

# Flexible Spectrum Management: Approaches for India

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## ABSTRACT

Radio spectrum for commercial mobile services continues to be scarce. Countries around the world have recognized the importance of efficient utilization of this scarce resource and have initiated regulatory and policy steps towards flexible approaches to spectrum management, including sharing of licensed spectrum, and releasing unlicensed spectrum for mobile services. Technologies for shared access and the associated standardization activities have also progressed towards possible large scale deployments. In this paper, we analyze the evolution of spectrum management policies using a causal model and indicate how the markets can lock in to either centralized or flexible approach. We also cite a use case of a flexible spectrum management approach using “spectrum band fill” option and indicate its suitability to the Indian context.

**Keywords:** Flexible Spectrum Management, Spectrum Harmonization, Licensed Shared Access, Cognitive Radio, Spectrum Scarcity, Spectrum Fragmentation

## INTRODUCTION

The ‘mobile-only’ Internet population will grow 56-fold from 14 million at the end of 2010 to 788 million by the end of 2015 (Sridhar & Hämmäinen, 2011). In emerging economies, including India, wireless access is expected to be the main driver for the uptake of broadband services. The rate of growth of mobile data traffic is expected to continue to be higher than that of fixed line data traffic. The following figure illustrates the above trends. Potential of wireless broadband for economic development is well documented (Ericsson, 2013).

Radio spectrum is an essential scarce resource for the provisioning of mobile services. While the demand for wireless services is growing exponentially, the capacity of networks has also been increasing. Wireless networks have been able to attain superior spectral efficiencies and are capable of providing hundreds of Megabits/sec. However, the spectrum available for access networks remains a constraint.

India in certain ways is unique with respect to licensed spectrum management. There are, on average, 10 operators in each Licensed Service Area in India. Typically, an operator holds miniscule 2 X 10 MHz across all the 800, 900, 1800, and 2100 MHz bands. Out of the globally harmonized 2 X 60 MHz in 2100 MHz (Band I) for 3G services, only 20 MHz has been released by the government so far. Each of the 4 operators has 2 X 5 MHz. In the 1800 MHz band, only about 2 X 40 MHz has been assigned to mobile operators out of the total available block of 2 × 75 MHz. Table 1 indicates the amount of licensed spectrum currently assigned and in pipeline, across different countries (Peha, 2012; Prasad & Sridhar, 2014).

In India, the allocation for mobile services is less than half of that in the rest of other countries, with the exception of China. However, most of the countries including China have initiated the process of vacating some of the spectrum held by incumbents such as government and public utilities as shown under the column “P”. For example, in addition to the 360 MHz shown in the table, unpaired Digital Dividend band 703-803 MHz may also be made available in China for mobile services once the

Figure 1. Fixed and Mobile Subscriptions

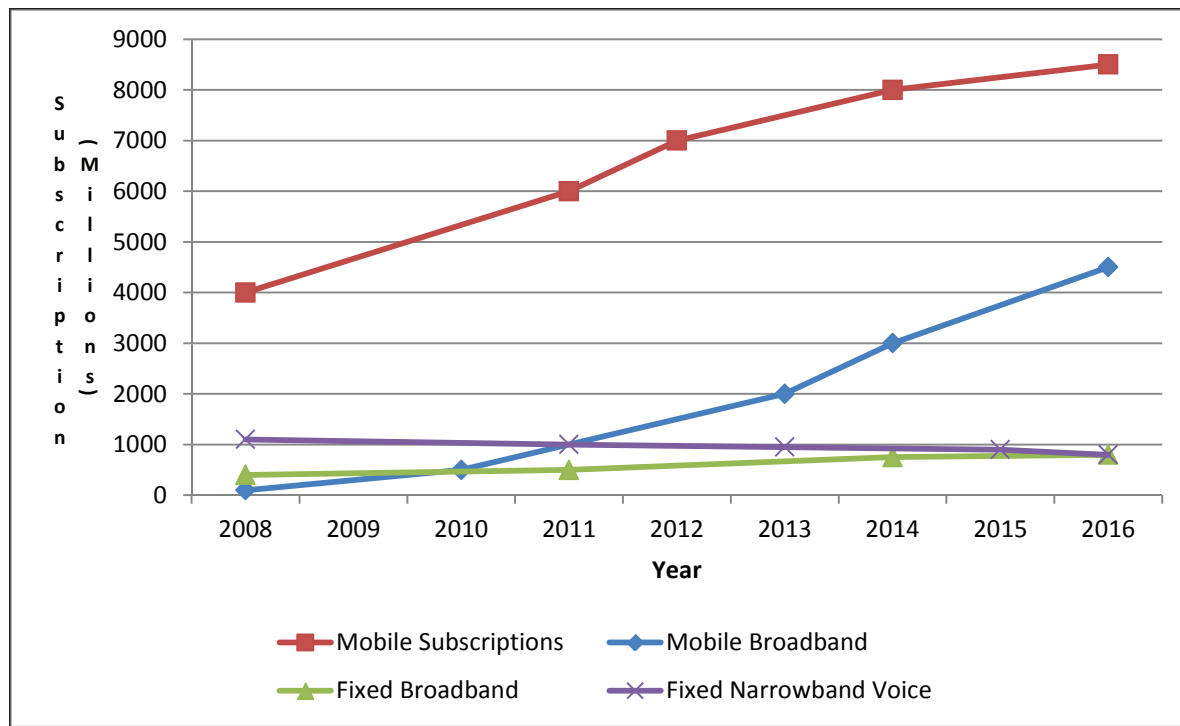


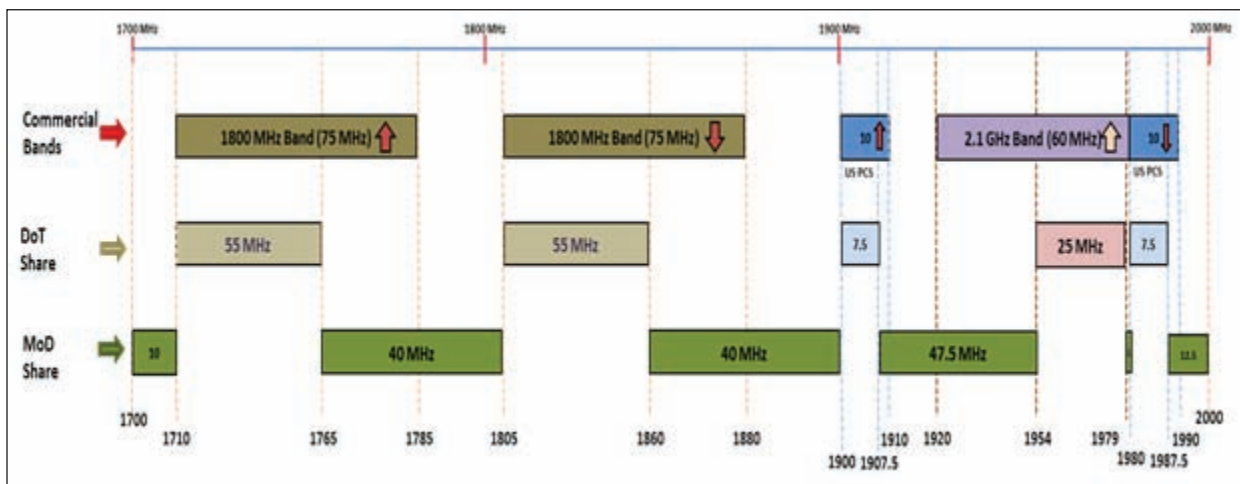
Table 1. Currently Available (CA) and in Pipeline (P) Licensed Spectrum Allocation Across Countries

Band	USA		Europe		Australia		Brazil		China		India	
	CA	P	CA	P	CA	P	CA	P	CA	P	CA	P
700 MHz	70					90						
800 MHz	64		60	0-60	40		65		20		23	
900 MHz			70		50		20		52		36	
1800 MHz		15	120-150	0-20	150		150		90	60	86	
1900 MHz	130	10	15-35		20		20		35	20		
2100 MHz	130	30	120		120		110		30	90	40	30
2300 MHz	20				98						40	
2600 MHz	194		150-190	0-50		140	175			190	40	
Total	608	55	540-615	0-60	478	230	554	0	227	360	265	30

country deploys Digital TV. Hence in about 2-3 years, most of the countries would have allocated 600-700 MHz of spectrum while India is only planning to release 30 MHz for commercial mobile services. The small amount of spectrum is assigned to a very large number of operators in India, with the result that each operator gets roughly one-fifth to one-sixth compared to rest of the world. The spectrum fragmentation is clearly seen in the spectrum Herfindahl-Hirschman Index (HHI): India: 0.13; USA: 0.28; Europe: 0.25; Australia: 0.26; Brazil: 0.21; China: 0.45 (higher value indicates lesser fragmentation).

India has the second largest mobile subscriber base in the world. About 900 million mobile users of which 233 million access Internet using mobiles and 75 million subscribers have a 3G subscription. The scarcity of spectrum does indeed result in poor quality of connectivity. Due to scarcity the operators pay huge sums for the auctioned spectrum, resulting a possible "winner's curse". India witnessed a high price of about \$6/MHz/population in some regions for 2100 MHz band compared to about \$0.30 in the U.S.

Figure 2. Spectrum Allocation between DoT and MoD in India



The main reason for this tiny amount assigned to operators is due to holding of the major portion of the rest of the spectrum blocks in globally harmonized bands of 1800 and 2100 MHz by the Ministry of Defense (MoD). There have been many initiatives to release spectrum from MoD for commercial mobile services recently. The Department of Telecommunications (DoT) in India, through the state owned operator(s) is building a fiber optic network in select places in the country to replace the 2100 MHz wireless network. This project has not progressed as planned. Figure 2 illustrates the above scenarios (Prasad & Sridhar, 2014).

In most countries defense occupies large swathes of spectrum needed for commercial mobile services. Hence there is a need to devise suitable mechanisms and policies for the optimal allocation of spectrum across different critical needs. After a command and control paradigm of spectrum management lasting from 2001 to 2008, the country has gone in for a phased transition to a liberalized regime. Notable elements of this change include the unbundling of spectrum from the service license, the choice of the auction mechanism for the assignment of spectrum, the freedom to use a spectrum block with any technology, the equalization of the spectrum usage charge (tax) across differing amounts of spectrum holdings, the recovery of all spectrum at the end of the license period for fresh auctioning, the enablement of secondary markets in spectrum through trading and sharing, the imposition of one-time fee for migrating administratively assigned spectrum to liberalized form, and the announcement of the new Mergers & Acquisitions (M&A) policy. Since 2010, four auctions have been held, at least two of which

can be deemed to have been relatively successful on account of the sale of blocks put up for auction.

Thus India is uniquely positioned to implement flexible spectrum management regime to take advantage huge tranche of unused and under-utilized spectrum available with government and other non-mobile firms.

## ELEMENTS OF FLEXIBLE SPECTRUM MANAGEMENT

Several markets are gradually moving towards flexible spectrum regimes. In the USA, mobile operators have traded spectrum from each other as well as from broadcasters and other niche spectrum holders. Mayo & Wallsten (2010) affirm that a secondary market for spectrum is already having a positive impact on the mobile industry in the USA. In Europe, though spectrum trading studies were initiated around the turn of the millennium, it is only recently that country regulators have allowed MNOs to trade spectrum. OfCom, the national regulatory authority in the UK, allowed spectrum trading in 900 MHz, 1800 MHz and 2100 MHz in 2011 followed by the recent announcement on 5<sup>th</sup> April 2013 for including the 800 MHz and 2600 MHz bands. Many other European markets are introducing similar policies; however, not much action has taken place as yet. In India, spectrum trading is being discussed since 2012, and only recently the Indian regulator, announced guidelines on spectrum trading (TRAI, 2014a) and sharing (TRAI, 2014b). Sridhar & Prasad (2011) suggest that spectrum trading is beneficial especially in a market with high spectrum

**Table 2. Difference between Command and Control and Property Rights Regime**

Aspect	Command & Control	Flexible regime
Assignment of spectrum	Administratively controlled; limited based on availability of licensed bands for commercial use; centralized.	Initially based on assignment mechanism, such as auction. Later, the spectrum is made available through secondary spectrum trading and the use of unlicensed spectrum; decentralized.
Allocation of spectrum (Technology and service deployed)	Mandated by the spectrum managers (regulator); can be rigid at times	User and market determined including dynamic spectrum access
Property rights of spectrum	Often exclusive use	Flexible, allowing spectrum trading. This trading may be based on spectrum reselling (the whole licensing) or on DSA technologies permitting to share the same spectrum band between two or more operators.
Market structure and spectrum concentration	Dictated by the spectrum manager (regulator)	Evolves based on successful adoption of technologies

fragmentation such as India. Table 2 illustrates the differences of these two modes of spectrum management (Prasad & Sridhar, 2014).

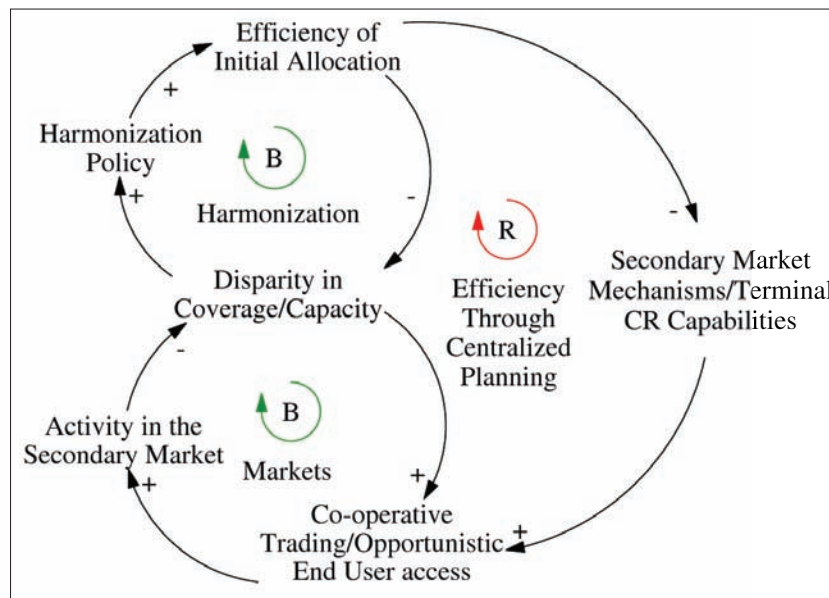
### THE CAUSAL MODEL OF POLICY DECISIONS

The spectrum management policies can be modeled as a causal loop and is shown in Figure 3 (Sridhar, et al., 2012). The model summarizes the spectrum policy differences between advanced markets and emerging markets such as India using the shifting the burden archetype (Senge, 1990) which describes how choosing one solution to

solve a problem makes it more difficult to choose another one thus creating a dependency on the approach chosen first. The model highlights the existence of all important cause-and-effect links and indicates the direction (cause → effect) of each relationship. The relationship is positive (or negative) if a change in the causal factor produces a change in the same (or opposite) direction in growth. A closed sequence of causal links represents a causal loop. The causal loop is “Reinforcing” ( or positive) if it has all positive links or even number of negative links. Otherwise, it is a “Balancing” (or negative) loop.

As indicated in Figure 3, the increased disparity in capacity and coverage can be handled by enforcing a

**Figure 3. Simplified Feedback Model Indicating the Differences Between Spectrum Policy in Advanced Markets and Emerging Market in India.**



**Table 3. Frameworks for Exclusive and Non-Exclusive Use**

	<i>Licensed Spectrum</i>				<i>Unlicensed spectrum</i>	
	Spectrum rights transferred		Spectrum rights not transferred			
	Between Operators	Between Operators and other entities	Between Operators	Between Operators and other entities		
Exclusive use	Trading, Acquisitions	NA	Intra and inter area roaming	Mobile Virtual Network Operators (MVNOs), Femto operators	NA	
Non-exclusive use	NA	NA	Spectrum sharing with equal access using DSA technologies	Opportunistic tiered access using DSA technologies including Licensed Shared Access, TVWhite Space access	Wi-Fi hot spots, CommunityWi-fi	

stronger harmonization policy leading to a more equal and efficient initial allocation and assignment of spectrum. This subsequently leads to the decrease of the disparity and a balancing loop ‘B-Harmonization’. On the other hand efficient centralized allocation means that operators do not need to conduct much market based sharing (or trading) and that end users do not have many options in terms of the different radio access possibilities which subsequently means that secondary market sharing or trading mechanisms between operators (such as national roaming) and cognitive radio type of capabilities (such as a multi-SIM functionality) in devices are not required. This in turn leads to a lower possibility for co-operative trading between operators and opportunistic end user access and subsequently to lower activity in the secondary market. The inability of the market to redistribute the spectrum resources in turn leads to a reinforcing loop (‘R-Efficiency through Centralized Planning’) that possibly locks the market on a path of enforcing a harmonization policy.

The market in India has followed the opposite dynamics. Increased disparity in capacity and coverage in India has been handled by the market in the form of co-operative trading between operators and opportunistic end user access (i.e. many data plans and multi-SIM phones). This in turn has led to what can be seen as a kind of a secondary market activity and subsequently to the decrease of the disparity and a balancing loop (‘B-Markets’).

When the markets tackle the disparities in coverage and capacity it leaves a smaller space for a harmonization policy which in turn leads to less efficient initial allocation and thus to a larger need of secondary market sharing and trading mechanisms between operators and cognitive radio capabilities of end-user terminals in order to efficiently use and redistribute the radio resources. This in turn leads to a reinforcing loop (‘R-Efficiency through Centralized Planning’) that works typically in the opposite direction

when compared to that in advanced markets and can lock the market on a path of tackling disparity in coverage and capacity via the markets.

The corresponding path dependency and the fact that these two market types can be seen as being locked on two opposite paths can have a significant impact on which market for cognitive radio type of systems will diffuse first (Sridhar & Basaure, 2014).

## DYNAMIC SPECTRUM ACCESS TECHNOLOGIES

Policy-led developments and market innovations demonstrate the feasibility and value of flexible spectrum management using a variety of models. The following Table summarizes the different frameworks available for both exclusive and non-exclusive use of spectrum (Prasad & Sridhar, 2014).

Of the above, we discuss the applicability of Dynamic Spectrum Access (DSA) technologies for non-exclusive shared use of licensed spectrum in an opportunistic basis. The DSA technology aims to improve capacity of mobile networks by defining a set of protocols and standards allowing users and operators to dynamically access unused or underutilized spectrum bands. Though coined by Mitola way back in 2000 as Cognitive Radio and despite large efforts in R&D, DSA technologies have not been successfully introduced into the mobile market (Mitola, 2000). Several technical, economic and regulatory challenges have been identified for this slow deployment. In practice, a dynamic management of the spectrum involves consensus and adoption by all stakeholders in the mobile ecosystem including end users, handset vendors, network equipment manufacturers, operators and finally regulators and policy makers.

Presently, there are several DSA technology standards being developing to offer different functionalities. On one hand, ETSI focuses on the development of sensing technologies, embedded in Software Defined Radio (SDR) in mobile devices to access spectrum spaces (Mueck et al., 2010). On the other hand, IETF has been investing efforts towards the standardization of spectrum database, and the associated protocol for accessing white spaces (Manusco, Probasco & Patil, 2013). Similarly, the European Communication Commission (ECC) has defined technical and operational requirements for accessing white space devices in geolocation databases (ECC, 2013). Finally, 3GPP is aiming to improve spectrum efficiency through LTE carrier aggregation that creates virtual wide band carrier from segments of spectrum across all licensed bands (Yuan et al., 2010).

In practice, DSA technologies may evolve towards two scenarios: (i) user-centric; and (ii) mobile operator-centric. In a user-centric scenario, the user accesses the available spectrum space through the DSA capable mobile handsets in a dynamic basis, along the lines of frameworks defined by ETSI. The user or an application in the device decides to some extent on the spectrum and the time of access. Most of the logic will be based on cognitive radio capabilities, such as described by Chapin & Lehr (2007). Sridhar et al. (2013) describe how multi-SIM handsets in markets such as India have initiated cognitive-like responses from end users. On the other hand, in an operator-centric scenario, the DSA capabilities and associated dynamic spectrum management services are provided by the operator to employ spectrum more efficiently. The network operator installed devices access spectrum spaces much as described in IETF and ECC standards.

The user-centric scenario is similar to unbundled handsets that have DSA capabilities that can be purchased directly from a retailer without any intermediation of a mobile operator. In an operator-centric model, the practice is similar to bundling of handsets with associated contract for services that is being practiced today in certain

markets such as the Japan or USA. The operator controls the spectrum space to be accesses and the time of access. However, in both scenarios, the underlying DSA technologies enable users or operators to exploit spectrum more efficiently. Table 4. summarizes user-centric and operator-centric approaches for using DSA technologies (Basaure & Sridhar, 2014).

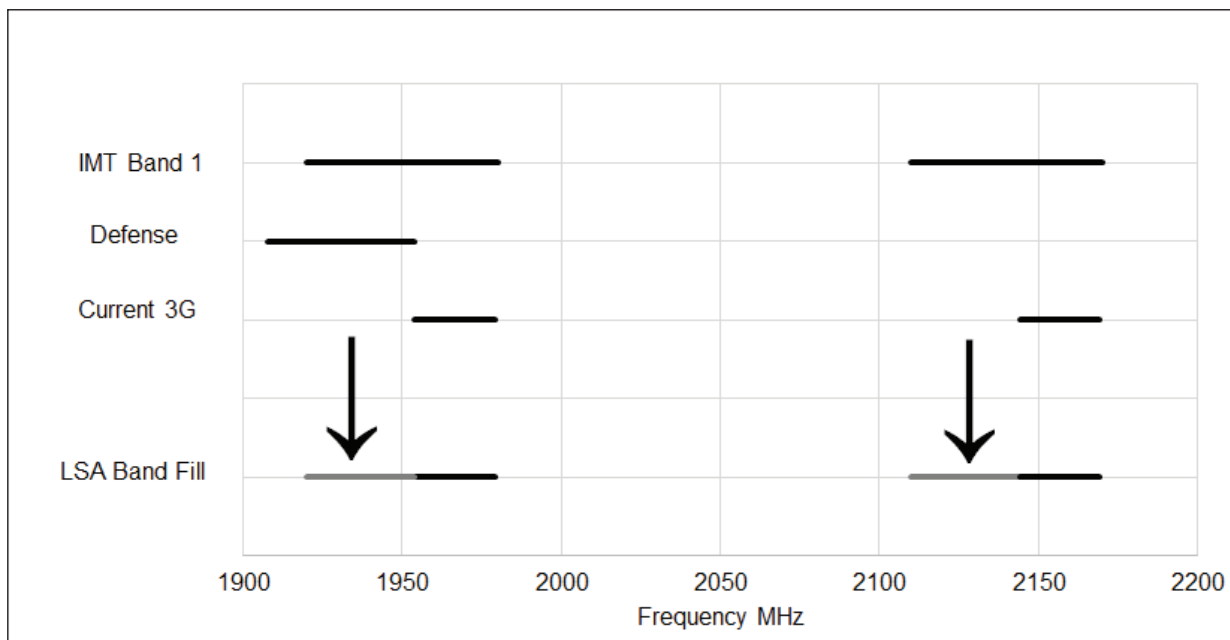
## CASE OF LICENSED SHARED ACCESS

European Commission released ECC Report 205 on Licensed Shared Access (LSA) in February 2014 [3]. LSA is a complementary spectrum management tool that facilitates the introduction of new users in a frequency band while maintaining incumbents' existing services on the same band. LSA ensures a certain level of guarantee in terms of spectrum access and protection against harmful interference for both the incumbents and LSA licensees. This is a case of operator-centric implementation of DSA technologies. In an option referred to as LSA Band Fill, the mobile operators have licenses only for a part of a 3GPP band. The rest of the band is licensed to other users. The mobile operators can get the missing parts of the band into use by utilizing the LSA licensing scheme. The same approach can be used to extend the geographical coverage of the existing mobile operator licenses to cover the areas that have been restricted from their license (Sridhar & Kokkinen, 2014).

In the areas where a 3GPP band is partially licensed to other users, LSA Band Fill brings a possibility to open the missing parts of the band to the mobile operators so that the existing users can continue their use of the spectrum. In addition to the benefits of the LSA Region Jump, in LSA Band Fill, the user equipment, which is currently available on the local market can immediately be used. In the network, new base stations need to be installed as the mobile operators want to keep their exclusive parts of the spectrum and the LSA extension of the frequency band separately. An illustration of LSA Band Fill is shown in Figure 4.

**Table 4. Deployment Scenarios for DSA Technologies**

<i>DSA diffusion scenarios</i>	<i>User-centric</i>	<i>Operator-centric</i>
Definition	Users or applications installed in mobile devices make decision on accessing spectrum	Devices installed by the mobile operators make decision on accessing the spectrum
Provider	Device manufacturers provide DSA capabilities to the user	Incumbent mobile operators provide DSA capabilities to the user either through their network capabilities or through bundled applications and services.

**Figure 4. Illustration of LSA Band Fill across Different Users**

## CONCLUSIONS

Flexible spectrum management is needed both for developed and emerging countries as data usage continues to increase exponentially. Reports indicate that all emerging markets experienced doubling of mobile data traffic from 2012 to 2013. The lack of adequate spectrum and associated capacity, especially in emerging countries is the cause for poor service experience and inadequate roll-out of mobile broadband networks. While regulators all over the world have been trying to free up more spectrum for exclusive use of mobile operators, it is often time consuming. It also requires coordination with the incumbent holders for vacating the spectrum and possibly building alternative communication infrastructure.

Though most countries have recognized the need for adequate spectrum for commercial mobile services, allocating spectrum for licensed and exclusive use is a tedious and lengthy process. The DSA technologies offer a flexible spectrum management approach. In this paper, we have highlighted how mobile markets such as India are ideally suitable for the deployment of DSA technologies. In particular we have demonstrated how operator oriented models such as LSA can be a possible option to overcome spectrum scarcity in the Indian market.

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