G) was introduced. 3G provides data rates up to 2Mbps
- Taking in to consideration the prominent advantages for the users in 3G system, Telecommunications Regulatory Commission of Sri Lanka (TRCSL) introduced 3G mobile service as the first in South Asia

- Sri Lanka was the first to introduce High Speed Packet Access (HSPA), which is the enhanced technology of 3G in South Asia

- Due to the ever growing needs for higher data rates, in 2013 4G technology was introduced in Sri Lanka. This made a paradigm shift in the data usage by the users. 4G technology is frequently used by the users for applications having high data rate requirements. These include high resolution video streaming, video calling, cloud gaming etc. applications

- Ever growing user needs gave the birth to 5G technology which is meant to offer extreme bandwidths, ultra reliability, ultra-low latency, support for massive density of devices and increased availability. Sri Lanka started trialing 5G services in 2017

- The increment in the telephone penetration in Sri Lanka was contributed by the expansion of the mobile services over the last decades of years [4]

Frequency Allocation to Cellular mobile Operators is depicted in the table 1.1 [4]

1.3 Scope of Work

Although Sri Lanka has been quick to introduce wireless technologies, the allocation of the spectrum has been adhoc, driven by operator demand rather than a part of the overall spectrum management plan having defined goals/objectives. An objective of this research is to identify the optimal spectrum allocation method. This is deduced based on the analysis of the spectrum policy changes in other countries specifically on the movement from an administrative approach to the market driven approach of spectrum allocation.

The switchover from analog to digital terrestrial television releases the spectrum for the use of other service. The switchover has an impact on the current broadcasters, the television subscribers as well as the government. Another objective of this research is to deduce how analog shut off can be implemented in Sri Lanka and to analyze the impact on the stakeholders. The learning from analog shut off in other countries is analyzed for this purpose.

Given that the optimal use of the released spectrum will be to use it for mobile communication and broadband, more specifically for long term evolution (LTE) and 5G, the performance of the released spectrum for LTE and 5G as opposed to other spectrums is assessed with the objective of identifying the need of using the released spectrum for mobile communication and broadband in Sri Lanka.

Source: TRCSL: Frequency Assignment

Table 1.1: Frequency Allocation to Mobile in Sri Lanka

Name of the Operator	Frequency Band		
	900MHz Band	1800MHZ Band	2GHz Band
Etisalat	900-907.5MHz 945-952.2MHz (2x7.5MHz)	1732.5-1740MHz 1827.5-1835MHz (2x7.5MHz)	1940-1950MHz 2130-2140MHz (2x10MHz)
Dialog Axiata PLC	907.5-915MHz 952.5-960MHz (2x7.5MHz)	1747.5-1755MHz 1755-1762.5MHz 1767.5-1777.5MHz 1842.5-1850MHz 1850-1857.5MHz 1862.5-1872.5MHz (2x(7.5+7.5)MHz) (2x10MHz)	1965-1970MHz 1970-1980MHz 2155-2160MHz 2160-2170MHz (2x(5+10)MHz)
Hutchison Telecommunications Lanka (Pvt) Ltd	892.5-900MHz 937.5-945MHz 2x7.5MHz)	1725-1732.5MHZ 1820-1827.5MHz (2x7.5MHz)	1950-1955MHz 1955-1960MHz 2140-2145MHz 2145-2150MHz (2x(5+5)MHz)
Mobitel (Pvt) Limited	885-892.5MHz 930-937.5MHz (2x7.5MHz)	1710-1720MHz 1720-1725MHz 1762.5-1767.5MHz 1805-1815MHz 1815-1820MHz 1857.5-1862.5MHz (2x(5+5)MHz) (2x10MHz)	1915-1920MHz 1920-1930MHz 1960-1965MHz 2110-2120MHz 2150-2155MHz 5MHz (2x(5+10)MHz)
Bharti Airtel Lanka (Pvt) Ltd	880-885MHz 925-930MHz (2x5MHz)	1740-1747.5MHz 1835-1842.5MHz (2x7.5MHz)	1930-1940MHz 2120-2130MHz (2x10MHz)
Electroteks	N/A	1777.5-1785MHz 1872.5-1880MHz (2x7.5MHz)	N/A

Chapter 2

Literature Survey

2.1 Spectrum Management

2.1.1 Spectrum

From a technical viewpoint, the portion of electromagnetic spectrum which host the radio waves is called the radio spectrum. From an economic view point, the radio spectrum is a non-exhaustible and non-storable asset utilized by a vast community, including both private and public bodies such as healthcare for emergency services, military services, for many applications, including broadband and narrowband mobile communications, marine and aeronautical communications, broadcasting services, and scientific applications as environmental sensing and radio astronomy [5].

It is interesting to note that unlike water and oil, this resource will never run out. However, it cannot be stored for later use and it is becoming congested rapidly.

As wireless technologies are one of the main methods of connecting households and businesses to internet, media services and voice, a significant improvement to the growth of a country can be achieved through the effective management of the spectrum. Policies for spectrum management should promote innovations and fast rollout of services by reducing the barriers to enter to the market.

2.1.2 Introduction to Spectrum Management

Spectrum management is the allocation of the spectrum for a particular use under specific technical and service rules. The spectrum manager governs these allocations. The allocations are crucial to ensure the performance of the industry as well as the national defense and public safety.

The spectrum management consist of planning, engineering, authorization and monitoring [5].

- Spectrum planning is the process of assignment of the segments of the frequency spectrum to specific applications. This is done taking in to consideration the technical characteristics of the spectrum and prospective use of distinct portions of spectrum, aligning to the national policies, priorities and international agreements

- Spectrum authorization is the procedure of allowing radio operators and radio communication equipment to access the radio spectrum resources under specified conditions

- Spectrum engineering is the process of developing radio equipment related specific standards to ensure the compatibility of electromagnetism to avoid hazards radiation

- Spectrum compliance and monitoring is the procedure of supervising the usage of the radio spectrum and enforcing rules and regulations to eliminate hazardous radiation and unauthorized usage

The government of the country can directly undertake the spectrum management as a duty of a ministry or can appoint an independent regulator functioning under legislative mandate to manage the spectrum. The spectrum can be leased to third parties by the band managers on a profit basis. The mechanism of leasing to be decided based on the institutional circumstances and history of the nation [5].

The positioning of the governance of the spectrum regulators is different from country to country but in general there are two categories,

- The regulator being an independent firm, setup by a statute, with defined responsibilities and capabilities; or

- The regulator being a part of a ministry in government [5]

Spectrum Management: Recent Innovations and Conventional Approaches

In early days, the spectrum assignment by the regulators have been done by providing specific users with a license for a particular purpose. This approach limited the access to the radio spectrum as well as the use of spectrum. A key feature of the administrative approach is that the spectrum manager is empowered to decide the allowed users to access the spectrum. Even though the proposals for spectrum allocation and its usage can be made by the potential users (service providers etc.), actual implementation will be standstill until the actual allocation is done by the regulator. Usage of such kind of approaches are often ineffective and delay the adoption of new technologies.

In recent days, regulators are more focused on producing genuine market opportunities for spectrum and licenses. With this, both the spectrum usage and the ownership can be varied during the license operation. This is a massive change compared to the conventional license auctioning which is not subjected to change in the usage and trading. However, with current regulations it is required to produce the full criteria and specifications of the allowed property rights of trading and utilization of spectrum [5].

2.1.3 Spectrum Management Policy and Planning

Spectrum planning is required to ensure effective and efficient use of spectrum. The prime objective is to ensure the availability of the spectrum when in need. The plans need to be documented and consist of properly defined objectives/ goals. The achieved results to be evaluated against the objectives of the plan and proper measurements to be taken to be aligned to the plan.

Planning could be long term, medium term or short term [5]

- Long term planning which are strategic in nature is essential to envision future spectrum requirements. Time span of these plans are 10+ years. This type of planning should accommodate unforeseen uses which are unpredictable during the inception
- Medium range planning is required to identify the changes needed to spectrum policies to accommodate the evolving needs of the users and technologies. Time span of these plans are 5 to 10 years. Changes could apply to national, regional or local policies
- Short term planning is essential to alter the previous decisions taken on spectrum policies according to the current spectrum governance. Time span of these plans are less than 5 years.

Before planning for the future applications, it is essential to fully understand the current usage of the spectrum. One foremost step in long and medium term planning is to develop a national table of frequency allocations. In most cases, a trade off can be seeing between the need for a stabilized policy and the need of being highly adaptive to the rapidly evolving technology and demand. Investment will not occur if any instability or uncertainty is perceived. Having continuous communications, consultations, and transparency with the stakeholders are very important in the process of policy and plan development for the usage of spectrum.

The spectrum restacking or reallocation is one of the main challenges faced by the spectrum managers and regulators. The reallocation of the frequencies for another use is very difficult when the particular frequency is being used for one purpose for a long time. Some of the approaches used by different spectrum regulators are as follow [5]

- The user to absorb the cost

- The beneficiaries of the change are required or invited to reimburse a part or all of the transition costs associated with the incumbent user
- A refarming fund is established by the regulator using a portion of revenue of the spectrum. Various stake holder groups need to be involved in such a process.

Regardless of the spectrum management approach used, it is important to reduce the possibility of harmful interference. Ensuring that the equipment that use the spectrum allocated meets certain technical standards is one way of reducing such interference.

Authorizing Spectrum Use

Authorization is the process of approval via which users obtain the permission to access the spectrum resources. This could be the assignment of a specific part of the spectrum to the users with or without the rights to spectrum transfer to others or it could be authorizing categories of equipment or a particular equipment for the use. In some occasions, private or public entities may carry out the actual assignment. The spectrum use authorization could be set out in the form of a certificate, a license, a permit or a letter of authority.

Apart from the spectrum authorization, radio communication equipment must be authorized by the spectrum manager for the use even in situations where a license won't be needing. Assuring the standards and specifications are met by the radio communication equipment is a way to mitigate hazard radiation and interference [5].

2.1.4 Spectrum Pricing

The spectrum authorization method used is the main factor contributing to the price of the spectrum. The change in the ownership of the spectrum and used application are allowed in fully liberalized markets. Hence the prices are derived based on the demand and supply of the interaction. During auctioning process, the license is obtained by the highest bidder. In some cases, number of licenses available to auction are reduces by the regulator to create and artificial scarcity. In such cases the bidding amounts will be excessive to win the auction. At the end, the subscribers will be penalized due to higher end consumer prices [5].

Combined approaches of administrative assignment of spectrum with spectrum efficient incentive prices, or administered incentive prices are done by some regulators to handover the unwanted or unused spectrum back to regulators by the licensees. In this approach, the focus is towards gaining revenue or to retrieve the operational expenditure of regulator instead of encouraging the use of spectrum efficiently. The regulators are encouraged to properly control and monitor their operational costs rather than taking above approaches [5].

Lastly, government or users (service providers) should not set the price levels too high as this will be a bottleneck for innovations and network expansion in the country.

It is essential to understand the different methods available to provide the access to the spectrum and the associated commercials. This could be granted based on first come first served basis. In priori planning, spectrum can be reserved for specific users or uses. Economic methods or competitive processes such as auctions or lotteries can be held to determine the frequency allocation for the users [5].

Spectrum Efficient Incentive Pricing

The spectrum pricing is derived taking in to account the relative factors as the spectrum scarcity, the amount being consumed, exclusivity or shared usage of frequencies. Objective of this approach is to achieve efficient usage of spectrum via such incentive pricing schemes. A trade off is commonly seen between fairness and simplicity when establishing these kind of prices [5].

Spectrum Royalties

Spectrum royalty is the payment done to regulator by the licensee based on the revenue generated due to the usage of the license. This could be a percentage of the income of a particular service provider/ mobile operator. In this process the risk of the commercial venture of the licensee is shared by regulator. The royalty agreement terms can be defined by the regulator or could come from a process like an auction. It could be termed as, the company inclined to pay the highest percentage of it's revenue will be awarded with the spectrum. The percentage of revenue can be coupled with other expenses such as annual administered fees. It is regulator's responsibility to assess the risks and benefits of the approach [5].

Lotteries

In this approach the spectrum is assigned randomly to the users usually at zero cost. There is no assurance of the efficient spectrum usage by the lottery winner. In some cases, if allowed, winners may sell their spectrum rights to a third party taking advantage of the situation [5].

Auctions

This is a competitive process used by the regulators to market the available spectrum by offering it up for bidding. Auction designs are of various types, some are in the nature of sealed bids and some are open outcry ascending price auctions which start with a reservation price. Auctions are complex processes, but a duly planned auction can make sure the spectrum will land on the entity who will utilize the spectrum to the fullest. It is regulator's responsibility to ensure that subscribers of that specific service will not be unfairly priced due to the higher biddings.

Having high bidding prices in an auction is a hint to the high demand for the radio spectrum, however, firms who have obtained the spectrums paying a huge sum would be withstood to see more licenses being given for the same use. There can be collusive bidding in auctions which could reduce the revenue to the government [5].

2.1.5 Spectrum Monitoring and Compliance

The spectrum monitoring and compliance is essential as the process helps to identify harmful radiation, interference and to avoid incompatible frequency usage. The usage planning of the spectrum and solution for spectrum scarcity can be perceived by analyzing the occupancy data of the spectrum. To maintain an interference free spectrum assignment, it is required to proactively conduct verification activities related to electromagnetic compatibility, monitor and enforce regulations to ensure user compliance with technical standards and license conditions [5].

Monitoring and Data Collection

The data which are required by the spectrum managers for decision making are collected by spectrum controlling and monitoring activities. The captured data which measure the spectrum utilization and occupancy is used to make assignment which includes frequency band clearing and spectrum reuse. In highly populated areas, the spectrum becomes a scarce resource. The spectrum engineering which consist of band sharing strategy development, tolerance level validation, probability of interference determination is used in such situations to overcome the issues. To support and maintain the authorization activities, spectrum monitoring is used to identify the locations of both illegal and legal transmitters, sources creating interference and any deviations from the approved parameters [5].

Enforcing Compliance

Another key focus of spectrum management is ensuring the users comply with technical specifications, license requirement, rules and regulations. Proactive enforcement procedures are required to ensure the integrity of the process of spectrum management. Appropriate processes and frameworks should be in place by the regulators to settle disputes and to manage complaints from users and public. Remedies, penalties, alternative mechanisms for dispute resolution and enforcement should be considered with the objective of faster resolution [5].

2.2 Spectrum Management Policy in Sri Lanka

2.2.1 Chronology of Reform and Legislation

In 1980, Sri Lanka started improving the telecommunication industry with the establishment of telecom department by the government. In 1991, a public corporation was built by converting the department of telecommunication under amendment of telecommunication no. 25. Telecommunication service operations of both national and international were taken under Sri Lanka Telecommunication Corporation (SLT) due to this change. A license was granted to SLT under the legislation to manage the voice traffic of both national and international. During the same year, as a regulator agency, the Office Director General of Telecommunication was established [6].

The National Telecommunication Policy (NTP) was issued in 1994 by the government. On demand telecommunication facility provisioning, cost based tariffs, communication services in all villages were some of its objectives.

Key Objectives of National Telecommunication Policy

- The achievement of defined goals for communication in both voice and data international and domestic communications
- Waiting lists elimination for telecommunication services
- Effective and prompt attention provisioning to consumer complains and improvement in public relations
- The gradual increment of local contribution in value chain of telecom projects

The Telecommunication Regulatory Commission of Sri Lanka was established under the amendment of Sri Lanka Telecommunications Act No. 27 to create the market competition. The spectrum management, facilitating recommendations on licensing, type approvals are some of the responsibilities of TRCSL. Table 2.1 provides the Duties of TRCSL [6].

Table 2.1: TRCSL Duties

Source: TRCSL: Functions Responsibilities

Constitutions	Objectives	Responsibilities	Functions
Chairman of the commission shall be the secretary to the ministry of the mister.	Ensure provisioning of telecommunication services in both domestic and international segments efficiently and reliably international and domestic.	Create sustainable and fair competition between the licensed operators.	Application processing for licensing.
The office is held by the Director General.	Promote and protect the affairs of purchasers, subscribers, and other users.	Considering the economy of the country and the affordability, reasonable pricing of the telecommunication services	Regulating tariffs.
Three members who are nominated by the minister have distinguished themselves in the field of law, finance, and management and who acquire any recognized qualifications.	Promote and maintain competition effectively between stakeholders engaging in commercial functions.	Controlling and managing of bottleneck facilities and scarce resources promoting good governance.	Ensuring and monitoring of licensed operators for the compliance with the licenses and the act.
	Promote sustainable and rapid growth of telecommunication facilities.	Ensuring all the telecommunication service providers have followed the social guidelines.	Replying to complaints of the subscribers.
			Ensure appropriate usage of the radio frequency spectrum

Until 2002, SLT was the only service provider in Sri Lanka for international traffic. The government of Sri Lanka opened the licensing for international traffic to move away from a monopoly market and to create healthy competition.

With the objectives of updating the Telecommunication act of 1996 and to introduce the communication convergence act, the National Telecommunication Policy was drafted in 2001. It was expected to create a fair competitive environment through the comprehensive regulatory scheme in the Convergence Act [6].

Another significant milestone is the establishment of Information and Communication Technology Agency (ICTA) of Sri Lanka via the Information and Communication Act in 2003 with the aim of ICTA driving Sri Lanka towards digitization and transform to a knowledge based community [6].

2.2.2 Spectrum Policy in Sri Lanka

In the early days Sri Lanka used first-come-first-serve basis spectrum allocations bundled with operating licenses. A new operator is first needed to apply for the system license (eg. data or voice category) and then needed to apply for the allocation of spectrum from TRC. An upfront fee was not paid by the operators but only an annual fee which was derived as per ITU guidelines for the usage of radio spectrum.

The 3G licenses in the 2GHz band was initially offered to the mobile operators in Sri Lanka by TRCSL. Each of the license cost USD 5 million. An expression of interest was given to a new mobile operator by TRCSL in mid of 2006 for 3G telephony at USD 4 million [6].

Later on with the introduction of 4G, an upfront fee as well as an annual fee derived based on the TRCSL guidelines were introduced.

2.2.3 Auction in Sri Lanka

In 2003, an exception incurred to the existing spectrum policy, additional frequencies in 1800MHz range were awarded to four cellular operators via a closed auction.

A transparent auction was brought in by TRCSL to auction 1800 GSM band in April 2003. Only Mobitel PVT LTD and Dialog Axiata PLC participated for the bidding from the list of four mobile operators in Sri Lanka. As only two operators participated for the allocated four slots in auction, lack of competitiveness was noticed in the process. The payment done by the bidders to obtain the spectrum was slightly higher than the reservation price set by TRCSL. Mobitel was awarded with 7.5MHz and Dialog with 6.5 MHz [6].

2.2.4 Spectrum Realignment in Sri Lanka

It was highlighted by the fixed wireless operators that CDMA technology could be a cost effective candidate for FWA, specially targeting the rollout in rural areas. Due to this demand as well as due to the inequities in spectrum assignment, the option of spectrum restacking/ realignment was looked into by TRCSL.

As per the guidelines by ITU, 806MHz to 960MHz band had been allocated for broadcasting, mobile and fixed services for Region 3 under which Sri Lanka is. The mentioned band was only allocated to mobile and fixed services at the time of spectrum restacking in

Sri Lanka. Even though the existing frequency assignments and defense considerations were constraints, WLL and mobile operators' demands were addressed by TRCSL. A consultation paper was set out by TRC in which the frequency scattering was identified, and approaches were proposed to streamline the spectrum assignments.

In October 2004, TRCSL brought out the consultation paper that dealt with the issues of Spectrum Realignment. At the time, initial focus was given to clear out the the existing capacity in the 1800MHz – 1900MHz frequency range. These were recognized as the major bands for future cellular communications.

A main issue with the first consultation paper on spectrum realignment was that it was not being a part of a larger spectrum management strategy which had clearly defined priorities and objectives. Furthermore, after the auction of 1800MHz band, TRCSL went back to an administrative allocation.

The second Consultation paper was issued by TRCSL to address the concerns raised by stakeholders and operators. Following issues were addressed in this.

- Ensure the distribution of the spectrum equally among the mobile and fixed operators
- Payment of Compensation – the operators demanded for an extension of 20 years to their existing licenses along with awarded spectrum in 1800 MHz band as a compensation. The view of the TRCSL was to sell the spectrum in 1800MHz band at the reservation price of the closed auction
- A proposal was brought up by TRCSL to utilize the spectrum in 1900MHz band for Regional Network Telecommunications Licenses

By end 2006, the reallocation process was completed, and all the fixed operators functioned in 800MHz band irrespective of the technology used [6].

2.3 Digital TV and Digital Dividend

2.3.1 Introduction to Digital Dividend

The transition from analog terrestrial television broadcasting to digital terrestrial television broadcasting is well in progress in many countries around the world. Digital television provides improved sound and picture quality along with a vast choice of programmes and channels. Leveraging the frequency required for one analog channel, multiple programmes can be offered simultaneously by the digital TV broadcasters. As the power consumption by the digital broadcasting transmitters are lower than the analog broadcasting transmitters, greenhouse gas emission is expected to reduce when using digital technologies. As multiple programmes can be transmitted simultaneously, it is feasible to reduce the number of transmitters required for broadcasting as well [7].

Since the early days, spectrum in VHF – very high frequency and UHF – ultra high frequency bands have been allocated for analog television broadcasting globally. As the spectrum is efficiently used in digital television, the frequency bands freed up due to analog to digital television switchover can be used for other applications. This is the concept of digital dividend [7].

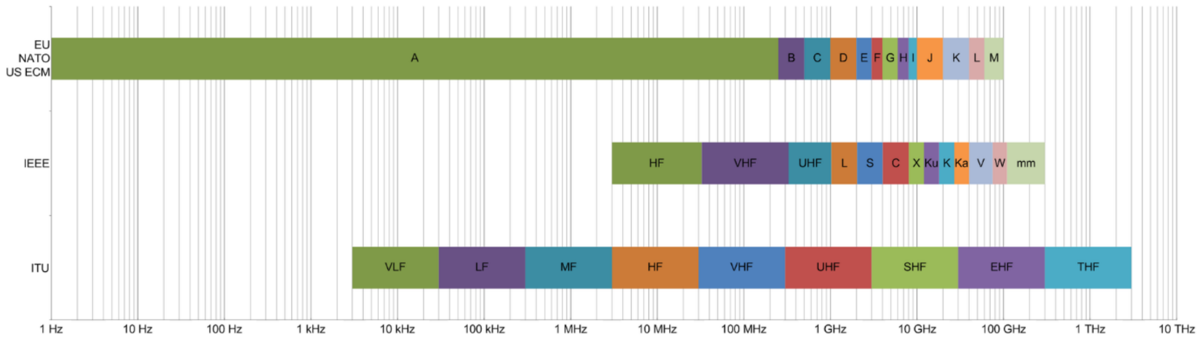

Figure 2.1: Radio Spectrum
Source: Internet: Wikipedia - Radio Spectrum

Around the globe, countries have initiated the planning of analog switch off due to switch over to digital terrestrial television broadcasting (DTTB). Almost all the countries in Europe have successfully completed this process. European countries are migrating to digital TV platforms, which offer subscribers both a wider range of television and radio services compared to analog transmission, as well as a new means to access numerous interactive services and data services. The digital transition offers broadcasters a way to deliver these services more effectively and efficiently: in the case of digital terrestrial television (DTT), the space currently occupied by one analogue channel can accommodate a multiplex of between four and twelve digital channels [2].

As the initial step in transition, broadcasting is made available in both digital and analog as a simulcast service to the viewers. It is expected to switch off the analog service when the digital service is widely spreaded among the viewers. As a means of encouragement to digital switch over, viewers are offered with incentives by the broadcasters. In some cases, government is taking the initiatives to encourage or force both broadcasters and subscribers to switch over to digital terrestrial broadcasting.

The simulcasting of analog and digital terrestrial services is determined by the spectrum availability in that particular country. Due to the spectrum limitations, some countries can launch digital terrestrial television only after analog switch over. Partial switch off of analog services took place in Switzerland before the launch of DTTB services. In countries like

Germany, simulcasting of analog and digital services was possible and time span was 3 to 9 months. In most cases, complete switch off of analog is necessary to build a near universal digital terrestrial television coverage [3] [8].

2.3.2 Benefits of Switch Over to Digital Television Transmission

The key advantage of implementing DTT is the release of the spectrum for other services. In addition to this there are several other advantages by switching on to digital TV [9] [10]. These are summarized in the table 2.2.

Table 2.2: Comparison of Analog vs. Digital TV

Source: Internet: Wonder of Science

Feature	Analog TV	Digital TV
Snowing	The analog signal weakens over distance due to blockages, which result causes snowy pictures	With Digital even at lower signal level, a clear picture can be obtained
Reflection / Ghosting	With analogue signals the multi path reflections from tall building causes ghosting	No ghosting with Digital TV
Resolution	Up to 575 lines (vertical) x 720 pixels (horizontal)	Up to 1080 lines (vertical) x 1920 pixels (horizontal)
Aspect ratio	4:3	16:9 (Widescreen)
Sound	Stereo sound	Multi sound channels (e.g. Dolby 5.1)
Number of Channels	In analog transmission, one frequency channel can transmit only one SD TV programme only	In digital transmission, one frequency channel can be used to transmit four or more SD TV programmes along with audio and data services or one HD TV programme along with audio and data services
Reception	Fixed reception only	Facilitates both fixed and mobile reception
Spectral Efficiency	To cover the service area, will require multiple frequency channels	Based on required quality of services and used technical parameters, one frequency channel can be used to broadcast 4-6 or more digital services
Coverage	To transmit the same TV programmes, different transmitters may use different frequency channels	Use of digital technology for transmission can increase the coverage area, thus minimize the digital divide

2.4 Digital Dividend for Mobile

2.4.1 Introduction

Currently there are more mobile than fixed users worldwide. Mobile promotes competition and allows many more citizens the access to voice (over 3.2 billion worldwide). Studies show that a 10% increment in mobile penetration gives a 0.6% boost to GDP growth in developing markets (source London Business School). Mobile economic benefit can approach 8% GDP (Philippines – source McKinsey) [3].

If around 100MHz or 25% of the spectrum utilized by analog television broadcasting (470MHz to 862MHz) can be reassigned to mobile services, fewer network infrastructure is needed to provide a broader mobile coverage due to the better signal propagation with low frequencies. This could be an ideal means to provide mobile coverage to rural areas at a minimal cost [3].

It is expected that the exponential growth in the broadband industry will be mainly driven by mobile broadband [11]. Refer figure 2.2

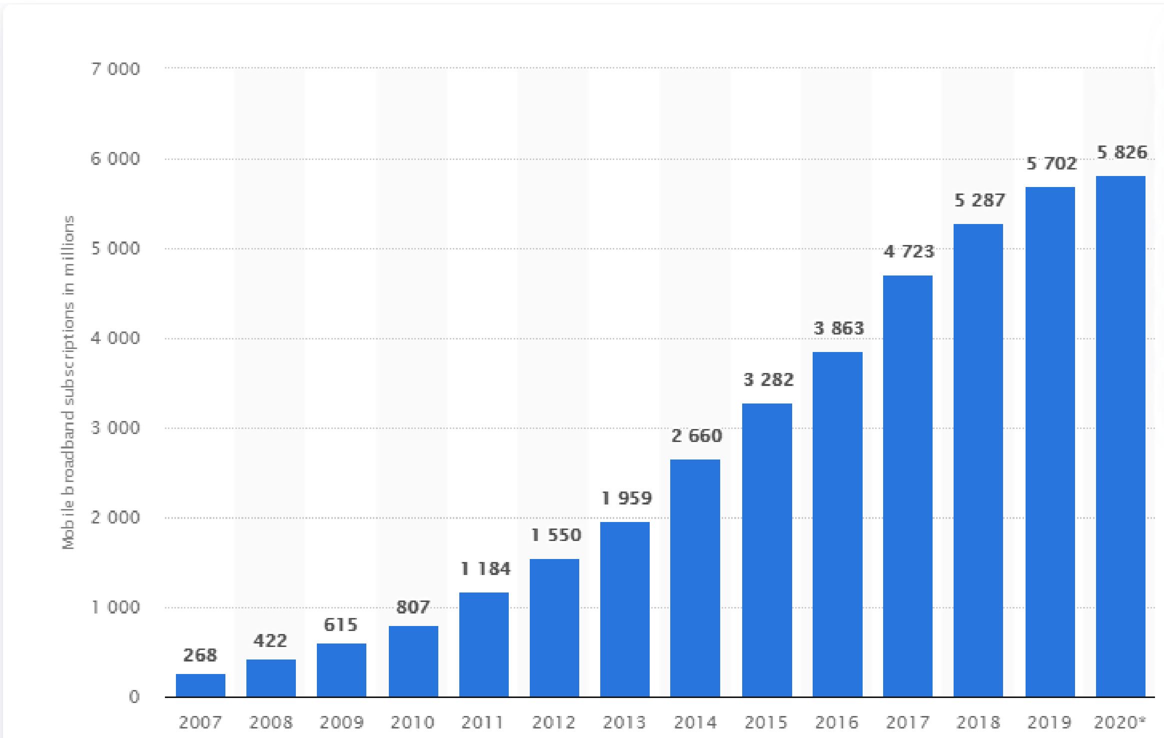

Figure 2.2: Global Mobile Broadband Active Subscriptions
Source: Internet: Statista

2.4.2 Impact of the WRC-07 on Terrestrial Bands

In 2007, WRC-07, the World Radio communication Conference 2007 was held in Geneva to analyze the radio frequency usage globally and to revamp the regulations for radio communications which is the international framework for the governing of frequency spectrum usage and satellite orbits [8].

2.4.3 Agenda Item 1.4

Under this, a main issue faced by the broadcasters was tabled for discussion, the allocation of frequency bands from 470MHz to 862MHz for mobile services which are currently reserved for conventional broadcasting. At the time broadcasting was the primary service, a request was received from some countries to provide a co-primary status for the mobile services.

The United States delegations supported the allocation of these bands for mobile services globally as this allows the wireless services development worldwide without needing to fear for market fragmentation. Every country under Region 2 and some countries in Region 3, including India and China, consented to this proposition allowing the use of frequencies from 698MHz to 862MHz for mobile services. Region 1 counties and the remaining countries of Region 3 however have mobile services limited to a smaller range of frequency [8].

Heated debates were raised for the European countries and arrived at a common ground after several long discussions. The agreement was to allocate frequency range 790MHz – 862MHz after 17th of June 2015 for Region 1 countries and Iran as per the agreement of Geneva 2006 (GE-06). However, all the countries did not agree to this compromise, 65 countries decided the immediate availability of these frequencies for mobile communications in two footnotes (5.316 and 5.316A) [8].

2.4.4 Resolutions Protecting Broadcast Services

In the final acts of WRC-07, two resolutions were agreed by all the national administrations to avoid hazardous situations due to mixing of broadcast services and mobile services in the same frequency range.

The measures in the GE-06 agreement are considered for the first resolution. Number 224 to protect the broadcast services from the interferences caused by international mobile telecommunications (IMT) services. The resolution emphasis that all the IMT services shall be subjected to the procedures defined in GE-06. In addition, it is essential to discuss and mutually agree with neighboring countries prior to any type of implementation of mobile services carried out in the frequency range 790MHz to 862MHz. Thus, the broadcast services are safeguarded from the establishment of mobile services by the resolution [8].

The Com 4/13, the second resolution is landed on ITU to study the usage impact of the frequencies from 790MHz to 862MHz by mobile services. It is important to determine the impact on broadcast services due to the introduction of non-broadcast services in the same frequency range. This resolution give the significance to protect the services to which the frequency range is currently applied [8].

2.4.5 UHF Band Allocation to Mobile

Below Table 2.3 is the allocation of UHF band arrived at WRC 07 [3].

Table 2.3: Spectrum Band Allocated for Mobile

Source: Internet: ITU

450MHz - 470MHz	• In Canada and US: no intended use • Most of the European countries will not use for implementation
698MHz - 862MHz	• Region 2: North and South America • Region 3: Nine countries inclusive of China, India, and Japan
790MHz - 862MHz	• Regions 1: Middle East, Africa and Europe • Region 3: All the remaining Asia Pacific
2.3GHz - 2.4GHz	• In Canada and US: no intended use • Most of the European countries will not use for implementation
3.4GHZ - 3.6GHz	• Region 1 (EMEA): primary basis on mobile allocation and identification for IMT in 82 countries by country footnote • In Region 2 (Americas): primary basis on mobile allocation in 14 countries (not in US or Canada) • Region 3: primary basis on mobile allocation and identification for IMT in some countries:

2.4.6 Optimal Frequency for Mobile

2 x 30 MHz slots with an 11 MHz duplex gap is the recommended plan for 790Hz - 862Hz. [11] [12] Refer Figure 2.3

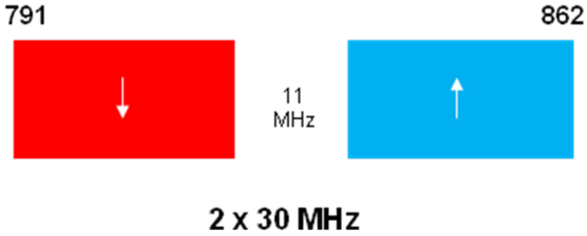

Figure 2.3: Optimal Frequency for Mobile
Source: Author

2.5 5G Cellular Technology

2.5.1 Introduction to 5G

5G is the latest commercially available standard for cellular communication technologies and is the successor of the 4G networks. The overall performance is significantly boosted by the new 5G network architecture compared to 4G. 5G offers latency in millisecond level, data rates over 10Gbps and ultra dense connections. 5G will be one of the key enablers of industrial revolution 4.0 (IR4.0) opening up unlimited opportunities due to its key features [13].

In 2035, 5G is expected to enable a global economic output of USD 13.2 trillion which is nearly equivalent to the combined spending of consumers in Japan, China, UK, France and Germany in 2018 (USD 13.4 trillion) [13].

2.5.2 5G Spectrum Requirements Across Multiple Layers

The 5G vision of ITU-R IMT-2020 comprises of three application scenarios: enhanced mobile broadband – eMBB, massive machine type communication – mMTC, and ultra reliable low latency communication – uRLLC. The key performance indicators (KPI) of 5G has huge improvements compared to the previous cellular generations [13]. Refer Figure 2.4

5G requires the access to frequency bands in high, mid and low ranges to fulfill the diversified needs of different types of envisioned usage scenarios. Specific characteristics from different segments of spectrum is exploited by 5G: Frequency range 2GHz to 8GHz (eg. 3300-4200, 4400-5000, 2500- 2690, 2300-2400, and 5925-7125 MHz) coupled with spectrum below 2GHz (eg. 700MHz) and more than 8GHz (eg. 24.25-29.5 and 37-43.5 GHz). An

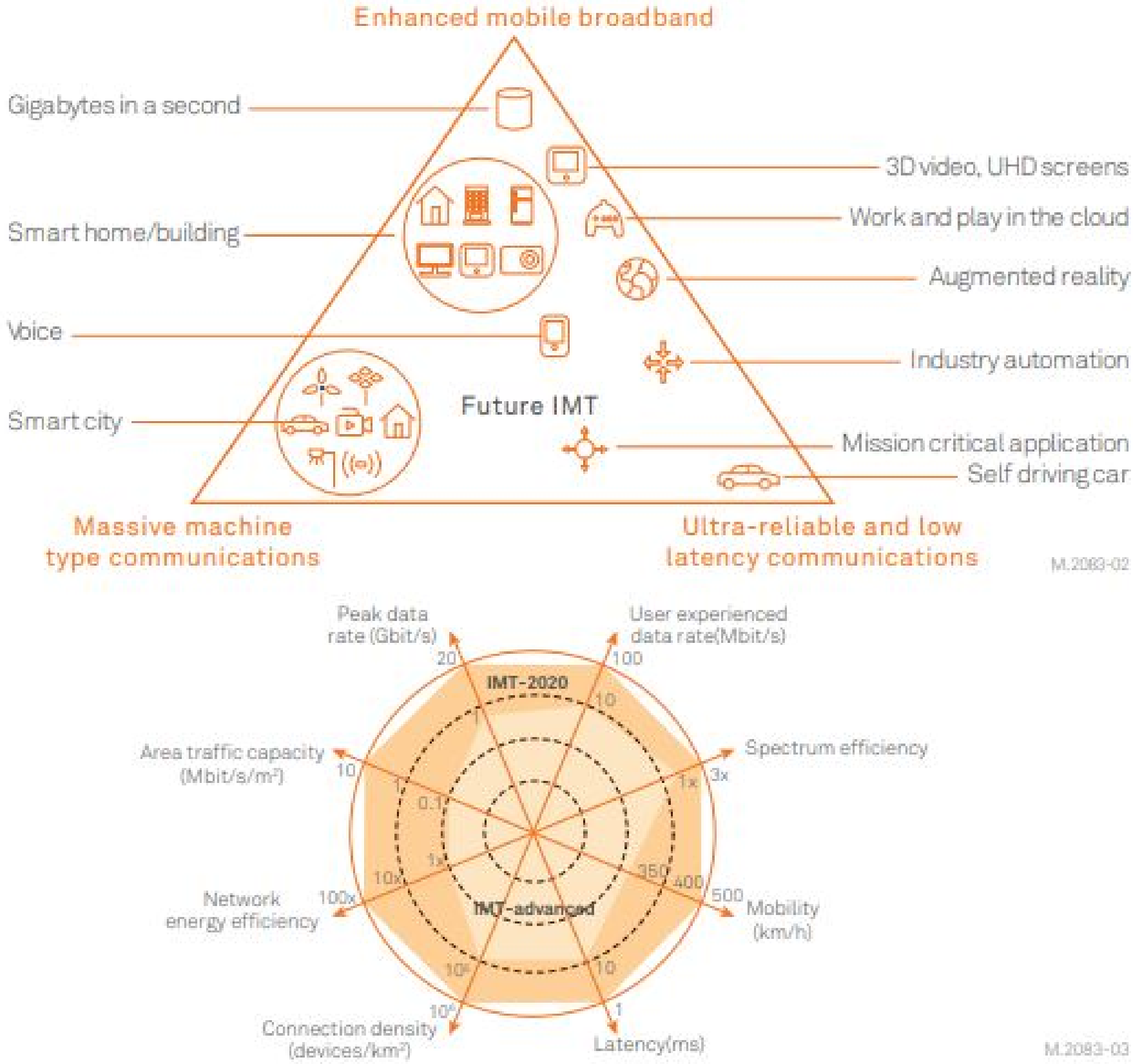

Figure 2.4: IMT-2020 Usage Scenarios and Key Capabilities
Source: Publication: Huawei 5G Spectrum Public Policy Position

adequate quantity of harmonized spectrum in each band should be given to the mobile operator in a timely manner by the regulator to implement 5G services. The allocation of adjacent spectrum in each band will reduce the network cost, improve the energy efficiency and reduce the carrier aggregation related system complexity [13]. Refer Figure 2.5

Mid bands provide the best compromise between high capacity and the wide area coverage. The frequency range between 2GHz to 8GHz is pivotal to address most of the 5G application scenarios. It is recommended to potion 5G with mid band range as eMBB services will be dominating during the initial stage of 5G. A contiguous spectrum bandwidth of no less than 80MHz to 100MHz from the mid band range should be allocated to each mobile operator for 5G as the initial step of the 5G multi layer spectrum allocation process [13].

Figure 2.5: Multi-layer Frequencies Approach for 5G Usage Scenarios
Source: Publication: Huawei 5G Spectrum Public Policy Position

Low band which is below 2GHz frequency range, provides the 5G penetration to deeper indoor areas and broader field. Services in mMTC and uRLLC will be greatly benefited by broader coverage at low bands. The low band frequencies (e.g. 700, 800, 900, 1800 and 2100 MHz) can be used for spectrum sharing of uplink of NR/ LTE to ensure cost effective deployment and faster network rollout [13].

High band which is above 24GHz range will address 5G eMBB applications which requires extreme data rates. It is advisable to allocate a contiguous spectrum bandwidth of no less than 400MHz to 800MHz from the high band range to each mobile operator for 5G during the later stages in 5G multi layer spectrum allocation process [13].

Low Bands

Releasing the mid band range is the initial step of 5G deployment as it can facilitate the eMBB service requirements. In order to provide wider and deeper 5G coverage, low frequency division duplexing (FDD) bands are used coupled with mid frequency bands. Taking in to consideration that large capacity requirements are low in some markets, low bands can be used to facilitate 5G during the early stages as well. New FDD in low band range as 600MHz or 700MHz can be utilized to establish a dedicated 5G spectrum while sharing the existing FDD bands in 2G, 3G and 4G via DSS – dynamic spectrum sharing. To address the coverage obligations commonly associated with the spectrum usage rights, low bands can be used to obtain better coverage in 5G [13].

5G NR Operating Bands in FR1 (3GPP TS 38.104 V15.7.0) are given in the Table 2.4 [1] [13]

Table 2.4: 5G NR Operating Bands in FR1

Source: Publication: Huawei 5G Spectrum Public Policy Position

NR Band	Uplink Band	Downlink Band	Duplex Mode
n1	1920-1980MHz	2110-2170MHz	FDD
n2	1850-1910MHz	1930-1990MHz	FDD
n3	1710-1785MHz	1805-1880MHz	FDD
n5	824-849MHz	869-894MHz	FDD
n7	2500-2570MHz	2620-2690MHz	FDD
n8	880-915MHz	925-960MHz	FDD
n12	699-716MHz	729-746MHz	FDD
n20	832-862MHz	791-821MHz	FDD
n25	1850-1915MHz	1930-1995MHz	FDD
n28	703-748MHz	758-803MHz	FDD
n34	2010-2025MHz	2010-2025MHz	TDD
n38	2570-2620MHz	2570-2620MHz	TDD
n39	1880-1920MHz	1880-1920MHz	TDD
n40	2300-2400MHz	2300-2400MHz	TDD
n41	2496-2690MHz	2496-2690MHz	TDD
n50	1432-1517MHz	1432-1517MHz	TDD
n51	1427-1432MHz	1427-1432MHz	TDD
n66	1710-1780MHz	2110-2200MHz	FDD
n70	1695-1710MHz	1995-2020MHz	FDD
n71	663-698MHz	617-652MHz	FDD
n74	1427-1470MHz	1475-1518MHz	FDD
n75	N/A	1432-1517MHz	SDL
n76	N/A	1427-1432MHz	SDL
n77	3300-4200MHz	3300-4200MHz	TDD
n78	3300-3800MHz	3300-3800MHz	TDD
n79	4400-5000MHz	4400-5000MHz	TDD
n80	1710-1785MHz	N/A	SUL
n81	880-915MHz	N/A	SUL
n82	832-862MHz	N/A	SUL
n83	703-748MHz	N/A	SUL
n84	1920-1980MHz	N/A	SUL
n86	1710-1780MHz	N/A	SUL

5G NR Operating Bands in FR2 (3GPP TS 38.104 V15.7.0) are given in the Table 2.5

Table 2.5: 5G NR Operating Bands in FR2

Source: Publication: Huawei 5G Spectrum Public Policy Position

NR Operating Band	Uplink (UL) and Downlink (DL) operating band BS transmit/receive UE transmit/receive	Duplex Mode
n257	26500-29500MHz	TDD
n258	24250-27500MHz	TDD
n260	37000-40000MHz	TDD
n261	27500-28350MHz	TDD

2.6 Analog Shut Off in Other Countries

2.6.1 European Union

As per the European Commission, Europe is following a coordination approach and in the process of switching from analog to digital television [7]. The focus of the Commission is to provide advantages of digital television to the end consumer and along with the evolving interactive services. Various types of transmission platforms will be available to the user to enjoy the services as IPTV solutions, satellite, cables, mobile and terrestrial.

Countries in European Union has gradually switched off the analog transmissions and moved towards digital broadcasting. The analog shut off is completed in almost all the countries such as Norway, Austria, Luxembourg, Croatia, Denmark, France, Greece, Hungary, Ireland, Netherlands and only a few borderline countries are remaining.

In Europe, the frequency band 790MHz to 862MHz is used for digital dividend which is significantly different to most of the countries in region 3. For international mobile telecommunication services below frequency band is considered at European Consumer Centre;

- Downlink: 790MHz to 820MHz. Uplink: 832MHz to 862MHz
- 42MHz of duplex separation for 30+30MHz FDD along with a 12MHz centre gap from 820MHz to 832 MHz [14]

2.6.2 Australia

Australia is adopting DVB-T/ T2 standards for digital terrestrial broadcasting. The work commenced in January 2001 in main cities as Melbourne, Perth, Sydney, Adelaide and

Brisbane. In June 2010, the shutting off of analog transmission was begun and by December 2013 it was completed [15].

Transition to digital television was very slow at the initial stages. Around 28% of households in Australia had adopted digital terrestrial by March 2007 even though around 96% of them had access to minimum of one digital service. By mid of 2010, 75% of them had transitioned to digital television and by the end of 2013, analog transmission was completely shut off nationwide [7].

2.6.3 India

Phase-wise deadlines have been set by the Telecom Regulatory Authority of India to shut off the analog transmission completely as below;

- Phase 1 (target: metro cities): 31st December 2019
- Phase 2 (target: cities with population over one million): 31st December 2021
- Phase 3 (target: reaming): 31st December 2023

Out of these, the Phase 1 is successfully completed as at August 2021.
The key points noted on analog shut off plan in India are as follows; [14]

- Primarily, frequency band from 470MHz to 890MHz is assigned for Broadcasting, Mobile and Fixed services
- Mobile and fixed services related requirements will be facilitated in the range 470MHz to 520MHz and 520MHz to 585MHz based on the need arise
- The frequency range 585MHz to 806 MHz is predominantly allocated to broadcasting services in India. Being vigilant on above, the range 698MHz to 806MHz is considered for broadband wireless access and mobile telecommunication services on case by case basis
- Mobile, satellite services and broadcasting is considered in the range 806MHz to 890MHz case by case basis

2.6.4 Japan

In July 2010 as a pilot trial, the analog switch off started in Suzu, Ishikawa. By July 2011, the remaining area of Ishikawa along with another 43 prefectures terminated the analog terrestrial transmission. The remaining three prefectures along with analog satellite service joined the shut off by March 2012.

By September 2007, analog television broadcasting was terminated in Japan leaving only analog cable services alive. A mandate was given to analog cable services to digital switch over by the government. From December 2003 to March 2012 was the simulcast period of Japan and nationwide analog transmission ended in 2012.

2.6.5 United States

February 2009 was the deadline set up by the US government to complete the transition to digital broadcasting nationwide. This was extended till June 2009. Conversion of nightlight and low power stations were exceptions to the above deadline. The new timeline for digital transition for translator and low power stations fell in September 2015 but was suspended in April 2015 due to concerns related to forthcoming spectrum auction for 600MHz. With the completion of auction in 2017, The Federal Communications Commission announce July 2021 as the new deadline for low power stations to switch off analog transmission. An extension was granted by the FCC in June 2021 to the state of Alaska to complete the analog shut off by January 2022 [1] [7] [16].

2.7 Optimal Frequency for Digital Terrestrial Television

The optimal frequency to be assigned for DTT based on a number of factors is discussed below.

2.7.1 Antenna Efficiency Facts

Integrated antennas have been used in mobile phones for past few years where users are fond of the easy practical usage. Commercial acceptance of external antennas will be very difficult to achieve. Thus, the antenna in the DVB H needs to be an integrated antenna. Key factors to be considered for antenna efficiency is given below [17]

The size of the antenna will be small, probably in the order $\lambda/10[6.4–3.5cm]$.

- Efficiency of radiation is directly proportional to volume of the antenna
- Real part of the antenna impedance will be small, most of the radiation comes from the ground plane [70%]
- The radiation in ground plane is smaller compared to λ

Resonant designs are impossible for high frequency range (UHF)

- Matching circuit which is tunable has to be designed
- Matching small resistive part of the antenna to receiver input with tunable circuit will be lossy
- Achievable antenna gain will be very low, in the order of -5dBi to –10 dBi

Combining VHF III to this kind of antenna would mean extremely low antenna gain, much less than –20 dBi.

- VHF III is unpractical and should be totally discarded

Table 2.6: Frequency vs Antenna Gain

Source: Report ITU-R BT.2140-3

Frequency [MHz]	Gain [dBi]
474 [channel 21]	-10
698 [channel 49]	-7
858 [channel 69]	-5

2.7.2 Interoperability with GSM

Frequency range proposed for DVB T/H is shown in the Figure 2.6 below

Considering the interference from wanted and unwanted signal the recommended maximum frequency that can be used for DVB T/H is 698 MHz.

2.7.3 Other Frequency Bands Available for DVB H/T

DVB-H has been piloted successfully with 1.6 GHz / 5MHz in the US. Although technically higher frequencies would deliver antenna gains by 5dB, it is not recommended due to the following reasons.

- Higher building penetration loss
- Smaller cells
- Higher number of transmitters
- Network cost for good indoor coverage will be higher than in UHF

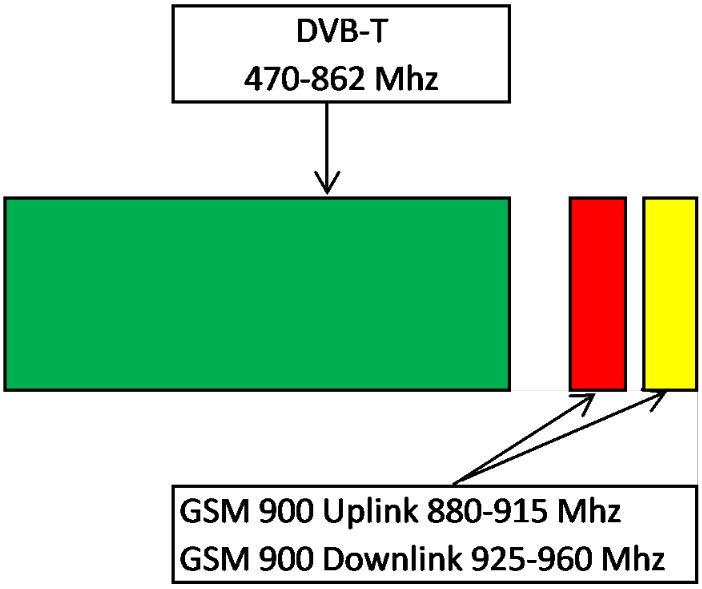

Figure 2.6: Frequency Range for DVB H/T
Source: Report ITU-R BT.2140-3

2.7.4 Optimal Frequency for DVBH/T

- Integrated DVB-H wideband antennas will have fairly low gain
- Only UHF should be considered, VHF III is not a practical band for hand held reception
- VHF III is well suited for normal fixed/portable digital television with DVB-T
- Interoperability with GSM 900 limits the usable UHF-band to 474 MHz (Channel 21) - 698 MHz (Channel 49)
- Higher frequencies are not recommended as it will not provide the most cost effective solution.

Chapter 3

Methodology

Based on the literature, although Sri Lanka has been quick in introducing the latest technologies, the spectrum allocation to facilitate digital TV has been adhoc based on the operator request rather than on clear objectives and a spectrum management plan. To formulate the spectrum policy framework for digital dividend in Sri Lanka, first the procedures followed by other countries for analog to digital TV switchover was analyzed which includes the spectrum allocation and analog shut-off approaches. Furthermore, the impact to the key stakeholders of analog shut-off both in social and economical aspects were analyzed along with digital TV transmission technology and success factors for analog shut off. Finally, the mobile coverage area which can be obtained from the freed-up spectrum was analyzed against the current spectrum in use.

3.1 Spectrum Allocation

The spectrum allocation approaches adopted in various countries was analyzed in this thesis to identify the optimal method for Sri Lanka, with special attention on the movement from the administrative approach to a market driven approach of spectrum management. Spectrum management policy in Australia, UK, India, Guatemala, Malaysia and Singapore has been considered for the analysis.

Both qualitative and quantitative data were gathered from the reports, publications and interviews with the Telecommunications Regulatory Commission of Sri Lanka (TRCSL), the International Telecommunication Union (ITU), and other authors.

3.2 Analog Shut-Off

Analog shut off implemented in Europe, US and Asian regions was analyzed here to understand the criterion for success, key stakeholders involved, impact on timing of the analog shut off and technologies used for digital TV, to deduce the optimal implementation for Sri Lanka.

It was identified that the government, analog broadcaster and the television subscriber are the three key stakeholders of analog shut off. Impact to each stakeholders were analyzed to formulate the policy frame work.

Data were gathered from the government publications of the respective countries and the reports from the International Telecommunication Union (ITU).

3.2.1 Subscriber

To view digital television, the subscriber is required to purchase a decoder (if the current television set is analog) or purchase a digital television set. The analog television penetration per household, the income and expenditure per household in Sri Lanka and the current cost of decoders were analyzed to identify the affordability and total cost to the subscribers due to digital TV transition.

Data were gathered using the reports; Economics and Social Statistics of Sri Lanka 2020 by Central Bank of Sri Lanka and Household Income and Expenditure Survey by Department of Census and Statistics.

3.2.2 Broadcasters

To broadcast the digital terrestrial television, the broadcasters need to change its current infrastructure as well as train the staff to install, operate and maintain DTT infrastructure and services to required standards. The approach taken by the other countries to implement the digital TV infrastructure, analog TV broadcasters information and high-level cost of infrastructure to convert to digital TV was analyzed.

Required data were gathered from the reports and interviews with representatives from Ministry of Mass Media, Telecommunications Regulatory Commission of Sri Lanka (TRCSL) and the International Telecommunication Union (ITU).

3.2.3 Government

In addition to educating the subscriber, the government needs to ensure that the broadcaster and the subscriber are inline with the implementation of analog shut off. To facilitate this government will required to provide compensation and support where necessary. The approaches taken by the governments of various countries were assessed to deduce best approach to Sri Lanka.

3.3 Digital Dividend

The current internet penetration, mobile density and mobile data demand growth in Sri Lanka have been looked at in order to identify the need of allocating the spectrum for mobile broadband in Sri Lanka.

The data were gathered from Digital Sri Lanka 2021 by DataReportal and Statista.com for the above analysis. Furthermore, a simulation of the coverage area which can be obtained from the freed-up spectrum was created using Infovista Planet, RF planning software and optimization tool to verify the benefit of the released spectrum. The results were compared against the current 5G spectrum in use.

The qualitative and quantitative data gathered above were structured to formulate the spectrum policy framework for digital dividend in Sri Lanka.

Chapter 4

Analysis

4.1 Spectrum Allocation

4.1.1 Spectrum Management Policy Changes

In general, there is a prominent movement from administrative based spectrum management towards a market driven spectrum management. In countries that have moved towards a market driven spectrum management, there has been a significant increase in the growth of the telecommunication industry post spectrum management reforms in addition to the efficient use of the spectrum. Auction and spectrum trading have become the key methodology of spectrum assignment. Below are some case studies to illustrate this trend.

Australia

Australia moved towards a market driven spectrum policy at a very early stage and has been one of the pioneers in Spectrum auction. The first auction was conducted in 1994 and auctions have been carried out on a regular basis since then. Furthermore, in 1997 spectrum trading was introduced in Australia. This enabled licensees who wish to trade part of a license to sub-divide the license into its component STUs (Standard Trading Unit - a small commodity-like unit of spectrum that would seem to be easily tradable) and sell them individually or in multiples [15].

United Kingdom

In the UK, auction was authorized in 1998, and the first auction took place in the year 2000. The first auction for 3G was hailed a success. The 2nd Auction (fixed wireless broadband) however was not successful with 60% licenses remaining unsold. Re-auction was done after some time with changed terms to allow a broader range of uses. In 2013, spectrum auction for 4G cellular technology took place and Everything Everywhere Ltd was the highest bidder with £588,876,000 base price [18].

India

Compared to its counterparts, India has a unique spectrum assignment policy. Only an initial allocation of spectrum will be received to the cellular operators who are newly licensed. Additional spectrum is assigned based on the subscriber growth on a first come first served basis. This has proven to give rise to very efficient spectrum utilization, promoting high levels of competition and also keeping sufficient provision for new entrants. However, the large number of operators in India in each circle limits the opportunity for existing operators and entrants to obtain capacity [19].

For the 3G frequency assignment, it is evident that India too has chosen the auction process as this is a more effective method of allocating the spectrum. Over 34 days the auction was administered along with 183 bidding rounds. Altogether 71 frequency blocks were auctioned in 22 service areas and whole lot were sold without any leftovers [20]. The government earned 167 Billion Indian rupees [21] (400 Billion Sri Lankan Rupees). BSNL and MTNL were awarded spectrum one year before the private companies were, on the condition that they would match the price at which the winners of the auction are allotted the spectrum [22]. This brought the total earning of the government to 677 Billion Indian rupees (1,635 Billion Sri Lankan rupees).

The key reason for the high earnings made by the government which is nearly double the expected earnings is clearly due to several factors: the scarcity of the spectrum, the high market potential in India and the high competition as a result of the high number of operators in India.

Guatemala

In Guatemala, from 1996 the spectrum was treated as a commodity in the same way real estate is. The established law in 1996 specially mentions that consolidating, subdividing, selling or leasing of Títulos de Usufructo de Frecuencias (TUF) is possible for a limited duration (fifteen years). It is also feasible to use the TUF as an equity exchange for an investment. Mediation between themselves is encouraged during conflicts. Telecommunication regulators has enforced rules during a failure of a private mediation. In addition to above, the party which is injured is eligible to prosecute for compensation in courts [23].

The regulator has issued more than 5,000 TUFs since 1996. For the Usufructo titles, 13,000+ applications have been received to SIT since the beginning. 80+ auctions were resulted due to 4,300+ applications which were for expression of interest. There are more than 1,050 owners of TUFs in Guatemala. By 2003, the revenue generated by auctions were over US$130 million [23].

It is a clear sign that there is an evolving secondary market when looking at the quantity of endorsements of TUF. By 2002, 26% of TUFs were issued. This view of secondary market is incompleted as there could be leasing of rights. As SIT was not reported with this commercial activitiy, the data is scarce [23].

According to available data there has been a significant growth in the market post 1996 [23].

- 1996-2001 total number of telephone users increased compound rate of 38% as against the 9% seen from 1985-1995
- Mobile sector in Guatemala has grown 1.5 faster than the Latin America on average
- Up to 1999, mobile subscribers' and television receivers' GDP of Guatemala was behind Latin America. Post 1999, it caught upto Latin America and has gained a substantial increment in the recent years

Malaysia

Malaysia's regulator the Malaysian Communications and Multimedia Commission (MCMC) conducted an auction for LTE in 2012. The spectrum 2.6GHz 4G licenses was awarded to eight companies. Furthermore, they are currently conducting a consultation for the reframing of 2G and 3G spectrum at 850MHz, 900MHz and 1800MHz for 4G. Here too we see the use of a market driven spectrum amendment policy as opposed to an administrative policy [24].

4.2 Analog Shut-Off

4.2.1 Analog Shut-Off in Other Countries

Analog shut off is already being completed in most of the European countries as Germany, Finland, Luxembourg, Sweden, the Netherlands, Belgium. US and Australia has completed the transition. In the Asian region digital terrestrial transmission is completed in Singapore, Malyasia, Japan etc. and launched in countries such as in India, China etc. [14].

Timing of Analog Shut-Off

Based on the cost model developed in UK by the Department of Trade and Industry (DTI), the Department for Culture, Media and Sport (DCMS), and (up to December 2003) the Radiocommunications Agency (RA) it can be seen that the switch off of analog is more beneficial than using both analog and digital at the same time. This is due to the additional cost of maintaining both the analog and digital systems simultaneously [25].

- More set top boxes will require changing or upgrading and more subscriber aerials swapped
- More re-planning of broadcasting networks will be needed

In some countries analog and digital terrestrial television was offered simultaneously, while in others digital terrestrial television broadcasting was launched upon the switch off of analog broadcasting. This is mainly driven by the spectrum availability as well as dependency of viewer on the terrestrial television transmission. Due to the high cost, simultaneous broadcast is not the optimal solution, and switch to digital terrestrial television transmission took place upon analog shut off.

In countries such as Luxembourg, the Netherlands and Switzerland analog shut off took place quickly as they are highly cabled countries and thus low dependency on analog terrestrial television.

In Germany, where there is a high dependency on terrestrial television, simultaneous transmission was done. However this was limited to a period of 3-9 months.

In Austria, Germany, Norway, UK, US and Sweden phased approach was followed where the analog shut off was done in low populated areas to minimize the impact. Learning from that area was used for the next area [8].

In the Asian region in countries such as Japan, Malaysia and Singapore digital terrestrial transmission was offered alongside analog transmission [1].

Government Initiatives

In countries where analog shut off took place the government has taken the lead in ensuring the smooth transition. This is visible in most European countries and the US. The governments have made a special effort in educating the subscribers. Subscribers have been educated continuously and concessions in the form of coupons have been offered to the subscriber to purchase decoders required by the analog television to receive digital signals. The government has taken the lead and formed several committees to lead this task (especially in the European countries). It must be noted that the scheduled shut off date has been postponed (e.g. – US) since the subscribers were not ready for the analog shut off.

Concession to Subscribers

Existing analog television sets can be used if decoders are used to view digital television transmissions. A concession can be offered to the subscribers in coupons to purchase the above mentioned decoders. A 40 USD worth of coupon was provided to each household in the US and yet the analog shut off date had to be postponed as all the subscribers had not purchased the decoder on time. There are guidelines published by European Commission with regard to the aid, which can be provided by government to smoothen the transition. In the UK, special concessions were offered to households with senior citizens (over 75 years) and citizens with disabilities. The charity organizations were approached by government to offer concession to the households which do not fall under the above mentioned categories. [8]

Concession to Broadcasters

It is observed that in other countries, the number of broadcasters to whom spectrum was allocated for analog terrestrial transmission is very much lower than the 14 broadcasters in Sri Lanka. Also in some locations the dependency of analog terrestrial transmission was lower due to the high availability of alternates such as satellite and cable television. However concessions have been provided to existing broadcaster in some instances. In Germany aid was provided to encourage the private broadcasters to join the transition [8]. However in Europe such subsidies require the consent of the European Commission to avoid claims of market interference.

4.2.2 Analog Shut-Off in Sri Lanka

Currently there are around 22 TV programmes broadcasting in Sri Lanka as mentioned in the Table 4.1.

Table 4.1: List of Television Programmes in Sri Lanka

Source: TRCSL: List of Channels 2019

TNL	Rupavahini	Eye	ITN
Vasantham	Hiru TV	Varnam	Swarnawahini
Sirasa	Siyatha	Shakthi	ART TV
Derana	MTV	TV1	CCTV
Yathra	Nethra	ETV	Buddhist TV
Shraddha	Rangiri		

Table 4.2 depicts the current status of the frequency channels usage in Sri Lanka

Table 4.2: Current Status of Analog Broadcasting

Source: TRCSL Publication

Description	Quantity
Number of TV programmes	22
Number of frequency channels used for ATT	48
Channels in VHF (30 - 300MHz)	09 (CH3 - CH12)
Channels in UHF (300 - 3000MHz)	39 (CH21 - CH47, CH49 - CH58, CH60, CH62)
Reserved frequency channels for DTT by TRCSL	Location: CH 33, 36, 38, 39, 40, 59 Island wide: CH 41, 43, 44, 50, 61, 62

Impact on Subscriber

Television penetration per household is depicted in the table 4.3 below. The highest penetration is shown to be in the Western province. However it must be noted that even in the urban and rural areas there is a relatively good television penetration [26]. It is clear that a change in the Television technology would affect majority of the population in Sri Lanka as there is a large percentage of subscribers dependent on analog terrestrial television.

Table 4.3: Television Penetration per Household

Source: Economics & Social Statistics of Sri Lanka 2020 by Central Bank of Sri Lanka

Province	Television (%)
Western	90.9
Central	87.7
Southern	87.8
Northern	72.2
Eastern	15.1
North Western	85.3
North Central	87.7
Uva	85.2
Sabaragamuwa	87.0
All Island	86.3

Table 4.4 below depicts the income and expenditure per household, monthly savings and expenditure on recreational activities [27]. The current cost of the decoder ranges from 15 - 90 USD, based on the technology selected. As shown in Table 4.5, the sum of both monthly savings and spend on recreational activities can be assumed to be the spend power or the additional sources of financing digital television conversion. It is however important to keep in mind that using this monthly saving for digital television conversion or for other needs will depend purely on the subscriber's choice.

Table 4.4: Income, Expenditure, Recreational Spend and Savings per Household

Source: Household Income and Expenditure Survey by Department of Census and Statistics

Province	Mean Household Income (LKR)	Mean Household Expenditure (LKR)	Entertainment and Cultural Activities (LKR)	Monthly Savings (LKR)
Western	84,231	74,505	1,463	9,726
Central	53,053	50,334	668	2,719
Southern	59,375	52,271	877	7,104
Northern	46,081	42,537	410	3,544
Eastern	43,168	38,407	216	4,761
North Western	60,398	55,514	725	4,884
North Central	60,298	48,176	533	12,122
Uva	51,635	39,140	545	12,495
Sabaragamuwa	49,057	42,810	1,196	6,247

Table 4.5: Spend Power per Household

Source: Economics & Social Statistics of Sri Lanka 2020 by Central Bank of Sri Lanka

Province	Spend Power Per Household (LKR)
Western	11,189
Central	3,383
Southern	7,981
Northern	3,954
Eastern	4,977
North Western	5,609
North Central	12,655
Uva	13,040
Sabaragamuwa	7,443

Impact on Broadcaster

Allocation of the new spectrum to 14 broadcasters to convert their own transmission infrastructure will not be cost effective to the broadcaster. Other countries have on average 3-6 broadcasters to provide the transmission facility. In Sri Lanka it has been estimated by the government that the loss to the operator would be around 130 million LKR [28]. To identify the exact loss to the broadcaster, an evaluation would need to be done based on the current transmission facility of each operator.

Frequency Allocation for Analog Shut-Off in Sri Lanka

The frequency allocated in Sri Lanka for VHF and UHF (up to channel 62) per location is public information provided by TRCSL but the frequency assignment beyond 806 MHz is only known per operator and not per location.

Based on the analysis done in the previous chapter the optimal frequency for DVB H/T is 474 MHz (Channel 21)- 698 MHz (Channel 49).

Sri Lanka falls under the category of Region 3, thus the spectrum applicable for mobile from the digital dividend is as given below;

790MHz - 862MHz	• Regions 1: Middle East, Africa and Europe • Region 3: All the remaining Asia Pacific

Figure below summarizes the current channel assignments to broadcasters in Sri Lanka.

Impact on the Government

The probable impact to the government is estimated considering compensation to existing broadcasters and subscribers based on the below assumptions.

- Compensation to exiting 14 broadcasters of LKR 130 million each [28]
- Compensation to the 1.8 million subscribers to issue LKR 5000 worth of coupon to purchase the decoders (considering 10% of total television subscribers to be below the National Multidimensional Poverty Index (MPI) of Standards of Living [27])
- Revenue generated by issuing spectrum to 5 Digital TV operators via an auction at LKR 880 Million each
- Revenue generated by issuing spectrum to 5 Mobile Operators via an auction at LKR 1.12 billion each

Table 4.6: Estimate of Income and Expenditure for the Government

Source: Author

Income / Benefits	Estimate (LKR million)	Expenditure	Estimate (LKR million)
Income from spectrum auction for digital TV infrastructure provider (5 x 880,000,000) [Assuming 10% increment to base price of 4G spectrum auction in Sri Lanka will be the auction price. 4G spectrum auction base price was LKR 800 millions for 10MHz from 1800MHz band in 2013.]	4,400	Compensation for current broadcasters (14 x 130 million) [130 million per broadcaster based on the estimate done by the government. Assuming equal compensation for all 14 broadcasters] [28]	1,820
Income from spectrum auction for mobile infrastructure provider (minimum) (5 x 1,120,000,000) [Assuming 40% increment to base price of 4G spectrum auction in Sri Lanka will be the auction price since the 700MHz band is superior comparing the propagation features, coverage area etc. 4G spectrum auction base price was LKR 800 millions for 10MHz from 1800MHz band in 2013. 4G spectrum winning bid amount: LKR 3,277 millions. Source: Dialog Axiata PLC]	5,600	Compensation to subscriber (1,800,000 x 5000) [issuing coupons worth of LKR 5,000 for the 1.8 million households with television sets(considering 10% of total television subscribers to be below the National Multidimensional Poverty Index (MPI) of Standards of Living)]	9,000

While the income and expenditure alone will not show the full picture, additional benefits that cannot be quantified such as saving in analog transmission cost, benefits of released spectrum for other purposes, exceeded coverage benefit etc. endorse the need of the analog shut off.

However, it must be noted that the spectrum auction income has been derived based on the auction held for the 4G spectrum in 2013. If the regulator models the auction successfully, more revenue can be generated from this process. Furthermore compensation to current operators has been based on the estimates done by the government, which may be overstated.

4.2.3 Transmission Technology

Analog Terrestrial Transmission in Sri Lanka

The Phase Alternate Line B/ G (PAL B/G) are the standards used for analog terrestrial transmission in Sri Lanka currently. It broadcasts at 625 lines, 50 fields (25 frames) per second. PAL B is used for VHF with 7MHz bandwidth and PAL G is used for UHF with 8MHz bandwidth. A channel consists of two signals: the picture information is transmitted using amplitude modulation (Vestigial Side Band Suppressed Carrier - VSBSC) on one carrier frequency at a 4.43195MHz offset, and the sound is transmitted with frequency modulation at a 5.5MHz offset from the picture signal. The clock recovery is done through the upper side band whereas 95% of the lower side band is filtered out [29].

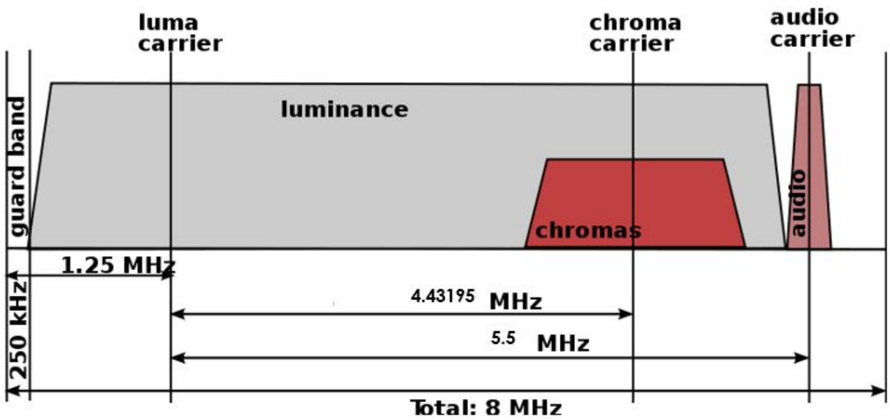

Figure 4.1: PAL B/G Modulation Spectrum
Source: International Radio Consultative Committee (CCIR) Publication

Digital Terrestrial Transmission

Figure 4.2 shows the digital terrestrial standards in used around the globe. Both ATSC and ISDB-T are highly customized standards for their specific regions [29]. As oppose to these, DVB-T and DVB-T2 are open source and the most extensively embraced standards for Digital Terrestrial Television (DTT). Due to its flexibility, efficiency and robustness, DVB-T2 is the most advanced standard for DTT. DVB-T2 is not designed to replace DVB-T in the short to medium term; rather the two standards will coexist in many markets for many years [30].

Compared to DVB-T, there is an improvement in the capacity in DVB-T2. Hence this can be used to offer more SD services or high bandwidth required services like HD.

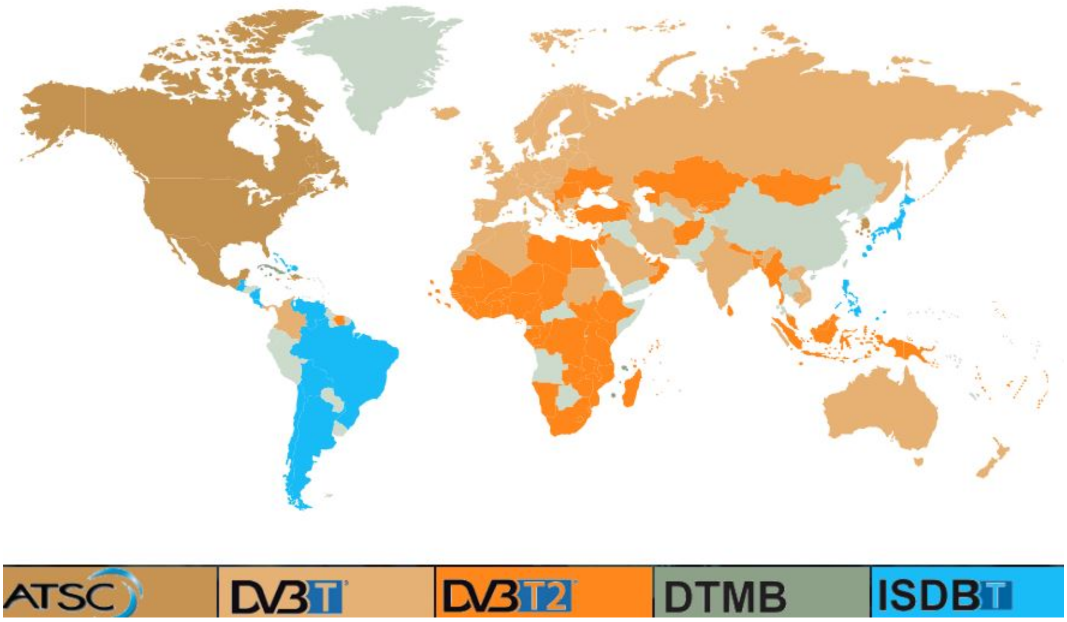

Figure 4.2: Digital TV Standards in Use
Source: ITU Publication

Table 4.7: DVB-T and DVB-T2

Source: ITU Publication

Parameter	DVB-T	DVB-T2
Forward error correction (FEC)	Convolutional coding + Reed Solomon	Low density parity check + Bose Chaudhuri Hocquenghem (BCH)
Code rates	1/2, 2/3, 3/4, 5/6, 7/8	1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Modulation	OFDM	OFDM
Modulation schemes	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM, 256QAM
Guard Interval	1/4, 1/8, 1/16, 1/32	1/4, 19/128, 1/8, 19/256, 1/16, 1/32, 1/128
Discrete Fourier transform (DFT) size	2k, 8k	1k, 2k, 4k, 8k, 16k, 32k
Scattered Pilots	8% of total	1%, 2%, 4%, 8% of total
Continual Pilots	2.6% of total	0.35% of total
Physical Layer Pipes	No	Yes

Number of channels supported depends on the compression algorithm and the coding scheme used. Under the assumption of 45Mbps of a bandwidth support by a DVB-T2 multiplexer, it is feasible to provide 19-20 SD services or 8-9 HD services. Number of channels can be increased with the usage of the statistical multiplexers as shown in the Table 4.8 and Table 4.9

Table 4.8: Estimated Bit Rate Per Programme for SD Format in Digital Broadcasting

Source: ITU - Handbook on DTT broadcasting networks and systems implementation

All Values are in Mbps	SD, H.264 without Stat Mux	SD, H.264 with Stat Mux (4+ programmes/ pool)
Video bit rate	1.875	1.5
Video bit rate + 0.8Mbps audio & data	2.675	2.3

Table 4.9: Estimated Bit Rate Per Programme for HD 1080p/50 Format in Digital Broadcasting

Source: ITU - Handbook on DTT broadcasting networks and systems implementation

All Values are in Mbps	HD, H.264 without Stat Mux	HD, H.264 with Stat Mux (4+ programmes/ pool)	HD, HEVC without Stat Mux	HD, HEVC with Stat Mux (4+ programmes/ pool)
Video bit rate	6 - 8	4.8 - 6.4	3.5 - 3.6	2.8 - 3.0
Video bit rate + 0.8Mbps audio & data	6.8 - 8.8	5.6 - 7.2	4.3 - 4.4	3.6 - 3.8

Although DVB-T2 is technologically superior to DVB–T, presently the cost of the decoder on DVB-T2 is higher than DVB-T. Current cost of decoder in USD is depicted in the Table 4.10 below [31]

Table 4.10: Cost of Decoders

Source: Internet: Amazon

	DVB-T (USD)	DVB-T2 (USD)
MPEG2 SD	15-20	
MPEG 4 SD	30-35	50-60
MPEG 4 HD	50-60	70-90

In 2019 the cost of the decoder ranged between 50-70 USD. Within a period of 2 years we can see that the cost has come down by 70% for the lower end products. Similar to the

DVB-T setup boxes the cost of DVB-T2 decoder is also expected to come down with mass production.

The success of a DVB-T2 service launch depends on subscriber demand for the service. In the case of a launch of HDTV services, consumer will need a DVB-T2 receiver as well as a HD display which could incur extra charges to subscribers. In addition there will be resentment from the subscribers on an additional purchase if the decoders were purchased recently for DVB-T. The selection of the technology plays a key role in the implementation plan.

4.2.4 Success Factors for Analog Shut-Off

The key success factors of analog shut off in other countries is the participation of all stakeholders until the completion of the switch over. It has been driven by both the subscriber demand and the push by the government.

Government Push

In some countries such as Estonia, France Germany Italy, Norway and United Kingdom organizations to steer the analog switch-off process were set up [8]. Communication by these organizations at both the national as well as the regional level has proven to be a success factor for analog shut off in many countries.

The governments have also looked at providing compensation to both the broadcasters as well as subscribers as an incentive to facilitate analog shut off. Further imposing regulations on consumer device importing and limiting them to DTT compatible devices is another way to reduce the future analog TV usage.

In Sweden, around a month before the switchover, 40% of the digital TV receivers were purchased. This is a fine example to ensure a smooth cut over by setting a firm analog shut off date and creating public awareness on the same.

Subscriber Demand

Coupons have been provided to the subscribers to motivate the subscribers to purchase the decoder. However this alone has not been sufficient as a motivation factor. Content offered to viewers have also been a motivating factor to switch over to digital terrestrial television.

Launch of new multi channel services which are freely available have helped the digital terrestrial platform to successfully compete with other television platforms. In Europe broadcasters have focused on increasing the number of services available for view [8].

4.3 Digital Dividend

4.3.1 International Practices for the 700MHz Band

The released spectrum due to digital switch over is used for many applications around the world. In general most of the countries have allocated the released spectrum to enhance the mobile communication and broadband. Below are some case studies illustrate the trend.

Australia

The 700MHz spectrum band is allocated for mobile broadband in Australia to providing coverage over a wide area and with high in-building penetration. An auction was carried out for this band by the Australian Communications and Media Authority (ACMA) in 2013. The auction ran smoothly and 3 applicants namely TPG Internet, Telstra and Optus Mobile secured the spectrum [32].

India

Indian government has allocated the 700MHz spectrum for mobile broadband. An auction took place in March 2021 for 700MHz, 2500MHz and 2100MHz spectrum bands and none of the operators bid for both 700MHz and 2500MHz due to spectrum being overpriced. This was the same reason for the auction failure for 700MHz band in 2016 [33].

Allocation of 5MHz to Indian Railway from the 700MHz band was approved by the Indian Government in June 2021. This will be used by the Railway Authority to provide LTE (long term evolution) service along the railway route to increase the security and the safety of the railway operations. It is expected that latest signalling will be facilitated by this to the train protection system and seamless communications between the main parties like guards and loco pilots [34].

Singapore

Infocomm Media Development Authority (IMDA) has allocated the 700MHz band for the provisioning of 4G mobile broadband and auction took place in April 2017. Total of 90MHz were auctioned from the 700MHz band. Singtel Mobile Singapore Pte Ltd, M1 Limited and StarHub Mobile Pte Ltd won the bid and acquired 40MHz, 20MHz and 30MHz respectively [35] [36].

Nepal

Nepal Telecommunication Authority (NTA) has decided to allocate 700MHz and 2600MHz bands for 5G spectrum in 2022. Full frequency ranges will not be able to utilized due to the overlap between the bands 700 MHz, 800 MHz and 850 MHz. Therefore the following band plan will be considered [37] [38]:

- Full range (2x45 MHz) of 700MHz band and upper half (2x15 MHz) of 800MHz band will be allocated. Upper portion of 700 MHz band will be assigned after the assessment of possible interference from 800 MHz signals
- As the phase-out process of CDMA services operating in 850 MHz band is in progress, further studies for optimal utilization of this band will be carried out.

Malaysia

The Malaysian Communications and Multimedia Commission (MCMC) had allocated the 700MHz, 3.5GHz and 26/28GHz as the pioneer spectrum bands for the 5G roll-out in Malaysia in July 2021. FDD band 703-743MHz and 758–798 MHz (2x40MHz) has been allocated [39].

4.3.2 Current Mobile Density Internet Users Sri Lanka

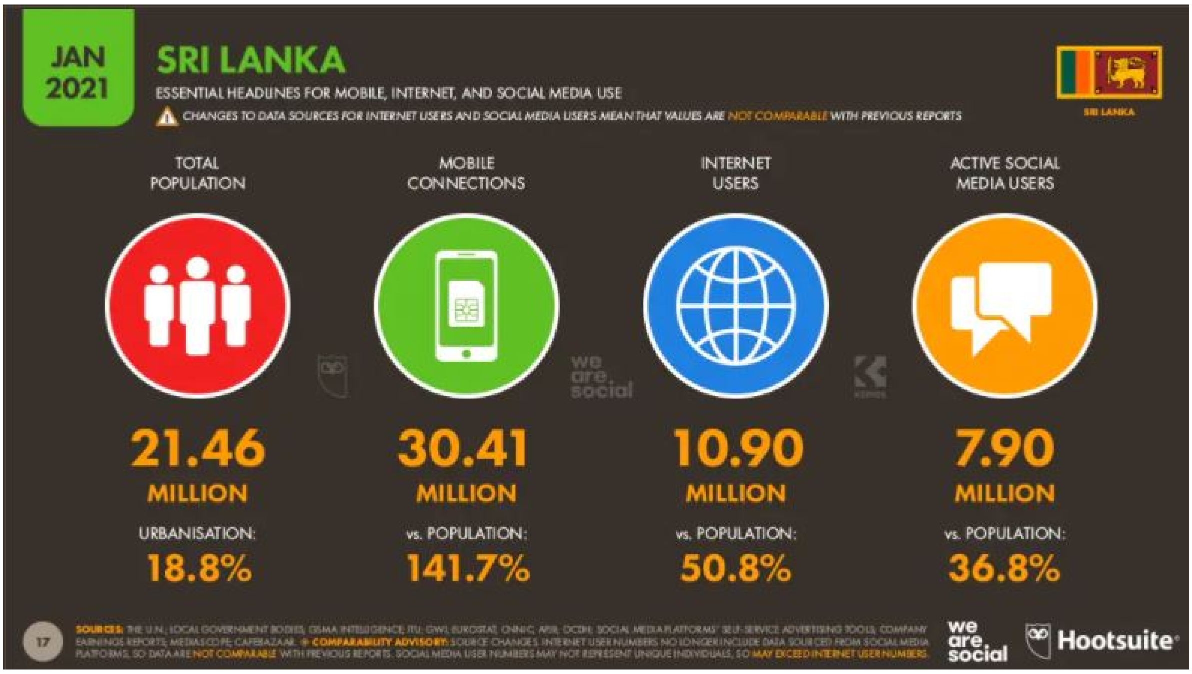

Figure 4.3: Mobile Connections and Internet Users in Sri Lanka 2021
Source: Digital Sri Lanka 2021 by DataReportal

Although there is a high increment in the number of mobile connections with a mobile density of over 141.7%, the number of internet users remains at around 50% as per the Figure 4.3 statistics. To increase the internet penetration in the island, one of the key requirements is the ability to provide internet to the rural areas which are home to a majority of Sri Lanka's population. A point to note here is that the number of mobile connection is not the active subscriber base, but the total number of connections sold by the operator.

Another point to note is that the internet users in Sri Lanka given are not limited to mobile broadband. Since 2003, mobile broadband has been introduced but the impact of the introduction of broadband is not captured by the regulator.It is of vital importance that in a fast growing industry such as this, the figures of active mobile subscribers and internet users per district be captured correctly and updated on a regular basis.

Due to the COVID-19 pandemic, there is a rapid growth of internet usage in Sri Lanka. It must be noted that for the purpose of the research internet density has been considered as an indicator and not the internet accessibility indicator.

4.3.3 Coverage Area Comparison

The results of the simulation of the coverage area for cellular mobile in the 3.5 GHz and the 790 MHz using the Infovista Planet spectrum planning tool is given below Figure 4.4 & Figure 4.5. The simulation was done for a base station in Colombo.

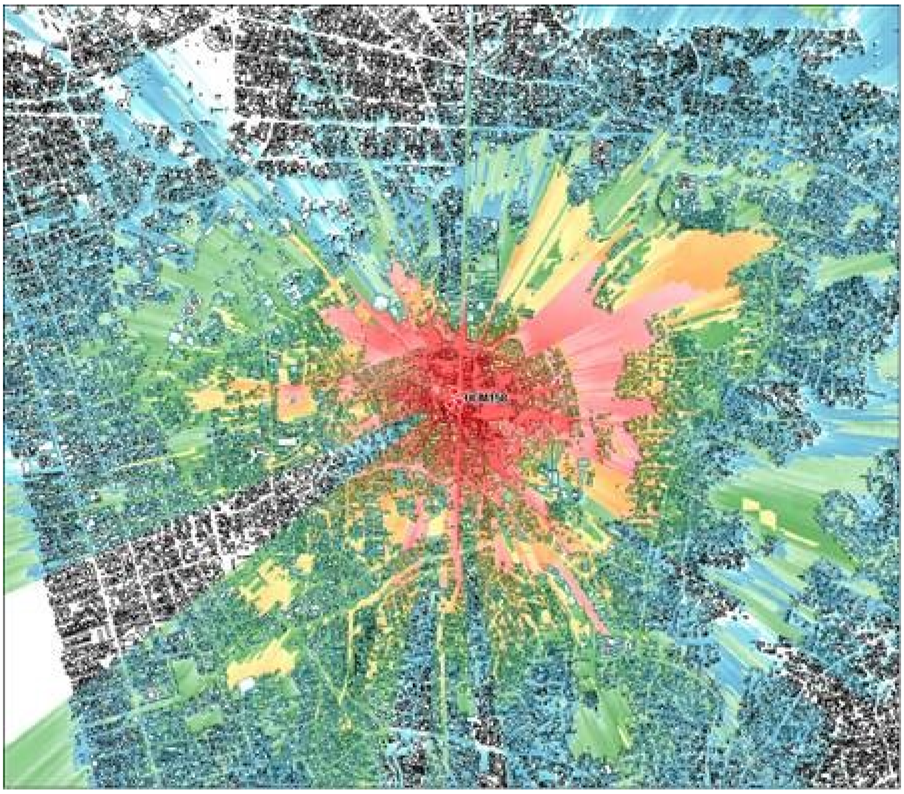

Figure 4.4: Coverage of 3.5GHz
Source: Author

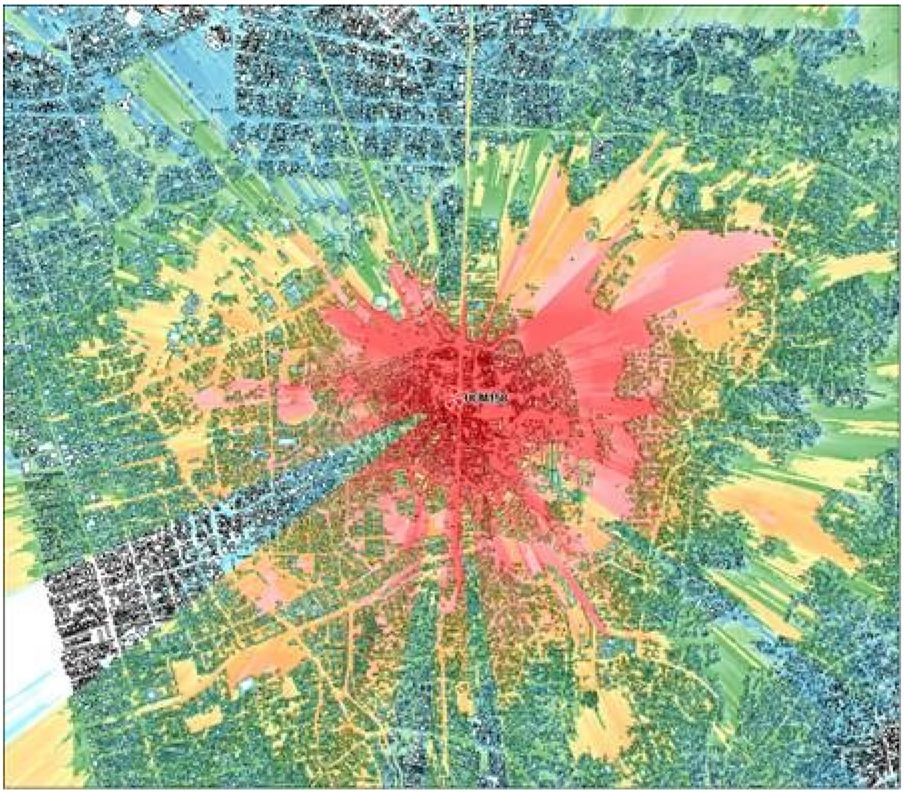

Figure 4.5: Coverage of 790MHz
Source: Author

4.3.4 Achievable Data Rate from 700MHz Band

For 5G New Radio, the approximate data rate for a given number of aggregated carriers in a band or band combination is computed as follows based on 3GPP TS 138 306 - V15.3.0 - 5G; NR; User Equipment (UE) radio access capabilities. Supported data rate by 700MHz is calculated using information in Figure 4.6 and 4.7. 20MHz of bandwidth is considered with 15kHz subcarrier spacing for 700MHz.

Table 4.11: Data Rates of 700MHz Band Considering NR Cell 20MHz Bandwidth with 15kHz Subcarrier Spacing

Source: Author

NRB	106
Take OH	0.14
Symbol Duration	7.14286E-05
Considering TDD DL:UL scaling factor for DL	1
No of users supported per cell with 100Mbps with 50% activity factor	9.0740664
No of users supported per cell with 50Mbps with 50% activity factor	18.1481328
No of users supported per cell with 10Mbps with 50% activity factor	90.740664
Total user number per site (10Mbps with 50% active factor)	272.221992

4.3.5 Using 700 MHz Band for the Rural Area

The key advantage of the 700 MHz band is the larger coverage area as opposed to the 2.1GHZ and 3.5GHz bands. Thus the number of base stations required will be reduced. Due to the distinct advantage of the excessive coverage, the capital expenditure for the deployment in rural areas is reduced.

To implement a LTE or 5G network in 700MHz will require two times lesser sites when compared to a network implementation at 2.5GHz or 3.5GHz. Hence it would be around 70% cost effective to deploy [14].

$$\text{data rate (in Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right)$$

J is the number of aggregated component carriers in a band or band combination

R_{max} = 948/1024

For the j-th CC,

$v_{Layers}^{(j)}$ is the maximum number of layers

$Q_m^{(j)}$ is the maximum modulation order

$f^{(j)}$ is the scaling factor

The scaling factor can take the values 1, 0.8, 0.75, and 0.4.

$f^{(j)}$ is signalled per band and per band per band combination

μ is the numerology (as defined in TS 38.211 [6])

T_s^{μ} is the average OFDM symbol duration in a subframe for numerology μ, i.e. $T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$. Note that normal cyclic prefix is assumed.

$N_{PRB}^{BW(j),\mu}$ is the maximum RB allocation in bandwidth $BW^{(j)}$ with numerology μ, as defined in 5.3 TS 38.101-1 [2] and 5.3 TS 38.101-2 [3], where $BW^{(j)}$ is the UE supported maximum bandwidth in the given band or band combination.

$OH^{(j)}$ is the overhead and takes the following values

0.14, for frequency range FR1 for DL

0.18, for frequency range FR2 for DL

0.08, for frequency range FR1 for UL

0.10, for frequency range FR2 for UL

Figure 4.6: Formula to Calculate Supported Maximum Bandwidth
Source: 3GPP TS 138 306 - V15.3.0 - 5G; NR; User Equipment (UE) Radio Access Capabilities

SCS (kHz)	5MHz	10MHz	15MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	217	245	273
60	N/A	11	18	24	31	38	51	65	79	107	121	135

Figure 4.7: Maximum Transmission Bandwidth Configuration for Each UE Channel Bandwidth and Subcarrier Spacing
Source: 3GPP TS 138 101-1 - V15.2.0 - 5G; NR; User Equipment (UE) Radio Transmission and Reception

Chapter 5

Conclusion

5.1 Optimal Spectrum Management Policy for Sri Lanka

According to the analysis, Sri Lanka needs to look at market driven approach of spectrum management as opposed administrative approach as this can lead to an increase in the growth of the telecommunication industry post spectrum management reforms.

Assignment of spectrum based on the subscriber growth is not an optimal practice in countries with large number of operators. However in the case of Sri Lanka, this could be considered as there are relatively smaller amount of operators. This methodology will ensure that the frequency assigned is used effectively and when linked to the number of subscribers, controls can be brought in to ensure effective use of the spectrum assigned. However, this method will give an advantage to the operator who has set up the network first and could result in creating a monopolistic environment which would stand in the way of a healthy competition between operators.

As illustrated in the above section, auction is the first step towards a market driven approach and spectrum trading is the most market driven method of spectrum assignment. To facilitate spectrum trading the spectrum needs to be in a tradable form. Sri Lanka is yet to reach this stage of spectrum assignment and as an initial step spectrum auction would be the recommended method. This is because an auction will give a fair idea of the market value and also generate income to the government.

When conducting an auction, care must be taken on selecting the correct technology to avoid situations such as the one experienced in Singapore WIMAX auction where the operator did not use the spectrum allocated. The obligations of the successful bidders must be monitored.

Looking at the experience of other countries as well as Sri Lanka, some auctions have not been successful and re-auction of the spectrum needed to be done. It can be deduced that the key reason for such situations has been flawed auction design. Thus the design of the auction is crucial. The rules of the auction must be set up in advance and should be in line with the overall spectrum plan. The number of licenses should not be reduced such that an artificial scarcity is created, as this will give rise to an increment of the cost to the broadcaster which will eventually reflect on the subscriber.

Key reasons for selecting the auction can be summarized as follows:

- Assigns spectrum quickly and successfully
- Auctions are transparent and fair
- Generates income for the government
- Provides the operator's estimate of the value of the spectrum
- Can be designed to incorporate public policy goals

5.2 Analog Shut-Off in Sri Lanka

For the analog shut off process to be successful a push from the government /authorities as well as a pull from the subscriber's end will be required. Based on the benefit of the analog shut off, the government will need to provide incentives to the subscriber such as coupons to encourage purchase of the decoder and conduct marketing campaigns to educate the subscribers.

To create the pull from the broadcasters, the government can impose regulations for the TV importers in Sri Lanka to limit them for DTT supporting devices.

To create a pull from the subscriber side broadcasters should work towards providing new content on the Digital terrestrial channel on the free to air basis such that the subscribers will be tempted to purchase the decoder.

5.2.1 Government Initiatives

To ensure that the subscriber will be prepared for the analog cut off, awareness programs must be initiated well in advance. Furthermore, the government must ensure that the decoders are available in all districts across the island. The Sri Lankan government will need to work with agents to ensure a wide and equitable distribution of the decoders. It is proposed that both government as well as private institutions be used for this purpose.

The following strategies are recommended as means to ensure the adaptability and affordability of the decoder to the subscribers.

- Create awareness programmes well in advance to educate the subscribers

- Establishing a dedicated governance committee to steer the analog shut off process
- Reduce the import tax/ custom duties applicable for the decoder. This will ensure that the decoder can be sold at an affordable rate and also reduce the illegal sale of equipment
- Control the market rate of the decoder being offered by operators/vendors/agents
- Provide a compensation to the 1.8 million subscribers to issue LKR 5000 worth of coupon to purchase the decoders. Considering 10% of total television subscribers to be below the National Multidimensional Poverty Index (MPI) of Standards of Living this will cost the government LKR 9,000 millions [26]. This will eliminate the spend power gap as depicted in Table 4.5 in rural areas where majority of the population below poverty line are living. This expenditure can be recovered from the income generated from spectrum auctioning to mobile operators and digital TV operators. Reference Table 4.6
- Ensure the agents offer an easy payment scheme for the decoder. For a 12 month period this will work out to be LKR 1000 per month with the coupon of LKR 5000, which is in line with the spend power per household that could be used for this purpose. Reference Table 4.5

In the US the Analog cut off had to be delayed as all subscribers had not purchased the decoder [25]. Thus to ensure that the subscriber will be ready for the analog cut of awareness programs must be initiated well in advance and set a reasonable cut-over date for the subscribers to be ready with the conversion.

Furthermore, the government will need to stop the import of analog TV sets into the country.

5.2.2 Broadcasters

Allocation of spectrum to the 14 broadcaster will not be cost effective; instead the spectrum can be allocated to few providers who will be digital terrestrial television transmission providers for the current and future content providers.

To ensure fairness, it is recommended to establish an independent consortium to facilitate the digital broadcasting transmission infrastructure. The government to float a request for proposal (RFP) to Design, Supply, Delivery, Installation, Testing and Commissioning of the Digital Terrestrial Television infrastructure in Sri Lanka and based on the technical and commercial evaluations, both state and private sector companies (3-4 providers) can be selected to be part of the consortium. The consortium will eliminate the need of current broadcasting stations to make direct investment in digital transmission equipment and promote coordinated and smooth migration into DTTB of all stations. The companies in the consortium, must have a business licence and a licence for frequency usage according to the existing laws of Sri Lanka in the broadcasting and telecommunication sector. A business licence can be issued when the legal Act to establish the consortium takes effect. A licence for frequency usage must be issued according to the channel plan of DTTB.

The frequency license should be limited to 3-4 providers in the consortium and the issue of this license can be done via an auction to generate part of the funding for the analog shut off. The criterion for being a transmission provider, rules and regulations on providing services to the content providers along with the expected rates and service level must be clearly defined and the bidders must agree to these terms prior to entering the auction process.

The regulator / government needs to provide compensation for the entire existing broadcaster for the analog transmission infrastructure. This needs to be done simultaneously to both the state and private content providers to avoid the creation of a monopolistic environment.

5.2.3 Timing

Even though Sri Lanka being a third world country it will be beneficial to avoid simulcast due to economical aspect, but it may not be practical as subscribers may not be ready for the transition and could lead to delay in obtaining the digital dividend. Evidence shows that even in the US the analog shut off had to be delayed as not all subscribers had purchased the decoder on time. Shut off is possible in location where the dependency on analog terrestrial transmission is low due to the high availability of alternatives such as satellite and cable television, which is not the case in Sri Lanka. Thus simultaneous transmission of analog and digital terrestrial television will need to be facilitated. The technical feasibility of simulcasting is further explained in subsection 5.2.4 Technology Selection.

Based on the analysis, Sri Lanka should look at the phased out approach of analog shut off. Analog shut off needs to be first done in low dense areas by switching off the analog transmitters in locations that have fewer broadcasters with infrastructure (eg- Deniyaya. Magalkanda. Karagahatenna, Yatiyantota ect). The reason for selecting these locations is due to the minimum impact on the population from an analog shut off. Prior to the switch off the geographical areas that are served by these locations need to be provided with digital terrestrial transmission reception. If the decoder price is set at the correct rate by the government, cost of purchasing the decoder in these areas will not be an issue. The locations serving the higher dense areas such as Colombo, Kalutara etc. need to be looked at next for analog shut off.

5.2.4 Technology Selection

Based on the analysis, considering the current TV programmes, 90% of them (20) are in SD and remaining 10% of the programmes (02) are in HD and TRCSL has allocated 06 island-wide channels and 06 location-wise channels for digital TV broadcasting in Sri Lanka during simultaneous transmission. Reference Table 4.2. Considering the Table 4.8 and Table 4.9, assuming DVB-T2 H.264 codec is used with a statistical multiplexer (which can transmit 4 or more channel at a time using the same bandwidth), 05 statistical mux (20/4=5) for SD transmission and 01 statistical mux (2/4= 1) for HD transmission to be used to broadcast the existing programmes. Hence it will require 21MHz of bandwidth to transmit the current programmes (5x2.7 MHZ + 1x7.2MHz). Based on the reserved bandwidth by TRCSL, 50MHz is available for DTT which is twice the required bandwidth to transmit the current TV programmes. Hence considering guard intervals, interference and provision for UHD and new TV programmes, proposed BW will be sufficient for DTT simulcast in Sri Lanka.

Based on above and due to high customization requirements in other proprietary standards (ISDB-T), DVB T2 is the recommended technology if Sri Lanka decides to start the digitization of terrestrial television broadcast within the next two years.

As per the Geneva 2006 Agreement, 17th June 2015 was decided as the date after which countries will no longer be required to protect the analog services from neighboring countries against interferences. Although this has minimum impact to Sri Lanka due to its geographical placing, this in turn would imply that the cost of digital televisions would come down and the manufacture of analog televisions would seize or be at a minimum. Thus it can be expected that the affordability of the HDTV and DVB T2 decoders would come down further.

5.3 Digital Dividend for Sri Lanka

Based on the analysis, as there is a huge need to increase cellular communication and internet penetration in Sri Lanka, the released spectrum can be effectively used for Voice over LTE (VoLTE), Voice over New Radio (VoNR) and mobile broadband services including 5G URLLC (Ultra Reliable Low Latancy Communication) and MMTC (Massive Machine Type Communication) application which require less than 1-3Mbps of data rates. The allocation of the spectrum to the operators must be done via an auction. The 700 MHz can be used optimally if allocated to facilitate services to rural areas.

5.4 Future Work

The implementation of analog shut off needs to be well planned considering the terrain in Sri Lanka. The network planning will need to be done prior to implementation as unlike analog terrestrial television, digital terrestrial television will have no signal beyond a certain distance as opposed to a low signal on analog. The ideal transmission locations and the order of shut off will be based on this network plan. The released spectrum could also be used by other technologies, and allocation of the spectrum such that it is technology independent could be the long term plan for spectrum management in Sri Lanka. To facilitate this, the spectrum will need to be in a tradable form and methodology on managing interference will need to be studied.

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