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Executive Summary

The aim of this policy brief is to recommend unlicensed spectrum policy to the Indian Government based on recent developments in wireless technology, community needs and international best practices. We seek to demonstrate the need for and importance of unlicensed spectrum as a medium for inexpensive connectivity in rural/remote areas and source of innovation by serving as a barrier-free and cost-effective platform for testing and implementing of new technologies.

The specific frequency bands that we request for unlicensing are: 433-434 MHz, 902-928 MHz, 1880-1900 MHz, 2483-2500 MHz, 5150-5350 MHz, and 5725-5775 MHz. These demands reflect the widespread market adoption in countries where these bands have already become unlicensed.

Interference concerns to licensed users, which are the predominant reason for the limited allocation of unlicensed spectrum, are greatly diminished. Interference-free spectrum use by multiple operators is enabled by the short-range, low-power nature of most of the technologies operating in these spectrum bands, as well as innovative techniques that facilitate spectrum sharing.

Technological advancements such as Wireless Local Area Network (WLAN), Ultra Wide Band (UWB), Radio Frequency Identification (RFID), Near -Field Communication (NFC) systems, and others have demonstrated that when an opportunity for cost-efficient and flexible spectrum usage is presented in the form of unlicensed spectrum, the market is likely to respond through innovation and expansion.

The value of unlicensed spectrum in bridging the digital divide has been demonstrated through community wireless networking projects as well as inexpensive ITES (IT enabled services) operating on unlicensed spectrum that have been created to spread connectivity to digitally-marginalized areas. As demonstrated by numerous case studies, such networks administer e-learning, e-commerce, telemedicine, e-agriculture, and many other initiatives that lead to equitable social and economic growth, making unlicensed spectrum a "public good".

The International Telecommunication Union (ITU), European Union telecom regulatory bodies, as well as leading state telecom policy makers and regulators such as the FCC (U.S. Federal Communications Commission) and OFCOM (UK Office of Communications) have recognized that the optimal use of radio spectrum is dependent on flexible spectrum management policies and the multi-time sharing of this precious resource. Of late, the relevance of unlicensed spectrum is being recognized by policy makers in India as well. This is evident from the National Telecom Policy 2012, as well as recent remarks on the subject made by senior government officials.

1. Introduction

1.1 The radio frequency (RF) spectrum is vital for wireless communications infrastructure.[1] Most operations on the RF spectrum require a licence provided by a national regulatory body or the government. However, many countries have allocated some spectrum for unlicensed use. Unlicensed spectrum bands can be general purpose or application specific. As Robert Horvitz, one of the founding members of the Open Spectrum Alliance, explains, "*Essentially any equipment that does not violate the technical standards can be used for any means in general purpose unlicensed bands. There are other unlicensed bands where that is not the case. For example, there is a band for the control of modern airplanes. There is no license needed to operate in it, but you can only use it for the control of modern airplanes.*"[2]

1.2 Unlicensed spectrum, by not requiring operators to obtain a costly license and special permission for its use, is an inexpensive and barrier-free option for meeting communication requirements. The broad market adoption of unlicensed spectrum is documented in Yochai Benkler's study which investigated eight different wireless markets: mobile broadband; wireless healthcare; smart grid communications; inventory management; access control; mobile payments; fleet management; and secondary markets in spectrum. The research shows that unlicensed spectrum applications are dominant in seven out of the eight markets. Findings indicate that 80 percent of wireless healthcare, 70 percent of smart grid communications, and 40 to 90 percent of mobile broadband data to smartphones and tablets are operated on unlicensed radio spectrum.[3] The unlicensed 902-928 MHz frequency range in the United States, for example, has fostered the growth of wireless technology for smart grid communications. In fact, only 1 percent of the smart grid communications market in the U.S. is captured by companies that use a licensed wireless carrier. Currently serving a quarter of the market,[4] Silver Springs Networks used unlicensed spectrum to build its smart grid RF Mesh.

1.3 Moreover, unlicensed spectrum has the vast potential to help bridge the digital divide. In September 2011, India surpassed the 100-million mark of internet users who predominantly access the web through mobile devices. India has the potential of becoming the largest internet-using country after China as current estimates show that five to seven million mobile internet users are added in India every month.[5] It is predicted that by December 2011, India will have 121 million users; 92 million out of the 121 million users will be from urban environments, which leaves a much smaller portion of rural internet users.[6] Projects by AirJaldi and the Digital Empowerment Foundation have used unlicensed spectrum to create community-wide wireless communication networks in rural India.[7] These networks facilitate initiatives such as e-governance services, distance education, telemedicine, and e-commerce. Local media are also large beneficiaries of this inexpensive and accessible internet

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[1] Ponappa, S. (2010). Understanding Spectrum. *Business Standard*. Retrieved November 21, 2011, from http://www.business-standard.com/india/news/shyam-ponappa-understanding-spectrum/387446/
[2] Horvitz, Robert. Personal Interview. 9 Sept. 2011
[3] Benkler, Y. (2011). Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption, pg. 1. *Berkman Center for Internet and Society*. Retrieved November 22, 2011, from http://cyber.law.harvard.edu/node/7211
[4] Ibid
[5] Manzar, O. (2011). Internet's Last-mile Challenges. *The Mint*. Retrieved November 22, 2011, from http://www.livemint.com/2011/11/13225841/Internet8217s-lastmile-cha.html?h=B
[6] (2011). Now India has 100 million Net Users. *The Hindu*. Retrieved November 22, 2011, from http://www.thehindu.com/sci-tech/internet/article2624851.ece
[7] Srivastava, Ritu (DEF). Personal Interview. 27 Dec. 2011.

connectivity. In large measure, these services can contribute to the greater social and economic development of the remote communities.

1.4 The Indian Department of Telecommunications (DoT) requires operators to obtain a licence before being granted the right to use radio spectrum. There are exceptions to this rule, such as the Citizens Band in the 27 MHz range and the Wi-Fi bands in the 2.4 GHz and 5.8 GHz ranges. India's National Telecom Policy 2012 recognizes the need to reserve more frequencies for unlicensed use. However, the country is still behind when compared to unlicensed spectrum availability in the U.S. and UK which have already integrated innovative spectrum management techniques in their telecom policies. These policies aim to create a flexible, market-driven approach to spectrum regulation and management through integrating spectrum sharing techniques and meeting the industry demand for unlicensed spectrum. India needs to follow suit in order to provide connectivity to remote/rural regions and encourage further innovation in the telecom domain. Therefore, additional frequencies should be freed up for unlicensed use according to demands from community groups, industry bodies, and experts in the field, in line with international best practices.

2. Unlicensed (Licence-exempt) Spectrum Policies at the ITU and EU

2.1 The changing nature of spectrum applications and the evolution of radio devices have greatly reduced the risk of interference between signals within the same spectrum band and created a need to evolve ways in which spectrum is managed. As per Robert Horvitz, *"...in the early days of radio, the primary applications were high-power, long-range, mission critical communications like military, ships at sea, shore stations, etc. These transmissions cover such large areas of the world, that you cannot have too many operators using the frequencies at the same time. However, as time has gone by, the predominant uses of radio have become very short range, very low power personal uses like mobile phones, Wi-Fi, RFID, cordless phones, etc. So even though the demand for radio uses has grown significantly, because of the technological advancements, the demand for range is very much less than it used to be. This allows people to reuse frequencies much more"* Modern technologies such as OFDMA, Spread Spectrum, Frequency Hopping, BDMA, FMC, ultra wide band (UWB) and the potential for software defined radio (SDR)[8], further facilitate spectrum sharing, enabling spectrum signals to coexist with each other without interference.[9] The carrying capacity of spectrum depends entirely on the technology that we use and it is increasing day by day.

2.2 The Role of the ITU in Spectrum Management

RF spectrum allocation is harmonized on an international level through the Radiocommunication Sector within the International Telecommunication Union (ITU). During the World Telecommunication Conference (WRC) held by the ITU in 2003, spectrum in the 5-6 GHz range was allocated for unlicensed use. Countries such as UK, U.S. and

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[8] Unlicensed Spectrum. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.2843
[9] Horvitz, Robert. Personal Interview. 9 Sept. 2011.

Canada have unlicensed these frequencies consistent with the decision made at the WRC.[10] India has also done this, although only partially.

According to the ITU, both vision and commitment are needed when implementing policies for spectrum unlicensing, which result in the most efficient and optimum sharing of the resource. Spectrum policies should motivate innovation, be flexible, and set out spectrum users' rights. Furthermore, there should be a framework for compliance monitoring as well as dispute resolution. The ITU advises all nations to follow the steps of regulators like the FCC and the US National Telecommunications and Information Administration (NTIA) by establishing a Spectrum Sharing Innovative Test-Bed. This facility can help in analysing spectrum-sharing technologies, which can also be used for licence-exempt bands.[11]

2.3 EU Approach to Spectrum Management

The idea of light regulation/deregulation of spectrum is gaining widespread acceptance among European nations. According to the European Commission, as the demand for the usage of spectrum rises, a more flexible approach is required for managing radio frequencies. This strategy involves loosening stringent allocations of spectrum to specific technologies or services which would result in a faster response rate to market developments and improvements, as well as the creation of infrastructure-based competition.[12]

The EU Authorization Directive lists regulations for the authorization of ICT services and networks within the European Union.[13] According to Article 5.1, "Member States shall, where possible, in particular where the risk of harmful interference is negligible, not make the use of radio frequencies subject to the grant of individual rights of use but shall include the conditions for usage of such radio frequencies in the general authorisation". Unlicensed and Class licensed[14] use of spectrum is implied by general authorization, whereas rights of use refer to licences.[15]

Licence-exempt bands have been harmonized throughout the European Union by the European Commission. In March 2003, the EC proposed that member states should use the 2.4 GHz and 5 GHz bands to administer unlicensed WLAN access to public electronic communications networks and services. These recommendations have resulted in an increase of Wi-Fi bands in most EC member states.[16] The move towards expanding licence-exempt spectrum use continues. The Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT) is responsible for developing recommendations for the harmonization of radio spectrum and

[10] Longford, G., & Wong, M. (2007). Spectrum Policy in Canada: A CWIRP Background Paper, pg. 2. *Community Wireless Infrastructure Research Project*. Retrieved November 23, 2011, from www.cwirp.ca/files/CWIRP_spectrum.pdf

[11] Implementing Spectrum Sharing. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.3414

[12] Radio Spectrum Policy: Flexibility, the Key to Competition and Innovation. *EUROPA - European Commission - Homepage*. Retrieved November 22, 2011, from http://ec.europa.eu/information_society/

[13] The EU Authorization Framework. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.539

[14] In a Class licensing scheme, users of a band are given non-exclusive licences that are usually accessible to all. These licences can be free or come with a nominal fee. Other requirements that may come with light licensing are the registration of locations for transmitters and the coordination of their deployment with other users

[15] Light Licensing, License-Exempt, and Commons. (2009). *European Communications Office Documentation Database*. Retrieved November 23, 2011, from www.erodocdb.dk/docs/doc98/official/Pdf/E

[16] Commission Frees up Frequencies for Wi-Fi. (2005). *EurActiv*. Retrieved November 23, 2011, from http://www.euractiv.com/infosociety/commission-frees-frequencies-wifi/article-142740

satellite orbits use within the European Union.[17] Recent reports produced by the ECC, such as the Report 132 and 137, discuss more flexible and market driven approaches to spectrum management.[18]

In addition, the elimination of sector-specific regulations and the creation of fair and efficient competition within the European Union is the aim of the New Regulatory Framework 2002. This policy relies on the market as a self-regulating force. According to the framework, little regulation is needed to allow for the linking of all public communication networks and providers to develop one interoperable network. In a strategy paper published in 2007, the European Commission calls for flexible spectrum management. According to EC's calculations, Europe's net gain from market-based spectrum management and flexible usage policies will be EUR 8-9 billion.[19]

3. Survey of International Best Practices

3.1 USA

The FCC is authorized to allow flexible utilization of spectrum under the Communications Act of 1996 where the use is in compliance with international agreements to which the U.S. is a signatory: the use must be in the public interest; the use should not hamper investments in the communications sector; and cannot cause harmful interference to other users.[20] In 2002, the FCC recommended licences to be as flexible as possible, and only restricted by interference prevention.[21] However, operators can use unlicensed or "licence-exempt" devices in the United States only if they use certified radio equipment and comply with the technical requirements of part 15 of the Federal Communications Commission Rules[22]

Some of the prominent unlicensed frequencies in the U.S. are:[23]

Band	Frequencies (MHz)
ISM/ Spread Spectrum	902-928, 2400-2483.5 & 5725-5850
Unlicensed PCS	1910-1930 & 2390-2400
Millimeter Wave	59,000-64,000
U-NII	5150-5350 & 5725-5825
Millimeter Wave (Expansion)	57,000-59,000

[17] The European Table of Frequency Allocations and Applications. *European Communications Office Documentation Database*. Retrieved November 23, 2011, from www.erodocdb.dk/Docs/doc98/official/pdf/

[18] Light Licensing, License-Exempt, and Commons. (2009). *European Communications Office Documentation Database*. Retrieved November 23, 2011, from www.erodocdb.dk/docs/doc98/official/Pdf/E

[19] Berlemann, L., & Mangold, S. (2009). *Cognitive Radio and Dynamic Spectrum Access*. Chichester: John Wiley and Sons Ltd.

[20] Spectrum Sharing in Practice. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.3380.html

[21] Spectrum Sharing in Practice. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.3380.html

[22] Title 47 Telecommunication § 1 U.S.C. § 15 (2011)

[23] (2002). Report of the Unlicensed Devices and Experimental Licenses Working Group, pg. 10. *Federal Communications Commission*. Retrieved November 25, 2011, from http://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf

To increase the efficiency of spectrum utilization, studies are conducted in the United States upon President Barack Obama's request "…to make available a total of 500 MHz of federal and non-federal spectrum over the next 10 years, suitable for both mobile and fixed wireless broadband use". The FCC, the National Telecommunications and Information Administration (NTIA), and Shared Spectrum Company (SSC) are among the many that are surveying frequency bands to identify opportunities for sharing spectrum. In the survey conducted by the SSC, which analyzed usage in the 30 MHz to 3 GHz range, it was found that many bands are highly underutilized, or are occupied by very weak signals.[24] Thus, more bands that can potentially be shared and unlicensed have been identified.

3.2 UK

The liberalization of spectrum usage rights is also becoming a policy for OFCOM, the UK regulator, with its increasing shift towards a flexible system of spectrum management. In order to foster efficient utilization of spectrum, OFCOM made the decision to be neutral in terms of services and technologies in its future spectrum assignments.[25]

There are many diversified bands of radio spectrum allowed in the UK for unlicensed use which contain a variety of applications: bands below 1 GHz are mainly occupied by telemetry services; frequencies between 2 GHz and 6 GHz are used by broadband wireless communications; and bands at 10 GHz and over are used for short-range radar and relays.[26]

In the UK, all licensed equipment falls under the regulations outlined in the Wireless Telegraphy Act 2006. Radio equipment and services which are exempt from licensing regulations of the WT Telegraphy Act 2006 fall under the jurisdiction of the Telegraphy (Exemption) Regulations 2003 SI No. 74.[27]

The exempt frequency bands set out in paragraph 3 of the regulations are:

Band	Frequencies
2.4 GHz	2400.0 to 2483.5 MHz
5.1 GHz	5150 to 5350 MHz
5.5 GHz	5470 to 5725 MHz
60 GHz	57.1 to 58.9 GHz

On October 20, 2011, Ofcom released draft regulations to allow the use of various devices on an unlicensed basis. Some of these devices are: personal locator beacons on land; wireless road safety systems; wireless access terminals in the 3400 to 3800 MHz band; 2 GHz mobile

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[24] General Survey of Radio Frequency Bands – 30 MHz to 3 GHz. (2010). *Shared Spectrum Company*. Retrieved November 30, 2011, from www.sharedspectrum.com/wp-content/uploads/2010_0923%20General%20Band%20Survey%20-%2030MHz-to-3GHz.pdf

[25] Spectrum Sharing in Practice. (2011). *ICT Regulation Toolkit*. Retrieved November 23, 2011, from www.ictregulationtoolkit.org/en/Section.3380.html

[26] Richards, E. (2011). Spectrum in an Age of Innovation. *ECTA Regulatory Conference 2011*. Lecture conducted from Brussels.

[27] Wireless Telegraphy (Exemption) Regulations 2003 SI No. 74 § 4 § (2011)

satellite service (MSS) terminals; mobile terminals connecting to the 2012 London Games Tetra Network**;** and Generic Short Range Devices (SRDs) in the 138 MHz band.[28]

4. Innovations in Unlicensed Spectrum Bands

4.1 Unlicensed spectrum enables decentralized innovation in wireless technologies very much like internet technologies, which is in contrast to the inflexible telecommunications-centric model of the 20th century. Special permission is not needed to deploy and test new technology on the unlicensed frequencies.[29] The reduced regulatory burden, as a consequence of the unlicensed spectrum model, has given rise to new technologies, innovative services and business models. The development of start-up companies is encouraged, since a costly licence is not needed for market entry. This in turn promotes competition and progressive growth of the market.[30] Some technologies which have emerged due to unlicensed spectrum policies are Wi-Fi, FMC-enabling technologies such as UMA, DECT, as well as RFID, Bluetooth, Zigbee, etc.

4.2 Wi-Fi: a case study

Wi-Fi is thought by many to be the first major communications application for unlicensed spectrum. It encompasses the technologies of Wireless Local Area Networks (WLAN) and is based on the IEEE 802.11 specifications. A Wi-Fi device can connect to the internet when it is near an Access Point (AP). The area covered by one or more Access Points is a hotspot. A hotspot can be as small as a room or as large as many square miles of merging hotspots. Wi-Fi applications include internet and VoIP phone access, gaming, and basic connectivity of consumer electronics.[31] This technology operates in the 2.4 GHz and the 5 GHz bands.

The development of Wi-Fi was triggered by the FCC's decision in 1985 to allow unlicensed spread spectrum systems in the 915 MHz, the 2.4 GHz and 5.8 GHz bands allocated for industrial, scientific and medical (ISM) applications.[32] In 1986, seeking to take advantage of the opportunity presented by the licence-exempt spectrum, NCR Corporate initiated a study of how wireless technology can be used in local area networking. The feasibility study ended with positive results, the outcome being a working design that was applied in the Wireless LAN Demo unit.[33]

Following the FCC's lead, an ad hoc group on Radio-LANs within the CEPT recommended the opening of the 2.4 GHz band meant for ISM applications for the unlicensed utilization of Radio-LAN devices. It also asked ETSI, the agency in charge of creating telecommunications

[28] (2011). Notice of Ofcom's Proposals for Changes to the Licence Exemption of Wireless Telegraphy Devices. *Ofcom*. Retrieved November 14 from http://stakeholders.ofcom.org.uk/binaries/consultations/notice-wireless-telegraphy/summary/main.pdf

[29] Benkler, Y. (2011). Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption, pg. 2. *Berkman Center for Internet and Society*. Retrieved November 22, 2011, from http://cyber.law.harvard.edu/node/7211

[30] Freyens, B. (2009). A Policy Spectrum for Spectrum Economics. *Information Economics and Policy*, *21*, 128-144.

[31] Wi-Fi Technology. (2007). *Imran's Everything Cellular*. Retrieved November 25, 2011, from http://www.mobileisgood.com/wifi.php

[32] Negus, K., Petrick, A. (2009). History of Wireless Local Area Networks (WLANs) in Unlicensed Bands. *Emerald Group Publishing Limited*, 11(5), 36-56.

[33] Hayes, V., & Lemstra, W. (2009). Licence-Exempt: the emergence of Wi-Fi, pg. 60. *Emerald Group Publishing Limited*, 11(5), 57-71.

standards in Europe, to formulate the standard and the measurement method for approvals.[34] These developments triggered a global allocation of frequencies for Wireless-LANs and permitted the expansion in the manufacturing sector.

In 1993, in a bid to unlicense spectrum further, the FCC allocated 40 MHz of unlicensed User-PCS in the 1890-1930 MHz band. Several years later, the FCC also unlicensed the 5.15-5.35 GHz and 5.725-5.825 GHz frequencies; this was the existing 5 GHz ISM band. The FCC also added 5.47-5.725 GHz to the unlicensed NII band.[35] These policies played an important role in facilitating the creation of the Wireless Fidelity logo (Wi-Fi).[36]

The efficiency of Wi-Fi networks eventuated in the burgeoning of Wi-Fi hotspots. Wayport, a company established to provide Wi-Fi access in public places, set up a connection in its first hotel lobby and bar in 1996. By 2003, Embassy, Four Seasons, Sheraton, Summerfield, Westin, and Wyndham were served by the company. However, it was Starbucks that popularized Wi-Fi as the most favoured method of providing internet connectivity in public places. Starbucks partnered with MobileStar and Microsoft in January 2001 to provide high-speed Internet connectivity in its locations. By the end of 2001, 500 Starbucks coffee shops had been equipped with Wi-Fi networks.[37]

According to Cisco projections, by 2015, the IP traffic channelled through Wi-Fi networks will be greater than the traffic channelled over wired networks.[38] Juniper Research estimates that 63 percent of traffic by smartphones and tablets is channelled through Wi-Fi networks. Projections show this amount to grow to 90 percent by 2015.[39] A study by Microsoft, which focused on only three Wi-Fi applications, Wi-Fi in homes, unlicensed wireless health records technologies, and unlicensed RFID tags in the clothing retail sector, found that the combined amount of annual revenues for the next 15 years generated by these applications will be USD 16 to USD 37 billion per year in economic gain for the U.S. economy.[40]

5. Unlicensed spectrum in India

5.1. Perspectives on Spectrum Allocation and Unlicensing of Spectrum

The Indian Supreme Court ruling of February 1995, declared airwaves to be public property. The landmark ruling was made by Justice P.B. Sawant and Justice S. Mohan in the case concerning the Union of India v. Cricket Association of Bengal (CAB). The dispute was over CAB's as well as BCCI's (Board of Control for Cricket in India) rights to broadcast sporting events. The decision specified that the use of airwaves "has to be controlled and regulated by

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[34] Ibid pg. 63

[35] Carter, K. R., (2009). Unlicensed to Kill: a Brief History of the Part 15 Rules, pg. 13. *Emerald Group Publishing Limited,* 11(5), 8-18.

[36] Hayes,V., & Lemstra,W. (2009). Licence-Exempt: the emergence of Wi-Fi. *Emerald Group Publishing Limited*, 11(5), 57-71.

[37] Ibid

[38] (2011). Adaptrum, Inc., Advanced Communications of Rome, Inc., AirLink Mobile, etc. Letter to Chairman Upton and Ranking Member Waxman.

[39] Benkler, Y. (2011). Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption, pg. 6. *Berkman Center for Internet and Society*. Retrieved November 22, 2011, from http://cyber.law.harvard.edu/node/7211

[40] Adaptrum, Inc., Advanced Communications of Rome, Inc., AirLink Mobile, etc. (2011). Letter to Chairman Upton and Ranking Member Waxman.

a public authority in the interests of the public and to prevent the invasion of their rights."[41] It would be in the greater interest of the public to exempt additional spectrum from licensing. Presently a large part of the RF spectrum is controlled by the government, with only a minimal amount of frequencies being allocated for unlicensed use. However policy makers are beginning to recognize the importance of allocating more unlicensed spectrum.

A. Existing licence-exempt bands in India[42]

Unlicensed Frequency Ranges in India	Application/Specifications
50-200 kHz	Very low power devices
13553-13567 kHz	Very low power radio frequency devices, indoor only
26.957 MHz-27.283 MHz	Low power wireless equipment (max. Effective Radiated Power of 5 watts)
335 MHz	Low power wireless equipment for the remote control of cranes
402-405 MHz	Medical RF wireless devices (max. radiated power of 25 microwatt) with channel emission band width within 300 kHz
865-867 MHz	Low power wireless device (max. transmitter power of 1 watt-4 watts Effective Radiated Power) with 200 kHz carrier bandwidth
865 MHz - 867 MHz	Radio Frequency Identification Devices (RFID) (MTP of 1 watt-4 watts ERP) with 200 kHz carrier band width
2400 MHz - 2483.5 MHz	Low power wireless equipment (e.g. Wi-Fi) (max. transmitter output power of 1 watt-4 watts ERP) with spectrum spread of 10 MHz or higher
5150 MHz-5350 MHz	Low power equipment for Wireless Access Systems (max. mean Effective Isotropic Radiated Power of 200 mW and max. mean Effective Isotropic Radiated Power density of 10 mW/MHz in any 1 MHz bandwidth) indoor only
5725 MHz-5825 MHz	Low power equipment for Wireless Access Systems (MMEIRP of 200 mW and MMEIRP density of 10 mW/MHz in any 1 MHz bandwidth) indoor only
5825 MHz- 5875 MHz	Low power equipment (MTOP of 1 watt-4 watts ERPower) with spectrum spread of 10 MHz or higher

In this context, P.K. Garg, the former wireless advisor to the Government of India, states that *"The government had de-licensed the present bands for reasons that their de-licensing would provide a benefit to society, and the regulation of the bands through licence issuance for such low power usage by common public would have been impractical normally. Hence to make the decision to de-license more bands, the spectrum regulator looks at the social benefit/ impact that it would make, and whether they can shift current licensed users to other frequencies if interference concerns are present"*.[43]

"Spectrum could be considered for de-licensing for certain technical parameters which shall not cause interference to existing usages in the band. " stated Milind Deora, the

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[41] The Airwaves are the People's Property. (2001). *India Together*. Retrieved November 30, 2011, from http://www.indiatogether.org/campaigns/freeinfo/sc95.htm

[42] Department of Telecommunications. Draft National Telecom Policy 2011.
[43] Garg, P. K. Personal Interview. 8 Oct. 2011.

Minister of State for Communications and Information Technology during a recent meeting held in Goa on International Mobile Communications.[44]

Moreover, the National Telecom Policy 2012 made the objective to:

- *De-license additional frequency bands for public use*.[45]

It is further specified under section 4.6 of the policy that the government will:

- *Identify additional frequency bands periodically, for exempting them from licensing requirements for operation of low power devices for public use.*[46]

5.2 Candidate Licence-exempt Spectrum Bands in India

Industry bodies in India such as the Internet Service Provider's Association of India (ISPAI), the DECT Forum, the Bidirectional Access Promotion Society (BAPSI), Google and Microsoft have been advocating for more unlicensed spectrum for low power wireless equipment based on international practices. These requests vary from being general purpose to being application specific.

It is consensual among Google, Microsoft, and the Internet Service Provider's Association of India (ISPAI) that additional frequencies need to be unlicensed for broadband access. One of the reasons for this request is that the existing 50 MHz of licence-exempt spectrum in the 5.7 GHz band has become choked up as many ISPs switch to providing services using these unlicensed frequencies. The situation is the same in the case of the 2.4 GHz band, which has become overloaded due to the unavailability of more unlicensed spectrum. Furthermore, most equipment for operations in the 5 GHz band is meant to use a larger spectrum range, because many countries have greater frequency allocations within the band. If Indian operators were to purchase this equipment, they would not be able to limit its operations to the 50 GHz of unlicensed frequency in the band.[47] Thus ISPs are limited in their choice of equipment. The consequences of this are poor quality of services and lack of further expansion within these bands.

The DECT Forum India, an industry association which represents suppliers, operators and users of DECT equipment, is advocating for the unlicensing of additional frequency ranges for low power cordless communication to meet the Residential and Enterprise Intra-Telecommunication Requirements. A consultation between TRAI and industry bodies is presently taking place on this issue. DECT Forum points to studies conducted by the CEPT which found that the 3G technology in the adjacent band does not incur interference from low power, indoor use of cordless telephony.[48]

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[44] Spectrum Audit and Pooling Under Consideration-Milind Deora. (2011). *Voice&Data Online - Resource Center on Indian Telecom*. Retrieved November 30, 2011, from http://voicendata.ciol.com/content/news1/111101401.asp

[45] Department of Telecommunications. National Telecom Policy 2012, objectives 22, 24.

[46] Department of Telecommunications. National Telecom Policy 2012, section 4.6.

[47] Philip, J. T. (2007). Govt Delicenses 50 MHz of Spectrum in 5.8 GHz Band for WiMAX Use. *The Economic Times*. Retrieved November 30, 2011, from http://articles.economictimes.indiatimes.com/2007-02-19/news/28444412_1_ghz-wimax-services-isps

[48] (2011). Consultation Paper on Allocation of Spectrum Resources for Residential and Enterprise Intra-telecommunication Requirements/ cordless telecommunications system (CTS). *Telecom Regulatory Authority of India.*

Presently, as requested by many utility companies in India, the Wireless Planning Coordination wing of the Department of Telecommunications is considering the de-licensing of spectrum for data telemetry. Other applications on the same frequencies would be alarms, anti-theft devices, baby monitors, garage door openers, and logistic systems.[49]

B. Bands requiring de-licensing in India

Requested Frequency Ranges for Unlicensing	Application	Current Allocation	Countries/Regions Where Exemption is in Place
433 MHz-434 MHz	Data telemetry[50]	Low power short range devices	Australia, Singapore, Malaysia, European Union and New Zealand[51]
902-928 MHz	Low power wireless equipment[52]	• 902.5-915 MHz: Additional requirements of cellular telephone systems, train control and mobile train radio systems • 900 MHz band: Micro cellular low powered telecommunication systems • 926-926.5: low power cordless telephone systems	U.S.[53]
1880 MHz-1900 MHz	Low power cordless communication[54]	Micro cellular wireless access systems (fixed/mobile) based on TDD access techniques	Europe[55]
2483 -2500 MHz	Broadband Access[56]	_____	_____
5150- 5350 MHz	Broadband Access[57]	Low power equipments for wireless access systems indoor only	U.S.[58], UK[59]

[49] Thomas, T. K. (2011). DoT May De-license Spectrum for Utility Services. *Business Line*. Retrieved November 30, 2011, from http://www.thehindubusinessline.com/industry-and-economy/info-tech/article2668933.ece?homepage=true&ref=wl_home

[50] Ibid

[51] Ibid

[52] Jit Singh Chima. Raman (Google India), Personal Interview. 9 Dec. 2011.

[53] (2002). Report of the Unlicensed Devices and Experimental Licenses Working Group, pg. 8. *Federal Communications Commission*. Retrieved November 25, 2011, from http://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf

[54] (2011). Consultation Paper on Allocation of Spectrum Resources for Residential and Enterprise Intra-telecommunication Requirements/ Cordless Telecommunications System (CTS). *Telecom Regulatory Authority of India.*

[55] Ibid pg. 6

[56] Jit Singh Chima. Raman (Google India), Personal Interview. 9 Dec. 2011.

[57] (2011). Response to the Draft National Telecom Policy 2011. *Internet Service Providers' Association of India*.

[58] (2002). Report of the Unlicensed Devices and Experimental Licenses Working Group, pg. 10. *Federal Communications Commission*. Retrieved November 25, 2011, from http://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf

[59] Wireless Telegraphy (Exemption) Regulations 2003 SI No. 74 § 4 § (2011)

5725-5775 MHz	Broadband Access[60]	Same as above	U.S.[61]

6. Impact of Unlicensed Spectrum on Rural Broadband and Mass Media

Communities that lack the infrastructure required for data connectivity and communications are deprived of the vast economic and social benefits of Information and Communication Technologies (ICTs). To address this digital divide, many communities have opted for wireless network systems based on licence-exempt spectrum such as Wi-Fi. As the ITU Secretary General's introduction at the World Summit on Information Society stated, "…indeed, it is precisely in places where no infrastructure exists that Wi-Fi can be particularly effective, helping countries to leapfrog generations of telecommunications technology and infrastructure to empower their people".[62]

Community wireless networks using unlicensed frequencies have the potential to provide marginalized communities with low cost and accessible sources of local information, as well as connection to the rest of the world at an affordable cost. Such networks can facilitate initiatives like telemedicine, e-governance, e-commerce, e-learning, and telephony service through Voice over Internet Protocol (VoIP) at a much lower cost.

Digital Empowerment Foundation

The Digital Empowerment Foundation (DEF) is a not-for-profit organization in India that seeks to create sustainable solutions for economic and commercial growth using ICTs and bridging the digital divide.[63]

As Ritu Srivastava, the Programme Manager and Research Executive of DEF explains:

"Starting 2010, DEF has implemented projects using wireless mesh networks on unlicensed 2.4 GHz and 5.8 GHz spectrum to provide Internet connectivity in remote areas. The first project, 'Wireless for Communities' was implemented in Chanderi, Madhya Pradesh. For this project, DEF decided to make the CWIRC centre as base, covering 20-30 km of the region. Through this setup, DEF covered 30 schools of the region and more than 50 panchayats to provide the connectivity. The network also serves two madrasas (religious education centres), a government health centre, a local radio station, shops, and a cybercafé.

Following the success of the pilot project, DEF created networks in other states, including Tura (Meghalaya), Sonapur (Assam), Baran & Tilonia (Rajasthan). And Tehri (Uttarakhand). It is also

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[60] (2011). Response to the Draft National Telecom Policy 2011. *Internet Service Providers' Association of India.*

[61] (2002). Report of the Unlicensed Devices and Experimental Licenses Working Group, pg. 10. *Federal Communications Commission*. Retrieved November 25, 2011, from http://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf

[62] Orne, P. (2004). Local Communities - A Global Initiative. *i4D: Information for Development*, *2*(4), 33. Retrieved November 29, 2011, from http://www.i4donline.net/issue/april04/content.htm

[63] (2011). *About DEF*. Retrieved December, 29, from http://defindia.net/who-we-are/about-def/

expanding the network to Dhaka, Bangladesh. The Net usage charges for all networks are free, since the project is supported by funding from the ISOC Internet Society.[64]"

AirJaldi (Dharamsala Community Wireless Network)

AirJaldi is a social enterprise established in Dharamsala, Himachal Pradesh. It began the Dharamsala Community Wireless Network in 2005. By mid 2007, the network covered a radius of some 70 km around the city and was a mix of point-to-point, point-to-multipoint and mesh topologies. The network links several villages, the Tibetan Children's Village, and numerous establishments of the Tibetan community.[65]

Michael Ginguld, the CEO and co-founder of AirJaldi, explains:

"The company presently operates four networks in Dharamsala, Garhwal, Ranchi, and Kumaon, and serves a variety of clients such as large institutions, not-for-profit organizations, hospitals, schools, monasteries, private users, and businesses.

Throughout the network, about 400 institutional and private clients, which together amount to approximately 10,000 users, are served. However, when taking into account that large institutions that are connected to the net also provide connectivity to its multiple employees and visitors, this number might reach as high as 410,000 individuals. It is in the plans to set up new networks in Bihar and potentially in Orissa, as well as extend the networks in the three states that the company already works in.[66]"

Village Telco

Another effective use of unlicensed spectrum in the 2.4 GHz range for low cost communication in rural and remote communities is the Village Telco wireless network. It operates on a Mesh Potato, which is a simple Wi-Fi device that connects to other such devices forming a network. It lets the users make free calls to anyone else in the network using any phone, and provides both voice and data services. The Mesh Potatoes can also be connected to any internet or telecom provider. Through access to the web, users can make cheap, long distance calls.[67]

Stephen Song, the founder of Village Telco, explains:

"The current price of a single device is USD 100, but this can potentially be cut by half. There are no other costs associated with setting up the Village Telco network, but extra costs are involved if the Mesh Potato is connected to the internet or the public switched telephone network. Each mesh potato has a range of about 300-400 m, but every device acts as a repeater for other Mesh Potatoes. As long as the next user of the device is within the specified range, the network can be expanded. Village Telco is used in countries such as East Timor, Brazil, Nigeria, Cameroon, and others.[68]"

Opportunities facilitated by e-commerce initiatives have opened doors for new business ventures and the expansion of new businesses in rural areas. AirJaldi supports rural Business Process Outsourcing (BPO) operating three branches of 150 people. In addition, rural banking supported by internet connectivity has enabled farmers to access loans with greater

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[64] Srivastava, Ritu (DEF). Personal Interview. 27 Dec. 2011.
[65] About AirJaldi. *AirJaldi*. Retrieved January 27, 2012, from drupal.airjaldi.com/node/32
[66] Ginguld, Michael (AirJaldi). Personal Interview. 15 Nov. 2011.
[67] Village Telco. *Village Telco*. Retrieved November 29, 2011, from http://villagetelco.org
[68] Ibid

ease and to raise collateral.[69] Online shops are another business opportunity successfully enabled through the DEF and AirJaldi networks. The DEF Wireless for Communities (W4C) project facilitated the Chanderiyaan Project, which supports handloom weavers of the Chanderi region and enables them to create their own e-commerce platform for the showcasing and trading of their products.[70]

Moreover, e-learning made available through internet access utilizing unlicensed spectrum has allowed inhabitants of remote areas to receive education without having to move from home. For example, AirJaldi has tested and shown successful live teaching and streaming applications which allow a teacher to simultaneously instruct 15 classrooms across different locations.[71]

Internet connectivity also allows patients from remote communities to directly connect with doctors in urban environments. Medical consultations/interventions are mediated remotely through Wi-Fi-enabled medical equipments. For example, medical tests such as electrocardiography (ECG), blood pressure and blood sugar tests are conducted at the government public health centre in Chanderi, where the Digital Empowerment Foundation (DEF) and Media Lab Asia have set up a telehealth facility. All reports, including photos and scanned prescriptions of the patients are sent to district headquarter hospitals for referral suggestions.[72]

Furthermore, inexpensive wireless connectivity enables the creation and spread of local mass media. *Chanderi ki Awaaz* is a community radio station which broadcasts from Chanderi, serving the community up to 10-15 km and uses the internet access provided by the DEF wireless network to further connect to its listeners.[73] The network created by AirJaldi has also served to greatly enhance mass media in the region. News agencies that are connected to the network stream local events, broadcasting them live by IPTV, YouTube, or other dedicated websites where one can access this programming.[74]

Providing internet access to those living in remote villages can be achieved through the provision of connectivity to panchayats,. There are 3 million elected Panchayat representatives in 250,000 panchayats across 635,000 villages. Connecting one panchayat to the internet has the potential to serve users from roughly two or three villages. The government has already allocated funding for this initiative through the RAJNISH (Rajiv Gandhi National Information Super Highway) project. Similarly, if the 1.4 million schools in India (most of which are in remote areas) were to be connected to the internet, teachers and students would also become beneficiaries of such connectivity. The most inexpensive option for realizing these goals is through exploiting the unlicensed bands in the 5.7 GHz and 2.4 GHz frequencies, as well as the to-be unlicensed frequencies in the 5.15 GHz-5.35 GHz and the 5.725-5.775 GHz bands for the last mile access.[75]

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[69] Ibid

[70] Srivastava, Ritu (DEF). Personal Interview. 27 Dec. 2011.

[71] Ginguld, Michael (AirJaldi). Personal Interview. 15 Nov. 2011.

[72] Srivastava, Ritu (DEF). Personal Interview. 27 Dec. 2011

[73] Ibid

[74] Ginguld, Michael (AirJaldi). Personal Interview. 15 Nov. 2011.

[75] Manzar, O. (2011). Internet's Last-mile Challenges. *The Mint*. Retrieved November 22, 2011, from http://www.livemint.com/2011/11/13225841/Internet8217s-lastmile-cha.html?h=B

7. Conclusion and Inferences

7.1 Unlicensed spectrum is a valuable public and social good precisely as it serves as an inexpensive and accessible source of connectivity for remote and marginalized communities.

7.2 Advances in technology have enabled a more efficient utilization of spectrum as they have allowed for the simultaneous use by multiple entities and technologies without interference or need for licenses.

7.3 Spectrum de-licensing is a flexible approach to spectrum management, which fuels innovation and market development. This can be seen in the case of WiFi (hotspots), which was created by industry efforts seeking to exploit spectrum that has been unlicensed by the regulators.

7.4 When compared to India, regulators like the FCC and Ofcom have allocated more spectrum bands for licence-exempt use. The United States has unlicensed spectrum in the sub-1 GHz (UHF) band. Both USA and UK have furthermore de-licensed a greater range of frequencies in the 5 GHz band. Also, the 433-434 MHz band has been unlicensed in Australia, Singapore, Malaysia, the European Union, and New Zealand.[76] In addition, the DECT frequencies in 1880 MHz-1900 MHz in Europe as well as 1900 MHz-1920 MHz and 1910 MHz-1930 MHz in some countries, including the United States, have been unlicensed.

7.5 Currently, many industry bodies and advocacy groups in India have specific requests for unlicensed spectrum. The requests cover candidate bands including, 433-434 MHz, more bands in sub-1 GHz, more slots under 2.4 GHz, 1880-1900 MHz, 5.15-5.35 GHz, and 5.725-5.825 GHz.

7.6 The Honourable Supreme Court of India had declared spectrum to be "public property" in 1995. Presently the policy environment in India appears to be showing support for more unlicensed spectrum for public use. The current Minister of State for Communications and Information Technology who is involved in the formation of new spectrum policies; a former regulator[77]; and the latest draft of the National Telecom Policy all speak positively for the future availability of unlicensed spectrum.

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[76] Thomas, T. K. (2011, November 28). DoT May De-license Spectrum for Utility Services. *Business Line*. Retrieved November 30, 2011, from http://www.thehindubusinessline.com/industry-and-economy/info-tech/article2668933.ece?homepage=true&ref=wl_home

[77] Dr. D. P. S. Seth, former member of TRAI

8. Policy Recommendations

8.1. The Wireless Planning and Coordination wing (WPC) of the Ministry of Communications should make more unlicensed bands available for internet and multimedia to fuel innovation and efficient spectrum utilization. Unlicensed bands need to be allocated in bigger chunks in various slots as is the prevailing trend in various international markets.

8.2. Frequencies in the 5.15 GHz-5.35 GHz bands, as well as 5.725-5.775 GHz bands are unlicensed for indoor use only. These bands should be unlicensed for outdoor use as well in order to facilitate the creation of wider wireless communication networks and the use of innovative technologies.

8.3 There should be more unlicensed spectrum in the 2.4 GHz range, beyond what is already unlicensed, for the expansion of wireless communication networks.

8.4 The1800-1890 MHz band, which is earmarked for the operations of low power cordless communication in India, should be unlicensed in line with international practices. Many bands for this use have already been unlicensed in Europe and the United States.

8.5 The 433-434 MHz band should be unlicensed for data telemetry as it is done in many countries such as Australia, Singapore, Malaysia, countries in the European Union and New Zealand.

8.6 Experimentation/trials for new technologies and applications in all of the above candidate bands should be permitted on licence-exempt basis immediately in order to facilitate innovation and application development.

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Annex-Glossary

BDMA (Beam Division Multiple Access): The BDMA method separates the antenna beam as per the locations of the mobile stations. An orthogonal beam is allotted to each mobile station during the communication between base stations and mobile stations. This increases the capacity of the system by allowing the mobile stations to give numerous accesses. Mobile stations and the base station know each other's positions precisely, being in a Line of Sight (LOS). Hence they can transmit beams that point to each other's position to communicate with no interference with the mobile stations at the cell edge.[78]

Bluetooth: Bluetooth is an unlicensed consumer device that is used for very short-range wireless personal area networks (WPANs). Bluetooth uses 2.4 GHz spread spectrum frequency hopping technology, and is included in devices such as mobile, radio, telephones, laptops, personal computers, printers, and personal digital assistants (PDAs). Some experts are predicting that it will become a regular feature in many consumer electronic devices.[79]

DECT: DECT technology is created for short-range use as an access mechanism to the main networks. The applications provided by DECT are cordless voice, fax, data and multimedia communications, wireless local area networks, and wireless PBX.[80] The advantage of this technology is that it provides good voice quality and very high radio link reliability.[81]

DECT is generally operated in the 1880-1900 MHz frequency range in Europe. This frequency is unlicensed and exclusive to DECT devices, which secures operation with almost no interference. Outside of Europe, frequencies ranging from 1900 MHz to 1920 MHz and 1910 MHz to 1930 MHz are also widespread. These ranges are also unlicensed but not solely for DECT use. Nevertheless interference is not a big concern in these frequencies either, as they are generally adequately free of other users.[82] About 60% of the cordless communication world market is controlled by this technology.[83] In India, the 1880 - 1900 MHz or the 1910 - 1920 MHz ranges need to be de-licensed to operate DECT devices.[84]

Fixed Mobile Convergence: Fixed Mobile Convergence (FMC) is one of the latest technological developments utilizing Wi-Fi technology. FMC uses the public IP network to spread all or part of the services offered by the wireless telecom service provider's core network (CN) to domestic, small and medium enterprise subscribers. Some of the benefits of FMC are:

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[78] Ali, I. (2011). Beam Division Multiple Access (BDMA) for 5G. *Telecom India Online*. Retrieved January 27, 2012, from http://www.telecomindiaonline.com/beam-division-multiple-access-for-5g.html

[79] Marcus, M., Burtle, J., Franca, B., Lahjouji, A., & McNeil, N. (2002). Report of the Unlicensed Devices and Experimental Licenses Working Group. *Federal Communications Commission*. Retrieved November 29, 2011, from http://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf

[80] DECT Technology Tutorial. *Radio-Electronics.com: resources and analysis for electronics engineers*. Retrieved November 29, 2011, from http://www.radio-electronics.com/info/wireless/dect/dect_basics.php

[81] Consultation Paper on Allocation of Spectrum Resources for Residential and Enterprise Intra-telecommunication Requirements/ Cordless Telecommunications System (CTS), pg. 21. (2011). *TRAI*. Retrieved January 4, 2012, from www.trai.gov.in/WriteReadData/trai/upload/ConsultationPapers/267/Consultation_Paper_on__CTS_%2026.12.2011.pdf

[82] Ibid pg. ii

[83] Air Cmde (Retd) Motial, Shubhangi (DECT Forum India). Personal Interview. 8 Nov. 2011

[84] Ibid

- There is greater technological practicality, because users only have one contact number, as well as use the same device for fixed and mobile services
- Indoor coverage is enhanced, because the wireless signal is disseminated from within the indoor environment
- There is a reduction in the bandwidth load, because voice and data traffic are offloaded from the wireless to the fixed portion of the network
- The expenses incurred by the service providers as well as subscribers are reduced

A viable option for delivering FMC is through Unlicensed Mobile Access (UMA). The UMA standard combines wireless cellular telephony and Wi-Fi networking for voice, data, and multimedia services available on one dual-mode handset (DMH). This method of communication allows the use of a single device indoors and outdoors without a loss in quality, and even a potential improvement. The DMH device can automatically alternate between an IP-based network and a cellular network; the network choice being dependant on where the strongest signal is coming from. UMA promises a solution for converging fixed wire services, mobile wire services, and VoIP services.[85]

Frequency Hopping: This is a modulation technique that is employed in the spread spectrum signal transmission. It involves the continuous switching of frequencies in the process of radio transmission. This reduces the chances of interception or jamming of signals.[86]

Near Field Communication (NFC): NFC is a radio technology that operates at a short range using the 13.56 MHz frequency. Communication between two NFC-compatible devices is activated when they are put within the proximity of about 4 cm. NFC can be applied to mobile handsets, enabling them to interact with posters, magazines, and various products. NFC applications also include electronic wallets which would act like credit cards through the handset.[87]

OFDMA (Orthogonal Frequency Division Multiple Access): Orthogonal Frequency Division Multiplexing (OFDM) is a method for transmitting a bulk quantity of digital data over spectrum. The advantage of this technique is that it reduces the amount of crosstalk within signal transmission. This is done by dividing the radio signal into several sub-signals and transmitting them to the receiver at the same time using different frequencies.[88] OFDMA provides for a multiple access on the same channel. It distributes subcarriers between all users so that everyone can transmit and receive simultaneously.[89]

RFID: Radio Frequency Identification (RFID) is used as a reference to a system that uses radio waves to wirelessly transmit the identity of an object or person in the form of a unique serial number. RFID applications include ID tags, EZPasses, SpeedPasses, and many others.

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[85] Yarali, A., & Saleeba, K. (2010). Unlicensed Mobile Access: Leading Technological Alternative in the Fixed Mobile Convergence Stable, pg. 1. *IEEE Xplore Digital Library*. Retrieved November 29, 2011, from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5532795

[86] Frequency-hopping Spread Spectrum. (2001). *TechTarget*. Retrieved January 27, 2012, from http://searchnetworking.techtarget.com/definition/frequency-hopping-spread-spectrum

[87] Ortiz, C. E. (2008). An Introduction to Near-Field Communication and the Contactless Communication API. *Sun Developer Network (SDN)*. Retrieved February 15, 2012, from http://java.sun.com/developer/technicalArticles/javame/nfc/

[88] (2010). The History of OFDMA and How OFDMA Works. *Webopedia*. Retrieved January 27, 2012, from http://www.webopedia.com/DidYouKnow/Computer_Science/2005/OFDMA.asp

[89] (2005). OFDM or OFDMA? *Mobile Development and Design*. Retrieved January 27, 2012, from http://mobiledevdesign.com/tutorials/ofdm-or-ofdma/

RFID technology operates without needing a contact or a line of sight for communication. RFID data can be traced through the human body, clothing, and non-metallic objects.[90]

The specific frequency allocation for RFID technology is decided by national radio regulatory bodies. The frequencies for RFID use are unlicensed and generally range from 125-134 KHz, 13.56 MHz, UHF (400-960 MHz), 2.45 GHz, and 5.8 GHz.[91]

The number of RFID tags sold in 2011 is expected to be 2.88 billion, which demonstrates considerable growth from 2.31 billion in 2010.[92] Large retailers such as Wal-Mart have contributed to the increasing usage of this technology.

Software Defined Radio (SDR): This is a compilation of hardware and software technologies where some or all of the radio's operating functions use modifiable software or firmware that operate on programmable processing technologies. SDR enables new wireless features and applications to be included in existing radio systems without the need for new hardware.[93] The potential for implementing SDR devices for spectrum sharing is through programming the technology to sense available spectrum in the vicinity of the device and coordinate with other communication endpoints to avoid interference.[94]

Spread Spectrum: This transmission method modulates a signal over multiple carrier frequencies at the same time.[95] As a consequence, the energy for transmitting the signal is spread over a wider bandwidth, appearing as noise.[96] Transmissions using spread spectrum are more secure, interference is reduced, and the bandwidth-sharing is enhanced.

Ultra Wide Band (UWB): UWB is a wireless technology that transmits large quantities of digital data over wide frequency channels at a short distance using very low power. It is mainly used for voice and data transmission utilizing digital pulses and radar applications.[97]

ZigBee: ZigBee is an open global standard of wireless technology which is used for low-cost, low-power machine to machine (M2M) networks. This standard uses unlicensed bands in the ranges of 2.4 GHz, 900 MHz and 868 MHz. ZigBee has the advantage of enabling the operation for years on inexpensive batteries for a variety of monitoring and control

[90] What is RFID? *AIM - The global trade association for automatic identification*. Retrieved November 29, 2011, from http://www.aimglobal.org/technologies

[91] RFID Frequencies. *High Tech Aid*. Retrieved November 29, 2011, from http://www.hightechaid.com/tech/rfid/rfid_frequency

[92] Das, R., & Harrop, D. P. (2011). RFID Forecasts, Players and Opportunities 2011-2021. *IDTechEx*. Retrieved December 18, 2011, from http://www.idtechex.com/research/reports/rfid_forecasts_players_and_opportunities_2011_2021_000250.asp

[93] (2011). What is Software Defined Radio? *Wireless Innovation Forum*. Retrieved February 15, 2012, from http://www.wirelessinnovation.org/Introduction_to_SDR

[94] Hou, W., Yang, L., Zhao, B. Y., Zhang, Z., Zheng, H. (2011). Papyrus: A Software Platform for Distributed Dynamic Spectrum Sharing Using SDRs. Retrieved February 15, 2012, from http://www.cs.ucsb.edu/~htzheng/publications/pdfs/papyrus.pdf

[95] Glossary Definition for Spread-Spectrum. (2011). *Maxim: Innovation Delivered*. Retrieved January 27, 2012, from http://www.maxim-ic.com/glossary/definitions.mvp/term/Spread-Spectrum/gpk/293

[96] An Introduction to Spread-Spectrum Communications. (2003). *Maxim: Innovation Delivered.* Retrieved January 27, from http://www.maxim-ic.com/app-notes/index.mvp/id/1890

[97] (2008). Ultra Wideband. *Whatis?com.* Retrieved February 15, 2012, from http://whatis.techtarget.com/definition/ultra-wideband.html

functions.[98] ZigBee has standards for energy management, home and commercial automation, health care, retail, telecom, and consumer electronics.[99] It is used for a multitude of purposes, such as smart energy/smart grid, AMR (Automatic Meter Reading), lighting controls, building automation systems, tank monitoring, HVAC control, medical devices and fleet applications.[100] About 40% of the 2010 IEEE 802.15.4 chipset shipments were composed of ZigBee products. It is estimated that this number will grow to almost 55% in 2016.[101]

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[98] ZigBee. (2011). *Digi: Making Wireless M2M Easy* . Retrieved November 29, 2011, from http://www.digi.com/technology/rf-articles/wireless-zigbee

[99] Understanding ZigBee. (2011). *ZigBee Alliance* . Retrieved November 30, 2011, from http://www.zigbee.org/About/UnderstandingZigBee.aspx

[100] ZigBee. (2011). *Digi: Making Wireless M2M Easy* . Retrieved November 29, 2011, from http://www.digi.com/technology/rf-articles/wireless-zigbee

[101] ZigBee Technology. (2011). *ZigBee Alliance*. Retrieved November 30, 2011, from http://www.zigbee.org/About/AboutTechnology/ZigBeeTechnology.aspx