Journal of Theoretical and Applied Information Technology
15th August 2022. Vol.100. No 15

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

INVESTIGATION OF SPECTRA OF MOBILE COMMUNICATION SYSTEMS USING RTL-SDR RADIO RECEIVER

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ABSTRACT

Mobile phones are becoming an integral part of our daily lives. In fact, the mobile Internet has become one of the most important components of our business transactions and social life. As a result, the number of mobile users has increased significantly. Mobile signal users are distributed across different countries with different densities. This is due to the fact that the provision of mobile services depends on mobile operators and the pace of technological development of communications in countries. And the rise in popularity of mobile communications has made the electromagnetic spectrum of mobile signals unevenly distributed across frequencies, resulting in spectral inefficiencies. Accordingly, some spectra are used extensively, and some are left unused. The relevance of the proposed work lies in the fulfillment of the prerequisites for solving the problem of inefficient use of this mobile spectrum. The uneven distribution of these mobile spectra causes spectrum shortages. More recently, this problem began to be solved with the help of a special technique, such as Cognitive Radio. Cognitive radio first studies the spectra of mobile signals and then determines the signal density. This work proposed to perform the first stage of Cognitive Radio with spectrum recognition of mobile communication standards such as GSM, UMTS and LTE for Kazakhstan using RTL-SDR radio receiver. Since this work is aimed at studying the technical capabilities of the RTL-SDR radio receiver for mobile signals, it considered the study of the standard of mobile signals, such as GSM, UMTS and LTE. The result of the study shows that the technical capabilities of the RTL-SDR radio receiver are fully supported for the GSM and UMTS standards and partially for the LTE standard as a research platform for use in the Cognitive Radio method.
Keywords: *RTL-SDR, Spectra of Mobile Communication Systems, Mobile Signals, GSM, UMTS and LTE.*

1. INTRODUCTION

It is impossible to imagine our modern life without mobile phones. And the standards for these mobile systems have evolved rapidly over the past 30 years. This rapid development was facilitated by an increase in the number of users [1]. First generation (1G) mobile phone signals were broadcast and the capabilities of 1G in the form of analog signals were limited. To remedy shortcomings such as analog technology and very low bandwidth, the GSM standard was developed, which belongs to the second generation of mobile communications (2G). 2G technology has been designed with advantages such as digital signal transmission, spectral efficiency and text. And the third generation of mobile communications (3G), providing users with high-speed Internet, appeared in Japan in the 2000s. Today, the fourth generation of mobile communications (4G) is used all over the world. Thus, mobile devices have become an integral part of our daily lives due to the increase in the speed of the Internet with the advent of their latest generations, as well as their mobile use in everyday business and household needs. And the number of mobile users has increased like never before. The rise in popularity of mobile communication has led to an uneven spectral distribution of mobile signals over frequencies, which has led to the problem of spectral inefficiency. Some spectra are widely used and some remain unused. The occurrence of this problem carries the risk of not providing new users in the near future due to the maximum use of certain frequency bands. In order to openly study this issue, it is necessary to conduct studies on the use of the spectrum through mobile providers. This issue can not be provided any research solutions for independent researchers without special permits and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

negotiations. But the emergence of affordable and easy-to-use RTL-SDR devices that allow receiving radio frequency (RF) signals made it possible to receive these mobile signals such as second, third, fourth generation radio signals (2G, 3G, 4G) standards and study their spectra [1].

Basically, different countries transmit mobile phone signals on different frequencies, as regulators have licensed mobile signals over the years due to advances in communication technology [1]. Figure 1 shows the spectrum of 2G, 3G and 4G signals transmitted in the UK [1]. The fixed frequency bands of one country can be used by other countries. This helps to save time and reduce costs when developing new technologies. In the USA and Europe, the frequencies of mobile standards GSM, UMTS and LTE are in different ranges [1]. And the range of mobile communication systems in Kazakhstan operates in the same range as in European countries. Mobile operators in Kazakhstan are increasingly developing and providing mobile communication standards at the level of developed countries. And compared to the countries of Central Asia, Kazakhstan is ahead of the development of mobile services, and the number of its users is increasing day by day. Similarly, the use of Mobile Internet is widespread due to its lower cost. Therefore, in this research work, we proposed to study the spectrum of the mobile signal for Kazakhstan.

The spectra of mobile communication systems used in Kazakhstan correspond to the spectra of mobile communication signals shown in Figure 1 as European countries. And as in Figure 1, the frequency range of mobile signals lies in the range of the technical detection range of the RTL-SDR radio receiver. This in turn allows us to find a solution by recognizing the spectral density of our mobile signals without violating any legislation.

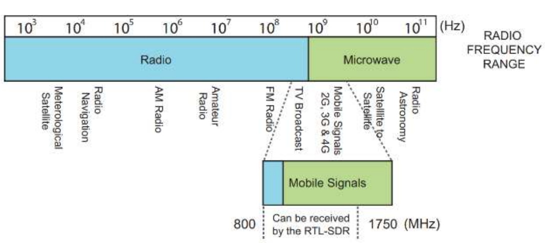

Figure 1: Ranges of cellular communication systems in the radio frequency spectrum with the reception area of the RTL-SDR device

Standards and frequency bands for mobile communication systems are controlled by the International Telecommunication Union (ITU, ITU). Consequently, ITU introduced IMT-2000 for 3G, IMT-Advanced for 4G, and new technology introduced IMT-2020 standards for 5G [2]. Since 1992 to the present, the ITU Radio Regulations (ITU RR) define several frequency bands for International Mobile Telecommunications (IMT). The first IMT frequency bands were introduced for the IMT-2000 system. Table 1 shows the IMT frequency bands identified for IMT systems in all three ILO regions (globally) or only in some or some of these countries [6]. Primarily, the aim of this work is to investigate the spectra range of GSM, UMTS and LTE standards for Kazakhstan using RTL-SDR. For this manner, the frequency ranges of mobile communication systems shown in Figure 1 and Table 1 were considered.

Table 1: Spectra determined for IMT

IMT frequency bands defined for the IMT system in the ITU radio regulations, MHz	WRC, (World Radiocommunication Conference)
450 – 470	WRC-07
470 – 608	WRC-15
614 – 698	WRC-15
694 – 960	WRC-2000, WRC-07, WRC-12
1427 – 1518	WRC-15
1710 – 2025	WARC-92, WRC-2000
2110 – 2200	WARC-92
2300 – 2400	WRC-07
2500 – 2690	WRC-2000
3300 – 3400	WRC-15
3400 – 3600	WRC-07
3600 – 3700	WRC-15
4800 – 4990	WRC-15

The RTL-SDR receiver is a radio receiver based on commercially available DVB-T TV USB receivers with the RTL2832U chip [3]. Moreover, MathWorks released a hardware support package for the RTL-SDR receiver in early 2014 that allowed it to interoperate and control the RTL-SDR receiver between MATLAB and Simulink. The RTL-SDR device can receive RF signals transmitted in the frequency range from 25 MHz to 1.75 GHz [1]. The importance of studying the spectra of mobile signals using SDR lies in the consideration of a method that allows an independent researcher to determine the spectral density of mobile signals that does not contradict any laws.

This work was organized into the following sections: the second section discussed the method of studying the spectra of mobile communication systems; the third section discussed the results of the study, and the last section summarized the results of the study.

2. RELATED WORKS

The study in work [4] discusses standards of 3G, 4G and 5G mobile technologies, [5] discusses research and comparisons for 2G, 3G and 4G networks, also channel coding schemes and frequency bands used in each generation, [6] considers 5G mobile standards, [7] investigates the use of spectra in broadband mobile systems, [8] examines the study of a mobile platform for experiments in wireless systems using SDR, [9] discusses the spectrum of wireless networks based on multi-agent architecture for 5G networks, [10] uses SDR flexibly on the fragmented spectrum and interference protection in professional mobile radio (PMR) networks in 5G networks, [11] studied the SDR-based non-orthogonal multiple access (NOMA) system for 5G networks. The authors of the work [12] proposed methods and algorithms for predicting free spectral ranges. These methods and algorithms are easily used by secondary users to access frequency bands and transmit data. The authors of the work [13] proposed a strategy based on repetitive gameplay that allows CR-enabled devices to increase bandwidth and reduce the likelihood of conflicts with other competing CR-enabled devices in the busy spectrum range. [14] presents a new method of joint spectral recognition, which is based on the optimal method for determining energy that reduces probability and can reduce the possibility of finding false, non-empty frequency bands in the spectrum. In the paper [15], the authors provided a complete overview of the main and irreplaceable methods for determining the media access strategies and spectrum used in cognitive radio. In general, as can be seen from the above works, the researched works in the direction of SDR have not yet received wide distribution. Analyzing the research methods of related works, this work began to study the spectra of mobile signals using the SDR method, which is a necessary condition for determining the spectral-frequency density of mobile signals in this region of Asia, especially in Kazakhstan.

3. METHODS

SDR is a technology that can be used for radio systems in which almost all physical layer tasks are implemented in software using digital signal processing (DSP) techniques. In fact, the ideal SDR receiver should have very little external hardware, just an antenna and a high-speed gigahertz sampler capable of capturing and digitizing a wide range of radio frequencies. The steps of the DSP technique such as demodulation, synchronization, decoding necessary to recover the information contained in the received signal can be performed in software that runs on an super-fast processor [1]. This study examines the spectrum of mobile signals in the region of Kazakhstan using the RTL-SDR receiver as part of the SDR method, which allows surveying through the frequency domain. Studying the spectra of mobile communication systems using the RTL-SDR radio receiver is a method that allows you to conduct research in any area that does not require large funds and special research centers. And our research is carried out very simply and conveniently using a personal computer or laptop, an RTL-SDR radio receiver and MathWorks software. The equipment used in the experiment is shown in Figure 2.

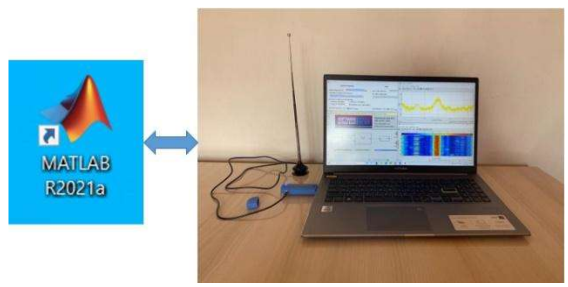

Figure 2: The process of conducting the experiment

The results obtained from the spectrum recognition of mobile communication systems using the RTL-SDR receiver will depend on the geographical area under study. During the study, the signal is examined in two spectrum analyzers. The first will be the waterfall analyzers, which consider the fast Fourier transform (FFT) with the bandwidth f_s, and the second will be the spectrum analyzers. FFT is a set of intelligent calculation tools that implement the Fourier theorem. The spectrum obtained in the FFT analyzer shows the frequency components of the input signal. Because FFT spectrum analyzers measure all frequency components simultaneously, they are hundreds of times faster than traditional analog spectrum analyzers [16].

Now, if we consider the operation of the FFT analyzer in more detail, the spectrum of the signal obtained in the FFT spectrum analyzer is in the frequency range of equation 1:

$$\left(f_c - \frac{f_s}{2}\right) \Leftrightarrow \left(f_c + \frac{f_s}{2}\right) \qquad (1)$$

where, f_c is the central frequency; f_s is the sampling frequency value. If we set the RTL-SDR

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

receiver to a central frequency of 801.4 MHz and a sampling frequency of 2.8 MHz, we receive RF signals in the range of 800 MHz to 802.8 MHz. Figure 3 shows that when the central frequency of the RTL-SDR receiver is assumed to be 801.4 MHz, the RF signals are reduced to a complex baseband, Fig. 3 (0 MHz) [1].

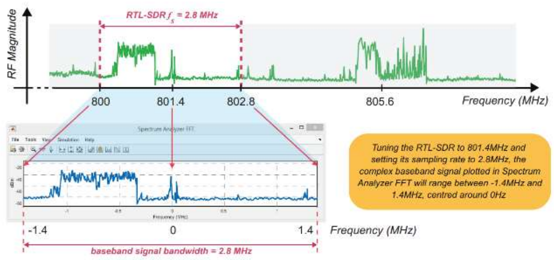

Figure 3: Demonstration of downsampling of RF signals to the complex baseband (0 MHz) when the center frequency of the RTL-SDR receiver is set to 801.4 MHz

The Waterfall spectrum analyzer also displays the frequency ranges obtained in the FFT analyzer and is active over time (last 50 ms). The color scale on the Waterfall analyzer indicates the power level. That is, the relative power levels of the frequency components in the received signals are displayed. The color scale ranges from dark blue (noise layer, weak signal) to dark red (high signal).

One of the most important aspects of the research method is the correct and necessary change of the parameters of the RTL-SDR receiver. The settings for frequency selection, center frequency and gain are most carefully adjusted. It is also possible to get a high signal strength by changing these settings. And these main parameters of the study on the spectra of mobile communication systems using the RTL-SDR radio receiver in the Simulink environment are given in Table 2.

3. *Table 2: Hyperparameters required for the study of the spectra of mobile communication systems with an RTL-SDR receiver*

Settings	Mobile communication standards		
	GSM	UMTS	LTE
Sampling rate, MHz	2.8	2.8	2.8
Central Frequency Center, MHz	800 – 1000	800 – 900	700 – 900
Gain, dB	0 – 50	0 – 50	0 – 50

As seen from Table 2, the sampling rate reflects a certain proportion of the signals received by the spectrum analyzers. That is, if the sample rate is assumed to be 2.8 MHz, the spectrum analyzer will display signals in the 2.8 MHz range of the selected center frequency. The sampling rate is in different frequency ranges. The central frequency setting directly contributes to good results. The frequency range of the signals under study is monitored during our study. Also, it is determined in which frequency range the highest signal can be received. Accordingly, the frequency range differs in different countries. Therefore, in this work, we conducted a study of mobile signals that are used in Kazakhstan, since the availability of affordable mobile communication services in our country leads to an increase in the number of new users.

Basically, 2G standard operates between 890 and 960 MHz with carriers spaced 200 kHz apart. In the UK, the highest signal in the GSM standard is transmitted in the frequency ranges of 949.2 MHz and 959.3 MHz [1]. Our research performed the investigation for Kazakhstan's mobile operator's signals. A high GSM signal is transmitted in the range of 942.6 MHz.

The UMTS 3G standard was a further evolution to mobile communications that was orientated for higher amounts of packet data. It uses a connectivity method called Wideband Code Division Multiple Access (WCDMA). While GSM channels are only 200 kHz wide, UMTS channels are 5 MHz wide, and signals are sent across the full band as a spread spectrum signal. The wider bandwidth associated with this standard allowed an increase in data rates while keeping the transmission efficiency high by affording multiple users access at the same time. Instead of relying on timeslots, each user's mobile phone can determine which broadcast signals are meant for it by matching its individual code with them. Although the majority of these signals are transmitted at 1700 MHz and above, there are still a number of 3G signals transmitted in the 800 – 900 MHz. Unfortunately, due to the bandwidth limitation of the RTL-SDR, our research limited us to view the full 5 MHz band simultaneously when using a single device, but it was possible to see the spread spectrum signal to recognize the differences between UMTS and the GSM signals [1].

In the UK, the highest UMTS signals are transmitted in the frequency bands of 932.5 and 933 MHz, while in Kazakhstan, the highest UMTS signal is transmitted in the band of 938.2 MHz.

LTE (Long Term Evolution) is one of the most recent mobile standards (4G) to be deployed around the world. It builds on the previous infrastructure, focusing once again on increasing data rates, due to the ever-increasing societal requirement for connectivity. The 4G standard (into which LTE does

Journal of Theoretical and Applied Information Technology
15th August 2022. Vol.100. No 15

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

not actually fall) specifies data download speeds of up to 1 Gbps to stationary devices, which put into context, is around x10 faster than the speed of most Ethernet networks. LTE aims to offer long term benefits by its progression to a statistical multiplexing technique called Orthogonal Frequency Division Multiple Access (OFDMA). This provides multiple access connectivity by using both time and frequency division to assign resources to individual users, in order to provide the highest and most efficient throughput. Tx and Rx channels for LTE signals can be found at 800, 900, 1800 and 2600 MHz in Europe and Central Asia, and at other frequencies around the globe. They can occupy various different bandwidths from 1.4 MHz to 20 MHz in the spectrum [1].

In the UK, the highest signal in the LTE standard is transmitted in the frequency ranges of 811, 815 and 818 MHz. Our research has shown a high LTE signal that is transmitted in the range of 815.3 MHz for Kazakhstan.

Mobile signal propagation ranges in the UK and Central Asian countries are shown in Table 3.

4. *Table 3: Comparison of signals of mobile communication systems in the UK and Central Asian countries*

Country	Mobile communication standards		
	GSM	UMTS	LTE
UK	949.2 MHz, 959.3 MHz	932.5 MHz, 933 MHz	811 MHz, 815 MHz, 818 MHz
Central Asia	942.6 MHz	938.2 MHz	815.3 MHz

As you can see in Table 3, different spectrum ranges are used to receive the highest mobile signals in the UK and Central Asian countries. In the UK, several frequency bands can be used in the spectrum to obtain high-speed, high-speed signals. In Central Asian countries, high signals are received only in one frequency range. This indicates the high quality of service of mobile communication systems in the UK. Therefore, the results of these studies and comparisons require improving the quality of functioning of mobile communication systems (operators) in Kazakhstan.

4. RESULTS AND DISCUSSION

This work was conducted in Simulink (MATLAB) to determine the spectra of mobile communication systems using the RTL-SDR receiver. The frequency ranges of each standard were explored by selecting mobile signals using the spectrum control panel in MATLAB. During the study, the main hyperparameters of the tuner were set by changing the center frequency, amplifier and sampling frequency. In particular, the proposed work carried out research on the GSM, UMTS and LTE standards for mobile communications in Kazakhstan. As a result, research data on the GSM standard are shown in Figure 4. In the case of the highest signal in the GSM standard: the central frequency was 942.6 MHz; the gain was 47 dB. The advantage of conducting a study using the Spectrum Analyzer Waterfall on the MATLAB platform is the simplicity of determining the signal level using a color scale. The saturation of the color indicates the power of the signal. Basically, working on a color model can be useful for machine learning methods as well.

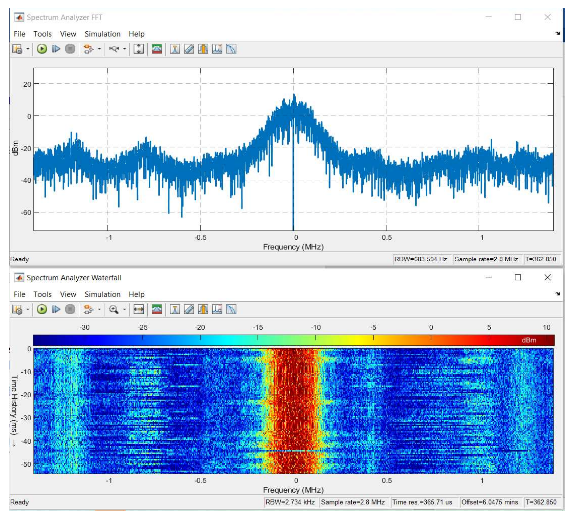

Figure 4: GSM signal spectrum: FFT analyzer on the top, waterfall analyzer on the bottom

In the next step, UMTS signals were studied. The results of research on the UMTS mobile standard are shown in Figure 5. The central frequency was 938.2 MHz, the gain was 40 dB for the highest signal in the UMTS standard.

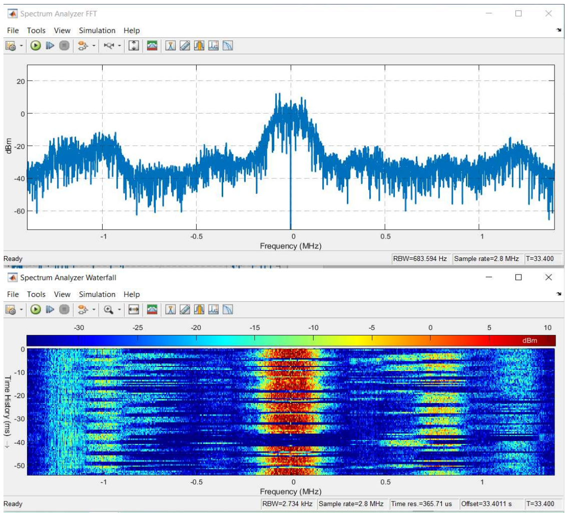

Figure 5: UMTS signal spectrum: FFT analyzer at the top, Waterfall analyzer at the bottom

The last stage of the experiment was the LTE standard, since the 5G standard has not actually been implemented yet. The results of research on the LTE standard are shown in Figure 6. For the highest signal in the LTE standard: the central frequency was 815.3 MHz, the gain was 35 dB.

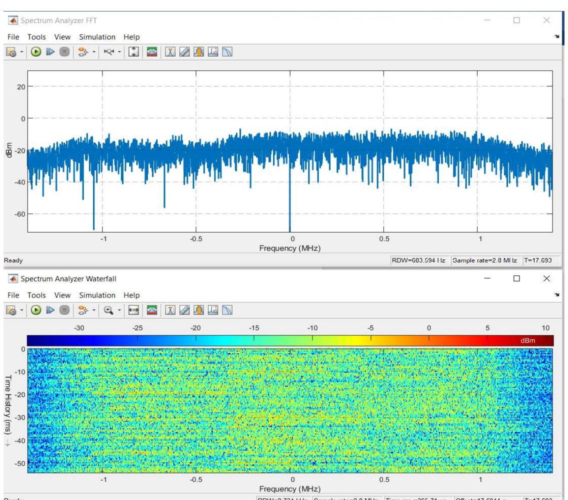

Figure 6: LTE signal spectrum: FFT analyzer at the top of the picture, Waterfall analyzer at the bottom

It was difficult to get the spectrum range LTE standard with RTL-SDR clearly. This limitation will be considered for research with antennas in the future work. Furthermore, the main parameters of the graphical user interface of the RTL-SDR receiver (CUI, Graphical user interfaces) were introduced and research was carried out during the experiment, according to table 2 in the section of the above methods. The quantitative values of the results obtained in the FFT and Waterfall analyzers using the RTL-SDR receiver are shown in Tables 4, 5. During the study, the same bandwidth and results were observed in both spectrum analyzers.

5. *Table 4: Results of GSM, UMTS and LTE standards in FFT analyzer*

Settings	Mobile communication standards		
	GSM	UMTS	LTE
Centre Frequency (MHz)	942.6	938.2	815.3
Gain (dB)	47	40	35
RBW (Resolution bandwidth), Hz	683.594	683.594	683.594
Sampling rate, MHz	2.8	2.8	2.8
Period T, s	362.850	33.400	17.693

At the research stage, the frequency bands and gains of mobile communication systems were changed by several values and the maximum possible signals were obtained. For the GSM standard, the center frequency was 942.6 MHz, the gain was 47 dB, the allowable bandwidth was 683,594 Hz, the sampling rate was 2.8 MHz, and the period was 362,850 s. The GSM base station was far from the study area. In Figure 4, the bright red colors seen in the Waterfall analyzer indicate that a high signal can be obtained in the 942.6 MHz frequency band. And for the UMTS standard, the center frequency was 938.2 MHz, the gain was 40 dB, the allowable bandwidth was 683594 Hz, the sampling rate was 2.8 MHz, and the period was 33400 s. The UMTS base station was found to be closer to the study area than the GSM base station. Figure 5 shows that the high signal is transmitted in the frequency range 938.2 MHz.

For the LTE standard, the central frequency was 815.3 MHz, the gain was 35 dB, the allowable bandwidth was 683,594 Hz, the frequency sampling was 2.8 MHz, and the period was 17,693 s. It was observed that the LTE base station is closer to the base area than other study stations. Figure 6 shows that a high signal can be received in the frequency range 815.3 MHz.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

6. *Table 5: Results of GSM, UMTS and LTE standards in Waterfall analyzer*

Settings	Mobile communication standards		
	GSM	UMTS	LTE
RBW (Resolution bandwidth), kHz	2.734	2.734	2.734
Sample rate, MHz	2.8	2.8	2.8
Time res. us	365.71	365.71	365.71
Offset, mins	6.0475	33.4011 s	17.6944
Period T, s	362.850	33.400	17.693

Studies have shown that the allowable bandwidth for the GSM standard is 2.734 kHz, frequency sampling is 2.8 MHz, allowable time per second is 365.71, constant frequency switching - 6.0475, period - 362.850 s.

The allowable bandwidth for the UMTS standard was 2.734 kHz, the frequency sampling was 2.8 MHz, the allowable time per second was 365.71, the constant frequency shift was 33.4011 s, and the period was 33.400 s.

The allowable bandwidth for the LTE standard is 2.734 kHz, the frequency sampling is 2.8 MHz, the allowable time per second is 365.71, the constant frequency.

Experimental results have shown that gain (Gain) is one of the most important parameters for obtaining a high signal. If the transmitter is located close to the RTL-SDR receiver, the gain must be reduced. This is because it is overloaded on the receiver, which prevents it from receiving a high signal. It also showed that if the signal is received remotely, it is necessary to increase the gain to amplify the signal and separate it from the noise.

It is recommended that the sampling frequency not exceed 2.8 MHz during the experiment. Investigations have shown that 2.8 MHz is the ideal frequency to obtain a clear, accurate and reliable spectrum. And it has proven to provide data transmission without any loss. It was observed that the model would not work if the variable sampling frequency did not match.

5. CONCLUSION

This work has studied the Spectrum Sensing of mobile communication systems based on the RTL-SDR receiver. In particular, radio frequency signals were received, propagating through the air in the study area. The advantage of this research work is that it can be done with just two main components such as Matlab and the RTL-SDR receiver. And the RTL-SDR radio receiver with its own antenna is available on the market at an affordable price. In addition, off-the-shelf programs such as SDR# and Matlab with the Mathworks calculation libraries are also available with FFT analyzers with fast signal processing. And our work investigated the signals in the Simulink/Matlab environment, and the spectrum was studied using the FFT and Waterfall spectrum analyzers. The high signals were given in bright red on the color scale. It was also found that the results obtained are directly dependent on the central frequency parameter and the gain.

The limitation of the study was that we were unable to obtain LTE signals very well. There are several reasons for this. The first reason is the geographic area in which the study was conducted. Our study area is located far from the base station, i.e. transmitter. Therefore, it was not possible to get a high signal. Secondly, the frequency range of the RTL-SDR receiver used was limited practically. That is, we could not use bands above the frequency range of 1800 MHz. Test results show that the RTL-SDR receiver needs to cover frequencies above 1800 MHz. The result of the study shows that the technical capabilities of the RTL-SDR radio receiver are fully supported for the GSM and UMTS standards. The LTE standard is partially detected and cannot be used as a research platform for use in the Cognitive Radio method due to the fact that RTL-SDR cannot detect the full range of the LTE spectrum. Therefore, future work will focus on the development of a wide range of frequency receivers and the study of the spectra of communication systems other than mobile.

The conducted research can be offered as a basis for mobile communication and SDR courses in the specialty of radio engineering, electronics and telecommunications in higher educational institutions.

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