Spectrum Challenges for Modern Mobile Services

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Abstract

Proliferation of wireless services and demand of greater mobility has exerted pressure on spectrum manager to make available additional spectrum in lower bands. With current spectrum management practice, no spectrum below 3 GHz is free/readily available for new services. Spectrum sharing is one solution to make available additional spectrum for new services. Sharing improves spectrum utilisation and provides enormous possibilities. This paper gives an idea about different aspects of spectrum sharing & spectrum trading and emphasized that Indian telecom market is good ground for trying various aspects of spectrum sharing. This paper is based on discussions held on utilisation of radio spectrum during several GISFI meetings held in India on standardisation.

Keywords: Radio spectrum, spectrum sharing, spectrum trading, cognitive radio, TV white space.

1 Introduction

The Radio Frequency (RF) Spectrum is a limited natural resource, which is governed by the laws of physics. Theoretically, the RF commences from approx. 9 KHz and extends upto 3000 GHz. However, in practical scenario, not every part of the spectrum is suitable for being used for all requirements.

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For example, long distance communication in a single hop is possible through HF (high frequency) bands or through troposcatter systems only. Also, at present, technologies/ equipment are available for general use of spectrum upto approx. 85 GHz only. Mobile communication is feasible upto approx. 6 GHz band, with currently available technology. Even within this practically usable spectrum as per current available technologies, cost effective equipment for a particular application may be available for use in still smaller/ limited frequency bands. This is the practical limitation on the spectrum due to propagation and availability of suitable equipment.

Today, large portions of the radio spectrum stand assigned to the authorized users by governments over the last one hundred years. This spectrum allocation policy refers to command- and control mechanism in which the Government may decide the following: ration spectrum, specify technologies and services for spectrum use, put in strict mergers and acquisition (M&A) norms, and confer non-sharable rights to spectrum holders etc. [1]. This static spectrum allocation mechanism causes frequency bands to be insufficient in various times and locations. This seeming waste is commonly referred to as the problem of "regulatory overhead". Even if all such users are paying the spectrum charges, the opportunity cost and benefits for the society at large are not fully derived. Only some small parts of the radio spectrum are openly available to license-exempt users, and changing the status of a licensed radio spectrum to unlicensed can be crucial challenge. This process takes time and needs close cooperation between technological and technical bodies to achieve efficient deployment of the new policies.

Figure 1 [2] illustrates the radio spectrum and thebroad range of frequencies in wireless communication context. Most of the fractions of the radio spectrum are licensed to traditional radio communications systems. Beside, practical measurements, prove that most of the licensed bands either are unused or partially used at different geographical areas at most of the times According to the FCC's report the licensed spectrum band utilization range from 15% to 85% at different times and locations [3].

The regulation of the radio spectrum can be differentiated into four approaches explained in table below.

While the number of wireless connections and high data rate networks increase, spectrum demand and spectrum congestion become critical challenges in the forthcoming all-encompassing wireless world. In fact, throughput, high reliability, high quality of service, mobility, and diversity of wireless services, devices based on multiple wireless standards are more and more demanded. Hence, future wireless networks will face greater spectrum scarcity due to

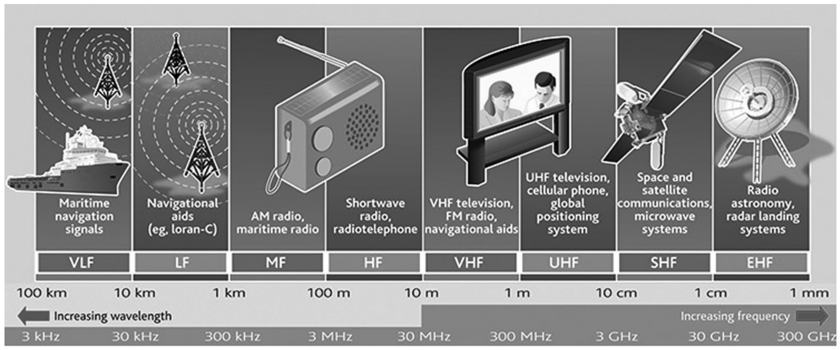

Figure 1 Radio spectrum [2].

the user's requirement such as high multimedia data rate transmission and diversity of communication technologies. The next section describes growing of spectrum demand in future wireless communication.

2 Increasing demands on RF Spectrum

Demands on RF spectrum are increasing extensively, for mobile services – broadband with ever increasing data rates (4G with 100 MBPS data rate) – futuristic 5G (ultra wide band – 1 GBPS)[4]. As per CISCO analysis of data usage [5], Mobile data traffic will grow at a CAGR of 66 percent from 2012 to 2017 mobile data traffic grew 70% in 2012 as compared to 2011, average data usage by smart phone devices is more than 50 times greater than the average data usage by basic feature phones, which comprise about 80% of the total connections/ devices globally. The predicted data usage in 2017 envisages average mobile data usage of about 7 GB per month by lap tops and netbooks, 2.5 GB by smartphone devices and more than 1 GB by non-smartphone devices. The overall mobile data traffic is expected to grow to 11.2 exabytes per month by 2017, a 13-fold increase over 2012. The 4G systems where deployed, have seen an average of 20 times more data traffic compared to existing systems. With cloud computing, the data usage is predicted to grow further. All this would need additional spectrum for meeting these growing requirements satisfactorily. Even now, need for additional spectrum of 500 MHz for mobile services is foreseen in near future in most of the countries.

As per Report ITU-R M.2078[6]: 'Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced', the predicted spectrum requirements for the mobile industry would be three times

Table 1 Regulation of radio spectrum (USA example).

Approach	***Description***	***Application***
Licensed Spectrum for Exclusive Usage	Protected through the regulator, transferable/ flexible usage rights	Universal Mobile Telecommunication System (UMTS)
Licensed Spectrum for Shared Usage	Restricted to a specific technology	Digital Enhanced Cordless Telecommunication (DECT), public safety services, secondary usage
Unlicensed Spectrum	Available to all radio technologies working with specified standards, no right for protection from interference	Unlicensed National Information Infrastructure (U-NII) bands
Open Spectrum	Anyone can access any range of the spectrum, minimum set of rules define by standards	Low power underlay spectrum usage, Cognitive, frequency agile radios, cooperation-based, self-reconfiguring

Table 2 Future spectrum requirements.

Demand scenario	***Total spectrum requirements (MHz)***		
	2010	2015	2020
High Demand Setting	840	1300	1720
Low Demand Setting	760	1300	1280

Table 3 Identified/additional spectrum requirements.

Total (MHz)	***Region-1(in MHz)***		***Region-2 (in MHz)***		***Region-3(in MHz)***	
	Identified	***Net additional***	***Identified***	***Net additional***	***Identified***	***Net additional***
1280	693	587	723	557	749	531
1720	693	1027	723	997	749	971

the spectrum than in the last 20 years (Table 2). The report also gives details about already identified spectrum and additional requirement of spectrum for IMT and IMT Advanced services to meet this demand is different for all the 3 regions (Table 3).

At the same time, the requirements of RF spectrum for other services for public – both satellite based and terrestrial based communication services, broadcasting as well as various navigational services, are also increasing. Further, the requirements of RF spectrum from other captive users – strategic users as well as other government and private users are also increasing significantly.

2.1 Trends Contributing to Increased Demand for Mobile Broadband

Despite its short history, mobile broadband seems to have a higher growth impact relative to communication technologies, such as fixed and mobile telephony and the Internet [7]. There is growing evidence that mobile broadband has a considerable socio-economic impact for individuals, firms, and communities. Mobile broadband traffic and number of subscriptions are dramatically increasing since last few years. New types of mobile devices, such as smart phones, dongles and tablets and new user behaviours have emerged, as well as new applications have been created by users.

As the mobile broadband is providing benefits for society and economics, it is expected that data traffic increase and convergence between mobile and other services, such as e-health, e-education, will provide further benefits. The demands for multimedia (uses multiple forms of information content and information processing (e.g. text, audio, graphics, animation, video, interactivity), along with e-education, e-health, mobile commerce, mobile broadcasting/multi-casting, are some emerging telecommunication services to mobile users that can be provided by 'IMT' and 'IMT Advanced'.

The new generation of mobile broadband networks will support higher data throughput rates, lower latencies and more consistent network performance through a cell site [8]. This will increase the number of applications and devices that can benefit from mobile broadband connectivity, generating a corresponding increase in demand for mobile broadband from consumers, businesses. Some 'trends' contributing to increased demand for mobile broadband are:

1. New type of devices, such as smart phones, dongles, tablets
2. Mobile Internet usage is increasing
3. Huge increase of mobile applications
4. Video traffic is growing dramatically
5. Media rich social networks go mobile
6. Machine-to-Machine traffic is growing rapidly
7. More capable network – user experience improvement
8. Cost reduction and price decrease
9. Several policy initiatives to promote mobile broadband
10. Potential area to increase data traffic

2.2 Developments in the Field of Computers and Wireless Communications

The developments in the field of computer software and mobile communication facilities have complimented each other. The modern communication systems make very extensive use of computer hardware and software facilities. The enhanced computing powers and larger memory capacities have helped in development of better communication systems. At the same time, more efficient communication systems allow exchange of much larger amount of data, thus allowing greater exchange of software development capabilities between any parts of the globe. The resultant volumes and economies of scale have helped bring down the cost of equipment, allowing much faster expansion of telecom facilities across the globe. All these developments have exponentially increased the volume of data travelling across various networks, including wireless networks. This has necessitated more efficient use of all available and usable frequency spectrum.

3 Technological Developments in Spectrum Utilization

The evolution of technologies has gradually allowed use of higher frequency bands, thus increasing the availability of spectrum. For example, about 25 years ago, mobile communications were feasible in frequency bands upto about 400 MHz only. As compared to that mobile communications systems are now available upto approx. 6 GHz – increase in spectrum availability by almost 15 times for mobile services. However, most of the frequency bands upto 6 GHz are heavily in use for variety of other services. So the spectrum shortage continues.

Similarly, the line-of-sight systems, which were generally available/ usable upto 15 GHz about 25 years ago, are now available upto almost 100 GHz band. Hence, the spectrum availability for such systems has also increased significantly. However, the demand/ requirements have grown at a much faster pace, thus resulting in continued shortage of spectrum.

On another front, the miniaturization of electronic components & systems has helped more efficient usage of spectrum. In this connection, introduction of multiple frequency bands in single equipment, due to miniaturization, allows enhanced dynamic sharing of frequency bands and the efficiency of spectrum usage is largely increased.

Hence, it has been practically observed that increasing demands on spectrum have outstripped the practical availability of spectrum, despite higher frequency bands becoming available for use through technological developments. In reality, the demands on RF spectrum have always been more than its practical availability – hence the need for its regulation/ management in an effective manner so as to derive maximum benefit for the nation and humanity at large, in the international scenario. Optimum spectrum sharing results in greater efficiency of spectrum usage. Greater sharing of frequencies and bands allows more data to be sent by different users in the same amount of available spectrum.

4 Spectrum Sharing

The concept of spectrum sharing [9] is sharing of a frequency band by two or more than two radio communication services or applications. At international level, different bands of RF spectrum are shared among multiple services. Each country can choose one or more of such services for utilization within their country – subject to the condition that services of other countries do not get any harmful interference [10]. Protection criteria for sharing among different services and applications are decided at international level taking into account various technical factors. With the development of technology, these sharing and protection criteria also undergo change periodically. Sharing has basically three dimensions; frequency, time and location. Spectrum sharing is not a new phenomenon. It has been in practice since longback. The frequency reuse concepts in existing telecom network, operation of point to point link on same frequency at different locations, FDMA & TDMA etc are example of spectrum sharing. Sharing of spectrum among homogenous/ similar services & applications is relatively easier and leads to greater spectrum efficiency as compared to sharing among heterogeneous services and applications (sharing among largely different services & applications) is more complex as well as provides relatively lesser increase in spectrum efficiency. In general, the digitally modulated carriers can work satisfactorily with lower protection criteria.

A lot of work is carried out in various study groups of ITU-R [11] for establishing sharing criteria among different services and applications. These criteria play a crucial role in appropriate sharing of spectrum and these are periodically reviewed in the light of various technological developments. With the development of technology, the sharing criteria undergo improvement continuously, resulting in denser utilization of and more traffic/data being derived from the same spectrum. As large number of countries participates in ITU-R studies, the criteria adopted by study groups are relatively conservative. For usage within the country or during bilateral discussions between two countries, it is possible to accept more liberal criteria, allowing still better utilization of spectrum.

4.1 Spectrum Sharing – US Scenario

The idea of spectrum sharing in the United States really started gaining traction after the National Telecommunications and Information Administration(NTIA) issued a report in November 2010 that found 115 MHz of spectrum currently in the hands of the federal government that could be used for wireless broadband [12]. That kicked off lots of conversations over whether and how wireless carriers could share spectrum with the federal government. Another NTIA report, in March 2012, found that 95 MHz of spectrum currently in federal hands, the 1755–1850 MHz band, could be repurposed for commercial wireless use, and as part of its review, the NTIA recommended both relocating federal users and sharing spectrum between federal agencies and commercial users [13]. In August 2012 the FCC granted permission to T-Mobile USA to test the concept of sharing spectrum between federal and commercial users in the 1755–1780 MHz band. AT&T Mobility, Verizon Wireless and T-Mobile USA recently inked an agreement with the Department of Defense to explore the possibility of sharing 95 MHz of spectrum that is currently used by the Pentagon and other federal agencies located in the 1755–1850 MHz band [14].Of late, AT&T and Verizon are on a buying spree, as they vie with each other in expanding their 4G LTE (long term evolution) networks. For example, in 2012, AT&T obtained approval to purchase 700 MHz and 2300 MHz band spectrum from the likes of NextWave Wireless, Comcast, Horizon Wi-Com and San Diego Gas & Electric Company. Verizon recently agreed to pay $3.6 billion to buy spectrum from a consortium of cable companies to augment its spectrum capacity. Sprint acquired Clearwire recently for its 2.6 GHz 4G spectrum [1].

The USA President's council of advisors on science and technology in their report last year, recommended about 1,000 MHz of federal spectrum holding to be released for shared access [15]. In a first ever move, the US military will experiment with sharing of spectrum that they use for aviation radars in the 3550–3650 MHz band for 4G LTE based indoor networks in hospitals [1].

The NTIA, in coordination with the Federal Communications Commission (FCC) and the Federal agencies, established a Spectrum Sharing Innovation Test-Bed (Test-Bed) pilot program to examine the feasibility of increased sharing between Federal and non-Federal users. This pilot program is an opportunity for the Federal agencies to work cooperatively with industry, researchers, and academia to objectively examine new technologies that can improve management of the nation's airwaves. The Test-Bed Pilot Program will evaluate the ability of Dynamic Spectrum Access (DSA) devices employing spectrum sensing and/or geo-location techniques to share spectrum with land mobile radio systems operating in the 410–420 MHz Federal band and 470–512 MHz non-Federal band [16].

4.2 Dynamic Sharing of Spectrum Using SDR and CR

Earlier the transmitter equipments were tuned to specific frequencies and provision for multiple frequencies/ channels/ carriers meant large extra cost. The development of 'Software Defined Radio (SDR)' allows the user(s) to use/ switch to different frequencies in a dynamic manner without large increase in cost of equipment;

Still the existing users were not comfortable with dynamic sharing and anticipated harmful interference to their systems, when they would need to use a particular frequency/ carrier / channel. The development of 'Cognitive Radio (CR)" along with Software Defined Radio (SDR) [17], has taken care of this concern of existing users to a large extent. In case of Cognitive Radio (CR), the system would first listen and if the channel is occupied, it would switch to some other vacant channel and use it. Also, such systems would regularly (& frequently) sense the carrier for other usages and the moment it finds some other licensed usage, it would switch to some other vacant channel/ carrier, thus causing no harmful interference to existing/ earlier licensed user(s).

Hence, dynamic sharing of spectrum is being adopted increasingly. It is a combination of administrative (regulatory), technical and market based techniques to enhance the efficiency of spectrum utilization [18]. Such dynamic sharing leads to enhanced and optimal usage of the RF spectrum.

Many strategic users as well as other public safety users (e.g. Disaster Management authority) need a small amount of spectrum for their regular use. However, in case of emergency/ public safety situation, they need much larger amount of spectrum to take care of the situation. It is not desirable to block their total spectrum requirements for all times and throughout the country, as it would let large amount of spectrum lying unused as well denying other users the opportunity to derive societal benefit from such unused part of spectrum.

Hence, Spectrum regulators in more and more countries are encouraging dynamic spectrum sharing with public safety requirements. In USA,one block of spectrum in 700 MHz band has been auctioned with the condition that public safety services would be able to pre-empt its usage in case of any emergency/ public safety requirements [19].

4.3 Dynamic Sharing of White Spaces

Another area of dynamic spectrum sharing, which has been of large interest recently, is commonly known as 'White Spaces' (in TV band).The TV broadcasters normally plan to repeat the same channel/ carrier at relatively larger distances, to avoid any interference especially at the edges/ border of the coverage areas of two adjacent broadcast transmissions on the same channel. However, there are large areas near the edge of the theoretical coverage area of any particular TV transmission, where there are very few people receiving the program. Thus the spectrum for that channel is not used effectively in such areas.

The broadcasters in general are quite sensitive, even touchy, for protecting the reception of their signals even beyond theoretical coverage areas. Hence, only low power systems, that too on pre-emptive basis can be considered for shared usage with the TV spectrum. With the passage of time and gaining of adequate confidence among all users, including broadcasters, gradually higher power levels for other sharing systems would be feasible.

5 India Scenario

Spectrum sharing to some extent has been allowed in India in controlled manner with regulator's approval in non-commercial bands. However, spectrum sharing in commercial bands has not yet been opened. But the Government committed in National Telecom Policy 2012[20] document that *"To move at the earliest towards liberalisation of spectrum to enable use of spectrum in any band to provide any service in any technology as well as to permit spectrum pooling, sharing and later, trading to enable optimal utilisation of spectrum through appropriate regulatory framework."*

The telecom industry in the country has witnessed a phenomenal growth in the last decade, mainly for mobile telephones. With 900 million mobiles phone connections at the end of March, 2013, India is today the second largest and fastest growing telecom market in the world in terms of number of wireless connections. It continues to grow at an average rate of 7 to 8 million connections a month. A significant part of this growth is now taking place in smaller cities and rural areas. Cellular Operator Association of India (COAI) has projected subscriber growth to 1516.8 million in 2020 with almost 45% increase from 2012 subscribers figure (Table 4).

India is unique in its excessive fragmentation of spectrum holdings, and hence requires more innovative approaches in spectrum management. The average spectrum holding by each telecom operator is 10 MHz across all bands (i.e. 800, 900, 1800, 2100 MHz paired bands), about one-fourth of the international average [1]. To some extent, spectrum sharing has been introduced by allowing 2G intra-circle roaming and the liberalisation of spectrum use in recently conducted auction. But these steps are not sufficient to accelerate the market. Operators need more spectrum commensurate with their counterparts in other countries. But due to the Government's inability to allocate more

Table 4 Wireless subscriber projection.

	2011	***2012***	***2013***	***2014***	***2015***	***2020***
Population (in Million)	1218	1233	1249	1265	1281	
Subscribers (in Million)	923.8	1049.1	1134.5	1185.3	1217.1	1516.8
Teledensity	75.85	85.09	90.83	93.70	95.01	

spectrum, it is better that Government allows operators to manage spectrum through spectrum sharing/trading.

It is worth to note that not a single operator got 3G spectrum in all the 22 service areas. Operators decided to share spectrum (without transfer of spectrum rights) through mutual agreements without Government permission, thus creating an "unofficial" secondary market. This is an excellent example of operator enterprise. However, the Government has just stopped this practice. It is time the Government legitimises it *ex-post* by allowing spectrum sharing and trading for the benefit of all which consequently provide better quality of service for subscribers, optimal utilisation of spectrum and increase in Government revenue [1].

5.1 Initial Investigation of Frequencies Bands for Flexibility

The following bands are being investigatedin many countries for more flexibility regarding additional spectrum. Total bandwidth under consideration is about 1330 MHz.

- 470–862 MHz: presently used for broadcasting services;
- 880–915 MHz / 925–960 MHz as well as 1710–1785 MHz / 1805–1880 MHz: these bands form the 900/1800 network for GSM mobile services;
- 1920–1980 MHz/ 2110–2170 MHz: these bands are used for third generation (3G) mobile services;
- 2500–2690 MHz (the 2.6 GHz band): this band is used for Broadband Wireless Access (BWA) services;
- 3.4–3.8 GHz: this band is proposed for use by IMT and IMT Advanced services.

5.2 Policies on Spectrum Utilization

Light Licensing

In this utilisation technique all stations must be registered in defined database spectrum map. Light Licensing is a novel concept in the US in the 3,650 to 3,700 MHz range(and in 70/80 GHz bands), which allows systems to share spectrum on a co-primary basis, whereby geographic location and signal sensing mechanisms are employed to ensure that no interference is caused among the involved systems (Fixed, FSS or Mobile). The IEEE 802.11y Working Group is one standard body that has focused on such concepts [21].

Spectrum fragmentation

Spectrum fragmentation is a further reason that new techniques are needed to exploit spectrum gaps and white spaces among the fragmented spectrum assignments [22]. The approach is based on a joint simultaneous use of different frequency bands in the frequency range of about 400 MHz up to about 6 GHz including the unlicensed frequency bands for WLAN applications.

Spectrum Harmonisation

Spectrum Harmonisation means defining technical conditions, including spectrum, band plan and technology, at a global and regional level, to ensure efficient spectrum use, seamless services over wide areas including roaming, system co-existence and global circulation of user equipment across borders.

Spectrum Liberalisation

Essentially, liberalisation of spectrum means the removal of technology restrictions to enable new access technologies to be deployed within the same band or bands as existing and legacy technologies – for example, UMTS or HSPA could be deployed in spectrum bands where traditionally GSM, CDMA or TDMA has been used.However, such usages should not cause harmful interference to any other adjoining usage in the band or nearby frequency bands.

6 Spectrum Trading

Spectrum trading is another aspect associated with spectrum sharing. In fact, spectrum trading is the case of spectrum sharing, where commercial aspects are also involved. Spectrum trading permits the purchaser to change the use to which the spectrum was initially put while maintaining the right to use. In such cases, it may involve transfer of rights to use the spectrum, rather than transfer of the licence itself [23]. Spectrum trading generally leads to an economically more efficient use of spectrum. This is because a trade will only take place if the spectrum is worth more to the new user compared to the old user. Trading, viewed by many as the key step to be taken in the reform of spectrum management regulatory practice, is capable of unlocking the potential of new technologies and eliminating artificial scarcities of spectrum, which find expression in inflated prices for spectrum-using services. USA and many European countries have introduced/ allowed spectrum trading in certain specific bands only, which are in demand for commercial use, with specified conditions.

6.1 State of Spectrum Trading

Following the initial assignment of spectrum rights and obligations to users, whether by auction or other means, circumstances may change causing initial license holders to want to trade their rights and obligations with others. Today this is not possible in many countries. However, in a few countries such as the UK, secondary trading – the trading of spectrum rights after the primary assignment – is possible [24]. The possibility to trade radio spectrum is argued by many commentators to be a critical factor in the promotion of more efficient radio spectrum use. Furthermore, it is increasingly recognized that the flexibility afforded by trading is helpful for innovation and competitiveness.

The successful implementation of spectrum trading requires a commitment to change current view of regulatory bodies with a solid base in understanding new technologies and operating systems. Spectrum policies must address the incentives for innovation in order to promote spectrum's assignment flexibility while clearly establish the usage rights and obligations of those who use the spectrum to transmit or receive information. Furthermore, the spectrum flexibility also demands new approaches and practical methods for the monitoring compliance, enforcement and conflict resolution.

In Europe, the European Commission (EC) is taking the lead in promoting harmonized trading for radio spectrum where its use has a European dimension. Emphasis is being placed on certain bands below 3 GHz, where it is estimated that the net benefits from trade may be substantial. Despite fairly widespread recognition that the current regime of spectrum management operating in most of the European Union is not sufficiently flexible to achieve the Union's objectives in promoting competitiveness and innovation, thus far the pace of reform is slow, although some necessary steps have been put in place, and the European Commission is promoting liberalization across the EU [25].

Secondary spectrum market is already running in several countries like USA, UK, Australia, New Zealand and most of European Union countries. Though secondary spectrum markets have not been successful in Australia, New Zealand and some European countries due to "market thinness", or lack of sufficient participation, the activity level is very high in the US. Mobile operators have bought spectrum from each other as well as from broadcasters and other niche spectrum holders.

6.2 Spectrum Transaction methods

Spectrum transfer, proceeds by the transfer of licence rights and obligations and necessarily involves the grant of a new licence to the transferee. Transfer may be for all or part of the licence duration (short time or long time).

Spectrum leasing, proceeds by a Contract between the parties without the need for National Regulatory Authority(NRA)to issue a new licence. The incoming user (the leaseholder) is not issued with a licence by NRA but is authorised to use the spectrum for the period of the lease on the basis of a contract with a licensee (the lessor).

6.3 Duration of Usage Rights

Long Period**:** In the case of auctioned spectrum, or spectrum granted by means of comparative or negotiation procedures, the duration is longer, between 5 and 20 years. In Denmark the default duration for the granted usage rights is 15 years.

Short Period: In the case of frequency assignments with no selection procedure, they are generally granted for a short period, one to three years, but the licence is automatically renewed, if the license fee has been paid (e.g. Cyprus, Estonia).

6.4 Spectrum Trading Procedure [25]

The procedures can be broken up in several steps, essentially what happens before the transaction and what happens immediately after the transaction.

1. Notification of the intention to trade, spectrum holder might notify NRA in selling spectrum band.
2. Publication of information prior to the transaction, at this stage information of both parties and information on frequency and technical details need to be published.
3. Approval of transaction by NRA, publication of information on the effective transaction, information of the transaction must be made public, such as Geographic area, frequency, expiration, and so on.
4. Monitoring system, in most cases NRA has responsibility on monitoring transaction of spectrum usage rights.

6.5 Spectrum Trading Benefits

The main benefits of spectrum trading encompass:

- More efficient use of spectrum*
- More flexibility in spectrum management, including removal of rigidities in primary assignment.
- Ability to evaluate spectrum licences, and gain knowledge of market value of spectrum
- Facilitating market entry.
- Encouragement of innovation, enabling new technologies and market development.
- Speedier process, with better and faster decision-making by those with information.
- Increase in competition and reduced barriers to market entry.
- Reduction in administrative workload.
- Reassignment of spectrum from low economic value uses to high economic value uses.
- Allows efficient companies to expand and displace less efficient companies.
- Increasing opportunities for entrepreneurs to access spectrum to introduce innovative technologies and services.
- Reduction in the transactions costs of acquiring rights to use spectrum.
- Permitting more rapid redeployment and faster spectrum access for innovators and new players without the need for regulators to re-plan and re-farm spectrum.
- Allowing new technologies to gain access to spectrum more quickly.
- Opportunity (for existing operators) to sell unused or under-used spectrum and make more flexible use of spectrum.

6.6 Significant Concerns in Spectrum trading

There are several significant concerns in spectrum trading and liberalisation includes:

- Low spectrum trading activity
- Inefficient use of spectrum*
- High transactions costs
- Risk of increased interference
- Impact of spectrum trading on anti-competitive conduct
- Impact on investment and innovation

- Impact on international co-ordination / harmonisation
- Windfall gains
- Disruptive effect on consumers
- Reduced ability to achieve public interest objective

(*The spectrum usage efficiency varies with different operators. The spectrum trading generally would see the spectrum moving from an operator who has relatively lesser need (hence lesser spectrum efficiency), to another operator who is starved of spectrum due to larger amount of network traffic. Hence, such movement of spectrum through trading would result in more efficient use of relevant spectrum. However, all spectrum trading deals might not be undertaken for spectrum efficiency only. In some cases, an operator may buy part of the spectrum for his immediate needs and some more for his foreseen future needs (or total spectrum for his foreseen needs), when such spectrum is available and the buyer sees a business case for the additional spectrum. Such a deal might result in sub-optimum spectrum efficiency for some time, but eventually the buyer would plan his network to derive the maximum traffic and efficiency from his spectrum holding.)

7 Conclusions

Thus it can be seen that enhanced spectrum sharing results in greater efficiency of spectrum usage, which is essential – almost unavoidable necessity for this limited and scarce resource. Although, there is always some cost associated with it, yet the overall benefits to the society are much larger. Spectrum trading is also a kind of spectrum sharing, though it is not much successful in many-countries but it would improve spectrum efficiency in both terms; technical as well as economic, if implemented in an objective manner, seeing the telecom scenario in India.

References

[1] V. Sridhar, Rohit Prasad. Nothing wrong with spectrum sharing. http://www.the hindubusinessline.com/opinion/nothing-wrong-with-spectrum-sharing/article 4992619.ece

[2] Radio Spectrum. http://kids.britannica.com/comptons/art-164539/Commercially-exploi ted-bands-of-the-radio-frequency-spectrum

[3] F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer Networks Journal*.

[4] Cornelia-IonelaBadoi, Neeli Prasad, Victor Croitoru, and Ramjee Prasad. 2011. 5G Based on Cognitive Radio. *Wirel. Pers. Commun.* 57, 3 (April 2011), 441–464. DOI=10.1007/s11277-010-0082-9.
[5] Cisco Visual Networking Index: Forecast and Methodology, 2012–2017.
[6] ITU-R M.2078Report. http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2078-2006-PDF-E.pdf
[7] DimitriZenghelis. The Economics of Network-Powered Growth. www.cisco.com/web/about/ac79/docs /Economics_NPG_FINALFINAL.pdf
[8] Heterogeneous Network. http://www.ericsson.com/res/docs/whitepapers/WP-Heterogeneous-Networks.pdf
[9] ITU_R M Report. www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2243-2011-PDF-E.pdf
[10] National Frequency Allocation Plan (NFAP) 2011 of India. www.wpc.dot.gov.in
[11] Study groups of ITU-R. http://www.itu.int/en/ITU-R/study-groups/Pages/default.aspx
[12] www.ntia.doc.gov/files/ntia/publications/ntia_fcc_letter_115_mhz_01192011.pdf
[13] http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf
[14] http://www.fiercewireless.com/story/att-verizon-t-mobile-forge-pact-explore-spectrum-sharing-government/2013-01-31
[15] http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf
[16] http://www.ntia.doc.gov/category/spectrum-sharing?page=2
[17] Simon Haykin. Cognitive Radio: Brain-Empowered Wireless Communications. IEEE Journal on Selected Areas in Communications, Vol. 23, No. 2, February 2005
[18] ICT regulation tool kit on spectrum sharing.www.ictregulationtoolkit.org/sectionexport/word/5.4
[19] The First Responder Network and Next-Generation Communications for Public Safety: Issues for Congress http://www.acuta.org/wcm/acuta/legreg/061213a.pdf
[20] National Telecom Policy 2012 of India. www.dot.gov.in
[21] IEEE 802.11y. http://www.wi-fi.org/sites/default/files/WFA_11y_Primer_final.pdf
[22] Visions and research directions for the Wireless World. http://www.wwrf.ch/files/wwrf/content/files/publications/outlook/Outlook5.pdf
[23] Radio Spectrum Management for a Converging World. http://www.itu.int/osg/spu/ni/spectrum/RSM-BG.pdf
[24] Ofcom spectrum trading guide. http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/spectrum-trading/tradingguide.pdf
[25] European practices in trading of spectrum usage rights. www.cept.org/.../**European**%20practices%20in%20**trading**%20of%20S

Biographies

Mr. P. K. Garg is presently a Member of the Radio Regulations Board (RRB) of International Telecommunication Union (ITU), Geneva and former Wireless Adviser to the Government of India (head of national spectrum management organization of India). In 2010, he was internationally elected for the second term on the RRB. He has been elected as Chairman of the Board for the year 2013.

The Board resolves various issues concerning implementation of ITU Radio Regulations, which is an international treaty among member countries of ITU for planning and use of the RF spectrum, as well as resolution of disputes, if any.

An engineering graduate with more than 40 years of experience in radiocommunications and spectrum regulations – nationally and internationally, Mr.Garg has widely travelled since 1980, for participation in various international and regional conferences of ITU, APT (Asia Pacific Telecomunity) and other international & regional bodies connected with telecommunications. He has also represented India on the Governing Council of ITU and served as the Senior UN & ITU Expert in Radio Frequency Spectrum Management in Saudi Arabia.

He has chaired as well as spoken at large number of national and international conferences and seminars in the field of wireless communications and RF spectrum management, both in India & abroad. He has published many papers on wireless communication and spectrum related issues.

He presently holds the following positions at international and national level:

1. Chairman, Radio Regulations Board, ITU, Geneva
2. Chairman, GISFI Spectrum Group
3. Fellow of Institution of Electronics & Telecom Engineers (IETE) India
4. Chairman, CII Sub-Committee on Telecom Licensing and Spectrum
5. Vice President, ITU APT Foundation of India
6. Executive Member, PTC India Foundation
7. Member, Telecom committee of ASSOCHAM India
8. Founder Member, NGN forum of India
9. Eminent Engineer for 2003 by Institution of Engineers (India), Delhi

T. R. Dua An engineering graduate with diploma in Business Management and export Marketing. Have an experience of over 35 years in the telecom sector. Experience includes all facets of telecom be it Product Development, Business Development, Telecom Licensing, Regulatory issues with respect to interconnection / roaming / unified licensing and infrastructure sharing / Mobile Number Portability, Spectrum Management, Spectrum Related Issues Like Spectrum Pricing, Efficient Utilization and Spectrum refarming etc. Have also been involved very closely with number of Joint Ventures / Technical Collaborations.

All these years he has held very prestigious positions as Director in leading telecom companies like BhartiAirtel Ltd., Shyam Telecom Ltd., Cellular Operators Association of India, Vice Chairman, Global ICT Standardisation Forum for India and Senior Director TAIPA. Besides other consulting assignments.

Have many first to credit like finalization of joint ventures, technical collaboration, introduction of new product, launch of cellular services in India and finalization of licence agreements / interconnect agreements.

Work very closely with institutions like ITU/APT/WWRF with regards to the spectrum matters. Very actively involved with various professional institutions / associations to promote the interest of telecom sector and published many papers in telecom.

Presently holding the following position in various Professional Institutions:

1. Vice Chairman – GISFI
2. Co Chairman – ITU APT Foundation of India
3. Vice President – PTC India Foundation
4. Fellow of Institution of Engineers (India)
5. Fellow of Institution of Electronics & Telecom Engineers
6. Member – Computer Society of India
7. Member – Indian Science Congress
8. Member – Optical Society of India
9. Member –WWRF
10. Member –FICCI/ASSOCHAM/CII Telecom committee
11. Chairman CII committee on GREEN ENERGY
12. Member - Amity Telecom Vision Board
13. Member Core Group “Mobility For Life “ EU Project

Dr. Ashok Chandra An Indian Engineering Services officer of 1976 batch did his Post graduate in Electronics and PhD in Electronics and Doctorate of Science (D.Sc.) in Radio Mobile Communications. He has worked as a Guest Scientist on DAAD Fellowship at the Institute of High Frequency Technology, Technical University (RWTH), Aachen, Germany during 1995 and 1999. During 2002, worked as a Guest Scientist on DAAD Fellowship at Bremen University, Bremen (Germany), where he undertook a series of research studies in the area of radio mobile communications. Dr. Ashok Chandra is having Technical Experience of about 35 years in the field of Radio Communications/Radio Spectrum Management including about 7 years of experience dealing with Technical Education matters of Indian Institutes of Technology, Indian Institute of Science etc. particularly their various research projects also in the areas of telematics/radio communications and presented over 25 research papers at various International Conferences in the areas of EMI, Radio Propagation etc. He has visited various technical Institutions and Universities namely Technical University of Aachen, Germany; Aalborg University, Denmark; Bremen University, Germany; and University of Lisbon, Portugal etc. and took several lectures in the area of radio mobile communications at Bremen University and Aalborg University. He has chaired various Technical Sessions at the International Conferences on Wireless Communications.

Dr. Chandra recently superannuated from the post of Wireless Adviser to the Government of India. In his responsibility as Wireless Adviser, he was associated with spectrum management activities, including in spectrum planning and engineering, frequency assignment, frequency coordination, spectrum monitoring, policy regarding regulatory affairs for new technologies and related research & development activities, etc. He was also associated with implementation of a very prestigious World Bank Project on National Radio Spectrum Management and Monitoring System (NRSMMS). This project includes automation of Spectrum Management processes and design, supply, installation/ commissioning of HF/VHF/UHF fixed monitoring stations; V/UHF mobile monitoring stations; and LAN/WAN communications network etc. He served as a Vice-Chairman, Study Group 5 of International Telecommunications Union (ITU)-Radio Sector. He has represented India to a large number of ITU meetings including World Radio Conferences (WRC). He served as Councillor from Indian Administration in ITU Council. Currently

Dr. Chandra is Adjunct Professor at the Indian Institute of Technology (IIT), Bombay.

His area of interest includes Technical Education, Radio Regulatory affairs for new technologies, Radio mobile communications, dynamic spectrum management and Cognitive Radio.