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Article

Practical Wireless Network in 5-6 GHz Band for Wireless Communication System Applications

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ABSTRACT

Radio spectrum is an essential resource for wireless communication supplied with the service providers. The most important fields are radio spectrum management and utilization accuracy. This paper offers the experience of using the 5-6 GHz band, in which more spectrums available, more channels, larger bandwidth, faster data transmission, higher data rate, higher speed, and better quality of service. In this paper, practical implementation and testing of a wireless network system, which measures spectrum accuracy in the 5-6 GHz frequency band at different locations and allows using its free band. The spectrum occupancy is performed using a cooperative system, which consists of a main sensor and different sensors. The measurement results for the practical system are compared with different previous measurements performed in different areas. They all agree that the spectrum is underutilized, and the spectrum needs to be better utilized to increase spectrum efficiency.



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1. Introduction

The growing need for radio spectrum is becoming a challenging task for the current frequency allocation chart. The need for spectrum channels is essential because of the increase in wireless devices and greater wireless data transmission rates [1-3]. The licensed spectrum channels are assigned to specific

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users who do not use the spectrum most of the time. As a result of the inefficient spectrum utilization, many spectrum accuracy measurements have been conducted worldwide at different locations, covering wide frequency ranges such as Ireland, Germany, Spain, USA, Europe, New Zealand, Singapore, South Africa, Vietnam, China, etc. [4, 5]. These measurements give important information about the efficiency and accuracy of the spectrum allocations and the availability of the spectrum for other users. Spectrum usage percentage varies with the location, time, space, and band of operation. These spectrum measurements show that the licensed spectrum is unoccupied, and the spectrum is inefficiently used [6-9]. But efficient utilization of the spectrum is required to overcome the spectrum scarcity problem, which increases due to the traditional fixed frequency allocation policy.

Although the spectrum is not used efficiently and the spectrum utilization rate is very low, there are many different bands that suffer from many services, many different applications, and a large number of users in their bands, which affects their service efficiency and quality. That is why we offer in this paper the experience of using the 5 to 6 GHz band service and its advantages, which overcome the problems of crowded bands [10-13]. In the 5-6 GHz bands, users have the advantages of large bandwidth, faster data transmission, higher data rate, higher speed, and better quality of service.

In this paper, a practical system is implemented and tested, which first measures the spectrum occupancy in the 5-6 GHz licensed band at different locations, finds the licensed users' activities, and identifies unused spectrum opportunities. Then it allows access to its unused spectrum without interfering with the licensed users in its band.

In this paper, we provide an explanation of practical system implementation and testing.

- Implementing and testing a new practical system, which allows the transition to the new 5-6 GHz free band.
- The implemented system objective is to measure the occupancy of the 5-6 GHz bands at different locations and then use the free bands by moving the users to the license-free 5-6 GHz band.
- The spectrum occupancy is performed at different locations. Each station scans the frequency band at least five times.
- The implemented system provides a higher data transmission rate, a large bandwidth, and a better quality of service compared to other over-crowded bands.
- The new system allows users a higher speed of transmitting, receiving, downloading, and transferring data.

The paper is organized as follows. Section 2 presents the related work. Section 3 gives an explanation of the practical system methodology, while Section 4 shows the experimental results of the proposed system, and conclusion in section 5.

2. Practical System

2.1. Related Work

There are many studies that measure spectrum utilization and characterize the radio frequency environment. These studies have been presented to evaluate the effectiveness of fixed spectrum allocation. Spectrum utilization percentage differs primarily based on location, time, and frequency band. The channels are unused efficiently. Spectrum surveys have been conducted at different locations, overlaying both wide frequency ranges and specifically licensed bands. Specific surveys have been performed in the USA [15, 16], New Zealand [17], Singapore [14], Ireland [18], Morocco [19], and Spain [20]. Spectrum accuracy measurements are introduced in [21]. The authors concluded that focused and carefully designed campaigns are of greater interest than extra generalized ones and that the results should be carefully scrutinized, considering that providing a simple spectrum occupancy value can lead to false conclusions. Spectrum occupancy in the Unlicensed National Information Infrastructure (U-NII) band exists. Only extensive bands lookup the use of high-performance spectrum analyzers connected to an omnidirectional antenna have been conducted.

In [22], an outdoor measurement on a rooftop in the city is evaluated. The authors concluded that the U-NII band is vacant mainly due to recognition variations of 2.4 GHz and 5 GHz Wi-Fi home networks. The authors in [23] report consequences from a spectrum occupancy measurement from two locations in Chicago and from a university campus in Finland. Cellular measurement deployment is used, and they discovered that the occupancy in the U-NII band is well below 5%. However, one long-term measurement positioned on an exposed tower is additionally presented. For this setup, the channel occupancy notably increases by up to 50%. According to the authors, the foremost reason is that, in the US U-NII band, transmissions are usually directed backhaul links at exposed locations. In [24, 25], the authors measured the spectrum occupancy in the 2.4 GHz band using 16 Wi-Fi cards attached to an omnidirectional antenna in an urban parking lot. Wi-Fi is the dominant service for wireless data traffic. A document commissioned by the European Commission confirmed that over 71% of all wireless information traffic delivered to smartphones and tablets used to be delivered via Wi-Fi. In 2013, the UK telecommunications regulator recognized that the 2.4 GHz band is much more heavily used than the 5 GHz band; the common occupancy of the 2.4 GHz band is about ten times that of the 5 GHz band. Although the current use of the 5 GHz band is exceptionally low, another study discovered that the current spectrum allocation for Wi-Fi at 2.4 and 5 GHz is likely to be under strain by 2022, and additional spectrum will be required to support the expected demand. Moreover, in 2019 the amount of traffic offloaded from smartphones and tablets was 54% and 70 %, respectively [26].

The related studies to our work are the following studies. A study on spectrum occupancy has been performed in Singapore to identify the potential candidate bands for secondary utilization in the context of CR [22]. The whole frequency band ranges from 80 MHz to 5850 MHz. Unlike other countries, the occupancy pattern in Singapore is also affected by the signal statistics of the nearby countries. The measurement system consisted of an antenna of model 3149; this antenna was connected to a rotator to achieve the omnidirectional effect. From the results, it was seen that the bands from 5755 to 5875 MHz remained unused, and most of the bands can be used dynamically to deploy cognitive radio successfully in Singapore. Another study in Barcelona goes as high as 7075 MHz, using 2 different antennas [27]. For the band between 5 - 6 GHz, the occupancy from location one was 1.98% and the measured spectrum occupancy from location two was 1.34% the scanned spectrum remained mostly underutilized.

Another study is in [28]; the authors presented a different technique for scanning and evaluating radio spectrum use. The technique was implemented using Software Defined Radio units and Radio software. The experiments were performed on the radio spectrum over a frequency range of 824 MHz to 5.8 GHz in Grand Forks, North Dakota. The spectrum occupancy was found to be less than 20%. The measurement of the occupancy values of channel 153 (5.765 GHz) of the 5.8 GHz band was very low, and most of the band remained unused. The occupancy is very low when compared to the 2.4 GHz band. The most related study to our work is in [29]; the authors measured the spectrum occupancy in the Unlicensed National Information Infrastructure (U-NII) band. Their testbed was located in the Rhein-Sieg area of Germany and covers rural areas as well as urban areas such as the Bonn Rhein-Sieg University of Applied Sciences. The testbed spans a few hundred meters up to 11 kilometers. The measurement results show that in rural areas, there are many vacant channels, and the mean spectrum occupancy in urban areas was measured at below 5%, which is very low.

So, in this paper, a new practical cooperative system is implemented and tested. This system measures the occupancy of the 5 - 6 GHz at different locations, then uses its free band by moving the users to the free-license 5– 6 GHz Wi-Fi band.

2.2. The Practical System Methodology

In the detection results, we used the power technique for detecting the received signals and estimating the occupancy utilization.

Power detection is based on measuring the received power in a frequency band and comparing it with the power of the noise floor. Figure 1 illustrates the cases when there is no user signal in the frequency band

and when there is a user signal. The power of the signal (P_s) is greater than the power of the noise floor (P_n). By comparing the two values, the user signal can be detected.

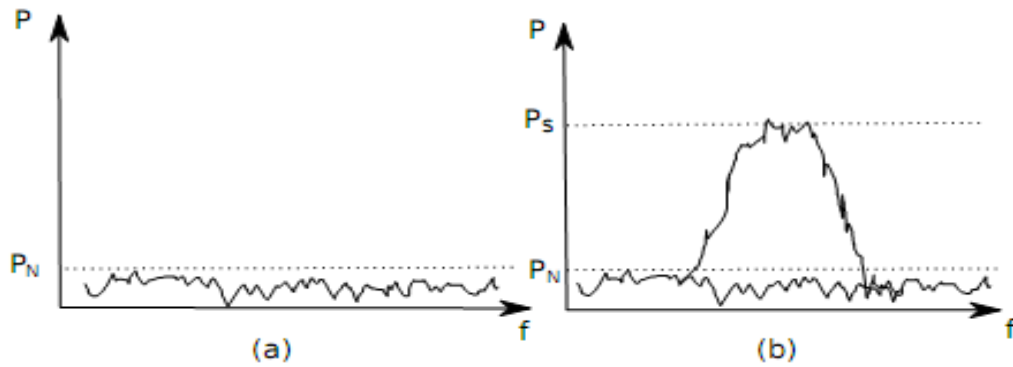


Figure 1. Power in a frequency band: (a) only noise is present (b) signal is present.

The power detection algorithm has several advantages. It is simple, and it has a low computational cost. The spectrum sensing performance is analyzed in terms of its spectrum occupancy efficiency.

$$\text{Spectrum Occupancy Efficiency} = \frac{\text{The number of the users signals}}{\text{The number of all scanned frequencies}}$$

This equation is the core equation to evaluate occupancy efficiency. Secondly, the five receivers (L_1 - L_5) scan the 5 - 6 GHz frequency bands to determine the spectrum utilization and to find free frequencies and channels for receiving signals.

A centralized cooperative center is used in our work; the master node is L_1 , which controls the other receivers' locations (L_2 - L_5) as shown in Fig. 2. The four location receivers (L_2 - L_5) perform their local process, and then they report their binary decisions to the master node L_1 . L_1 collects sensing information from L_2 to L_5 , identifies the unused spectrum, broadcasts the information to L_2 to L_5 , and directly controls the traffic.

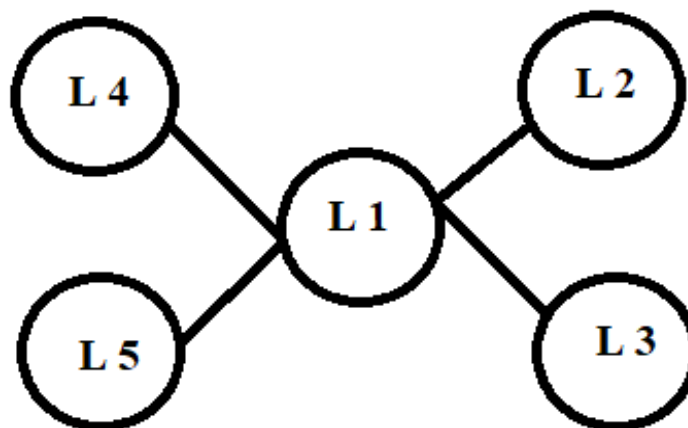


Figure 2. Cooperative practical system.

In a centralized scheme, a fusion rule is adopted to evaluate the final decision about the presence or the absence of the primary user transmission.

The measurement configuration employed in this work in five locations relies on spectrum analysis, where different external devices have been added in order to improve the detection capabilities and hence obtain more accurate and reliable results. Our testbed was conducted in five different locations and covers different areas. We focus on a practical build-up by mainly exploiting rooftops. The outdoor

measurements give us some insights into the spectral activity that would be perceived by users operating in outdoor environments, at various physical locations of practical interest.

The system covers an area of up to 25 km at five different locations and offers users the service in the range of 5 - 6 GHz, offering them a higher speed, higher data transfer rate, and more bandwidth. Also, the service reaches users in places not accessible by other system services. The system chart is shown in Fig. 3.

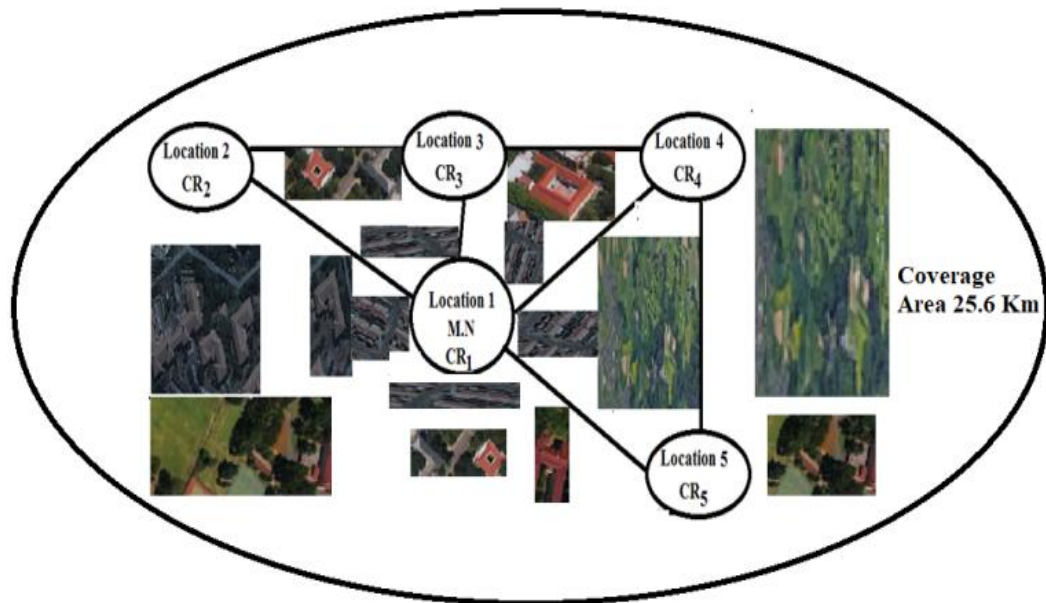


Figure 3. The system chart

2.3. Spectrum Occupancy Results

2.3.1 First Location Results (L1) (First Step)

The first step is performed using the first sensor at location 1. The antenna is used to scan the frequency band from (5-6) GHz to determine the spectrum occupancy and detect the free frequencies and channels to use for new wireless applications. The antenna scans the band many times, in each time the scanning results show many unused frequencies, as shown in Table 1. In each scan, the scan time and the occupancy efficiency are determined.

Table 1. The summary of all L₁ scans.

Scanned Frequency band (GHz)	(5– 6)
Number of scanned frequencies	22 frequencies
Number of detected frequencies	5
Number of scanning times	5
Average Occupancy Efficiency	23 %
Average Sensing time	9 sec

As shown in Table 1, after confirming five scans, the average spectrum utilization is 23 %, and the average sensing time is around 9 sec.

2.3.2 Second Location Results (L2)

In the second location spectrum scanning shown in Table 2, the frequency is scanned from 5 to 6 GHz, where the sensing took a time of 85 sec. The estimated occupancy of the frequency spectrum equals (2/77), which is only about 2.6%.

Table 2. L₂ scan.

Scanned Frequency band (GHz)	(5– 6)
Number of scanned frequencies	77 frequencies
Number of detected frequencies	2
Number of scanning times	5
Occupancy Efficiency	2/77 = 2.6 %
Sensing time	85 sec

As shown in Table 2, after confirming five scans, the spectrum utilization is 2.6%, and the sensing time is 85 sec.

2.3.3 Third Location Results (L₃)

In the third location, the spectrum is scanned many times, as shown in Table 3. The frequency is scanned from 5 to 6 GHz, the average spectrum utilization is 13.334%, and the sensing time is 16.6 sec, as shown in Table 3.

Table 3. The summary of all L₃ scans.

The number of scans	Sensing Time (Sec)	Utilization Efficiency
First Scan	17	13.33 %
Second Scan	16	11.67 %
Third Scan	16	11.67 %
Fourth Scan	17	15 %
Fifth Scan	17	15 %
Average	16.6	13.334 %

2.3.4 Fourth Location Occupancy Results (L₄)

In the fourth location spectrum scanning shown in Table 4, the frequency is scanned from 5 to 6 GHz, and the sensing took a time of 16 s.

Table 4. L₄ scan.

Scanned Frequency band (GHz)	(5– 6)
Number of scanned frequencies	60 frequencies
Number of detected frequencies	3
Number of scans	5
Occupancy Efficiency	5 %
Sensing time	16 sec

As shown in Table 4, after performing five scans, the spectrum occupancy is 5% and the sensing time is 16 sec.

2.3.5 Fifth Location Occupancy Results (L5)

The spectrum scanning is shown in Table 5.

Table 5. CR₅ scan.

Scanned Frequency band (GHz)	(5– 6)
Number of scanned frequencies	60 frequencies
Number of detected frequencies	1
Number of scanning	5
Utilization Efficiency	1.7 %
Sensing time	14 sec

As shown in Table 5, after performing five scans, the spectrum utilization is 1.7%, and the sensing time is 14 Sec.

Table 6. Summary of all locations (L2-L5) results.

Receivers	Occupancy Efficiency
L ₂	2.6 %
L ₃	13.334 %
L ₄	5 %
L ₅	1.7 %
Total average	5.65 %

As shown in Table 6, after performing many scans for each location receiver (L₂–L₅), it is demonstrated that the total average spectrum utilization is 5.04%, most of the scanned spectrum is empty, and hence, the spectrum needs to be better utilized to increase spectrum efficiency.

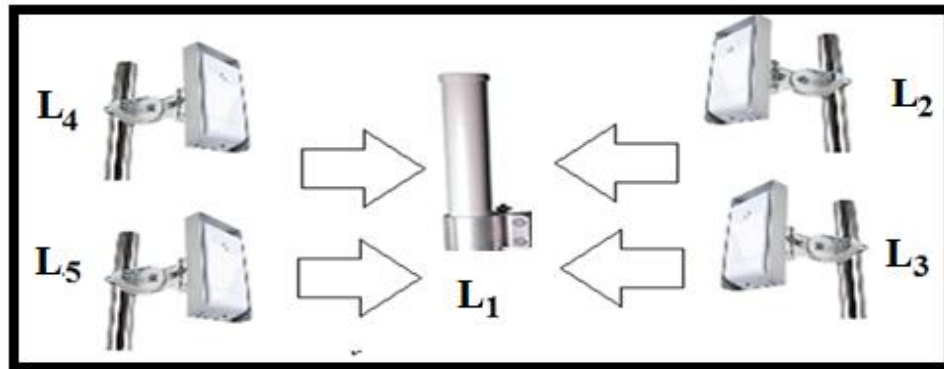
Finally, Table 7 shows a comparison of the experimental occupancy results at the five locations and other previous related studies. The study on spectrum occupancy has been performed in Singapore, the results of the study show that the bands from 5755 to 5875 MHz remained unused. The study in Barcelona shows that between 5 - 6 GHz, the occupancy from two locations was 1.66 %. In North Dakota (USA), in the frequency range of 824 MHz to 5.8 GHz, occupancy was less than 20% in certain bands of the radio spectrum. The results also show that the occupancy changes depend on the time, day, and channel. The occupancy values of channel 153 (5.765 GHz) of the 5.8 GHz band were very low. The most related study to our work is that performed in Germany, where the authors measured the spectrum occupancy in the Unlicensed National Information Infrastructure (U-NII) band. The measurement results show that in rural areas, there are many vacant channels, and the mean spectrum occupancy in urban areas was measured to be below 5%, which is very low. The experimental results of our implemented system show that after performing five scans using an omnidirectional ROC antenna at the first location, the average spectrum utilization is 23%, and after performing five scans for each nano station receiver (L₂–L₅) at the other locations, the total average spectrum utilization is 5.65%. The experimental results of our implemented system agree with each other and agree with other studies that most of the spectrum is under-utilized at their respective locations and show that some bands have a near-zero percent occupancy rate. This study indicates that there is an available spectrum that can be exploited by more spectrally efficient technology systems.

Table 7. Comparison of our implemented model and the previous related studies.

Spectrum Occupancy	Frequency Band	Percentage
Singapore [14]	5.755 to 5.875 GHz	0 %
Barcelona [27]	5 GHz to 6 GHz	1.66 %
North Dakota (USA) [28]	5.765 GHz	20 %
Germany [29]	5.180 - 5.700 GHz	5 %
Location 1 Experimental Results	5.735 to 5.84 GHz	23 %
Locations 2 to 5 Experimental Results	5.16 – 5.84 GHz	5.65 %

2.3.6 The Third Step

After each location (L_2 – L_5) is scanned, the bands are scanned many times at the locations. Their scanning results are fed to the master node (L_1) at the first location to make the final decision about the frequency bands, confirm the cooperation results with the master node, and confirm the frequency and channel of the receiving signals. A centralized cooperative system has been used in this work as shown in Fig. 4, L_1 is the master node, and L_2 – L_5 are the cooperative radios that perform local sensing and report the results back to L_1 . L_1 collects sensing information from L_2 – L_5 , identifies free spectrum, and broadcasts the information to L_2 – L_5 .

**Figure 4.** L_1 and L_2 – L_5 .

Now the 5 - 6 GHz system is ready for use. Users can access the system using the 5 – 6 GHz services with faster speed, much less time, and better quality of service than other systems.

3. Conclusion

In this paper, a practical cooperative system was presented and tested. The practical system goal is to measure the occupancy of the 5 - 6 GHz band at different locations, then use the free band. The spectrum measurement is done at different locations; each station scans the frequency band at least five times. We found few different “Alternative Networks” operating in the new license-free 5 GHz band, especially for our desired scenario, but the spectrum utilization remains very weak, as the total average spectrum utilization of all stations was 7.993 %. The results of measurements were compared to the results of the previous studies in Singapore, Barcelona, North Dakota (USA), and Germany. All the results showed that the spectrum is underutilized at their locations and that the spectrum should be exploited efficiently by new technology systems. Then, we used a centralized cooperative system between the master node L_1 and other locations (L_2 – L_5). The performance of the proposed 5- 6 GHz cooperative system achieves a very high quality of service compared to other systems. Users can access and use the free license 5-6 GHz higher-speed transmission, receiving, downloading, and transferring data through the system network with their new faster speed. Our system covers an area of up to 25.6 km and delivers the service in the range of 5-6 GHz to other users, offering them a higher speed, higher data transfer rate, more bandwidth, and the service reaches users in places not accessible by other systems.

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