A Programmable Testbed for Spectrum Survey in the Philippines - Measurements and Analyses

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Abstract – *This This study investigates white spaces in the frequency range 410 MHz to 960 MHz using a programmable measurement testbed. Radio spectrum scanning was performed for a total of 144 hours (6 days at 24 hours/day) with the main objective of identifying and quantifying the white space contained in the said bandwidth as a preliminary phase in developing a repository for spectrum utilization in future work. Channel occupancy based on NTC's 2016 channel plan was evaluated herewith. Results show underutilization of the observed bandwidth, with highest average channel occupancy to be 45.12% which is utilized by Cellular Mobile Telephone System in the frequency band, 925 to 960 MHz. Occupancy results show that the observed frequency band contains a large amount of white space. This could be used for different applications, whether for connectivity improvement, government's social services or simply public awareness of the spectrum utilization. This study serves as a foundation for future studies that may include a real-time spectrum observatory and similar applications.*

Keywords—white space, channel occupancy, channel plan, average power levels, power spectrum

I. INTRODUCTION

The increasing ubiquity of wireless communication systems that enable high speed and high quality mobile connectivity has led to increasing demand for the radio spectrum resource. In the Philippines, the proliferation of smart phones reflects the increasing use of social media with a current estimate of 48 million active users contributing to forecasts of 119.8% mobile telecommunications penetration and 16.5 million broadband subscriptions by 2020 [1]. This growth that also comes with significant increase in the demand for wireless connectivity motivates the need for more efficient utilization of available spectrum. In every territory, a national regulatory agency is responsible for implementing allocation of radio frequencies to various end uses. In the Philippines, the National Telecommunications Commission (NTC) is the mandated agency that implements the National Radio Frequency Allocation Table (NRFAT) [2], which summarizes the assignments or allocations for various uses of the electromagnetic (EM) spectrum in telecommunications, TV/radio broadcast, radar, industrial, scientific and medical applications. These allocations are *fixed*, i.e. once allocated to a specific system, i.e. an "incumbent" or "primary user", it may not be readily utilized for and by a different system even if the incumbent user is not active. The practice of fixed allocations has led to a tendency to inefficiently use the radio spectrum [3,4] since other users currently requiring service are prevented from occupying an allocated frequency band despite the possibility of said band actually being unoccupied.

An example of a system with significant allocation of radio spectrum is television (TV) broadcast. The carrier frequencies for the TV broadcast range from Very High Frequency (VHF) to Ultra High Frequency (UHF), i.e. 54 – 88 MHz for low band VHF, 174 – 216 MHz for high band VHF and 512 – 698 MHz for UHF channels in the Philippine NRFAT [2]. With the advent of digital TV broadcast, the 6MHz bandwidth allocation for each TV channel can accommodate more content through time division multiplexing techniques. As such, the switch from analog to digital TV broadcast is seen to further "free up" additional radio spectrum that may be reallocated to other applications. An evaluation of spectrum occupancy within the TV broadcast frequency allocation can provide an assessment of so-called available "TV white space", which can then serve as basis for permitting the use of said frequencies by secondary users. The use of white space has been identified as one possible solution in providing better connectivity [5] especially in areas with no broadband infrastructure. In the Philippines, a thorough investigation of available white space will play a major role in improving connectivity that supports different socio-economic services, i.e. public governance, agriculture, disaster response, education, and health care [5]. Part of the country's effort to accomplish this is through the Department of Information and Communications Technology's project on Spectrum Policy Assessment System (SPAS), which is based on the ITU recommendations on frequency channel occupancy measurements (Recommendation ITU-R SM.1536), mobile spectrum monitoring unit (Recommendation ITU-R SM.1723-2), and automation and integration of spectrum monitoring systems with automated spectrum management (Recommendation ITU-R SM.1537). Through the SPAS project, a nationwide RF spectrum monitoring system would be implemented using hundreds of sensors installed all over the country to gather RF signals. Monitoring units will include both Fixed Spectrum Gathering Unit (FSGU) and Mobile Spectrum Gathering Unit (MSGU) positioned in high radio-density areas considering user density in the area [6].

Spectrum survey has been conducted in numerous studies in different countries to determine white space in different frequency allocations. To cite a few, a study was conducted in Singapore to evaluate the frequency range from 80 MHz to 5.85 GHz [7]; another one in Europe investigated the bandwidth between 400 MHz to 3GHz [8]; other studies made in Beijing [9], Chicago [10], Kuala Lumpur [11], Spain [12] and California [13] monitored spectrum occupancy in the frequency ranges from 450 MHz to 2.7 GHz, 30 MHz to 3 GHz, 470 to 798 MHz, 75 MHz to 3 GHz, and 108 MHz to 19.7 GHz respectively. Although these studies had a common goal, which is to evaluate spectrum occupancy in their respective bandwidths of observation, results from these studies cannot be used solely as a basis for deducing spectrum occupancy in our country since broadcast channels are assigned locally by the Philippine government. Hence, a survey of our country's assigned frequency spectrum presents a unique result which could be used as a basis in future studies to be conducted in our country. Although a spectrum survey was conducted here in the Philippines in 2012 [14], this was based on the old frequency allocation for UHF and VHF TV channels. Since NTC released a new channel plan in 2016 [2], this is an opportune time to conduct a spectrum survey to evaluate the new frequency allocations.

Such is the main objective of this study. Using a programmable testbed, white space between 410 MHz to 960 MHz is identified. This study serves as an initial phase of testing, providing a stationary gathering of data. Therefore, with only a few stations, and the need for mobility and a wider geographical reach temporarily ignored, spectrum surveying will only have a variance in time but not space. The creation of multiple measuring stations and a real-time observatory of white space may have merits for future studies. Programmable testbeds allow for new and more complex algorithms to be implemented in assessing spectrum occupancy, such as in [3] and [4].

The paper is divided into five sections. Section II describes the measurement set-up used for the testbed. In Section III, measurement results and analysis are discussed. Lastly, conclusions were drawn from the results, and recommendations were given for a larger scope of spectrum surveying in Sections IV and V respectively.

II. MEASUREMENT SYSTEM

1.1 Measurement Equipment

The study was conducted at the University of the Philippines Diliman, situated in Quezon City, the largest and most populated city in the National Capital Region. It is a highly urbanized city of tall buildings home to telecommunications companies. The measurement system was set up at the Electrical and Electronics Engineering Institute (EEEI) Building rooftop and WCEL laboratory as illustrated in Figures 1 and 2. Figure 2 shows the block diagram of the measurement system wherein the signals received by the antenna are processed by the spectrum analyzer, with additional post-processing done in Matlab.

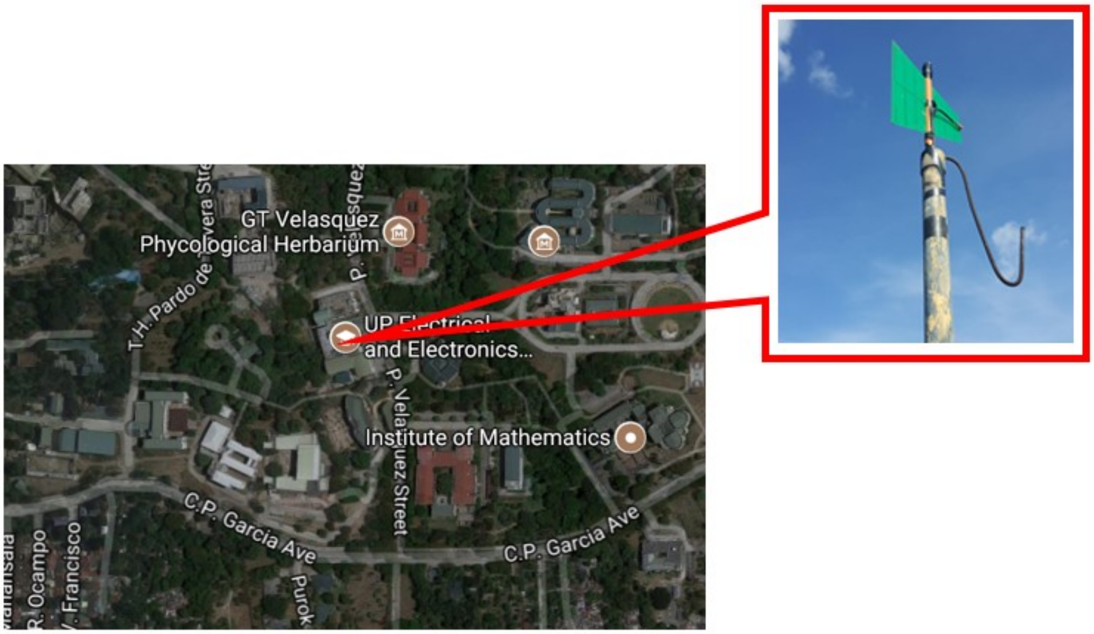

Figure 1. Log Periodic Antenna mounted on the UP EEEI rooftop.

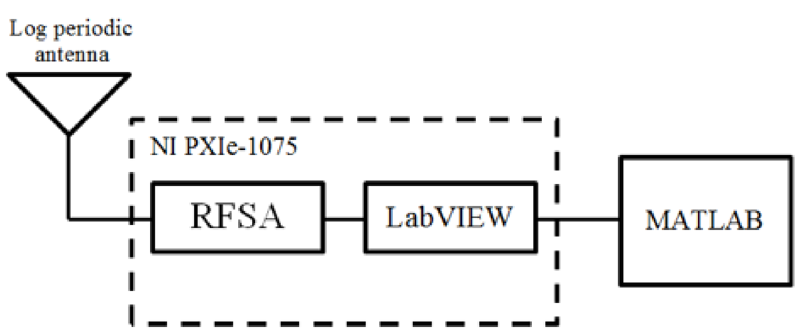

Figure 2. Block diagram of the Measurement System

The spectrum analyzing equipment used was a PXIe-1075 with a PXIe-5601 (RF Downconverter) from National Instruments. The downconverter module has a frequency range of 10 MHz to 6.6GHz and can perform spectrum measurement. LabVIEW 2014 was used to control the operation and measurement of the PXI. The Log Periodic antenna of Kent Electronics with an operating bandwidth of 400 - 1000 MHz was used for the set-up. This was mounted on the rooftop at the 5th floor of the UP EEEI building as seen in Figure 1. The antenna was connected to the PXI equipment, shown in Figure 3, at the WCEL laboratory on the 4th floor of UP EEEI via cable with total loss of around 2 dB.

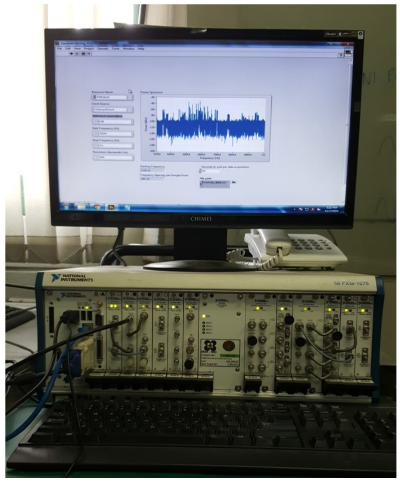

Figure 3. NI PXI at the WCEL Laboratory.

1.2 Software Control

The LabVIEW code was built on a case structure to facilitate proper data flow and timing. A built-in VI (RFSA Getting Started Spectrum) was used as a starting point, and was modified to include the recording and scheduling features. The settings for the start and stop frequency, the resolution bandwidth, and the delay between consecutive measurements are taken from the front panel controls shown in Figure 4. These settings are then passed onto the niRFSA initialization and configuration chain and the spectrum is measured. Before the measurement is recorded, the column headers for the .csv formatted file is prepared. The headers are important for future database management, and easier parsing of data from the .csv files. The header and the measurements from the initial reading are recorded, and the code proceeds to alternate between a read and write state. Figure 4 shows part of the LabVIEW code block diagram where settings such as Start Frequency, Stop Frequency, Reference Level, Resolution Bandwidth, and Delay between Measurements can be adjusted. Default operating band of 310 MHz to 1 GHz was used with a 500-Hz Resolution bandwidth, 60-second interval between measurements, and 0 dB Reference.

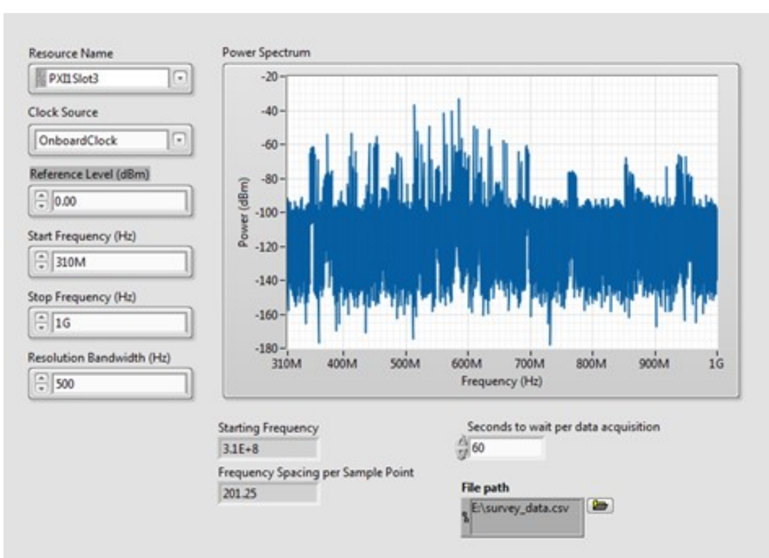

Figure 4. Front Panel of LabVIEW code.

The block diagram of initial read state of the LabVIEW code is illustrated in figure 5. Upon start-up, the program runs this case by default. Settings from the front panel is fed into the initialization chain and the initial measurement is read. This is almost the same as the regular read state, the difference being this state proceeds to the header initialization state.

The programmability of the measurement system is achieved by utilizing the NI PXI as the system hardware and NI LabVIEW as the software environment. System integration is simplified through the use of a single software environment and by taking advantage of the multi-vendor open standards in implementing a flexible system than can be repurposed or enhanced. Development time is also reduced by the intuitive graphical programming platform. Using LabVIEW, custom user interfaces that display measurement-specific data can easily be provided to effectively visualize results.

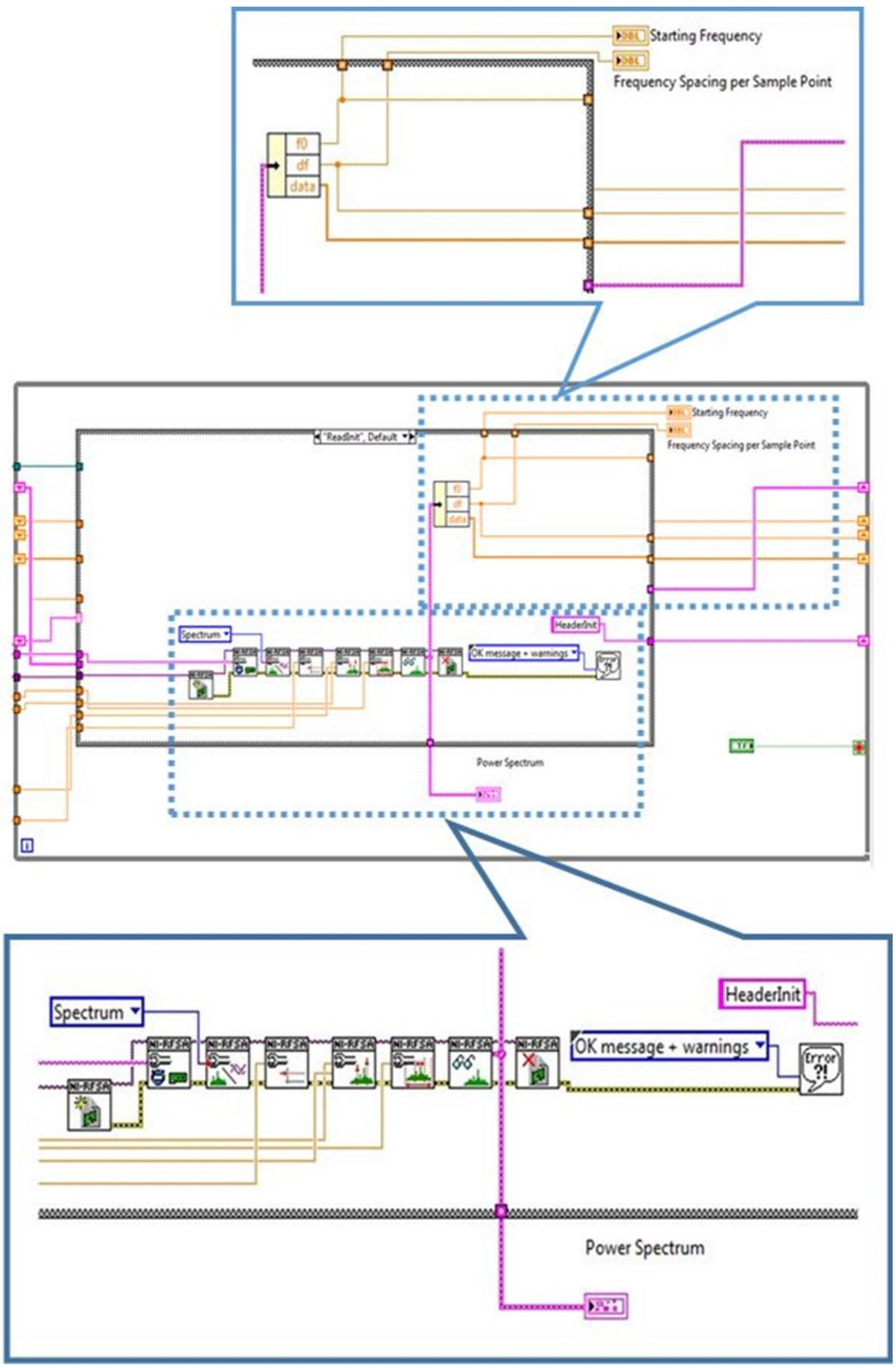

Figure 5. Block diagram of initial read state of the LabVIEW code.

III. MEASUREMENT RESULTS AND ANALYSIS

Measurements recorded using the set-up covers the frequency range from 410 MHz to 960 MHz. Table 1 shows the frequency allocation of the said bandwidth according to NTC's channel plan as of 2016 [2].

Table 1. NTC Channel Plan for the frequency range 410-960 MHz

CHANNEL PLAN	FREQUENCY ALLOCATION (MHz)
Broadband Wireless Access	410-430
Amateur Radio	430-450
Broadband Wireless Access	450-470
Short Range Devices	470-512
TV Broadcast	512-698
Point to Point, Point to Multipoint	689-806
Public Trunked Radio System	806-824
Cellular Mobile Telephone System, 3G	824-849
One-Way Radio System	849-851
Trunked Radio System	851-869
Cellular Mobile Telephone System, 3G	869-890
Cellular Mobile Telephone System	890-915
Point to Point, Point to Multipoint	915-918
RFID	918-920
Studio Transmitter Link	920-925
Cellular Mobile Telephone System	925-960

Data was gathered for six days, including 3 weekdays and 3 weekends. Channel occupancy was based on a noise threshold of -100 dBm which was determined from the measuring equipment's noise floor. Data was taken with an interval of 201.25 Hz between sample points.

The power that each frequency data point contained was measured during the entire duration. The average power for each frequency data point was obtained and considered as one sample point for occupancy evaluation. Occupancy for each sample point was then evaluated as follows:

$$occupancy_{sample\ point} = \begin{cases} 1, & \text{if } P_{ave}(f) > -100\text{dBm} \\ 0, & \text{if } P_{ave}(f) \leq -100\text{dBm} \end{cases} \tag{1}$$

The occupancy percentage was then obtained by:

$$\%\ occupancy = \frac{O}{T} \tag{2}$$

where O is the number of frequency sample points with power levels above -100dBm and T is the total number of frequency sample points used in the entire bandwidth being observed.

Table 2. Average Occupancy per Channel

CHANNEL OCCUPANCY					
FREQUENCY RANGE	**maximum average power**	**minimum average power**	**number of pts > -100 dBm per channel**	**number of sample pts per channel**	**channel occupancy (%)**
410-430 MHz	-90	-113	31	99379	0.03
430-450 MHz	-93	-113	10	99379	0.01
450-470 MHz	-86	-114	30886	99379	31.08
470-512 MHz	-74	-114	3005	208695	1.44
512-698 MHz	-51	-114	196400	924224	21.25
698-806 MHz	-87	-113	67200	536646	12.52
806-824 MHz	-93	-113	20	89441	0.02
824-849 MHz	-92	-113	12	124224	0.01
849-851 MHz	-104	-112	0	9938	0.00
851-869 MHz	-84	-112	1361	89441	1.52
869-890 MHz	-91	-111	33435	104348	32.04
890-915 MHz	-92	-112	17	124224	0.01
915-918 MHz	-105	-110	0	14907	0.00
918-920 MHz	-87	-112	107	9938	1.08
920-925 MHz	-93	-112	4	24845	0.02
925-960 MHz	-73	-112	78464	173913	45.12

Results from the occupancy evaluation are presented in Table 2 and Figure 6. Figure 6 shows the power spectrum and corresponding frequency band occupancy from 410 MHz to 960 MHz. As seen in Figure 6a, average power levels, with a maximum of -51 dBm according to Table 2, are evident between 512 MHz and 698 MHz, the bandwidth allotted to TV Broadcasting. Correspondingly, Figure 6b shows the channel occupancy.

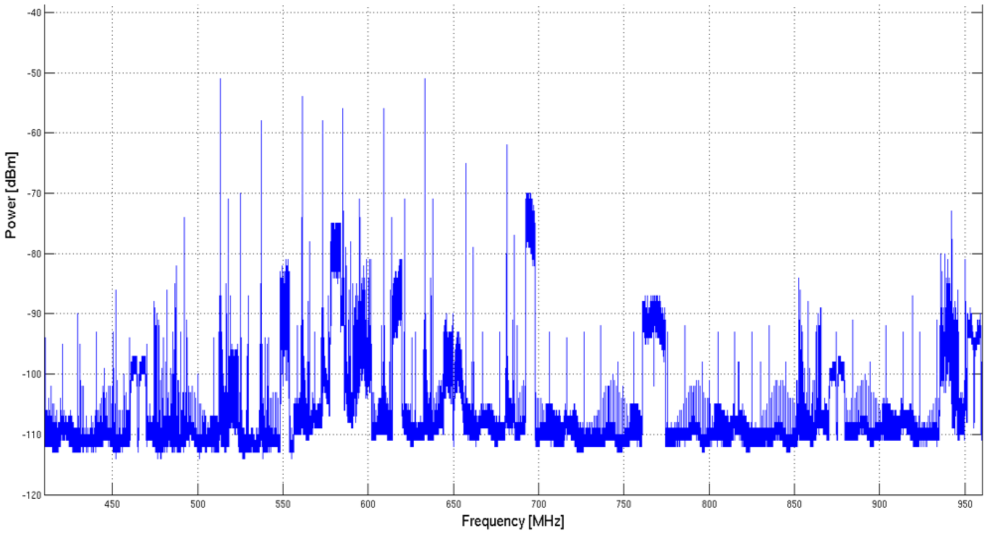

Figure 6a. Power Spectrum (410MHz - 960MHz)

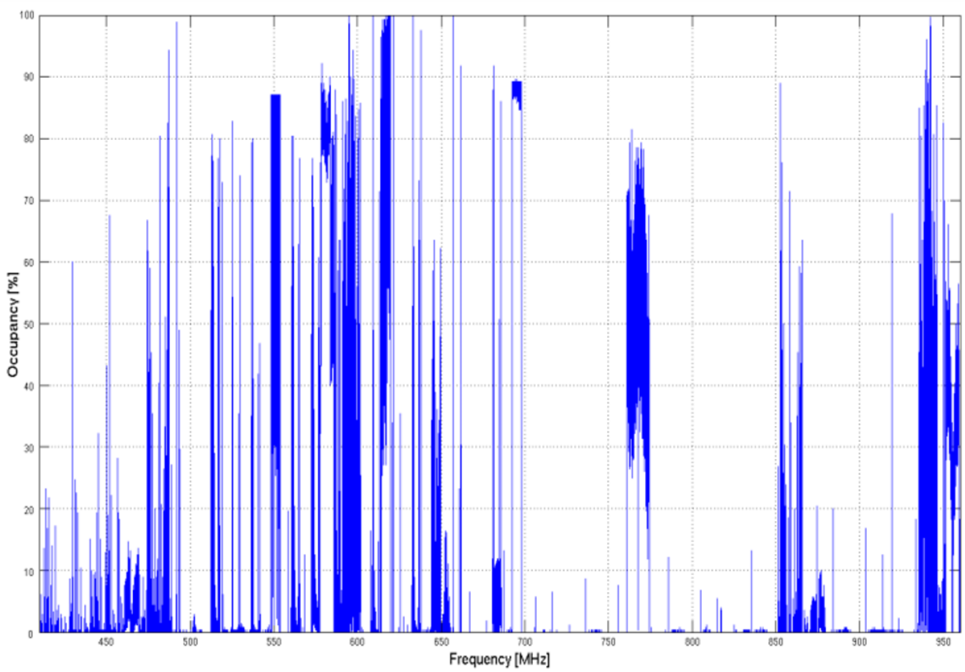

Figure 6b. Frequency Band Occupancy (410MHz - 960MHz)

Figure 6. Power Spectrum and Frequency Band Occupancy (410MHz - 960MHz)

As shown in the figure, the frequency range assigned to TV Broadcast has a very high occupancy. Moreover, this is also noted in the frequency range between 760 MHz and 775 MHz, included in the bandwidth allotment for Point to Point and Point to Multipoint applications, 689 MHz to 806 MHz. Another high-occupancy band evident in the figure is between 930 MHz and 960 MHz, which is part of the frequency range allocated for Cellular Mobile Telephone System (CMTS), 925 MHz to 960 MHz. It could also be observed from the graph that although the frequency bands mentioned have very high occupancy percentages seen visually in the graphs, there are still frequencies in between them with very low occupancy.

To further investigate the channel occupancy of the bandwidth being considered, it is subdivided arbitrarily into four frequency ranges: 410 to 512 MHz, 512 MHz to 698 MHz, 698 MHz to

890 MHz and 890 MHz to 960 MHz. The power spectrum and frequency channel occupancy of each band are shown in the succeeding graphs and analyzed in detail in the following discussions. Average power and occupancy percentage values are based on Table 2.

Figure 7a shows the power spectrum for frequencies between 410 MHz to 512 MHz with an average power reaching a maximum of -74 dBm. Its corresponding channel occupancy is presented in Figure 7b. It could be observed from the graph that the bandwidth assigned to Broadband Wireless Access ranging from 450 – 470 MHz is the mostly used band among the four bands in this frequency range, having a channel occupancy of 31.08 %. This band is allotted for International Mobile Telecommunications [2]. The other band allocated to Broadband Wireless Access within the frequency range 410 – 430 MHz has a very low channel occupancy of 0.03%. Since this band is used for space research service limited to space-to-space communication links with an orbiting, manned space vehicle [2], the signals transmitted here could not be detected by the antenna used in this study as only signals in line-of-sight with the antenna could be detected. Moreover, the band assigned to Short Range Devices ranging from 470 to 512 MHz is not entirely utilized. Although a high occupancy is observed between 475 MHz and 493 MHz, the average occupancy of the frequency band is only 1.44%. Lowest occupancy among the four bands in this frequency range is that used for Amateur Radio (430 – 450 MHz), with an average occupancy of 0.01%.

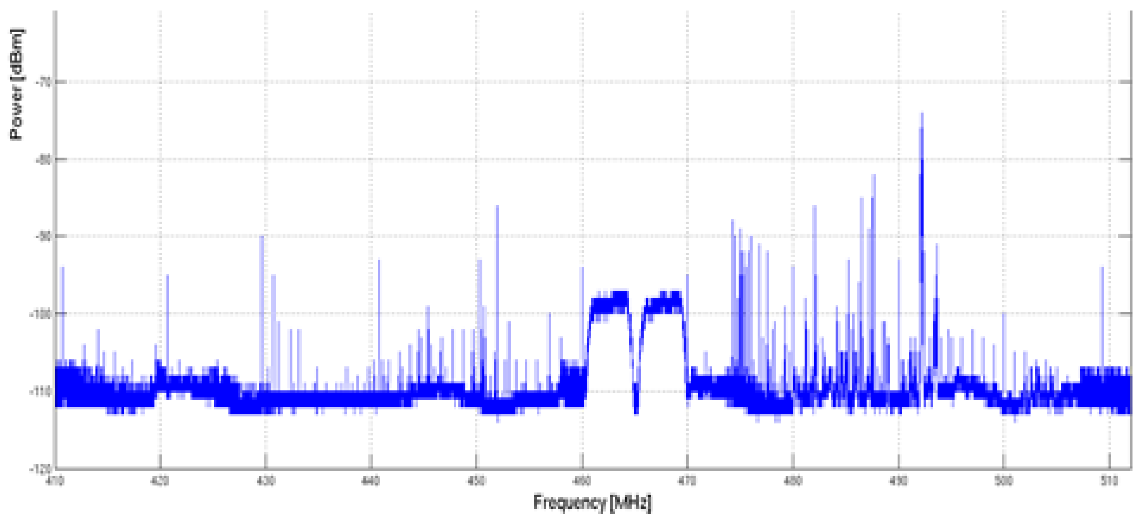

Figure 7a. Power Spectrum (410 MHz - 512 MHz)

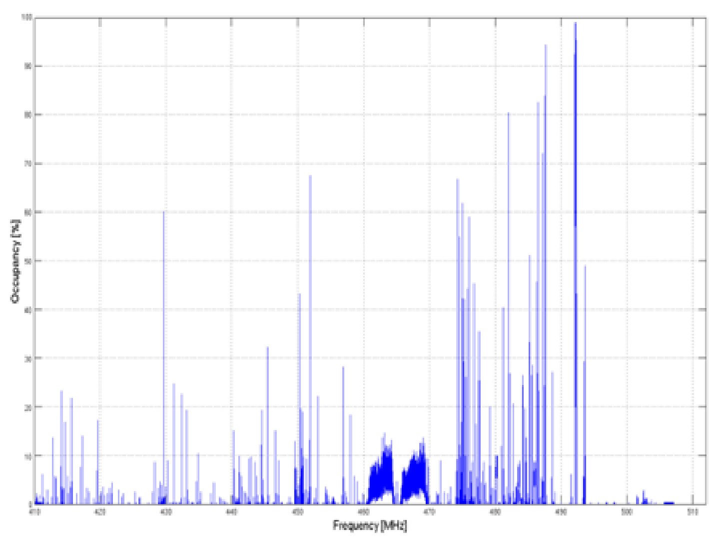

Figure 7b. Channel Occupancy (410 MHz - 512 MHz)

Figure 7. Power Spectrum and Channel Occupancy (410 MHz - 512 MHz)

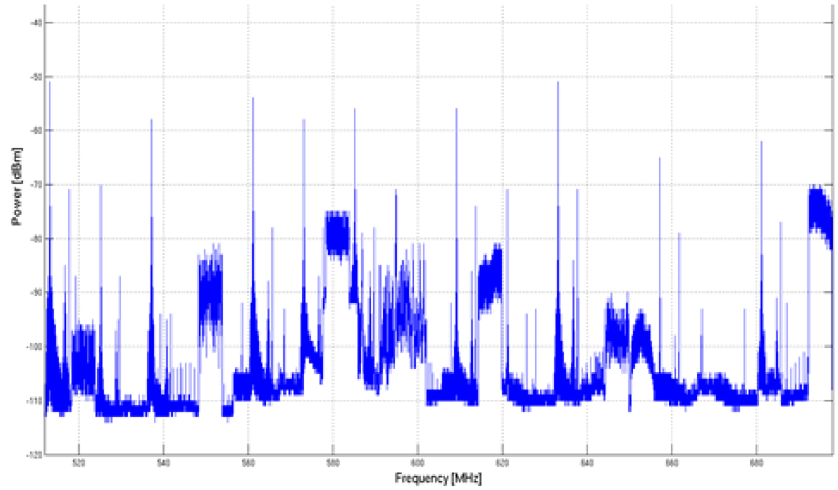

Figure 8a. Power Spectrum (512 MHz - 698 MHz)

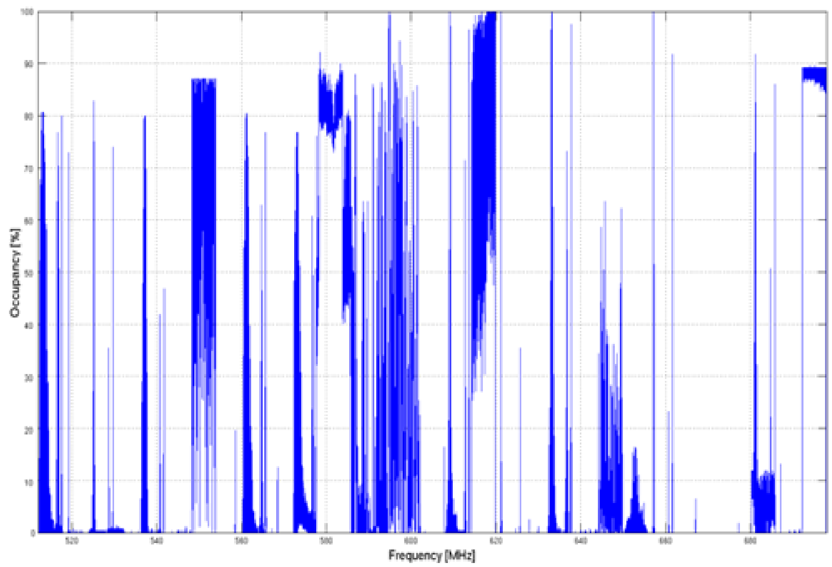

Figure 8b. Channel Occupancy (512 MHz - 698 MHz)
Figure 8. Power Spectrum and Channel Occupancy (512 MHz - 698 MHz)

The next frequency band in consideration is 512 MHz – 698 MHz, allocated for TV Broadcast. Its power spectrum and channel occupancy are shown in Figures 8a and 8b respectively. A maximum of -51 dBm average power is evident in this bandwidth, which is also the highest average power observed in the entire bandwidth monitored. This may be attributed to the fact that TV broadcasting uses high power levels to operate. Although from visual inspection, it may appear to be the mostly utilized band basing from an occupancy of 100% for more frequencies in this bandwidth compared to the other frequency ranges in consideration in this study, channel occupancy calculation shows that only 21.25 % of the frequency band is utilized.

For frequencies ranging from 698 MHz to 890 MHz, the power spectrum and channel occupancy are illustrated in Figures 9a and 9b respectively. The average power from the measurement in this frequency range reached a maximum of -84 dBm. Results from Table 2 show that the most utilized bands here are those used for Point to Point/Point to Multipoint applications at 698 – 806 MHz and Cellular Mobile Telephone Systems/3G applications from 869 to 890 MHz with occupancy percentages of 12.52% and 32.04% respectively. Further investigating the graph in figure 9b shows a high occupancy percentage only for frequencies ranging from 760 MHz to 775 MHz.

Other communication systems in NTC's channel plan in this frequency range have very low utilization, from 0.01 % to 1.52 %. These include the Public Trunked Radio System at 806 – 824 MHz; Cellular Mobile Telephone System/3G between 824 to 849MHz; and Trunked Radio System at 851 – 869 MHz with occupancy percentages of 0.02%, 0.01%, 1.52% respectively. One-Way Radio System occupying the bandwidth 849 – 851 MHz shows no utilization.

Although the bandwidths used by Point to Point/Point to Multipoint applications and Cellular Mobile Telephone Systems/3G applications are mostly utilized among the communication systems in the frequency range observed here, channel occupancy is not very high, with a maximum of occupancy percentage of 32.04 %.

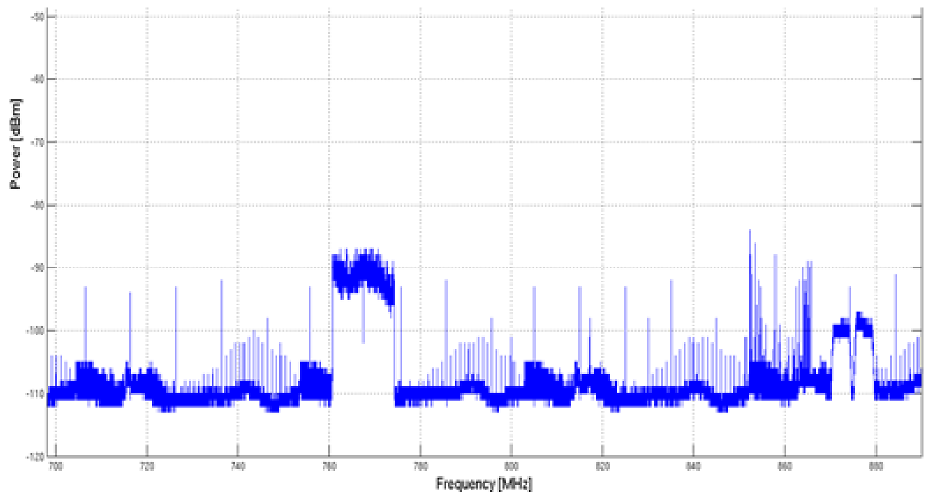

Figure 9a. Power Spectrum (890 MHz - 960 MHz)

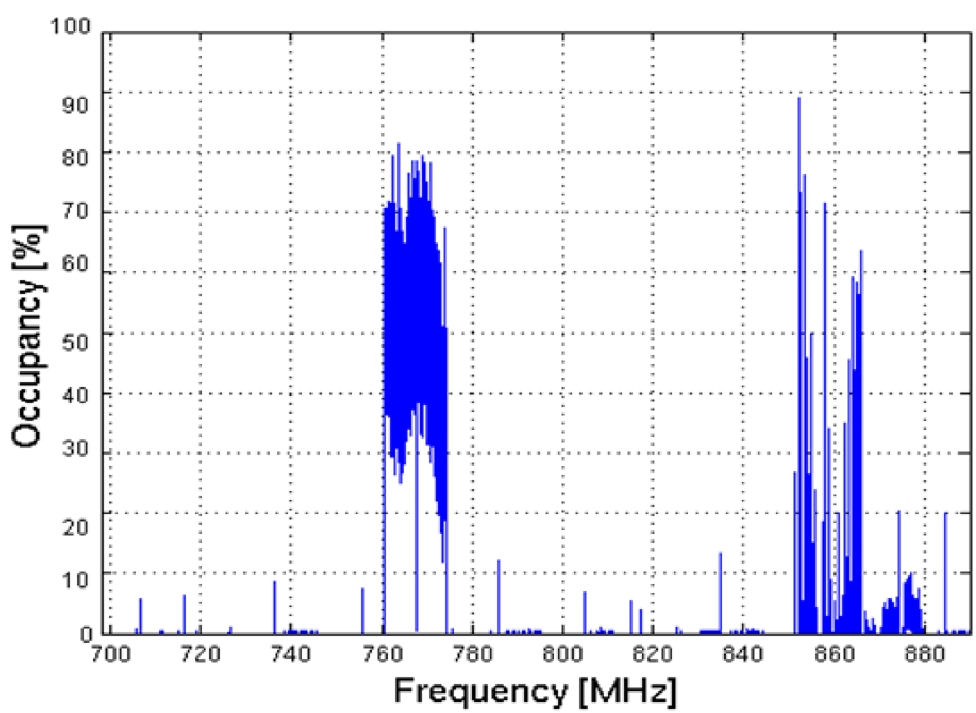

Figure 9b. Channel Occupancy (698 MHz - 890 MHz)

Figure 9. Power Spectrum and Channel Occupancy (698 MHz - 890 MHz)

Figure 10 illustrates the last part of the observed frequency range, 890 MHz to 960 MHz. The power spectrum in Figure 10a shows a maximum of -73 dBm average power. Channel occupancy is described by Figure 10b. The frequency from 925 – 960 MHz, dedicated to Cellular Mobile Telephone System, is highly utilized as compared to the other applications allocated in NTC's channel plan here. This band, allotted to CMTS downlink, has an average occupancy of 45.12 %, making this the most utilized among all the bands observed in this study. Conversely, the other frequency ranges assigned to different applications have very low occupancy. These include the Cellular Mobile Telephone System (890-915MHz), Point to Point/Point to Multipoint applications (915-918MHz), RFID (918-920MHz), Studio Transmitter Link (920-925MHz), with channel occupancy percentages ranging from 0 % to 1.08 %.

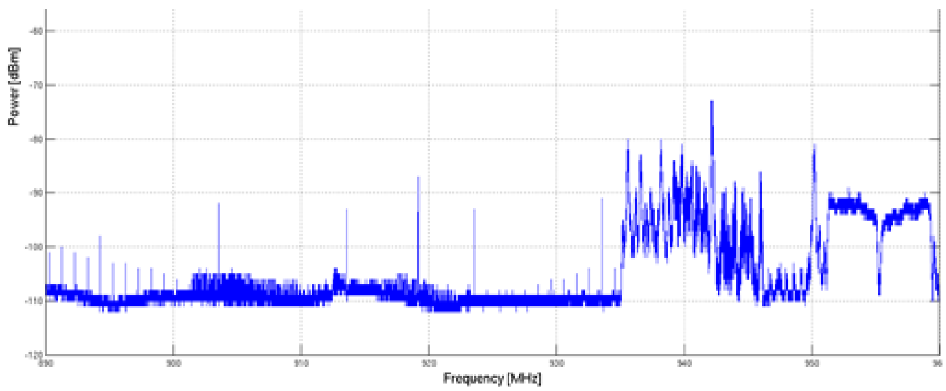

Figure 10a. Power Spectrum (890 MHz - 960 MHz)

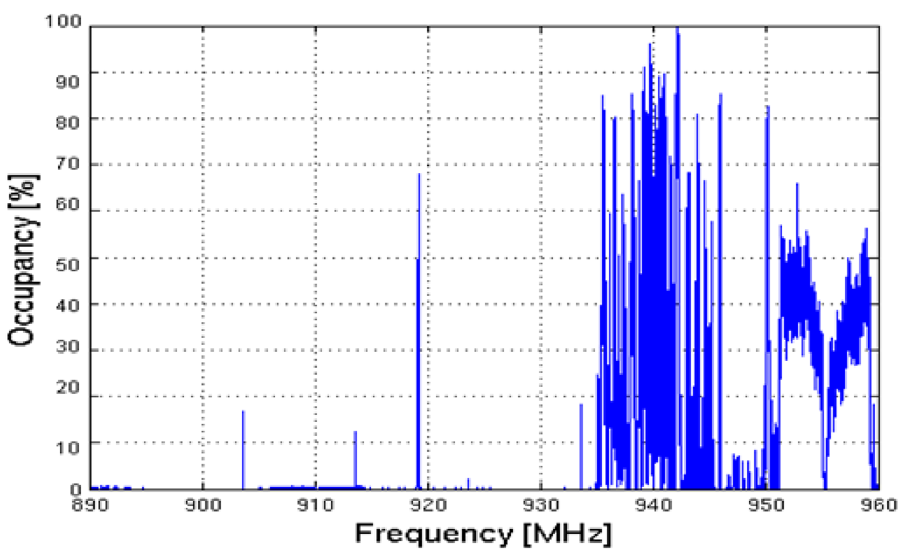

Figure 10b. Channel Occupancy (890 MHz - 960 MHz)

Figure 10. Power Spectrum and Channel Occupancy (890 MHz - 960 MHz)

Figure 11 indicates specific occupancies of the said communication systems corresponding to the summary of channel occupancy results in Table 2. It could be seen here that Cellular Mobile Telephone Systems have the greatest occupancy percentage of 45.12%. This demonstrates that the mobile communications industry is the most used communication system in the Philippines. It should be noted that although the Cellular Mobile Telephone System ranging from 890 MHz to 915 MHz shows a low occupancy percentage of 0.01%, this band is dedicated to uplink emissions, thus does not include low-powered emissions of mobile units not detected by the antenna. However, utilization for this band could be similar to the utilization observed in the downlink bands allotted to Cellular Mobile

Telephone System between 925 MHz to 960 MHz and Cellular Mobile Telephone System 3G ranging from 869 MHz to 890 MHz since mobile units utilize both uplink and downlink bands.

An observation of the graph in Figure 11 also implies that the observed frequency bands are underutilized, with a very low occupancy between 0 and 1.52 % for the frequencies between 410 MHz to 450 MHz, 470 MHz to 512 MHz, 806 to 869 MHz, and 890 MHz to 925 MHz. Thus, these bandwidths contain a great percentage of white space that could be used for different purposes. Although the other channels are more utilized than these channels, maximum average channel occupancy only reached 45.12 %, meaning that more than half of the time, the observed band is not being used. This gives more flexibility in the use of the said bandwidth for secondary subscribers through white space utilization.

Results from this study is comparable to the band utilization of Singapore [7], Europe [8] and Beijing [9], all situated in highly industrialized locations. In these studies, the GSM 900 band, was found to have the highest spectrum utilization. The CMTS frequency band is also the most utilized band in the Philippines according to the results of this study. From these results, it is evident that the frequency bands used for cellular mobile services could become easily congested in a few years. Therefore, there is a need to utilize the other frequency bands' white space for applications such as mobile communications to prevent the CMTS and GSM 900 frequency bands from being overly utilized with the rapid technological development that requires connectivity.

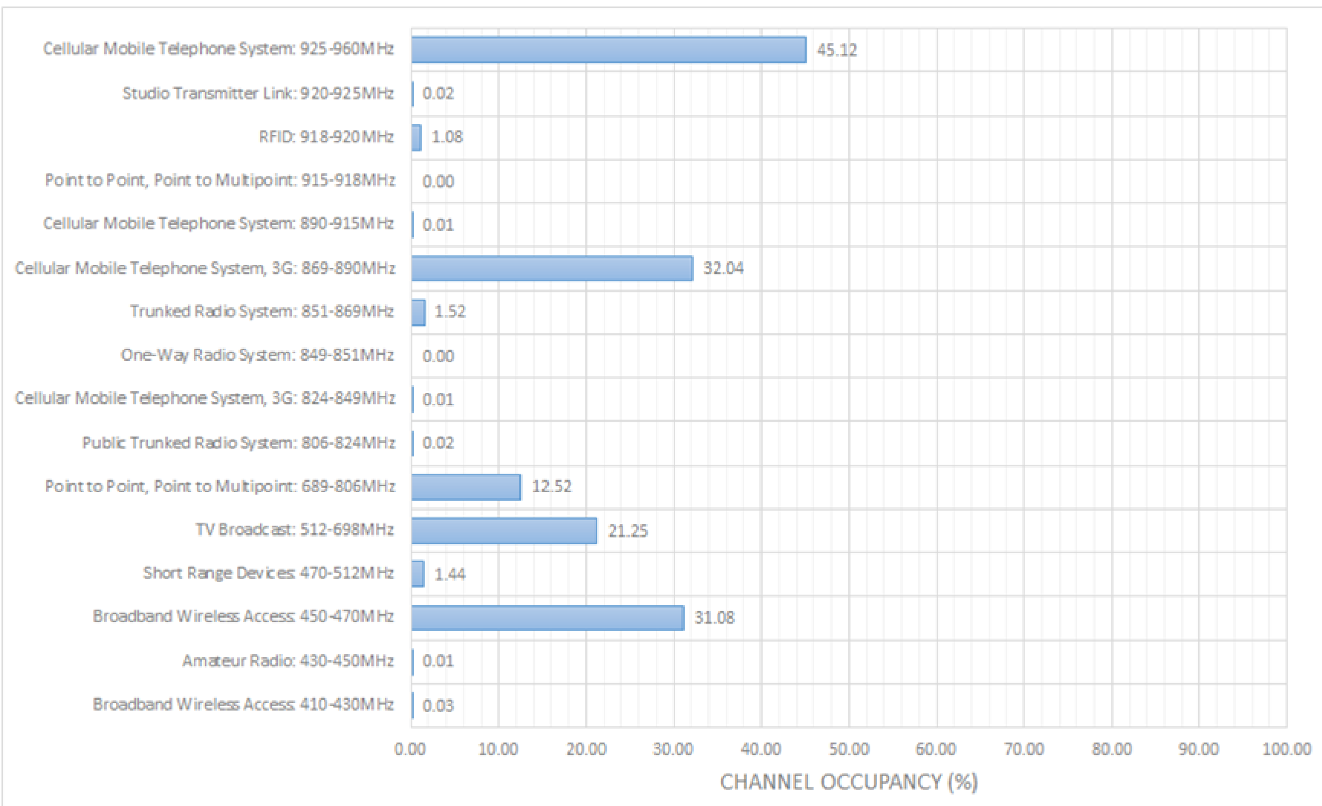

Figure 11. Channel Occupancy

IV. CONCLUSIONS

The measurement system used in this study consists of a Log Periodic Antenna, a PXIe-1075 spectrum analyzer with a PXIe-5601 RF Downconverter also capable of performing spectrum measurement, a LabVIEW 2014 used in the downconverter module to control the operation and measurement of the PXI. Results show that majority of the channels in NTC's channel plan of 2016 within the frequency range studied herewith contain a large amount of white space as per average channel occupancy measurements with a highest recorded average channel occupancy of 45.12% utilized by Cellular Mobile Telephone System. It could be concluded that the frequency range between 410 MHz and 960 MHz is heavily underutilized and could be used for applications involving white space.

V. FUTURE WORK

On a larger scale, the data from spectrum surveying will be able to create a local/national repository for spectrum utilization data that can be easily accessed by the public. The benefits to this are threefold: (1) the users will be able to monitor how well providers are offering their services, (2) it may urge users to obtain license for bands should they see an opportunity to do so based on the data, and (3) it will be an additional resource for those who research into the spectrum. Multiple measuring stations should ideally cover a local area of interest. Such a repository does not yet exist in the Philippines and the information it will provide will be a great tool for ensuring proper spectrum utilization and service.

VI. NOMENCLATURE

Symbol	Description	Units
F	frequency	[MHz]
$P_{ave}(f)$	average power at a given frequency	[dBm]
O	number of frequency sample points with power levels above -100dBm	[-]
T	total number of frequency sample points used in the entire bandwidth being observed	[-]

VII. ACKNOWLEDGMENT

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