
Analysis of Radio Frequency (87.5 – 108 MHz) For Short Range Low Power Smart Device Utilization

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ABSTRACT

This paper presents the analysis of radio frequency range (87.5 – 108MHz) for short range low power smart device utilization. This analysis was done in Benin City taking four locations as a case study to investigate and validate the presence of underutilized spectrum and vacant spectrum in frequency modulation that can be used by smart devices. The Register Transfer Level - Software Defined Radio (RTL-SDR) captured the FM radio spectrum measurements using MATLAB/Simulink. The RTL-SDR interfaces with the HP 2000 series laptop via the USB with R820T antenna. From the analysis, it is evident that there are vacant spectrums available in frequency modulation spectrum in Nigeria. That quantify the average number of frequency modulation stations that have protected coverage; the unallocated frequency modulation spectrum; the vacant frequency modulation spectrum and the potential Cognitive Internet of Things (CIoT) bitrates across Nigeria, and result also provides a detailed analysis of selected locations, of varying population densities, which show the relationship between population and the number of frequency modulation stations for 37 locations in Nigeria.

KEYWORDS: Frequency Modulation (FM), Cognitive Radio (CR), Radio Spectrum, Radio Frequency (RF), Internet of Things (IoT) .

INTRODUCTION

Smart Devices (SD) which is also referred to as Internet of Things (IoT) is increasing every day and is gaining focus because most organization and individual are using the devices. Internet of Things refers to billions of physical machine around the globe that are linked to the internet, assembling and sharing data. Any physical entity can be transformed into an internet of things machine if it can be linked to the Internet and controlled. Home automation like switching ON and OFF of devices using a smartphone app is an IoT machine, as well as smart watches, smart TVs, smart speakers, wireless headphones, wireless printers, motions sensors and other machines capable of collecting and sharing data (Hsu et al, 2016).

As of 2016, the prediction of the Internet of things has advanced due to the convergence of numerous technologies, as well as wireless communication, real-time analytics, machine learning, product sensors, and embedded systems. The acceptances of RFID (Radio Frequency Identification) tags (low power chips that can communicate wirelessly) resolved some of this concern. The accessibility of broadband internet, cellular and wireless networking also helps in facilitating the growth of Internet of Things (Hus et al, 2016).

Internet of Things also finds application in checking electric grid, telecommunication at real time (Hus et al, 2016; Kang et al, 2017). Internet of Things also helps to encourage

healthy living by use of consumer machines such as linked scales or wearable heartbeat checker (Hus et al, 2016; Kang et al, 2017).

With the advancement in communication technology the IoT machines have introduced a new class of low-power short-range wireless machines that use radio spectrum for the sending of information (Asghar et al, 2015). The requirement for these machines is creating irresistible demand on the radio spectrum (secondary licensing) (Asghar et al, 2015); thereby causing shortage of frequency. Other wireless machines that use secondary spectrum had been facing problems from interference (Otermat et al, 2015; Singh et al, 2014), since it is free spectrum any user can use any spectrum that he/she assume is good for his/her machine not considering other users (Stankovic, 2014). The number of Internet of Things (IoT) machines is predicated to reach 200 billion by the year 2020 (Asghar et al, 2015; Stankovic, 2014). This rapid growth of internet of things machine is introducing high demand for the frequency spectrum.

To solve the shortage of radio frequency and throughput, IoT machines are required to intelligently recognize unoccupied radio frequency that can be used through the use of cognitive radio (CR). With the help of cognitive radio, we can predict the spectrum hole and identify the unused spectrum through the use of Cognitive Radio (CR) (Otermat et al, 2016). CR enables a machine to adjust its transmission parameters, such as frequency and transmit power, to capitalize on the conditions of the unoccupied radio spectrum. Cognitive IoT (CIoT) machines, will assume the role of a secondary user with respect to the primary license holder of the unoccupied spectrum.

METHODOLOGY

Measurement Locations

The measurement location that was chosen in Benin City had is latitude and longitude as shown in table 1

Table 1: shows the measurement locations perimeter

Locations	Latitude	Longitude
1, University of Benin	6.39641	5.60374°
2, Benson Idahosa University	6.33986	5.60375
3, Well Spring University	6.28246	5.58768
4, Igbinedion University, Okada	6.34572	5.62899

Measurement hardware

The FM radio spectrum measurements were made using the R820T antenna and the NooElec RTL-SDR. The R820T antenna operates over the entire FM, UHF and approximately half of the VHF frequency bands. The RTL-SDR Software Defined Radio (SDR) captured the FM radio spectrum measurements using MATLAB/Simulink. The RTL-SDR interfaces with the HP 2000 series laptop via the USB.

Receiving antenna

The R820T antenna, shown in Figure 1, is a dipole antenna, it has a gain of 25 dB and has an operating bandwidth of 20 MHz to 1800 MHz. Since the majority of FM radio receiving antennas are vertically polarized e.g. the receiving antennas used on automobiles, FM radio stations are permitted to transmit using circular or elliptical polarized antennas.

FM radio station antennas are primarily circularly polarized to mitigate the excessive polarization loss, on the order of 20 dB, that would occur by having a transmitting antenna that is horizontally polarized and a receiving antenna that is vertically polarized. Because FM radio station broadcasting antennas are typically circularly polarized and the receiving antennas are vertically polarized, the polarization loss is approximately 3 dB. The 3 dB loss occurs because only the vertical component of the circularly polarized electromagnetic wave, which is comprised vertical and horizontal components received, receiving only half of the polarized components results in a loss of 3 dB.



Figure 1: R820T antenna

The R820T antenna has an N-Type connector and the RTL-SDR as shown in Figure 2. It has a female MCX connector. In order to interface the R820T antenna with the RTL-SDR, a RF coaxial cable with N-Type and male MCX connectors is used. This cable assembly has an insertion loss of 0.284 dB at 250 MHz.



Figure 2: The RTL-SDR

The RTL-SDR has a variable gain and a power offset that is a by-product of performing the FFT operation. The variable gain is set in MATLAB/Simulink. The power offset across the FM radio frequency band was set to zero.

The measured RSL is calculated using equation 1.

$$R_F = R_{R-S} - 20 + 0.284 - 2 \text{ dB} \tag{1}$$

In equation 1, the 20 is the variable gain, which was set at 20 dB. The 0.284 value is the insertion loss of the PE-SR405FL RF cable. The PE-SR405FL RF cable was used to interface the N-type connector on the antenna to the MCX connector on the RTL-SDR. The last value, 2, is the nominal gain of the R820T antenna, when the analysis was done a sample of the test was shown in the graph (allocated and vacant/unallocated) as shown in figure 3.

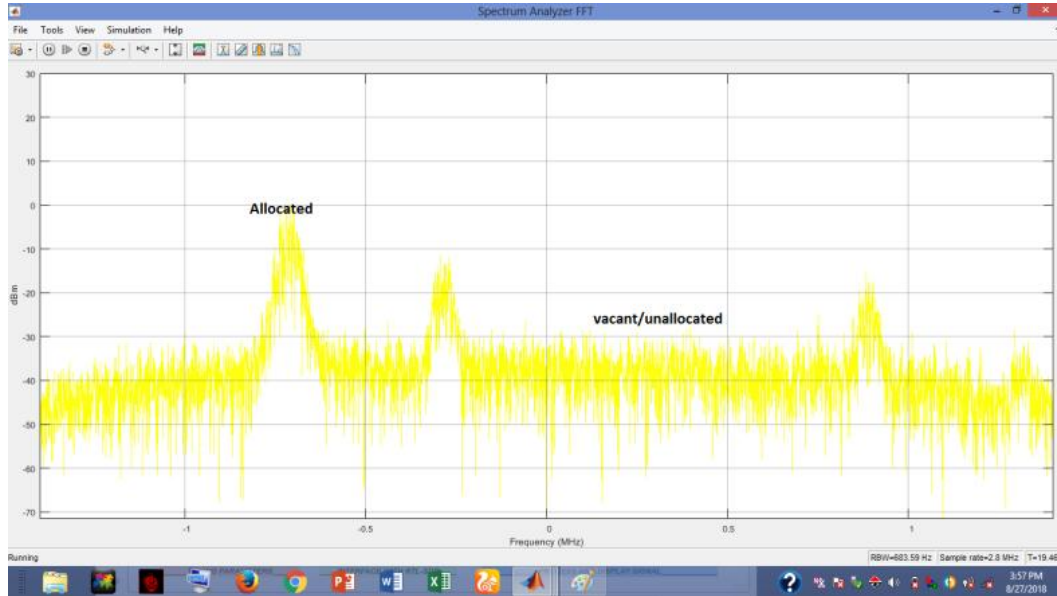


Figure 3: graph showing allocated and vacant spectrum

Allocated and vacant FM radio spectrum

In order to get the allocated and vacant FM radio spectrum, a range of FM stations was taken into consideration 88 MHz to 108 MHz. The center frequency for each of the FM radio channels starts at 88.1 MHz and increases in increments of 200 kHz up to 107.9 MHz. Therefore, the spectrum range is divided into 100 channels and each channel is allocated 200 kHz of bandwidth for broadcast transmission. FM radio stations that have been approved for In-Band On-Channel (IBOC) digital radio, which provides High Definition (HD) radio broadcasting, utilize 400 kHz of bandwidth. The transmission of the HD digital radio occurs in the sidebands above and below the center frequency. The FM radio station’s digital signal is transmitted in addition to the existing analog signal. In order to calculate the amount of unallocated FM radio spectrum at a coordinate equation 2 is used;

$$S_u = 20 - \frac{x+y}{5} \tag{2}$$

Where x is the total number of FM radio stations and y is the number of HD FM radio stations. It is important to note that this complexity builds the case for CIoT. Since the stations may obtain licenses for HD broadcasting whenever they are ready, the situation in any given location may change over time. This necessitates the CIoT equipment that is adaptable to the changing radio conditions.

To account for the spectrum used, an unpredicted bandwidth α is calculated using;

$$\alpha = 0.2x' + 0.2y' \tag{3}$$

Where x' is the total number of unpredicted stations and y' is the subset of the total number of unpredicted stations that are approved for HD broadcasting. To calculate for the vacant FM radio spectrum, equation 4 is used;

$$S_v = S_u - \alpha \tag{4}$$

Using equations 1, 2, 3 and 4, the result of the analysis is shown in table 2, representing the unallocated, vacant and percentage underutilized. In Edo State, there are 10 radio stations of which 3 are not in Benin City which are Izizibili FM (94.3MHz), Hillside FM Auchi

(94.1MHz) and Ray Power FM IkhuenNiro (105.5MHz) and in the Third Location, during the time of the measurement, two FM signals were unavailable which are Silver Bird Rhythm (93.7MHz) and EBS (95.7MHz) while the fourth Location, during the time of the measurement, one FM signal wasn't available which is Silver Bird Rhythm (93.7MHz).

Table 2: Locations and their percentage underutilization in Benin City

S/N	Location	X	Y	S _{Unallocated} MHz	S _{Vacant} MHz	Percentage Underutilization
1	University of Benin, Benin City	7	0	18.6	18.6	93
2	Benson Idahosa University, Benin City	7	0	18.6	18.6	93
3	Well Spring University, Benin City	5	0	19	19	95
4	Igbinedion University, Okada, Benin City	6	0	18.8	18.8	94

Coordinates Under Analysis

The measurements and the respective algorithm result that is shown in table 2, where gotten using single latitude and longitude coordinate. In order to perform a large-scale analysis to predict the FM radio spectrum characteristics across Nigeria, the algorithm must be executed on a large matrix of coordinates. The Nigeria Geological Survey provides a matrix that contains the latitude and longitude component of every human inhabited location in Nigeria. Having a matrix of human inhabited locations is preferred over a matrix that contains of mixture of locations that are and are not inhabited by humans. From the analysis that was shown in table 2, an algorithm was proposed for Nigeria as shown in table 3 noting the population of the locations, because low-power short-range IoT devices and networks are likely to be employed in locations that are inhabited by humans.

Table 3: FM radio stations and their percentage utilization

S/N	State	population	FM Stations	S _{Unallocated} MHz	S _{Vacant} MHz	Percentage Underutilization
1	Abia	2,833,999	10	18	18	90
2	Adamawa	3,168,101	6	18.8	18.8	94
3	Akwa Ibom	3,920,208	8	18.4	18.4	92
4	Anambra	4,182,032	19	16.2	16.2	81
5	Bauchi	4,676,465	4	19.2	19.2	96
6	Bayelsa	1,703,358	6	18.8	18.8	94
7	Benue	4,219,244	7	18.6	18.6	93
8	Borno	4,151,193	6	18.8	18.8	94
9	Cross River	2,888,966	7	18.6	18.6	93
10	Delta	4,098,391	14	17.2	17.2	86
11	Ebonyi	2,173,501	2	19.6	19.6	98
12	Edo	3,218,332	10	18	18	90
13	Ekiti	2,384,212	4	19.2	19.2	96
14	Enugu	3,257,298	13	17.4	17.4	87

S/N	State	population	FM Stations	S _{Unallocated} MHz	S _{Vacant} MHz	Percentage Underutilization
15	Gombe	2,353,879	6	18.8	18.8	94
16	Imo	3,934,899	11	17.8	17.8	89
17	Jigawa	4,348,649	8	18.4	18.4	92
18	Kaduna	6,066,562	19	16.2	16.2	81
19	Kano	9,383,682	21	15.8	15.8	79
20	Katsina	5,792,578	4	19.2	19.2	96
21	Kebbi	3,238,628	3	19.4	19.4	97
22	Kogi	3,278,487	5	19	19	95
23	Kwara	2,371,089	9	18.2	18.2	91
24	Lagos	9,013,534	36	12.8	12.8	64
25	Nasarawa	1,863,275	8	18.4	18.4	92
26	Niger	3,950,249	7	18.6	18.6	93
27	Ogun	3,728,098	17	16.6	16.6	83
28	Ondo	3,441,024	15	17	17	85
29	Osun	3,423,535	10	18	18	90
30	Oyo	5,591,589	29	14.2	14.2	71
31	Plateau	3,178,712	11	17.8	17.8	89
32	Rivers	5,185,400	18	16.4	16.4	82
33	Sokoto	3,696,999	6	18.8	18.8	94
34	Taraba	2,300,736	4	19.2	19.2	96
35	Yobe	2,321,591	1	19.8	19.8	99
36	Zamfara	3,259,846	1	19.8	19.8	99
37	FCT	1,405,201	29	14.2	14.2	71

Source: <https://www.informationhood.com/nigeria-states-population-ranking/>

Each state in the Country has an average of 5-12 FM radio stations. Since there are 100 possible radio channel that could be occupied for every latitude and longitude coordinate, on the average, the FM radio channels in the country is 89% underutilized

CIoT Deployment Bitrates

Predicting the bitrates of a CIoT deployment is challenging because each deployment has unique design parameters such as receiver sensitivity, required bit error rate, the phase of the carrier is varied to represent two or more different signal elements. Both Peak amplitude and frequency remain constant as the phase changes, data rate (bit rate) and the signal rate (baud rate) can be define for digital transmission. The relationship between them is;

$$S = N \times \frac{1}{r} b$$

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Where; N is the data rate (bps), r is the number of data elements carried in one signal element. The value of r in analog transmission is $r = \log_2 L$, where L is the type of signal element, not the level. The bandwidth is proportional to the signal rate (baud rate) However, there is normally another factor involved, called β , which depends on the modulation and filtering process. The value of β is between 0 and 1. This means that the bandwidth can be expressed as shown, where S is the signal rate and B is the bandwidth.

$$B = 2 \times f_c$$

6

$$B = (1 + d) \times S$$

7

The equation 5, 6 and 7 show that the bandwidth is twice the center frequency and the required bandwidth has a minimum value of S and a maximum value of 2S. For QPSK, the value of r is 2, while for 8-PSK, the value of r is 3. Using table 2 to calculate the bitrate of QPSK, 8-PSK as shown in table 4 with a larger coverage using table 3 to calculate the bitrate of QPSK, 8-PSK as shown in table 5

Table 4: Locations and their possible bitrate in Benin City using a maximum value of 2S

S/N	Location	S _{Vacant} MHz	Bitrate(Mbps)							
			β=1		β=0.75		β=0.5		β=0.25	
			QPSK	8-PSK	QPSK	8-PSK	QPSK	8-PSK	QPSK	8-PSK
1	University of Benin, Benin City	18.6	37.2	55.8	42.5	63.7	49.6	74.4	59.5	89.3
2	Benson Idahosa University, Benin City	18.6	37.2	55.8	42.5	63.7	49.6	74.4	59.5	89.3
3	Well Spring University, Benin City	19.0	38	57	43.4	65.1	50.7	76.0	60.8	91.2
4	Igbinedion University, Okada, Benin City	18.8	37.6	56.4	42.9	64.4	50.1	75.2	60.2	90.2

Table 5: Potential CIoT deployment bitrates in Nigeria

S/N	Location	Population	S _{Vacant} MHz (bandwidth-B)	Bitrate(Mbps)							
				β=1		β=0.75		β=0.5		β=0.25	
				QPSK	8-PSK	QPSK	8-PSK	QPSK	8-PSK	QPSK	8-PSK
1	Abia	2,833,999	18	18	27	20.57	30.86	24	36	28.8	43.2
2	Adamawa	3,168,101	18.8	18.8	28.2	21.49	32.23	25.07	37.6	30.08	45.12
3	Akwa Ibom	3,920,208	18.4	18.4	27.6	21.03	31.54	24.53	36.8	29.44	44.16
4	Anambra	4,182,032	16.2	16.2	24.3	18.51	27.77	21.6	32.4	25.92	38.88
5	Bauchi	4,676,465	19.2	19.2	28.8	21.94	32.91	25.6	38.4	30.72	46.08
6	Bayelsa	1,703,358	18.8	18.8	28.2	21.49	32.23	25.07	37.6	30.08	45.12
7	Benue	4,219,244	18.6	18.6	27.9	21.26	31.89	24.8	37.2	29.76	44.64
8	Borno	4,151,193	18.8	18.8	28.2	21.49	32.23	25.07	37.6	30.08	45.12
9	Cross River	2,888,966	18.6	18.6	27.9	21.26	31.89	24.8	37.2	29.76	44.64
10	Delta	4,098,391	17.2	17.2	25.8	19.66	29.49	22.93	34.4	27.52	41.28
11	Ebonyi	2,173,501	19.6	19.6	29.4	22.4	33.6	26.13	39.2	31.36	47.04
12	Edo	3,218,332	18	18	27	20.57	30.86	24	36	28.8	43.2
13	Ekiti	2,384,212	19.2	19.2	28.8	21.94	32.91	25.6	38.4	30.72	46.08
14	Enugu	3,257,298	17.4	17.4	26.1	19.89	29.83	23.2	34.8	27.84	41.76

15	Gombe	2,353,879	18.8	18.8	28.2	21.49	32.23	25.07	37.6	30.08	45.12
16	Imo	3,934,899	17.8	17.8	26.7	20.34	30.51	23.73	35.6	28.48	42.72
17	Jigawa	4,348,649	18.4	18.4	27.6	21.03	31.54	24.53	36.8	29.44	44.16
18	Kaduna	6,066,562	16.2	16.2	24.3	18.51	27.77	21.6	32.4	25.92	38.88
19	Kano	9,383,682	15.8	15.8	23.7	18.06	27.09	21.07	31.6	25.28	37.92
20	Katsina	5,792,578	19.2	19.2	28.8	21.94	32.91	25.6	38.4	30.72	46.08
21	Kebbi	3,238,628	19.4	19.4	29.1	22.17	33.26	25.87	38.8	31.04	46.56
22	Kogi	3,278,487	19	19	28.5	21.71	32.57	25.33	38	30.4	45.6
23	Kwara	2,371,089	18.2	18.2	27.3	20.8	31.2	24.27	36.4	29.12	43.68
24	Lagos	9,013,534	12.8	12.8	19.2	14.63	21.94	17.07	25.6	20.48	30.72
25	Nasarawa	1,863,275	18.4	18.4	27.6	21.03	31.54	24.53	36.8	29.44	44.16
26	Niger	3,950,249	18.6	18.6	27.9	21.26	31.89	24.8	37.2	29.76	44.64
27	Ogun	3,728,098	16.6	16.6	24.9	18.97	28.46	22.13	33.2	26.56	39.84
28	Ondo	3,441,024	17	17	25.5	19.43	29.14	22.67	34	27.2	40.8
29	Osun	3,423,535	18	18	27	20.57	30.86	24	36	28.8	43.2
30	Oyo	5,591,589	14.2	14.2	21.3	16.23	24.34	18.93	28.4	22.72	34.08
31	Plateau	3,178,712	17.8	17.8	26.7	20.34	30.51	23.73	35.6	28.48	42.72
32	Rivers	5,185,400	16.4	16.4	24.6	18.74	28.11	21.87	32.8	26.24	39.36
33	Sokoto	3,696,999	18.8	18.8	28.2	21.49	32.23	25.07	37.6	30.08	45.12
34	Taraba	2,300,736	19.2	19.2	28.8	21.94	32.91	25.6	38.4	30.72	46.08
35	Yobe	2,321,591	19.8	19.8	29.7	22.63	33.94	26.4	39.6	31.68	47.52
36	Zamfara	3,259,846	19.8	19.8	29.7	22.63	33.94	26.4	39.6	31.68	47.52
37	FCT	1,405,201	14.2	14.2	21.3	16.23	24.34	18.93	28.4	22.72	34.08

Population source: <https://www.informationhood.com/nigeria-states-population-ranking/>

Table 5, contains the bitrates for state using modulation types, Quadrature Phase Shift Keying (QPSK) and 8-PSK. These two modulation types use the vacant FM radio spectrum multiplied by the bandwidth utilization factor β to generate the potential bitrates for low-power short-range CIoT deployments. The bandwidth utilization factor ranges between 0 and 1 and represents the percentage of bandwidth being used for data transmission. The bandwidth not being used for data transmission is used for guard bands, filtering, etc. For the purposes of this analysis the bandwidth utilizations of $\beta = 0.75$ and $\beta=0.5$ are used.

FM radio spectrum geo-location database

The FM radio spectrum data generated for Nigeria can be used to populate a database that contains the number of FM radio stations and the corresponding vacant FM radio spectrum for a respective area. The FM radio spectrum data for specific geo-graphical areas can be queried based on latitude and longitude coordinates. Therefore, CIoT devices will need to have an embedded GPS device to pinpoint their location and determine which FM radio channels are vacant and can be used for transmission.

Two methods proposed to access the vacant FM radio spectrum database. The first method is having a local copy of the vacant FM radio spectrum database located within the CIoT device. The local copy of the vacant FM radio spectrum database would be periodically updated. This method is advantageous because the FM radio stations that service a specific geo-graphical location do not regularly change. This method also mitigates the need to have consistent access to the remote vacant FM radio spectrum database. This method is ideal for CIoT devices that are used in mobile, non-stationary, applications. The second method is geared towards stationary CIoT devices that would have regular access to the remote master vacant FM radio spectrum database. Since the FM radio spectrum footprint does not regularly

change, the CIoT device using this method could access the remote master vacant FM radio spectrum database upon device power on.

Ultimately, the method of access to the vacant FM radio spectrum database will be driven by the application, mobile or non-stationary, of the CIoT device. Regardless of the access method, each CIoT device will need a back-up ability to sense the FM radio spectrum to determine which FM radio channels can be used for transmission in the event that vacant FM radio spectrum database cannot be accessed.

Spectrum Sensing

Spectrum sensing is a primary component of CR technology. Spectrum sensing is the ability of a CR device to detect, in real-time, the presence of primary users in a given frequency band. Spectrum sensing is the subject of ongoing research in both academia and industry and multiple approaches have been developed. One spectrum sensing algorithm that could be implemented in CIoT devices is the energy detection algorithm.

Power Management

To help ensure that there is no interference to the FM radio stations and other secondary CIoT devices is mitigated, utilization of a vacant FM radio spectrum database and an energy detection spectrum sensing system, for back-up situations can be used. The vacant FM radio spectrum database and back-up spectrum sensing system, provide the transmission channels by making the decision whether the FM radio channel, or another secondary CIoT device, is occupying those specific channels. Once the decision of channel occupancy has been made, a proper power management is employed to ensure the following:

FM radio stations in adjacent radio channels are not subjected to interference. Note that sufficient frequency guard bands need to be established and filtering needs to be implemented in the transmission path to aid in limiting interference to adjacent radio channels. Interference between secondary CIoT devices is mitigated. Reuse of the vacant FM radio channels by multiple secondary CIoT devices can be achieved and will increase the number of CIoT devices able to operate.

Though it has been previously stated, it is of utmost importance to mitigate interference to the primary user, the FM radio stations. Therefore, once a FM radio channel has been determined to be vacant and can be used for transmission that does not mean that the secondary CIoT device is free to transmit at any power level. The CIoT device would be required to limit its transmit power level to mitigate interference to adjacent FM radio channels. The mitigation of interference is not only achieved by limiting transmission power but also by implementing guard bands and implementing a transmission filter. The transmission power will also be limited to facilitate reuse of the vacant FM radio channels between multiple CIoT devices. By reusing vacant FM radio channels, the effective capacity of each vacant radio channel increases at a rate directly proportional to the number of CIoT devices using that radio channel.

CONCLUSION

This paper has been able to show that locations with less FM station yielded high vacant FM radio spectrum. Spectrum management plan that address controlling access and utilization of the vacant spectrum was discussed, to manage access to the vacant spectrum two methods were presented, a FM Radio Spectrum Geolocation Database, similar to the database that manages access to the TVWS, and spectrum sensing technology, which is a fundamental

concept of CR. To manage utilization of the vacant spectrum frequency multiplexing and proper power management schemes should be used.

This paper will also have a significant impact on the deployment of low-power short-range IoT machines, if the considered methods for providing access to underutilized spectrum through the novel use of CR is applied. As more IoT machines are deployed, therefore ensuring that IoT machines have access to radio spectrum for communications. It is very important that these IoT machines use unoccupied radio spectrum such as the unoccupied FM radio spectrum for their throughput. Low-power short-range IoT machines are becoming an integral part of industries, institution and medical issues. Poor communications and interference, caused by scarcity of spectrum, will cause loss of data and may perhaps lead to absolute phase where there is absolute loss of communications.

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