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Moving from Command and Control to Flexible Use and to a Spectrum Commons

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Abstract

In most countries, the command and control approach is usually the starting point of the liberalization of the telecommunications industry, which had previously been entirely in the public sector. The command and control approach is useful for achieving early roll-out and rapid growth. However, there are attendant risks of regulatory failures including spectrum getting 'stuck' in lower value uses, and absence of mechanisms to put under-utilized spectrum to a better use. The command and control regime begins to fail in the face of several new developments including the maturation of competition, development of new technologies in pre-existing bands. Moving to a hybrid model of flexible spectrum use and spectrum commons is the need of the hour.

The transition to the new model cannot be made in a single stroke since the elements of the C&C framework are inter-linked and bound together by an inherent logic. For instance moving to spectrum auctions requires the dismantling of ascending spectrum usage charges, but political pressure may require that the move be revenue-neutral. This paper highlights aspects of a phased approach to arriving at the new paradigm of spectrum management.

1. Introduction

In most countries the starting point of the liberalization of the telecommunications industry, previously entirely in the public sector, is the command and control approach. As a result of remnants of old ways of thinking, the government initially tries to benefit from the financial resources and operational efficiency of the private sector without giving up control on the objectives and modes of operation, and continues to have a strong public sector presence in the industry. The strong grip that the government has on the industry's operations is significantly based on strict terms and conditions related to spectrum, the critical input in the provision of mobile services.

However, the paradigm of regulation has shifted from pure coordination and planning to the creation of a competitive and sustainable environment for various services, including telecommunications. Technologies have also evolved to accommodate flexibility in spectrum management. As a result countries are migrating in different degrees, and at different speeds to flexible spectrum management regimes.

2. Command and Control versus Flexible Use

In the command and control approach, the government may do all or some of the following: decide the number of players, select them through an administrative procedure, fix a subsidized price for the license and spectrum (which is often bundled with the license), determine specific technologies and services for spectrum use, put in place 'use-it—or-lose-it' rollout obligations under which the promoter's stake cannot be sold till time-bound network deployment does not take place, tie the assignment of incremental spectrum to achieving subscriber milestones, put in place a usage charge regime that increases with the amount of spectrum held, and impose a universal service obligation.

In contrast, in the flexible approach the government uses market mechanisms for spectrum assignment, accords freedom in the choice of technologies and services in those bands, promotes secondary markets for trading and leasing of spectrum, and separates universal service obligations from license terms. The rationalization of government spectrum is an important element of this approach as it frees up spectrum bands for commercial use.

Table 6-1 describes the differences between the two approaches:

Table 6-1. Difference between Command and Control and Flexible Use Regimes

Aspect	Command & Control	Flexible
Allocation of spectrum	Limited number of bands available for commercial use	Greater number of spectrum bands made available, including by rationalizing government spectrum
Spectrum use	Specified technology and service	User determined technology and service
Assignment of spectrum	Administratively determined price; exclusive use (i.e. only primary market in spectrum functions)	Market determined price (through auctions); trading and leasing of assigned spectrum possible through secondary markets
Roll-out obligations	Mandated	Allows coordination amongst the spectrum owners to meet rollout targets

The command and control approach is useful for achieving early roll-out and rapid growth. The low price of license and spectrum is believed to keep prices of basic voice telephony low and promote diffusion. The stipulations on spectrum use and rollout are meant to ensure efficient use of spectrum in the context of spectrum scarcity and the low number of operators. The universal service conditions address the obligation of the government to provide service in under-served regions. However, there are attendant risks of regulatory failures including spectrum getting 'stuck' in lower value uses, and absence

of mechanisms to put under-utilized spectrum to a better use. The command and control regime begins to fail in the face of several new developments:

1. Growth of advanced services in new spectrum bands: As 2G technologies give way to 3G technologies that allow advanced services like IPTV, VOIP, and video-conference, there is no need to subsidize the corresponding spectrum bands. Hence, if the command and control framework were to continue for lower generation spectrums, there would be a dual spectrum regime in which 2G spectrum is subsidized and higher generation spectrums are priced according to the market. The administration of such a regime would become intractable as operators are likely to be holding several bands simultaneously, and servicing subscribers using a combination of bands. For example, it may not be possible to segregate subscribers in different bands in order to apply the subscriber linked criteria for assigning additional 2G spectrum.
2. Growth of advanced technologies in old spectrum bands: Spectrum bands originally allocated for voice services may become suitable for advanced technologies. For example the 900 MHz band originally deployed for 2G technologies has developed a rich eco-system for 3G services. This leads to spectrum getting stuck in lower value uses for the period of the operator's license.
3. Convergence of services: In India certain basic service operators were able to use the limited amount of spectrum assigned for mobility in the local loop to provide unrestricted mobility. Such possibilities make a service-specific license restrictive.
4. Growing maturity of competition: In the initial years of the telecommunications industry there is usually a paucity of spectrum. Hence only a few operators can be introduced. However as more spectrum gets released and more operators are introduced, competition matures to a point that government strictures are no longer necessary to ensure the efficient use of spectrum. In India, in 2002, the year in which the SLC was announced, there were 4–6 operators in every circle. In 2010, the average number of licensees in each circle had gone up to 15. Any inefficiency in the use of spectrum was sure to be penalized by market forces and did not need to be administratively monitored.

When we move from the command and control approach to the liberalized approach we have to carefully untangle the different elements of the command and control approach which are bound together by an inherent logic. The task of creating well-functioning spectrum markets lies at the heart of the task. This requires rationalization of the use of government spectrum in order to ensure a good supply of spectrum in the primary market, changing the licensing framework, creating secondary markets for trading and sharing, putting in place a facilitative M&A regime, allowing flexible use of spectrum, and removing universal service obligations from the commercial license terms.

3. Rationalization of government spectrum

Public sector spectrum in most countries accounts for the major portion of the holding of spectrum below 3 GHz. This spectrum is mainly used for defense purposes. In the UK, for instance, defense accounts for 75% of public sector spectrum. Other uses of public sector spectrum include civil aeronautical, emergency and safety services, and science and maritime applications.

Over the years, the uses of commercial spectrum have grown. Technology innovations in telecom continue to give birth to new applications that interfere with legacy applications. For example Wi-Max technology that operates in 2.5 GHz and 3.5 GHz band, interferes with INSAT communications of the Department of Space (DoS), Government of India. Mobile TV applications that use 700 MHz interfere with traditional TV broadcasting.

As a result, attention has increasingly become focused on whether public sector bodies use their spectrum efficiently. In May 2003, the US government signed a memorandum requiring federal departments to improve the efficiency of spectrum use. In the same year the UK government commissioned an independent audit of spectrum holdings, focusing particularly upon public sector spectrum use.

The lack of rationalization of use of public sector spectrum can lead to a severe paucity of spectrum for commercial use. Table 6-2 indicates the extent of variation in the allocation of spectrum for commercial mobile services across India and Finland and the low availability of commercial spectrum in India:

Table 6-2. Spectrum Allocation for Commercial Services in Finland and India

Factor	In India	In Finland
Average spectrum allocation per operator per License Service Area	2×7 MHz in 900 and 1800 for 2G; 2×2.5 MHz in 800 for 2G/3G; 2×5 MHz in 2100 for 3G; 20 MHz unpaired in 2300 for BWA (Sridhar & Prasad, 2011; Sridhar, 2011)	2×11.3 MHz in 900; 2×24.8 MHz in 1800; 2×15 MHz in 2100; 4.8 MHz unpaired in 2100; 2×20 MHz in 2600 MHz

Public sector spectrum is usually considered to follow different rules from commercial spectrum. The possible reasons are that it is indispensable for functions like defense and radar, and, further, the service itself has a high priority, for example, defense or ambulance services. However if well functioning spectrum markets develop that cover a large number of frequencies and provide predictable trading opportunities, then it is conceivable that the public sector can acquire its spectrum on the market rather than by fiat. Conversely, spectrum markets are unlikely to develop unless public sector bodies participate, since the public sector has built up large spectrum holdings in the command-and-control phase, including in frequencies that are valuable for commercial use.

If public sector spectrum users are to participate effectively in spectrum markets, certain pre-conditions have to be fulfilled. Public sector spectrum use is often cloaked in secrecy. In many jurisdictions, government departments are not issued with detailed licenses specifying rights and responsibilities.

Wherever possible, information necessary for potential users to make decisions about the purchase, leasing or sharing of public sector frequencies has to be made available.

The following intermediate steps can pave the way for bringing more efficiency in public sector use of spectrum and facilitating the growth of spectrum markets, overall (Cave et al 2007). Many of these are currently under consideration by the US government.

1. Valuation of spectrum: The valuation of spectrum using techniques outlined in Chapter 5 will enable a fuller comprehension of the opportunity cost of spectrum in the public sector.
2. Audit of actual use: Audit of spectrum use is highly desirable in order to identify areas of under-utilization, but may not be feasible due to the sensitive nature of the use of public sector spectrum
3. Incorporation of valuation in investment decisions: The value of spectrum should be incorporated as a cost in project appraisals. This would encourage those engaged in procurement to examine the scope of substitution between spectrum and other resources.
4. Compensation of public sector users: Suppose public sector spectrum has a valuable private use and can be replaced by alternate frequencies, the concerned department should estimate the cost of the transition to the new frequency, and be compensated from the auction proceeds of the previously occupied spectrum. In case the auction proceeds fall short of the cost of migration to the new frequencies then the process should stop as public sector spectrum has been shown to be efficiently employed in its current use.
5. Special pre-emption powers for the public sector: Participation of the public sector in the market may be encouraged if there is a clause for the pre-emption of spectrum in an emergency. This clause should not, however, be allowed to undermine the efficiency of the market. Hence public sector users should have to pay market prices for spectrum obtained in this manner; and the procedure should be used sparingly and in strictly defined circumstances.

3.1. Responsibility of Executive Head

Often the National Frequency Allocation Plan (NFAP) document that allocates spectrum between different uses and ministries is entrusted to a wireless planning division under the Ministry of Communications, which is also directly responsible for the assignment of commercial spectrum. This results in the Ministry of Communications having to adjudicate between different peer ministries for the allocation of spectrum. This adjudication is often stalled because of the conflict of interest involved and the absence of a suitable adjudicating authority. As a result, inter-ministerial disputes are not handled with an appropriate process causing unnecessary delays and inconsistencies in the allocation of spectrum.

Ideally spectrum allocation should fall under the purview of the office of the Chief Executive of the country which has the necessary standing to settle the allocation of spectrum between ministries and chart out a strategy to achieve the country's strategic goals in international forums like the ITU. Countries such as France have recognized the importance of spectrum as a key national resource and brought spectrum under the direct supervision of the executive head.

A useful case study in the re-allocation of spectrum from government to commercial use lies in the release of 'digital dividend spectrum' in India.

3.2. Release of Digital Dividend Spectrum in India

The digitalization of terrestrial TV networks has started in most of the advanced markets. This process frees-up a significant amount of the Ultra High Frequency (UHF) band which can be potentially allotted for commercial mobile services. This spectrum, referred to as the "Digital Dividend" spectrum, varies between countries and regions, but amounts to approximately 100 MHz (108 MHz in USA, 128 MHz in UK, 72 MHz in France, and 54 MHz in Korea). Since the Digital Dividend spectrum is in the UHF range, it has very good propagation characteristics (being less attenuated by obstacles such as buildings). It is approximately 70 percent cheaper to provide mobile broadband coverage over a given geographic area using UHF spectrum than with the 2100 MHz spectrum widely used for mobile broadband today. The low frequency characteristic makes this spectrum particularly well suited to providing mobile broadband coverage in rural and suburban areas.

In June, 2009, all the US terrestrial broadcasting stations switched off their analog transmission and turned on digital transmission, thus freeing up spectrum for mobile and emergency services. The European Commission issued a mandate in 2008, to the Conference of European Post & Telecommunications (CEPT) to carry out investigations to define technical conditions for the use of the 790-862 MHz Digital Dividend spectrum by fixed/mobile communication networks (Karimi et al 2010). The switchover from analogue to digital terrestrial television, expected to be completed in Europe by the end of 2012. Finland started TV digitalization process in June 2008. A spectrum block of 2 X 30 MHz in 791-862 MHz block has been made available for commercial mobile services.

In India, the relevance of over the air broadcasting has reduced over the years due to cable and Direct To Home (DTH) satellite television. Currently only the government operator provides over the air broadcasting. There are about 60,000 Local Cable Operators and 7 DTH providers in the country with close to 80% of the 135 Million TV sets are either connected to Cable TV or DTH. Further the government has set a deadline of digitalization of cable TV. The first phase of Cable TV digitization has been relatively successful. If the second phase proceeds smoothly, India will be well on its way to joining the elite club of many advanced countries in sun-setting analogue television. However, though the Telecom Regulatory Authority of India (TRAI) specified 585-862 MHz for mobile TV services way back in 2008, the spectrum has not yet been released due to continued tenancy by the Ministry of Information and Broadcasting.

4. New Licensing Framework

In most countries the service and spectrum licenses are delinked from each other. The service license is obtained by paying a nominal annual fee and is automatically renewed in the normal course. It includes standard terms on doing business and may relate to a set of services (or may be a universal service license allowing all telecommunications services). The spectrum license is allocated to the licensees for fixed periods of time based on certain methods including auction and may specify a technology (for instance 2G) or may be open to flexible use.

In those countries where the service license comes bundled with spectrum, explicit delinking of license from spectrum is required to move to a market-oriented mechanism for spectrum. An unbundled spectrum license is amenable to trading and leasing, including to parties that may not hold an operator license. With a bundled service and spectrum license issues like a mismatch between the remaining license tenure of the buyer and seller can exert a chilling effect on transactions. The necessity to remove clauses related to spectrum use from the spectrum license is detailed in a subsequent section.

4.1. Annual spectrum usage charge

One of the features of the licensing framework of command and control regimes is an annual spectrum charge that varies with the amount of spectrum held. The escalating percentage is a way of charging for additional spectrum which does not attract an upfront payment. It is also meant to bring about the efficient use of spectrum. With a market-oriented mechanism such as an auction, and sufficient competition in the market, escalating annual spectrum charges are no longer required. Such charges would create unnecessary heterogeneity between bidders who would be holding different quantities of spectrum at the time of bidding. They would also create complications in the trading and leasing of spectrum (described in a later section).

The government may desire that the migration to uniform rates of usage charges should be revenue-neutral. In view of the additional revenues accruing from auctions, the government need not worry unduly about the loss of revenue on account of the annual usage charge. [Sridhar \(2006\)](#) argues that regulatory levies such as spectrum charges should be in proportion to the cost of administration. However, if there are political compulsions to maintain revenues from usage charges at previous levels then one option would be to take the average usage charge rate for the industry and fix this as a uniform rate. Uniformity of annual spectrum charges across all frequency bands and technologies would facilitate change of use and effective use of assigned spectrum.

5. Creating Secondary Markets

Secondary markets in spectrum allow the trading and leasing of spectrum. The presence of such markets reduces the risk for participants in primary markets.

5.1. Trading of Spectrum

Crocioni (2009) defines trading as a process in which there is a change in ownership of a license for economic consideration. In a trading regime, licensees are allowed to aggregate and disaggregate their spectrum endowments (either geographically, by frequency, or by time). Thus, spectrum gravitates to those who value it most, allowing for the establishment of dynamic and competitive wireless communication markets. Caicedo & Weiss (2011) as well as Crocioni (2009) point out that such spectrum markets can be viable if sufficient numbers of market participants exist and the amount of tradable spectrum is balanced to the demand. Trading can be via mutually agreements between the parties or via exchanges as indicated in Caicedo and Weiss (2011). A uniform spectrum usage charge homogenizes the taxes faced by the buyer and the seller and promotes transactions.

In the active secondary spectrum markets of the U.S., mobile operators have bought spectrum from each other as well as from broadcasters and other niche spectrum holders. Of late, AT&T and Verizon are on a buying spree as they vie with each other in expanding their 4G LTE networks. Since the 2011 collapse of AT&T's \$39 billion bid for T-Mobile USA, it has been working to acquire spectrum from a variety of other sources. For example, in 2012, AT&T obtained approval to purchase 700 MHz and 2300 MHz spectrum from the likes of NextWave Wireless, Comcast, Horizon Wi-Com and San Diego Gas & Electric Company. In 2011, AT&T also bought a sizable chunk of spectrum from Qualcomm, which the chip company had used for its failed "Flo TV" venture. Verizon recently agreed to pay \$3.6 billion to buy spectrum from a consortium of cable companies to augment its spectrum capacity. Table 6-3 indicates cases of trading amongst different operators.

Table 6-3. Examples of partnerships in Spectrum trading

Year	Transaction	Valuation
??	Verizon bought 700 MHz spectrum from SpectrumCo, a group including Time Warner, Comcast and other cable companies	\$3.6 billion
2011	AT&T bought 700 MHz from QualComm	
2013	AT&T is planning to buy 700 MHz spectrum from Verizon Wireless	\$1.9 billion
2013	Verizon planning to buy 2.5 GHz spectrum from Clearwire	\$1.5 billion

As can be seen above, most of the trading is in 700 MHz due to the broader coverage of this spectrum and the accompanying eco-system for 4G LTE services.

Though spectrum trading studies were initiated in Europe around the turn of the millenium, it is only recently that country regulators have given the go ahead for spectrum trading between MNOs. OfCom, the telecom regulator in the UK, allowed spectrum trading in 900 MHz, 1800 MHz and 2100 MHz in 2011 followed by the recent announcement on 5th April 2013 for allowing trading in 800 MHz and 2600 MHz. However, not much action has taken place as yet in the European market. Spectrum trading is not yet allowed in India.

5.2. Enabling Sale of Inefficient Spectrum

The potential sellers of spectrum include those who are unable to make optimal use of it. In the command and control regime, such operators may have got spectrum cheap, and stand to make windfall gains by selling in spectrum markets. In many cases such a gain comes with a political risk for the government which may be seen as having transferred national wealth into private hands. To guard

against this, the government introduces a lock-in period for stake sales by a promoter, i.e. someone with significant share capital in the licensee, and whose net worth has been taken into consideration when determining eligibility for granting the license. If the firm fulfills all the network roll-out obligations then the lock-in period is waived. The main objective of such rules is to block the unearned gains arising from transactions in stakes of promoters particularly when the value of spectrum is not getting correctly reflected in the license fee.

Without the participation of such licensees, the sellers' side of the secondary market in spectrum could be virtually non-existent as it is quite likely that incumbent licensees may be unwilling to part with any of their spectrum. This creates market "thinness" as explained by Bykowski (2003). Therefore the lock-in period should be waived provided the consequent opportunity for unearned windfall gains is addressed. Such windfall gains can be moderated by levying a spectrum transfer charge on all such transactions. The case for levying a tax on net windfall gains from spectrum trades should be balanced by the consideration of encouraging the efficient use of spectrum.

The importance of having low transaction costs in ensuring efficient market in spectrum has long been recognized (Coase 1960). The spectrum transfer charge should be chosen such that it provides adequate rate of return for both the buyer and the seller of the transaction. While such an approach to fixing the rate of transfer charge may not ensure that the full value of the spectrum accrues as revenues to the government, it will ensure that spectrum reaches the hands of an entity that values it the most and puts this scarce resource to its most efficient and optimal use. It is this efficient and optimal use of the spectrum resource that should be the primary objective of the government, rather than the maximization of revenues. In other words, the trading policy should create a conducive environment for spectrum sale without undue windfall gains to licensees.

5.3. Leasing of Spectrum: Spectrum Manager Model

On occasion, operators may want to enter into agreements to lease spectrum without transferring the rights and obligations of the original license holder (Sridhar & Prasad) who continues to act as a spectrum manager. This is sometimes referred to as spectrum sharing although the term is more appropriate for situations where two entities use a common block of spectrum in a non-exclusive manner. Leasing can be beneficial: (i) amongst operators having non-uniform and complementary subscriber bases in different parts (say, urban and rural) of a service area, i.e. intra-region leasing (ii) when operators hold spectrum in complementary service areas and want to provide national coverage to their subscribers, i.e. inter-region leasing. While parties in a leasing agreement obtain exclusive rights to certain frequency bands, the original license holder continues to be responsible for abiding by license terms and conditions. In case the original license holder has acquired the spectrum at subsidized rates and is within the lock-in period, leasing charges should be levied in a manner similar to transfer charges in the case of trading.

Instances where the need for leasing exists are commonplace. In India, the 3G and BWA auctions took place in 2010. 2×5 MHz paired frequency blocks in 2100 MHz and 20 MHz unpaired frequency blocks in 2300 MHz for 3G and BWA respectively were auctioned. Bids for pan-India spectrum were as high as \$3.7 billion and \$2.85 billion respectively. Inadequate spectrum and bullish expectations on wireless

broadband demand were possible reasons for the high bids. However, due to escalating prices, none of the bidders got 3G spectrum for all the 22 LSAs. In the BWA auction held after the 3G auction, all bidders except one received spectrum for only 4-5 LSAs. The disparity in spectrum allocation across different LSAs for wireless broadband services (see Table 6-4) creates the need for inter-region spectrum leasing to provide services across the entire geography of India.

In Finland, 3G spectrum was allotted using administrative hearings (‘beauty contests’). Though all operators have been given a national license, not all of them have 100 percentage of the mainland area covered. Even the Finnish archipelago needs coverage due to habitation during the summer season. Since the demand for network access in these areas is seasonal and often not bandwidth intensive, there is a case for leasing spectrum and the associated infrastructure (e.g. cell sites, backhaul capacity) to minimize cost.

Table 6-4: Disparity of spectrum allocation for wireless broadband services in India

LS A	Op-1	Op-2	Op-3	Op-4	Op-5	Op-6	Op-7	Op-8	Op-9	Op-10	Op-11	Op-12	Total
1	3G+BWA	BWA	3G	3G		3G				BWA			6
2	3G+BWA	BWA	BWA	3G		3G		3G					6
3	3G+BWA	BWA	3G	3G		3G				BWA			6
4	3G+BWA	BWA	3G		3G			3G+BWA					5
5	3G+BWA	BWA			3G	3G	3G				BWA		6
6	3G+BWA	BWA	3G+BWA				3G	3G					5
7	3G+BWA	BWA	BWA		3G	3G	3G						6
8	3G+BWA	BWA	3G			3G		3G+BWA					5
9	3G+BWA	BWA			3G	3G	3G			BWA			6
10	3G+BWA	BWA			3G		3G	3G		BWA			6
11	3G+BWA	BWA		3G	3G		3G					BWA	6
12	3G+BWA	BWA	BWA	3G	3G		3G	3G					7
13	3G+BWA	BWA	3G	3G			3G				BWA		6
14	3G+BWA	BWA			3G	3G		3G			BWA		6
15	3G+BWA	BWA	3G		3G		3G				BWA		6
16	3G+BWA	BWA	3G	3G		3G		3G+BWA					6
17	3G+BWA	BWA	3G	3G				3G+BWA					5

18	3G+BW A	BW A	3G	3G				3G+BW A	3G				6
19	3G+BW A	BW A	3G	3G	3G				3G		BWA		7
20	3G+BW A	BW A	3G	3G	3G			3G+BW A					6
21	3G+BW A	BW A	3G	3G				3G+BW A					5
22	3G+BW A	BW A		3G				3G+BW A	3G				5

Source:

An operator that does not have radio access infrastructure in specific geographical areas can possibly use the spectrum and the associated infrastructure of other existing operators to provide coverage. This is often referred to as 'national roaming'. National roaming accelerates competition by allowing new operators to provide services within shorter time frames. Though national roaming agreements normally have a sunset clause, they can be made mandatory in specific locations, especially in rural and remote areas (Shanab, et al., 2007). Though leasing of spectrum is not allowed in India, 3G operators have already started sharing of spectrum in select areas of the country.

Administering leased spectrum is difficult when spectrum usage charges are non-uniform across different blocks of spectrum. The original licensee may have to pay at a higher rate even while controlling a spectrum holding smaller than the licensed block of spectrum. On the other hand, the lessee may get away by paying a rate incommensurate with the size of the block they control. Setting a uniform usage charge would help to avoid these issues.

5.3.1 Leasing between MNOs and MVNOs/ ISPs

Economical and technical efficiency gains, especially in markets such as India, can also accrue when there are pockets in an LSA where an operator has under used spectrum and wants to lease it to Mobile Virtual Network Operators (MVNOs)¹, Internet Service Providers (ISPs), venue owners (i.e. hotels, hospitals, malls, airports), or Femtocell operators.

It is to be noted that such transactions do not involve a change of property rights. The original licensee continues to be responsible for abiding by license terms. In some cases some obligations also devolve directly upon the MVNO. The possibility of such trades will increase the demand for spectrum in markets where property rights are exchanged.

5.4. Femtocells

¹Mobile Virtual Network Operator is a licensed/ registered telecom operator who normally leases/rents spectrum and other associated facilities to provide mobile communication services.

Femtocells allow traffic to be diverted from the carrier's macro cellular network to a localized network operating in the licensed band. They use low power access points that communicate with the voice/data network over a broadband connection such as DSL or a cable modem. Standard mobile cellular network protocols such as GSM, CDMA, WCDMA, LTE, or Mobile WiMax are used to communicate with the mobile handset. Though Wi-Fi at home resembles Femtocell, it requires dual-mode handsets and is mainly meant for data services. Femtocells can deliver both in-home and mobile voice and data services with existing handsets. They require certain portion of spectrum holding to be refarmed by the operators.

The architecture of a typical 3G Femtocell approved by 3rd Generation Partnership Project (3GPP) is given in Figure 6.1.

Figure 6.1. Femtocell as envisioned by 3GPP

While the macro radio network connects the subscriber to the mobile core network outside the house, the hand-off to the Home Node takes place once the subscriber gets in to the house. From thereon, the subscriber generated voice and data traffic is captured by the home node and sent through the broadband connection over the Internet to the Gateway, which then passes them on through the defined interfaces to the mobile core network. It is to be noted that the Home Node incorporates both the functions of BTS as well as that of the Radio Network Controller (RNC) for radio resource management functions. This is referred to as a flat architecture. The Femto Cell Gateway (FTG) installed in the operator's network is a very important component in the Femtocell network architecture. The FTG acts as a concentrator aggregating traffic from a number of similar Home Nodes, thus hiding the millions of home nodes to the operators' Core Network. Thus FTG enables the Home Nodes to be deployed seamlessly without any modifications to the operators' core network functions.

Femtocell home base stations deployed in combination with the macrocellular network have the potential of significantly reducing the total network costs. The fundamental reasons for the savings are that the macro network radio frequency coverage is overburdened when attempting to provide indoor coverage, especially due to severe signal attenuation inside homes compared to the streets. The operator incurs significant capital and operational expenditure to provide more macro coverage. Also, studies have proven that while the savings in costs for the operator are more for high bandwidth data traffic, operational efficiencies accrue even in the case of traditional voice services. Moreover, the

Femtocell box sitting at the user home can learn the usage pattern and hence can provide valuable data to the operators to provide personalized service offerings. While Femto Forum (www.femtoforum.org) with over 100 members (including fixed, mobile and integrated operators) is actively promoting the use of Femtocells, commercial deployment is still limited to certain pockets (Denver and Indianapolis in the US) and the first set of launches in Europe and Japan are expected only this year. Femtocell is proving itself as a disruptive technology that provides a win-win for operators as well as subscribers. The cost of a Femtocell is as low as \$50 (the cost of a TV Set-Top box; less than a Wi-Fi access point) and is slated to further go down as volumes pick up and hardware technology improves reducing the cost of components.

The Ofcom in the UK has allocated 2 MHz of spectrum for use by micro-cell operators. Such operators can cater to the high data requirements of office complexes or residential apartments and handover traffic to one of more of the wide area carriers. This reduces spectrum congestion, increases competition in the market for services, and allows greater innovation in the development of new devices and applications.

The various kinds of transactions possible in secondary markets are summarized in Table 6-5.

Table 6-5. Types of transactions in spectrum in secondary markets.

	Licensed Spectrum			
	Spectrum rights not transferred		Spectrum rights transferred	
	Between Operators	Between Operators and other entities	Between Operators	Between Operators and other entities
Exclusive use	Intra and inter circle roaming	MVNO, Femto operators	Trading, Acquisitions	NA

6. Flexible Use

Procedures for changing use or other parameters of the license vary significantly across countries. For example, in Australia and New Zealand, the property rights are broadly defined according to technical or core parameters that set the maximum level of emissions. If this level is exceeded, the affected licensee has a right to force the licensee that causes interference to take measures to reduce its emissions.

However, the licensee is free to act as it wishes including modifying the type and nature of the services offered and the technology used, as long as interference guidelines are followed (Crocioni, 2009).

However in many countries in the early stages of spectrum liberalization, there are rigid guidelines on services and technologies. For instance, in India, spectrum assigned for 2G use in the 900 MHz and 1800 MHz bands, cannot be used to provide 3G/4G services even though there are vibrant eco-systems for the provision of CDMA-EVDO, and WCDMA based 3G services on these bands. 3G services can only be provided only in the 2100 MHz band. The use restrictions hinder the value of spectrum in the hands of the buyer and hence the incentive to trade. Further, the existing commercial users of spectrum have very little incentive to sell excess or unused spectrum if the buyer will use its acquired spectrum to provide a service that is currently provided by the seller (e.g. 2G or 3G).

Consequently the number of participants in such a spectrum market is likely to be very low. Such market “thinness” decreases the likelihood that a trade will take place. For example, in Australia the low activity levels in the trading market are attributed to lack of portability and the nature of property rights specified in the license (Xavier & Ypsilanti, 2006). Hence change of use of a spectrum band should be allowed after trading so that the buyer deploys the acquired spectrum block in its most effective use. Such a spectrum trading market would allow firms to choose technologies based on market conditions rather than on standards dictated by the government. This will also allow a de facto standard to emerge through competition, if appropriate.

7. Smaller and More Frequent Auctions

Researchers have pointed out that when small blocks of frequencies become available at different intervals of time as in the case of India, there may be benefits from holding smaller and more frequent auctions as soon as spectrum becomes available rather than wait and assign the whole spectrum in one go. For example, the number of auctions held since 2002 has been particularly high in the US with 29 instances with fewer in Australia (4), New Zealand (4) and Norway (5). In the UK, a handful of auctions have been held after spectrum trading was introduced. In India also, spectrum should be auctioned in small blocks of 2 X 1 MHz, as and when available. This procedure will provide enough quality information to the secondary market as well regarding the value of the spectrum, thus making it efficient.

8. Spectrum Sharing Frameworks

There are two dimensions along which spectrum use can be categorized. The first relates to whether exclusive use relates to licensed or unlicensed spectrum bands. There is considerable evidence that the non-exclusive use of unlicensed spectrum has huge economic value. Recent estimates place the value created by current applications of unlicensed spectrum at USD 16-37 billion a year in the US alone (Milgrom et al 2011). Sharing of licensed spectrum bands is also generating enormous value.

The second dimension along which sharing agreements can be categorized is the geographical span of the shared spectrum. Some sharing agreements, for instance TV white spaces, span a wide geographical area. We call these macro-cellular sharing agreements. Others are limited to specific locations, like airports or homes. These are called micro-cellular sharing agreements. There may also be, in some cases, a hierarchy of use, with graded levels of access rights. In others, all users may have equal access.

The various models of spectrum sharing can thus be arranged in the following Table 7-1. The following sections elaborate upon the specific sharing agreements involved.

Table 7-1. Frameworks for Non-Exclusive Use

	Macro-cell		Micro-cell	
	Equal access	Tiered access	Equal access	Tiered access
Unlicensed	Community Wi-Fi (both equal and tiered access)		Wi-fi Hotspots (both equal and tiered access)	
Licensed	Spectrum sharing, Dynamic Spectrum Access Network	TV white spaces	NA	NA

Within some of these frameworks, users may need licenses for non-exclusive use, while in others no licenses may be required

9. Wi-fi

The story of Wi-Fi, a WLAN technology standard that ensures connectivity between devices, is the most important example to date of the enormous benefits unleashed by unlicensed spectrum. Just as cellular networks allow the same frequencies to be re-used in different geographic cells, Wi-Fi technology allows multiple low power devices to make intensive use of spectrum by reusing spectrum many times. Compared to cellular networks, the smaller transmission radius involved allows much more reuse.

Wi-Fi has its origins in the 1985 decision of the FCC to open up the 900 MHz, 2.4 Ghz, and 5.8 GHz frequency bands for unlicensed use. These bands previously had limited use for unlicensed devices such as micro-wave ovens. Earlier WLANs used proprietary equipment and technologies which implied that equipment from one vendor could not communicate with equipment from other vendors. In the late 1980s, vendors collaborated with the IEEE in an attempt to establish a common standard. The basic specifications of the 802.11 standard were agreed upon in 1997. The Wi-Fi standard made use of spread spectrum technology.

Apple introduced the first Wi-Fi compatible laptop in July 1999. Within a few years nearly all laptops were sold with in-built Wi-Fi capability and Wi-Fi access points appeared across college campuses, coffee shops, airports and private homes as a means of connecting computers to the internet and to other computers and devices. Commercial vendors also began to sell access to the internet by offering Wi-Fi hotspots.

Today Wi-Fi certified devices include personal computers, printers, video game consoles, streaming devices, security cameras, medical devices, MP3 players, digital cameras, smartphones and tablets. Worldwide about 200 million households use Wi-Fi networks and there are about 750,000 Wi-Fi hotspots. About 800 million new Wi-Fi Devices are sold every year. More than 58% of Wi-Fi devices are

mobile devices, exceeding the number of traditional computers. The range of Wi-Fi applications continues to expand.

9.1. Community Wi-Fi

Community Wi-Fi refers to the provision of internet connectivity to large swathes of an area using unlicensed spectrum in a public-private partnership mode. Such a service has been provided in Paris, and is being tried in San Francisco (with Google leading that initiative), Minneapolis and other cities. Both the access to the network and the backhaul are usually wireless making connection to the power source the only wired point in the access network. This is why Wi-Fi transceivers are often slung on public lamp-posts. The service may be free, or provided using a usage fee or advertising model. Usage of such networks has so far been shown to be light.

9.2. Wi-Fi Hotspots

One area that has seen considerable innovation is the integration of Wi-Fi networks with cellular networks. Wi-Fi offloading is a method by which the traffic is diverted from the carrier's macro cellular network to a localized Wi-Fi network operating in the unlicensed band, installed typically in homes, enterprises or public locations, thus relieving the licensed spectrum. Such Wi-Fi hot spots can be deployed by the owner of the venues as 'private hot spots' (e.g. homes, office premises, cafes and restaurants such as Starbucks, Costa Coffee, hotels); or by the Internet Service Providers (ISPs) as 'public hotspots' typically in areas such as airports and malls; or by mobile operators, either by themselves or in partnership with ISPs, as 'carrier Wi-Fi hotspots'. Deployment in the former two cases is fairly common in India (though the number of public Wi-Fi hot spots is low compared to other countries) but carrier Wi-Fi is yet to take off. Wi-Fi offloading is primarily meant for data offloading unlike Femtocells that have evolved to handle both data and voice traffic.

In case of private or public Wi-Fi, the hand-off from the carrier network often requires human or application intervention. Typically the hand-off requires authentication by the user or the application to the nearby hot spot. Moreover, since the carrier network and the Wi-Fi network do not necessarily collaborate in the hand-off, the IP address needs to be allocated when the device moves in to Wi-Fi zone and the connection needs to be reestablished either at the session layer level or at the data link layer level, leading to possible jitter and delay or even disconnects. Moreover, when traffic is offloaded from the operator's cellular traffic to the Wi-Fi network, the same level of security and integrity as applied in the cellular network needs to be applied on the Wi-Fi air interface as well. The Wi-Fi Protected Access (WPA) protocol deploys SIM based authentication as one of the options to achieve the cellular network level security and integrity along with the seamless mobility between the cellular and Wi-Fi networks. The SIM credentials are used for authentication in the Wi-Fi network, obviating the need for manual or application intervention. The architecture of the carrier Wi-Fi network elements as per the latest 3GPP Release 10 specifications is illustrated in Figure 7.1.

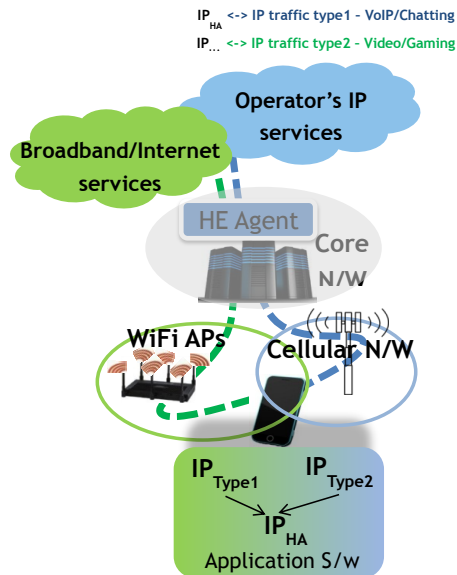


Figure 7.1. Architecture of the carrier wi-fi network elements
(AP - Access Point; HE - Home Environment; IP - Internet Protocol)

As can be seen in the Figure, the seamless mobility for all the mobile devices is supported with the help of a well-integrated infrastructure at the current cellular core network. This integration brings in a new node named Home Agent (HA) at the core network.

This HA is responsible for allocation of IP address for each subscriber based on the International Mobile Subscriber Identity (IMSI) from the respective SIM card. The HA assigned IP, referred to as the HA-IP, is bound with the Care-Of-Address assigned by the network based on the type of service. The HA provides the encryption keys retrieved from the Home Environment against each subscriber identity for each of the mobile devices after a proper device authentication procedure. These provide the required seamless mobility and security².

There has been general reluctance by the operators to deploy any Wi-Fi solutions. In 2009, AT&T, the US mobile service provider who bundled Apple's iPhone 3G handsets along with its access service put restrictions on the use of 'Skype over Wi-Fi' and made available only the restricted 'Skype over 3G', to protect their call revenues. However, indications are that independent Over-The-Top (OTT) VoIP providers such as Microsoft-Skype dominate the VoIP market today. Carriers need to align themselves and get in to VoIP offerings. Carrier Wi-Fi provides them a viable alternative to do so.

Similarly while AT&T banned the use of the Sling Media player that streams the broadcast TV content over the Internet on to mobile as it consumed precious capacity, it was not quick to adopt options to divert such traffic through the Wi-Fi network. In India, such off-loading can be even more critical as each operator gets much lower quantities of spectrum compared to their US and European counterparts.

Today, Wi-Fi bandwidth and speeds are exploding thanks to the advancements in coding and multiplexing. The recent IEEE 802.11 ac specifications provide a theoretical capacity of 1 Gbps - much more than the Long Term Evolution (LTE) network speeds. The access points conforming to IEEE 802.11u onwards have carrier Wi-Fi specifications implemented and the devices are already available in the market. With US operators adopting them vigorously, the chipset and device prices are expected to drop dramatically making it a financially viable alternative compared to Femtocells or any other In-Building Solutions. Future Wi-Fi innovations include in-home video and Wi-Fi Direct which is a new technology that supports the connection of mobile devices, such as phones, cameras and gaming devices to each other, without joining a traditional home or office network.

10. Spectrum Sharing

Spectrum sharing or pooling is a situation where two or more operators with limited spectrum in a licensed service area pool their spectrum to reap the advantages of trunking efficiencies. They use the combined spectrum in a non-exclusive way using administrative and engineering solutions, including cognitive radio to solve the problem of mutual interference. The Indian regulator has reiterated the need for spectrum sharing, at least in the context of a possible shortage of 2G spectrum (TRAI, 2010). It recommends that:

1. Permission for spectrum sharing within the LSA will be permitted initially for a period of 5 years.
2. Spectrum can be shared only between two spectrum holders. In other words, a non-licensee or licensee who has not been assigned access spectrum as yet cannot be a party to spectrum sharing.
3. Spectrum sharing will be permitted subject to the condition, inter alia, that the total quantum of spectrum (i.e. the total spectrum held by the parties in a sharing agreement), as a result of the spectrum sharing, shall not exceed the limit prescribed in case of mergers of licenses.

However, the above recommendations have not yet been accepted by the Ministry.

While introducing spectrum sharing, one has to consider a number of issues related to the obligations of licensees including spectrum usage charges, rollout, and emissions limits. With increasing spectrum usage charges common in command and control regimes, the government would need to decide the usage charges to be levied on the two parties in a sharing arrangement. There are three options: continue with the charges prior to sharing; charge both the parties the higher or lower of the two rates fixed prior to sharing; apply the rate applicable to the combined spectrum block on the assumption that each party uses the whole block. Each of these options comes with its own challenges. Sharing of spectrum amongst licensees will be facilitated if the annual spectrum usage charges are made uniform for all bands irrespective of the amount of spectrum held.

In the case of the sharing of spectrum, each licensee is deemed to enjoy the benefit of the aggregate shared spectrum. For the purpose of assessing the total spectrum holding of a UAS/CMTS licensee, the total shared spectrum should be counted in the hands of each licensee. In case one of the licensees sharing spectrum has already fulfilled the roll-out obligations, there should be no further penalties on

any of the licensees sharing spectrum. In the case where none of the licensees has fulfilled the roll-out obligations, penalties for unfulfilled roll-out obligations need to be applicable on each licensee separately. In case of sharing it will be necessary to prescribe responsibility related to frequency, power limits and interference jointly and severally for compliance of license conditions of the entire shared spectrum.

In the case of sharing of spectrum not acquired at market rates, since sharing of spectrum permits a licensee to, indirectly, derive the market value for spectrum acquired at a low price, sharing should only be permitted on payment of 'sharing charges' to the Government for the quantity of spectrum shared, in the same manner and of like amount as applicable in case of transfer of the spectrum (this does not apply to liberalized spectrum). In the interest of facilitating sharing, when two operators share spectrum, sharing charges should be levied on the smaller of the two spectrum blocks being shared. In case three operators share spectrum, sharing charges should be levied on the smaller two spectrum blocks being shared. Since spectrum sharing arrangements may sometimes stop, the policy may also provide for retention of sharing charges only to the extent levied for the actual period of the sharing on a pro-rata basis, and refund of the difference. In case of subsequent sale of the spectrum, transfer charges should be payable, pro-rata on the balance period of the spectrum assignment (in the case of subsidized spectrum).

11. Transition to New Paradigm: Commons of Government Spectrum

As spectrum is moved from command and control or flexible use to a commons, the rights of licensees under the old regime need to be safeguarded. This issue acquires even greater importance in the context of spectrum held by government departments. In this context, the President's Council of Advisors on Science and Technology in the United States has proposed a model of spectrum sharing with a hierarchy of license types.

The paper of the President's Council argues that since measurements show that less than 20% of the capacity of prime spectrum (below 3.7 GHz) is used even in the most congested urban areas, we need to evolve a new spectrum architecture that enables more efficient use. Today wireless architecture is less commonly being built out for wide area coverage but is being built for higher aggregate capacity over small areas. Spectrum architecture is moving from a macro-cell to a micro-cell approach. This brings high frequency spectrum at par with low frequency spectrum due to the irrelevance of propagation over a large area.

The paper argues that we should move from a narrow-band approach where small swathes of spectrum are licensed to single entities over a large area, to a wide-band approach where wide swathes of spectrum (up to a factor of two in frequency) over localized regions are given to prioritized licensees who share the spectrum in accordance with their place in the pecking order. In order to provide a test case they have recommended that 1000 MHz of Federal spectrum be reallocated for sharing with three categories of licensees:

Federal Primary Access – users would register their actual deployments in a database and would be guaranteed protection from harmful interference in their deployed areas. Users would have exclusive use of the spectrum when and where they deploy network assets or in locations where, or times when, underutilized capacity can be put to use without causing harmful interference.

Secondary Access: users would be issued short-term priority operating rights in a specified geographic area and would be assured of interference protection from opportunistic use. However they would be required to vacate when a user with Federal Primary access registers a conflicting deployment in the database. There may be multiple levels of secondary access, either because of payments (eg. Auctions) or because of a public interest benefit.

Generalized Authorized Access(GAA): users would be allowed opportunistic access to unoccupied spectrum if no Federal Primary or secondary users are registered in the database for a given frequency band, specific geographical area, or time period. GAA users would be obliged to vacate once a conflicting Federal Primary or Secondary Access deployment is registered. GAA devices should have the ability to operate on multiple bands, use dynamic frequency selection, so that there is no dependency on access to a particular frequency. Certain bands could also be subject to a device registration requirement.

In the new architecture, entities who manage traffic in the small, high capacity cells could become important players in their own right and provide competition to the wide area network carriers.

12. Conclusion

As policy-led developments and market innovations demonstrate the feasibility and value of spectrum sharing using a variety of models, important questions are raised on the optimal model of spectrum sharing for the future. Table 7.2 summarizes the different frameworks available for both exclusive and non-exclusive use.

Table 7-2. Frameworks for Exclusive and Non-Exclusive Use.

	Licensed Spectrum				Unlicensed spectrum	
	Spectrum rights not transferred		Spectrum rights transferred			
	Between Operators	Between Operators and other entities	Between Operators	Between Operators and other entities		
Exclusive use	Intra and inter circle roaming	MVNO, Femto operators	Trading, Acquisitions	NA	NA	

Non-exclusive use	Spectrum pooling	TVWS (non exclusive for others)	NA	NA	Wi-fi hot spots, Community Wi-fi
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Regulatory approaches must allow maximum flexibility of experimentation with new approaches while reserving small bands in high-propagation spectrum bands for sharing in urban areas and much larger bands in rural areas.

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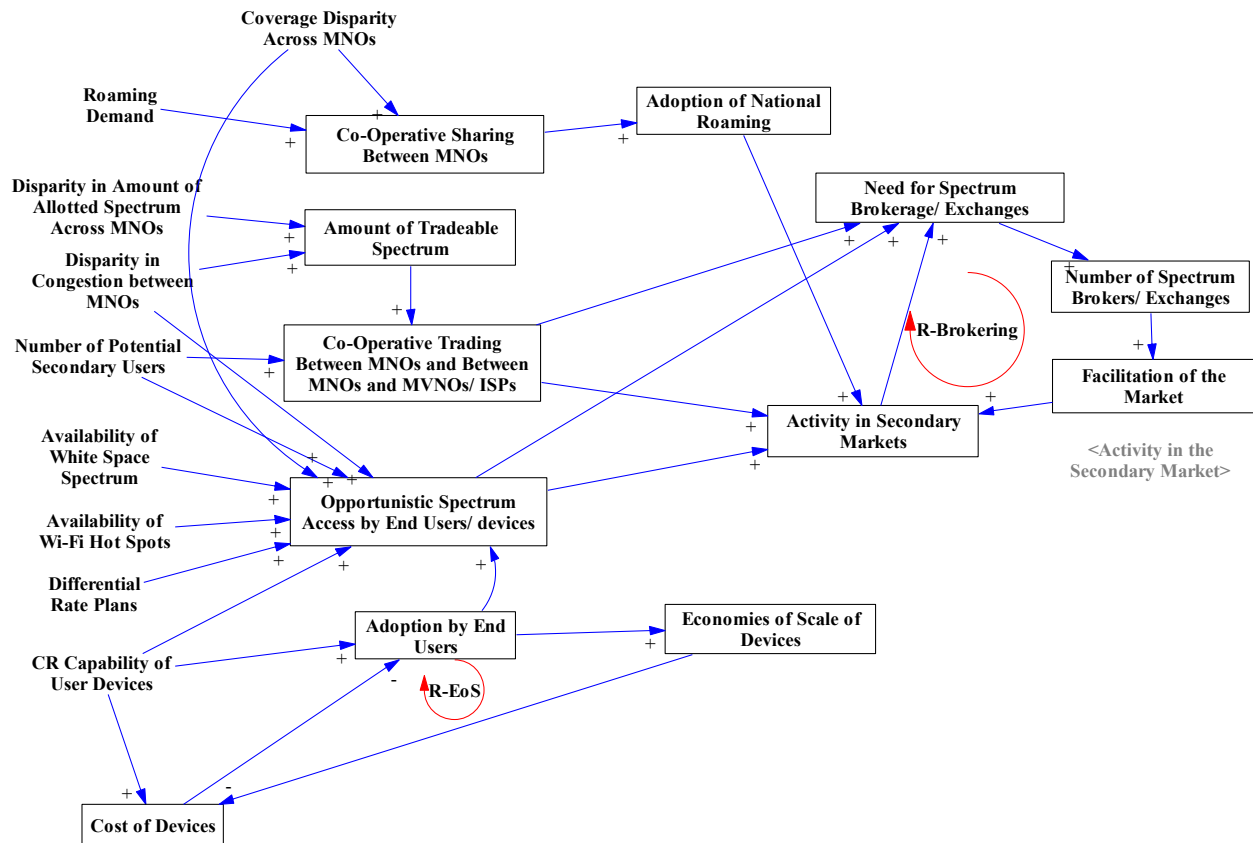
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Rough

Causal model depicting secondary market (adapted from Sridhar, et al., 2012)



The above figure explains the causalities related to the activity of the secondary market. On an overall level the market activity is driven by the disparities in coverage and capacity which leads to co-operative sharing and trading between mobile operators. Demand for roaming and coverage disparity drives sharing between MNOs and hence promotes national roaming. As pointed out by Caicedo & Weiss (2011) important elements for a viable spectrum market and co-operative trading between MNOs and between MNOs and MVNOs/ ISPs, are the sufficient number of potential secondary users (i.e. operators) taking part in the market and the sufficient availability of tradable spectrum. Furthermore opportunistic spectrum access by the end users and devices is driven by the availability of white spaces, the existing base of (intelligent) Wi-Fi hotspots (and other base stations) in position of providing service over the white spaces and the cognitive radio capabilities of devices. Cost of such devices (e.g. cognitive radio capable devices and multi-SIM handsets) can be driven down by the economies of scale effects as indicated by reinforcing loop 'R-EoS'.

All of these together contribute to activity in the secondary markets and to the need for spectrum brokerage and exchanges, which in turn can increase the number of spectrum brokers and further facilitate the market, leading to a reinforcing loop 'R-Brokering'.