# An Empirical Assessment of Quasi-Permanently Vacant Channels in Mobile Communication Bands for Cognitive Radio

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***Abstract*****: Basis of cognitive radio is to exploit unused frequency channels in licensed band. Recently standardised IEEE 802.22 set of cognitive radio protocols envisages fixed and nomadic receivers at below 800 MHz bands. Radio link design for this cognitive radio consider that the channels are available only dynamically to secondary users. Scanning period is thus embedded in link layer control as overhead and reduces overall efficiency of cognitive radio technology. For mobile receivers, availability of permanent channels for radio link control is essential for in-band signalling. Existing mobile communication system uses CDMA 800, GSM 900, GSM 1800 and WCDMA 2000 MHz bands for which approximately 1/8th of the band capacity is used for in-band signalling. Present work provides an assessment of vacant channels in mobile communications range which were permanently available at the time of measurement. The study used conventional Radio frequency scanners available for different bands and dedicated engineering handsets for tracking active frequencies. The tests were performed with assemblies carried in a vehicle and across the length and breadth of each city. The allotment of frequencies by Frequency Regulatory Authority to local mobile operators along with the frequency bands reserved for further distribution were also considered. The experimentally collected data were analysed using RF analysis software and spread sheet database. An analysis of the collected data lead to arrive at the conclusion that more than 1/8th part of resources of each band are nearly permanently vacant which is enough to design in-band common control signalling methods for cognitive radio. Also, from collected data of eight cities, an empirical relationship has been established which can be taken as a thumb rule for projection of channel occupancy from densely populated core areas of big cities to scanty populated township areas when population is known.**

## I. INTRODUCTION

The continued success of mobile wireless industry is placing more demands on an already scarce and valuable radio frequency resources banking on commercially successful technologies. Regulators of every country put an eye to oncoming recommendations arising out of standardization institutes and mark corresponding blocks as reserved for future licensing. This has been added up with continued demand for higher bandwidth due to data and video. As a result, one most promising technology has come up for efficient spectrum utilization of the unused channels in the licensed band termed as Cognitive Radio (CR). Cognitive Radio users are termed as secondary users whereas licensed users are termed as primary users. Since secondary user uses the same band as that of a primary user, the former has to take care that the later one is not (or minimum) disturbed in terms of access and interference. CDMA in 800 MHz band, GSM at 900MHz and 1800 MHz bands, WCDMA in 2000MHz band, LTE in 2300 MHz band and WiMAX at 2500MHz and 3500MHz bands are dominant players in mobile communication radio. Wi-Fi and other low power radios play at ISM band at 2400MHz band. To give space to a demanding frequency channel of a band to a primary user, secondary user has to keep track of all the vacant channels of all bands and their respective qualities in terms of SNR and throughput. Thus, cognitive radio users deploying opportunistic spectrum access has to scan continuously the whole range of spectrum with a reasonable bandwidth and scanning frequency. This is a very cumbersome and computing intensive mechanism. Alternatively, a scanner which scans only predefined channels of specified bandwidths and across licensed mobile radio frequency bands only, shall be very efficient and trustworthy. Matched filtering and coherent detection technique is most suitable in such environment for it's short detection time, high SNR, low probability of missed detection and false alarm [1]. Matched filtering closely resemble to SDR compatible Mobile Station (MS) available commercially and also in digital RF scanner used for drive test purpose. Also, most of the communication system needs a pilot and dedicated control channels which remains as fixed during the entire period of communication between two users. This needs association of a permanent frequency channel with cognitive radio, preferably in-band hired channel along-with primary users or select a channel out of band. In opportunistic spectrum access, secondary users will use licensed spectrum when primary users do not transmit. According to Beibei Wang and K J Ray Liu, availability of such a global control channel is not realistic since there may be no permanent channel available for secondary users [2]. Probability to get an opportunistic control channel in licensed band for all nodes in cognitive radio network has been narrated as dramatically small by Antonio De Domenico and co-authors [3]. Thus, exploration for availability of Quasi-permanent channels in licensed mobile communication bands for cognitive radio shall truly facilitate with the advantages of working with common control channel in MAC layer. In the present study, the licenses allocated to mobile service providers of India has been taken into consideration for estimation of grossly available vacant channels of reserve bands and drive tests were conducted in six different cities for completely allocated GSM bands. It was established that more than one-eighth part of all bands are vacant which closely resembles to the requirement of one signaling channel for seven traffic channels.

The remainder of the paper is organized as follows: Section II explains the signaling channel part requirement as a fraction of channel capacity for mobile communication technology systems which enable us to draw empirical statement for access of the whole licensed band by cognitive radio. Section III covers literature survey indicating the availability of channels in different commercial bands. Section IV discusses about the reserve spectrum and actual allotment of channels by the spectrum allocation authority. Section V describes the measurement plan and collection of data at different cities. This is followed by presentation and discussion of the collected results in Section VI. Finally, the conclusions are presented in Section VII. Present work is an extension of earlier work presented and published in ICACT 2013.

## II. EMPIRICAL STATEMENT

Regulatory Authorities of every country identify frequency bands for public mobile communication technologies e.g. CDMA, GSM, WCDMA, WiMAX etc. Each band is divided into radio frequency (RF) channels for license purpose. Based on technology deployed, operators divide each RF channel into communication channels which consists of common control (CC) channels and data (traffic) channels. Common Control channels services traffic channels and are within licensed RF i.e. in-band. In 800 MHz band, CDMA IS-95 uses 1.25MHz bandwidth as communication channel with one pilot and seven common control channels i.e. total 8 channels out of total 64 Walsh code channels. Walsh code count was 128 for CDMA 2000 1x i.e. one RF. In 1x EV- DO there are 8 control channel time slots out of total 256 time slots and 96 chips of pilot is embedded in each data slot of 1024 chips which together counts for $1/8^{th}$ part of the channel. In WCDMA, out of total radiated power of 20Watts, primary and secondary control channels and pilot channels constitutes 2.585 Watts leaving 17.415 Watts for traffic. In GSM, if there is one RF, the first time slot works as the pilot and common control channel for remaining 7 time slots. In case of 2 or more RFs, on an average, one time slot of first RF is used as control channel for each additional RF. In OFDMA, for a 5 MHz channel, there are 60 pilot sub-carriers for 360 data sub-carrier and 92 null sub-carriers and thus the ratio is slightly higher than $1/8^{th}$ part of the whole RF channel.

Thus, approximately $7/8^{th}$ part of a licensed RF channel of a frequency band is available for useful communication and the remaining part is used for control purpose. As a corollary of the above, we can say that $7/8^{th}$ part of a band is used for purposeful data communication and remaining $1/8^{th}$ part for common control and signaling purpose. Alternatively, if $1/8^{th}$ part of a frequency band is permanently available as spare and the same is used for common control purpose, the total band can be completely accessed for cognitive radio communication purpose.

Designers of mobile network communication distributes the communication access system equipments based on population density at different places. The population density has been identified as dense-urban, urban, sub-urban, highway and rural. Conventional 3 sectored antenna system is used for all cell sites except highway sites where only 2 sectored antenna is deployed. We take into consideration 3 urban areas where occupancy of deployed channels are considerably higher. It shall be fair enough to estimate that a minimum of 30% of the channels are occupied in the sub-urban areas even if operators uses them inefficiently. Occupancy grows linearly with population at lower population areas and the efficiency of channel utilization increases. With increase of population occupancy of channels increases, operators use different optimization techniques for maximum use of available channels but slowly attains saturation. The increased need of channels with population increment and counter-balancing the need through efficient optimization techniques can be mathematically expressed as negative requirement of channels and graphically it can be expressed as saturation. With further increase of population, operators has to borrow traffic channels from higher frequency band lowering the occupancy at lower frequency band and consequently it may be reflected as occupancy depression in lower band. Thus, the occupancy of channels with increase of population can empirically be expressed by the relation

$$y= 30+15x-x^2$$

where

y= percentage occupancy of channels in lower frequency band and

x= population size in millions.

## III. LITERATURE SURVEY

An extensive measurement campaign was conducted in the city of Aachen located in Germany near to the border to Netherlands and Belgium. The spectrum occupancy of several frequency bands was measured over longer time periods up to seven days. The Authors deployed the amplitude probability distribution method to decide spectrum occupancy data which can help to optimize the search for unused spectrum i.e. white space[4]. The Authors identified FM radio bands around 100MHz and the GSM channels bands around 900MHz as the measured minimum level was above -80 dBm. Marc McHenry did large scale spectrum occupancy measurement and observed that the spectrum occupancy in several American cities was found to be always below 25%, which is mostly caused by a rather high decision threshold between -90 and -105 dBm [5]. In Qatar, A comprehensive wideband spectrum occupancy measurement was performed over multiple dimension (time, frequency and space) concurrently over an utilized bandwidth in the 700 − 3000MHz band over a three day measurement period.Across four different locations, the bandwidth utilization varies between 4% and 15%. It was observed that bandwidth utilization is time variant with peak times ranging from afternoon to sunset in almost all of the locations [6]. In Romania, corresponding to the downlink communication direction i.e. for 880 - 960 GSM, E-GSM, Military bands, occupancy level was found by Authors to be 46.80% and for 1710 - 1880 GSM 1800, occupancy was 22.86% [7]. A survey was conducted in Barcelona, Spain [8] to carry out a broadband spectrum measurement campaign which covered the frequency range from 75MHz to 3GHz in an outdoor urban environment. The measured frequency range was divided into six consecutive 500 MHz blocks. Each block was measured during a continuous period of 48 hours and was observed that only 22.57% of the whole frequency range between 75MHz and 3GHz was occupied. A similar type of survey was conducted in Singapore [9] to find the spectrum usage pattern in frequencies from 80 MHz to 5.85 GHz. The 24-hour measurement had been taken at the roof top of Institute for Infocomm Research's building over 12 weekday periods, which indicated that the average occupancy on the frequency range from 80 MHz to 5.85 GHz was only about 4.54%. In a survey at the Loring Commerce Centre [10], the measurements were made during a normal work week for 3 days for the frequency ranges between 100 MHz to 3 GHz. Based on the results of the study, it was observed that the average spectrum usage during the measurement period was 1.7%.

The static measurement shows that the mobile licensed bands and ISM bands are partly occupied and the remaining parts of the spectrum resembles noise. It is apparent that no study has been made to assess actual occupancy of mobile communication bands based on measurements at different locations of the same city in licensed band. Also, no study has been made to find variation of channel occupancy for different type of cities. These studies shall help us to accurately identify the frequency channels with low or no active utilization and successfully deploy them in cognitive radio technology.

## IV. RESERVE SPECTRUM AND ALLOCATION

In India, the radio frequencies are being used for different types of services like mobile communication, broadcasting, radio navigation, satellite communication, defense communication, etc. The National Frequency Allocation Plan (NFAP) forms the basis for development and manufacturing of wireless equipment and spectrum utilization in the country. Frequency bands allocated to various types of mobile communication services in India are mentioned in Table I.

TABLE I

LICENSED BANDS OF DIFFERENT WIRELESS TECHNOLOGIES

| Technology used | Band and Channel Width | Technology Bandwidth in MHz | *Allocation | *Occupancy/Remarks |
|---|---|---|---|---|
| CDMA | 890-915MHz; 935-960MHz; Channel B/W 1.25MHz FDD; 20 channels | 25+25 | 5 Operators – 2 RF each | 50% vacant |
| GSM 900MHz | 824-849MHz; 869-894MHz; 124 channels of 200 kHz spacing | 25+25 | 4 Operators | Fully Licensed- vacant channels to find out experimentally |
| GSM 1800 MHz | 1710-1785MHz;1805-1880MHz; 374 channels | 75+75 | 4 Operators | 60% vacant channels; actual to find |
| WCDMA | 1920-1980MHz;2110-2170MHz | 60+60 | 3Operators – 5 MHz each | 75% vacant channels |
| WiMax & 4G | 2500–2690MHz | 190 | 3 Operators- 15 MHz each | 77% vacant channels |
| WiMax (fixed) | 3400-3600MHz | 200 | One -20MHz | 90% vacant channels |

*As per available information.

So far CR technology has been developed keeping into consideration that all channels in licensed bands are dynamically accessed and released. Game theory is applied for capturing a vacant channel inviting competition amongst CR operators. Further, there is a possibility of occupying a vacant band by CR secondary user in the guise of a primary user. In addition, a concept of bidding for vacant channels has also come up for use by secondary users at a comparative cost. All these factors introduces the concept of business out of the unused channels of a licensed user with or without having a permanent infrastructure for CR. It is thus envisaged that mainly public authorities providing public utility services at almost zero cost may be authorized to operate over unoccupied spectrum even though licensed. However the number of such public utility service providers is expected to be very limited. Table I clearly indicates that one out of total eight communication channel in each band is permanently available as vacant for using as pilot and signalling purpose which is necessary for the working of Cognitive Radio communication except GSM 900 MHz band. Conduction of field test is absolutely necessary for assessment of quasi-permanently vacant channels for use of in-band common control signalling purposes.

## V. MEASUREMENT SETUP AND DATA COLLECTION

The measurement setup used is a drive test equipment which performs tests in a cellular network and collects data on a moving vehicle. The software and hardware used are: Laptop with charger and USB hub, GPS and data cable, Digital RF Scanner, License dongle for TEMS, Cell site database and Link budget, Clutter diagram from Google website, MapInfo software, Engineering handsets with 4 (2G/3G) SIMs of different operators mounted simultaneously and cable terminal. In the setup, data collection software is installed in the laptop which uses a mobile phone along with GPS system. Drive test route was carefully selected and data was collected accordingly. GPS collects the data of latitude and longitude of each point while mobile collects data like signal strength, uplink and downlink frequency, etc. All the information is stored with their respective date and time as well as their geographical locations. File sizes are kept within limit of about 25MB in each part trace and a new file is open in each part. Data from all part files are grouped from collection software and are stored in some output file. Using the above setup, measurement was taken on eight cities at different geographical locations viz. Kolkata, Patna, Ranchi, Dibrugarh, Jaipur, Shillong, Bhopal and Port Blair which have population ranging from 1.5 million to 6.6 million shown in Table 2.

Figure 1 shows the measurement route map of Jaipur. Jaipur city has a population of about 6.66 million. One side of measurement route is heavily populated while it is less populated on the other side. The lower band of frequency channels is distributed among three operators while the upper band is allocated to one operator. While moving from location having $75.82894^0$E and $26.91442^0$N, it is found that in lower band of Operator1 - 14 BCCH are occupied namely 71,73,75,76,77,78,80,81,82,87,88,111,112,113 while 29 BCCH are vacant (72,74,79,83 to 86,89 to 110) of which BCCH no. 89 to 110 is not used at all. Among hopping channels, two hopping channels 114 and 121 are vacant. While in Operator2, 13 BCCH (1 to 13) and 18 hopping channels (14 to 31) are fully occupied. In Operator3, 13 BCCH (50 to 62) and 18 hopping channels (32 to 49) are also fully occupied .The frequency band is switched to upper band used by Operator 4, in which 15 BCCH (530 to 544) and 15 hopping channels (546 to 560) are occupied while one

BCCH number 545 is vacant. So, on an average 75% of frequency spectrum of lower band is utilized.

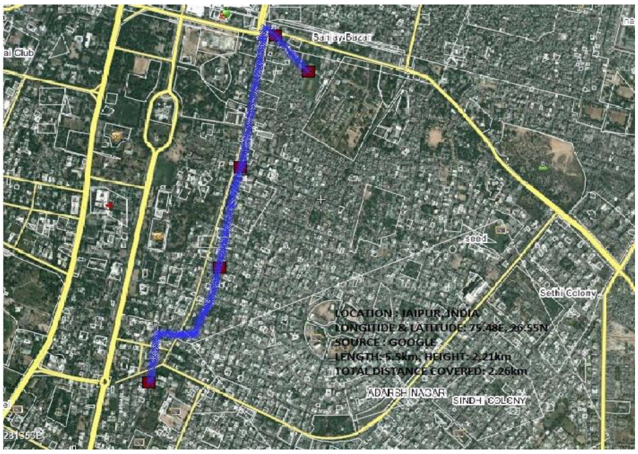


Figure 1. Measurement Route map of Jaipur

Kolkata is a densely populated city which has a population of about 4.48 million in core Municipal area. During the survey, the area selected was busiest one which has tall buildings towards right side at North and scattered single storied structure towards the river. Towards South, it is almost green field; measurement route is shown in Figure 2, it is found that the lower band and upper band of frequency channels is distributed among three operators. In the two operators of lower band in Kolkata all the BCCH viz. 70, 71,73 to 76, 78,80,82,87,88,111,112,113 in Operator 1 and 50 to 62 in Operator 2 are fully occupied but 30 BCCH i.e. 72,77,79,81,83 to 86, 89 to 110 are vacant in third operator; and 4 hopping channels i.e., 40,48,49,96 are vacant. In the upper band only one BCCH, i.e., 873 is vacant among the three operators; while no hopping channels are available. In Kolkata, it is found that average spectrum occupancy is about 72.58%.

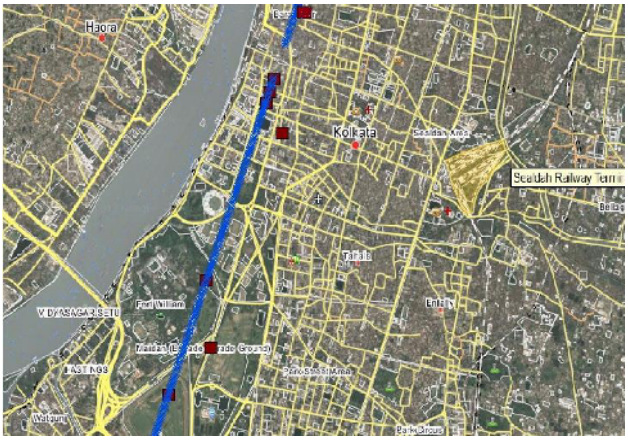


Figure 2. Measurement Route map of Kolkata

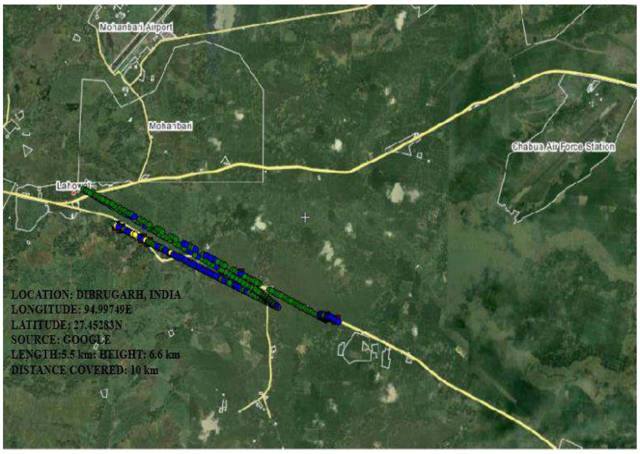


Figure 3. Measurement Route map of Dibrugarh, Assam

Figure 3 shows the measurement route map of Dibrugarh. Dibrugarh district, well known as the “Tea City of India”, has a population of about 1.5 million. It is one of the least populated district where the Brahmaputra river flows in its north. The lower band of frequency channels is distributed among three operators while the upper band is allocated to two operators. While moving from location having 94.99749$^0$E and 27.45283$^0$N, it is found that in lower band of Operator1 - 7 BCCH are occupied namely 1,3,4,5,6,7,8 while 3 BCCH are vacant (2,9,10) and none of the hopping channels are vacant. While in Operator2, 4 BCCH (23 to 26) and 5 hopping channels (27 to 31) are fully occupied. In Operator3, 8 BCCH , i,e; 74,76,78,81,87,88,111,113 and 16 hopping channels namely 63,64,66 to 69, 115 to 120, 122,123,124 are fully occupied .The frequency band is switched to upper band used by Operator4, in which 13 BCCH (536,537,538,867 to 870, 872 to 875,747) and 10 hopping channels (876 to 885) are occupied while 18 BCCH are vacant. In the upper band of Operator2 all 9 BCCH and 3 hopping channels ( 845 to 847) are occupied. So, on an average 50% of frequency spectrum of lower band is utilized.

## VI. RESULTS AND DISCUSSION

Data was also collected for spectrum occupancy measurements in GSM at 900MHz bands in an outdoor environment other cities viz. Bhopal, Patna, Ranchi and Dibrugarh, Shillong & Port Blair. Figure 4 depicts the spectrum occupancy in eight cities of India. In Bhopal, the spectrum occupancy in lower band is 74.19% while in Ranchi it is only 52.42% as it switches to upper band where it has a spectrum occupancy of 83%. The measurements shows that the spectrum occupancy in lower band of Patna is 75.8%. Shillong, capital of the state of Meghalaya of India is located at 25.57° N and 91.88° E on a plateau in the eastern part of the state. The total population of the city is 1.43 million, has a spectrum occupancy of 54%. Port Blair is the capital city of Andaman and Nicobar Islands in India. Located at 11° 40' N and 92° 46' E, Port Blair is the municipal council in the southern part of Andaman, a part of India's Union Territory. Being the least populated place, its spectrum occupancy is 43% .

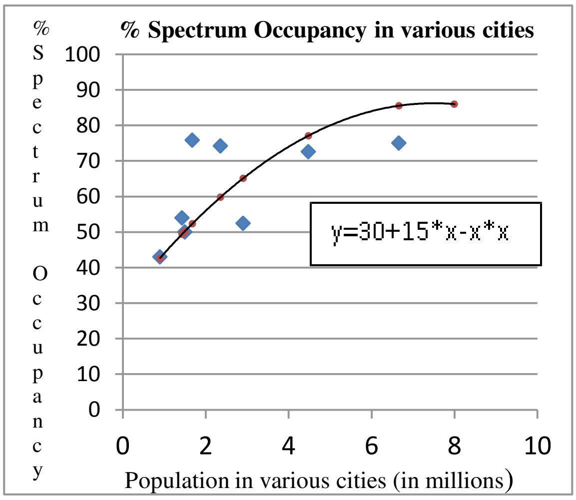


Figure 4. Population Spectrum Graph

In figure 4 above, it is projected that even the most sub-urban area with scanty population shall have nearly 30% occupancy. For population between 1 million to 4 million the increase is nearly linear. The occupancy saturation is observed in the range of 4 million to 7 million. Also, with projected expansion of densely populated city core areas to 8 million, occupancy level is estimated go upto 86%, leaving a clear space of 14% of channels for use of cognitive radio.

TABLE II POPULATION SPECTRUM CHART

| S.No. | City | Population (in millions) | % Spectrum Occupancy |
|---|---|---|---|
| 1 | Bhopal | 2.36 | 74.19 |
| 2 | Patna | 1.68 | 75.8 |
| 3 | Kolkata | 4.48 | 72.58 |
| 4 | Ranchi | 2.91 | 52.42 |
| 5 | Jaipur | 6.66 | 75 |
| 6 | Dibrugarh | 1.5 | 50 |
| 7 | Shillong | 1.43 | 54 |
| 8 | Port Blair | 0.9 | 43 |

The obtained results demonstrated the existence of significant amounts of spectrum potentially available for the future deployment in CR networks in lower bands of GSM which are not at all used.

## VII. CONCLUSIONS

Discussion from above reveals that more than 20% of the completely licensed bandwidth is practically vacant in a saturated market environment. This is well above the requirement of $1/8^{th}$ part of the band to get access to the whole of the bandwidth at a time by cognitive radio and adequate to take additional MAC level overhead required for Cognitive Radio. There is no immediate necessity of these channels by the licensed operators which can be safely deployed as common control channel for cognitive radio purpose. Further, to doubly enhance protection of common control channel, a disaster recovery common control channel may be designated which will hold the replica of allotments and processing status of CR Primary Common Control Channel. Also, depending upon the population, it is possible to approximate channel occupancy and hence cognitive radio technology planners can draw a long term plan for efficient use of them in public benefit. Use of commercially stable technologies with minimum changes at Operator Transceiver equipment and user mobile equipment for adaptation to Cognitive Radio technology shall lead to development of a economically deployable system.

## VIII. REFERENCES


[1] Ying Chang Liang, Kwang Cheng Chen, Geoffrey Le Li and Petri Mahonen, “Coginitive Radio Networking and Communications: An Overview”, in Proc. IEEE Transactions in on Vehicular Technology, 2011.

[2] Beibei Wang and K J Ray Liu, “Advances in Cognitive Radio Networks: A Survey”, IEEE, February 2011, 1932-4553.

[3] Antonio De Domenico, Emilo Calvanese Strinati and Marie Gabriella Di Benedetto, “A survey on MAC strategies for Cognitive Radio Networks”, IEEE 2012, 1553-877X/12.

[4] Matthias Wellens, Jin Wu and Petri Mahonen, Department of Wireless Networks, RWTH Aachen University Kackertstrasse, Germany, “Evaluation of Spectrum Occupancy in Indoor and Outdoor Scenario in the Context of Cognitive Radio”

[5] M. A. McHenry, P. A. Tenhula, D. McCloskey, D. A. Roberson, and C. S. Hood, “Chicago Spectrum Occupancy

Measurements & Analysis and a Long-term Studies Proposal," in Proc. of Workshop on Technology and Policy for Accessing Spectrum (TAPAS), Boston, USA, August 2006.

[6] Khalid A. Qaraqe, Hasari Celebi, Ali Gorcin†, Amer El-Saigh‡, Huseyin Arslan†, Mohamed-slim Alouini , "Empirical Results for Wideband Multidimensional Spectrum Usage", supported by Qatar Telecom (Qtel)

[7] Alexandru Marţian, Calin Vladeanu, Ioana Marcu, Ion Marghescu, "Evaluation of Spectrum Occupancy in an Urban Environment in a Cognitive Radio Context", International Journal on Advances in Telecommunications, vol 3 no 3 & 4, year 2010, http://www.iariajournals.org/telecommunications/

[8] Miguel Lopez-Benitez, Anna Umbert and Fernando Casadevall, "Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications", IEEE, 2009, vol.no. 978-1-4244-2517-4/09, IEEE Xplore.

[9] Md Habibul Islam, Choo Leng Koh, Ser Wah Oh, Xianming Qing, Yoke Yong Lai, Cavin Wang, Ting-Chang Liang, Bee Eng Toh, Francois Chin, Geok Leng Tan and William Toh, "Spectrum Survey in Singapore: Occupancy Measurements and Analysis", IEEE Xplore.

[10] Tugba Erpek, Mark Lofquist and Ken Patton, "Spectrum Occupancy Measurements Loring Commerce Center Limestone Maine", September 2007, www. sharedspectrum.com.