APPLICATION OF COGNITIVE RADIO TECHNOLOGIES FOR BUS TRAVEL IN-FORMATION SUPPORT

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Background: The current tasks of information support for bus travel are limited to general information about the trip and excursions, for example, in the form of the purpose and duration of the tour as a whole and individual trips to the objects of the tour, the plan and cost of excursions. During the main part of a sufficiently long trip, a qualified guide or accompanying person gives standard information about the history and sights of the points visited or passed on the route. On the way back to the place of permanent or temporary deployment, travelers are usually offered to watch a movie from the standard collection or just relax. The main problem here is the lack of functionality, flexibility and efficiency in the formation of information content, the limited channels for its delivery. One of the solutions to this problem is local radio broadcasting using a variety of information sources and the use of cognitive radio technologies for information delivery. It is understood that the preparation of information content can be performed in real time. The study of the effectiveness of this proposal is the purpose of this work. Methods: The substantiation of the possibility and effectiveness evaluation of the cognitive radio technologies application was carried out by devices prototyping using USRP devices in conjunction with the LabVIEW package. Results: the following tasks are solved: scanning the frequency range to determine the free area sufficient for high-quality reproduction and select desired information content; receiving and writing to a file of a radio signal digitized samples with a given quality; real-time rebroadcasting of found content in a selected section of the frequency range; file multimedia and speech content transmission in the selected section of the frequency range with a given quality using FM radio standard. Conclusions: The rich tuning and indication set of the developed prototypes allows using these also for educational and research purposes, including in distance educational mode.

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1. Introduction

The creation of new systems of information interaction of migrating subscribers in various activity fields, using the principles of radio access, run into the problem of a shortage of the necessary frequency band.

Potentially, this problem can be solved by using cognitive radio technologies, which force the use of frequency bands that are dynamically released during the operation of other systems.

This publication presents an experimental justification for the possibility of building such a system using the existing database for the purposes of information support of tourist groups moving along a tourist route, as well as an evaluation of the effectiveness of such a solution. An original way of building a system based on the method of prototyping software and hardware devices using USRP devices together with the LabVIEW software package is proposed.

The publication represents the first step in a large comprehensive study of the prospects to use of cognitive radio technologies in order to increase the efficiency of using a scarce and expensive resource - the frequency band. Undoubtedly, this will require the creation and analysis of very complex mathematical models and testing of prototypes. In particular, the influence of the spectrum dynamics of complex signals on the possibilities of using the vacated frequency bands, and the evaluation of the scope and methods of possible use of these dynamically vacated frequency bands, require research. At the same time, the prototyping method is a completely justified and widely used research method, provided that the architecture, composition and components of the prototype are displayed as accurately as possible on real tasks of information interaction, and this is possible only on the basis of a reliable experimental justification of the principles and characteristics of the prototype components used.

This publication allows you to see how this idea can be implemented technically for the selected application. The results of the experimental study of this implementation convincingly demonstrate the possibility of preparing and adapting content to the schedule of tourist transport.

The stated tasks of information service for bus (and other) travel are divided into three subsets:

– search, collection, systematization of the required information content;

– substantiation and selection of competitive methods and delivering information content channels to the consumer, including in real time;

– substantiation and selection of the most effective methods and means of implementing the delivery of information content to consumers.

The analysis of sources showed that the tasks of the first subset are given the most attention.

Existing tourism technologies are intensively developing through the use of information technology. In the early stages of the formation of interest in tourist tours, modern multimedia technologies and communications are intensively used. In particular, virtual 3D tours using global satellite navigation tools allow tourists to remotely, but visually get acquainted with accommodation facilities, places of recreation and excursions [1]. Other multimedia technologies are also developing rapidly, such as audio tours and audio guides [2]. There are works devoted to automating the search, collection, storage, filtering and systematization of information to increase the flexibility and efficiency of its use by a specific consumer [3–5]. Of interest are studies that consider information technology as a tool for understanding the world, allowing to solve the problems of economic security of tourism and most effectively meet the complex needs of tourism services [6].

The considered particular problems of the first subset and their solutions are undoubtedly interesting for the development of tourism and travel, however, the area and objects of information services considered in this paper make it necessary to look for solutions focused primarily on mobile consumers. At the same time, it is important to use existing sources of information content (broadcast networks, pre-prepared audio and sound file content), or information content generated in real time.

The second subset of information service tasks - substantiation and selection of competitive methods and channels for delivering information content to the consumer, including in real time - is associated with the use of digital or analog channels and relevant standards for delivering information content to consumers. In [7], to intermodal support of the tourists transportation, it is proposed to use mobile service platforms (Mobility Service Platforms), which allow using standard smartphones as client devices. In [8], the use of dedicated automotive ad-hoc networks (VANETs), as well as FM radio broadcast networks, for access to infotainment content is considered, which reduces the cost of distributing content and increases system scalability.

Analysis of sources, as expected, showed the advantage of using digital content delivery channels and their corresponding standards and protocols [9]. However, digital and analogue broadcast technologies coexist with their own advantages and disadvantages, which should be evaluated according to the conditions of their use in travel information processes. For example, digital channels can only be used if there is an appropriate digital infrastructure: mobile Internet, wireless network infrastructure (for example, wifi), etc. In addition, the use of ordinary, in particular, news content is possible only if the client devices support the appropriate protocols and standards. Despite all the advantages of digital channels, it is quite obvious that the infrastructure of the bus and other mobile travel under consideration does not allow for full compliance with the formulated requirements. Apparently, the most popular and accessible (at least on the Russian Federation location) channel for the distribution of universal and news content is analog FM broadcasting. An important factor is the fairly wide support for receiving an analog FM signal by popular mobile devices.

The third subset of information service tasks – substantiation and selection of the most effective methods and means to implement the delivery of information content to consumers – is aimed at creating and experimental testing of prototypes of software and hardware devices that economically and at the same time provide the travel industry with the necessary information content.

Existing technologies are able to expand the range of information services provided, including to mobile consumers. The space of mobile consumers is mainly provided by wireless networks using cognitive radio technologies (Cognitive Radio - CR). The reasons for the creation, application and development of CR technologies are based on the following factors:

– inacc ssibility to use standard radio frequency channels;

– inefficiency of standard channel usage in time-frequency space.

A number of directions and applications of CR are described in [10, 11]. One concept is to share a known frequency resource, and the other is to look for a free frequency resource to use in real time. This approach is called dynamic spectrum frequency assignment and helps reduce the cost of systems based on CR. The development of CR technologies has led to the emergence of a number of standards related to dynamic spectrum use, such as IEEE 802.22 [12]. The standard defines policies and procedures for sharing communications between primary and secondary users of a common spectral region.

The development of CR technologies and their practical application are associated with software-defined radio (SDR) technology. The modern application of SDR technologies is also aimed at reducing the cost characteristics of CR [13]. It is expected that the intelligence of CR systems will lead to their ability to find available frequency bands and adapt SDR parameters to changing characteristics of the frequency spectrum. In [14], the idea of using CR technologies in the tasks of providing information services is developed.

One of the most advanced SDR architectures is the Universal Software Radio Peripheral (USRP) by National Instruments. Its potential capabilities make it possible to develop software-controlled transceivers adapted to specific applications for efficient use of the spectrum [15 – 19].

One such application is the reuse of frequency channels allocated for FM radio by so-called secondary users with little degradation in EMC performance, similar to the sharing of frequency channels in GSM mobile telephony. The peculiarity of broadcast channels (radio or television) is that these channels are busy all the time, regardless of the user's actions. This raises the problem of rational construction and use of the broadcasting network [20]. A separate issue is related to the characteristics of the source of information and the functionality of secondary users.

In [21], a variant of building a prototype information system to provide a small community of people with important local information based on USRP and LabVIEW using the concept of CR is presented. The main goal of the proposed solution resonates with the goal of this work in terms of creating an economical solution for the broadcasting system.

In [22, 23], the problem of monitoring the content of an information source and the technical quality of programs in broadcast channels is considered. Content monitoring can be used to model and predict problem situations based on the collection, processing and analysis of information. A striking example of a source of such information is broadcast news programs. In [24], one of the variants of such solutions is presented in the form of a hardware-software complex based on USRP and LabVIEW, which allows real-time rebroadcasting of streaming content selected by an expert on a given and free frequency channel. This solution also satisfies the need to deliver certain information content to the end user over a radio channel over a long period of time (during a trip), during which the frequency plan of radio stations can change many times.

An important feature of information messages transmitted over radio broadcasting channels is that after a while the information message becomes inaccessible to listeners. This circumstance dictates the need for prompt storage of the most significant fragments of information messages of broadcast channels on a file medium. A variant of such a solution is presented in [24] in the form of a hardware-software complex based on USRP and LabVIEW. It can be directly used to store in an IQ sample file an RF signal containing desired content for later playback on the selected channel.

For information support of long trips and excursions, there is a need to broadcast pre-prepared information content to consumers. At the same time, it is also rational to use free sections of FM radio frequencies. There are solutions that broadcast sound files prepared in a certain format according to the FM radio standard at a selected frequency [25].

Summarizing the above, we can draw the following conclusions:

- FM radio broadcasting standards are advantageous to use for information support of bus (collective) trips due to the fact that users do not need specialized receiving devices – standard FM receivers are sufficient;
- the use of cognitive radio technologies in the FM radio bands is quite well developed and can be used to solve the tasks;
- there are basic of hardware and software solutions options to support the individual information tasks, in particular, saving, reproducing and retransmitting information content, however, all of them are diverse (heterogeneous) in their software and hardware implementation, which makes it difficult to use them together as part of a single complex;
- users need methods and tools that provide them with prompt access to information content of any type, as well as tools that automate the search for free channels for broadcasting with the necessary information content.

The review and analysis of sources showed that cognitive radio technologies themselves are designed to solve two main tasks:

- search for free and sufficient to ensure the required quality of the signal transmission section of the FM frequency range;
- transmission of a signal containing the required information content in the selected frequency section of the FM band.

In general, however, the development of software and hardware devices that support the implementation of the formulated information support tasks follows three directions.

The first of them is aimed at enabling the operation of radio receivers that are not fully compatible in terms of frequency range, for example, automobile, smartphone receivers, etc.

The purpose of the second direction is to retransmit the signal of the selected broadcast channel on a different frequency. Such a problem arises in the process of moving travelers from one region to another, when the selected channel follows a different frequency plan in regional broadcasting. In Table 1 for example, a fragment of frequency plans for FM radio in Moscow and St. Petersburg is shown.

Table 1

Fragment of FM radio frequency plans

Radio stations	Frequency, MHz	
	Moscow	St. Petersburg
Radio Rossii	66.44	66,3
Business FM	87.5	107,4
Retro FM	88.3	88
Yumor FM	88.7	88,9
AvtoRadio	90.3	88,4
Radio Sputnik	91.2	91,5

The implementation of such a function allows travelers to listen to a pre-selected channel (or a plurality of selected channels). As you can see, in this application, there is a need to quickly detect a free and compatible part of the frequency range.

Finally, the third direction aims to broadcast the prepared information content on the selected frequency of the FM radio band. This content can be a previously recorded FM broadcast, as well as content chosen by the tour guide (such as an audio or music file). In the latter case, a software or firmware implementation of the corresponding modulator will be required. Note that a student can act as a traveler, and a lecture, presentation and other pre-prepared material can be used as content. In our opinion, this direction may be in demand in the current process of active use of distance forms of the educational process.

To solve the formulated tasks, the following set of tools is required:

- a tool to scan the selected frequency range (for example, the FM radio range) in order to select a free and sufficient, in terms of playback quality, part of the frequency range;
- a tool to scan the selected frequency band (for example, FM radio band) in order to select a channel with the desired information content;
- tools to perform, save and playback IQ-samples of the signal on the selected frequency of the FM radio band;
- a tool to quick (i.e. real-time) rebroadcasting of selected content in the specified frequency range;
- a tool to playback the multimedia content files in the FM radio standard in the selected frequency range;
- a tool to real-time transmit the speech information in the FM radio standard in the selected frequency range.

In particular, software and hardware solutions for scanning the selected frequency range using various types of USRP tools are quite fully considered in the sources [26-28].

An analysis of the existing solutions mentioned in the links above showed that all of the listed tools as a whole and individually can be implemented, however, they have a number of disadvantages and limitations, such as:

- lack of unity of software and hardware implementation, since they use different versions of the software development environment and equipment;
- they lack align information flows mechanisms, in particular, mechanisms to align the record, playback and retransmit streams of IQ-samples, necessary to ensure the continuity of playback, especially musical content;
- software components of well-known solutions practically do not use the full productivity of modern multi-core processors, thereby limiting the possibilities of computer processing of information.

Thus, one of the main tasks is to develop a set of virtual instruments, made in the same style, using the same development environment. A preliminary decision from this point of view is the choice of a compatible software development environment for virtual instruments, including version and release.

2. Materials and Methods

The goal and objectives of developing a hardware-software complex for prototyping information support tools stated in this paper can be achieved and solved only when using equipment that implements the principles of SDR and is supported by appropriate software. To date, there are, in our opinion, only two competitive options for such an implementation. Both options are similar in that they use a single hardware platform from Ettus Research, named as USRP. A feature of the current business process is that Ettus Research, owned by National Instruments (NI), is launching a number of self-branded off-the-shelf hardware products on the market that are partially compatible with similar NI products. At the same time, compatibility is achieved only at the level of the hardware platform (boards), and is destroyed when interacting with the corresponding software platforms. Obviously, we are talking about drivers that provide an interface with the corresponding software. Unfortunately, the sources contain extremely conflicting information about the levels of such compatibility. The most reliable, in our opinion, is an indication of the complete incompatibility of drivers for two conditionally "compatible" branches of USRP devices - by Ettus Research and by NI. However, each line has its own ways of building software and hardware prototypes of radio devices.

The "native" line from Ettus Research is aimed at open solutions built on the Linux OS and GNU Radio software (https://www.gnuradio.org/). NI's commercial line of devices has a much broader range of device support along with their drivers. However, only Windows OS is supported, and only native hardware. Limited Linux support exists only for LabVIEW, which allows only limited simulation problems to be solved that do not meet the goals of this study.

Unfortunately, during one experimental study with the same (or similar) set of USRP devices, it is not possible to obtain a comparative characteristic of prototype implementations using both described lines. The reason is the incompatibility of the firmware of the respective devices.

Based on the foregoing, the USRP hardware platform, integrated with NI's proprietary LabVIEW simulation software package, turned out to be a practically uncontested choice. The range of USRP devices is quite wide, but not all types of devices meet the conditions for solving the problem, despite their performance and price. So, bearing in mind the frequency range in which wireless networks of modern standards operate (2.4 GHz, 5 GHz), the selection conditions allow the use of only the following types [10]: USRP-2900/2901, USRP-2943-2945, USRP-2953-2955 and USRP-2974. Devices starting with USRP-2943 are classified as RIO, which dramatically increases their complexity and cost. In fact, the USRP-2900/2901 devices, if they can solve the tasks set, are the main contenders for the role of the created hardware platform.

The economic factor does not allow using either a standard spectrum analyzer, or the option of using USRP 2920 devices and others given in [15] for spectrum analysis in order to identify a free area cannot be used. It is important that the claimed USRP 2900/2901 devices have a significant advantage over the USRP 2920 device in terms of carrier frequency tuning range. The maximum frequency at which the USRP 2900/2901 can operate is 6 GHz, which hypothetically allows these devices to be used to solve many wireless communication problems [16].

Further, as basic solutions, a set of virtual devices presented in [14] is considered. This type of solution is classic for the LabVIEW software platform. Its advantage is not only an external presentation (front panel), like the appearance of a real measuring instrument, but also an extremely effective way to implement both interaction with USRP devices and simulation of signal generation and processing. The latter is directly related to the original programming paradigm using its own graphical language G. We note two important features of this design method. The first is the high speed of creating a project through the use of a powerful object library and the visibility of the implementation process, which is extremely important not so much in scientific research as in the educational process. On the contrary, in experimental scientific research, the most important feature is performance, and it is supported in many ways. Among them are the traditional interfaces with the .NET standard libraries, the file system, and other programming objects. But the main component, from our point of view, is the productive support for parallelism, which is one of the main features of the programming paradigm in LabVIEW. This topic requires special consideration and, of course, will be touched upon in future studies by the authors.

3. Results

3.1. Development of virtual instruments to scan the selected frequency range and make the spectral analysis

In [14], two virtual instruments are proposed, the first of which performs broadband scanning of the spectral range, and the second performs a detailed analysis of the spectrum. Both devices use the same device, but in different development environments. Broadband spectrum analysis is resource intensive, and as such, it was only possible to use the USRP 2901 in combination with the NI LabVIEW 2018 design environment. However, it was possible to implement detailed spectrum analysis in the more advanced (in terms of graphics) NI LabVIEW Communications Design Suite 2.0 environment. The reason for this is that LabVIEW Communications Design Suite 2.0 uses the graphics capabilities of the .NET platform for display, which requires additional computer resources. The found solution demonstrated the possibility of using the USRP 2901 device for the purposes of spectral analysis, however, it contradicts the requirement of the unity of software and hardware implementation formulated above.

Considering Microsoft's end of support for Windows 7, the minimum available version of LabVIEW Communications Design Suite is version 3.0. On the other hand, well-known and high-performance models built in the LabVIEW environment are also not competitive due to the limited support for the range of modern USRP devices. This means that the virtual instrument "WB Spectrum Example VIs (952012)" presented in [11] and described in [14] cannot be used further.

However, sufficiently accurate wideband analysis of the VHF and FM radio spectrum can be performed by the “Spectral Monitoring (Interactive)” virtual instrument, which is part of the LabVIEW NXG design environments versions 3.0 and 4.0.

Figure 1 shows the front panel of a virtual instrument that performs a broadband analysis of the spectral range relative to a selected center frequency. Note that when developing virtual instruments, we deviate from the traditional National Instruments front panel background, which is associated with the image of physical instrument panels.

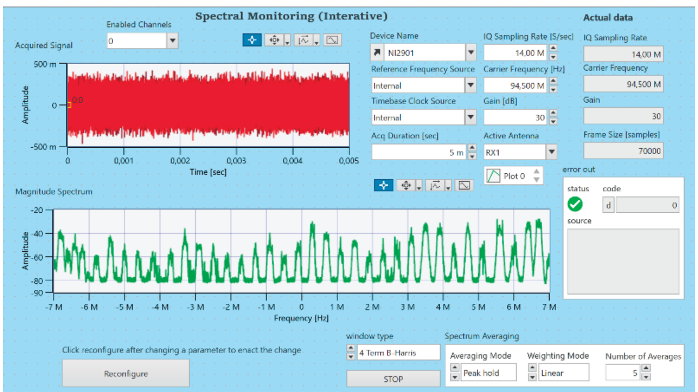

Figure 1. Wideband Spectrum Analysis VI front panel relative to selected center frequency

Instead, we use the concept of graphical association with VI functionality. For example, more clearly, from our point of view, the color separation of virtual instruments for recording a signal from virtual instruments for their playback.

To select the most promising section of the range, it is necessary to use a more accurate analyzer. Studies have shown that the virtual device described above (Figure 1) can be used in this role. A detailed analysis of the selected section of the spectrum is carried out by adjusting the center frequency (Carrier Frequency) and sampling rate (IQ Sampling Rate). Other VI settings are useful for experimental evaluation of the practically achievable characteristics of the software/hardware VI. And they are determined both by the characteristics of the computer component of the VI, and by the characteristics of the USRP device. The latter may have different characteristics that differ from passport data.

Note that the device is able to apply new settings in the current session, i.e. without restart. On Figure 2-4 shows the spectrum of the unused section of the range with a center frequency of 90.55 MHz, although such sections, as can be seen from Figure 1, you can choose quite a lot.

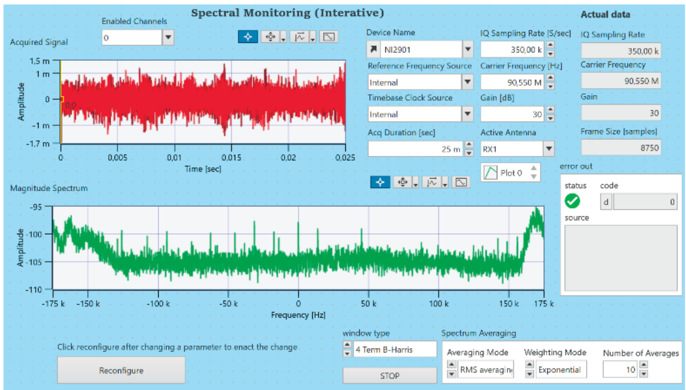

Figure 2. Spectrum shape of radio signal samples obtained with a sampling rate of 350 kHz

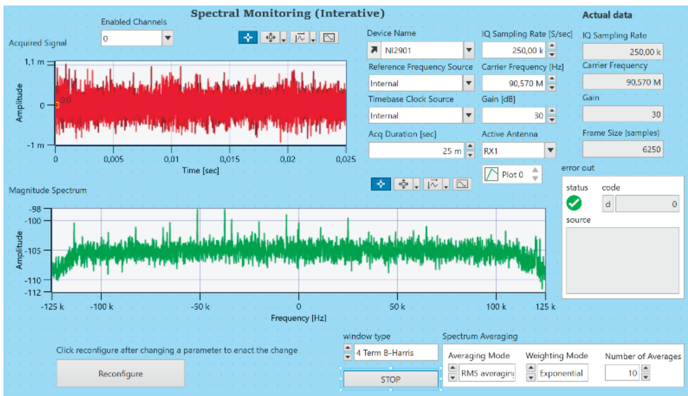

Figure 3. Spectrum shape of radio signal samples obtained with a sampling rate of 250 kHz

The spectrum shown in Figure 2 has an estimated value and is used to make a final decision on the possibility of using a free frequency section and its characteristics.

It was taken at a sampling rate of 350 kS/sec and clearly shows that the limiting sampling rate is 250 kS/sec and the center frequency should be increased by 20 kHz. The spectrum of this frequency section is shown in Figure 3.

The choice of the sampling frequency is critical to achieve minimum crosstalk while ensuring a sufficiently high quality of the broadcast signal of the selected radio station, as well as minimizing the overhead during transmission, in particular, minimizing the size of the file containing the recording of the IQ samples of the broadcast signal.

3.2. Development of virtual instruments to record, playback and retranslate the radio signals

The second object of development are virtual devices designed to record IQ-samples of the radio signal to a file and then play it back from the file at the selected frequency of the FM radio band. All the virtual instruments necessary for this have been developed and described in [14]. For completeness and convenience of perception, below (Fig. 4, 5) are the front panels of these devices.

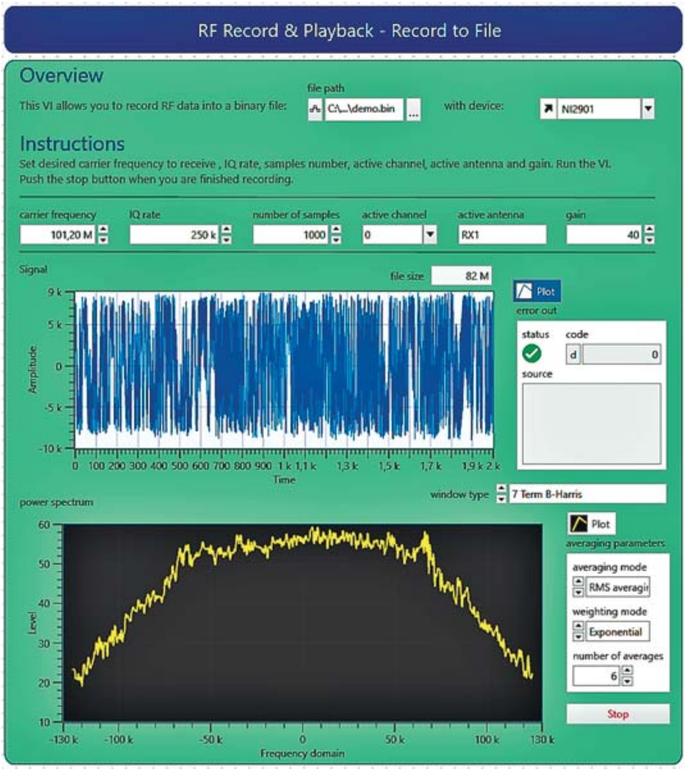

Figure 4. Virtual instrument to record the radio signal IQ-samples to a file

A distinctive feature of these devices is the ability to use both channels of transceivers present in the USRP 2901 devices. This feature was later used to develop the repeater VI.

The device also described in [14] was chosen as a prototype of the virtual repeater device. The control part of the front panel of this device is shown in Figure 6. Another interesting feature of the virtual instrument is the automatic configuration of the instrument to the connected USRP device. Note that the main property of the device is the ability to interactively re-tune it to another station, which allows you to smoothly, without acoustic artifacts, listen to the stream of broadcast broadcasting programs.

The disadvantage of the developed device is the lack of clarity (automation) of the choice of the broadcast channel and monitoring of the peak signal level. The property is also useful to design the conventional digital receivers, since, as a rule, in devices of wide application it is often impossible to select a channel whose signal level is below the threshold level chosen by the receiver designers.

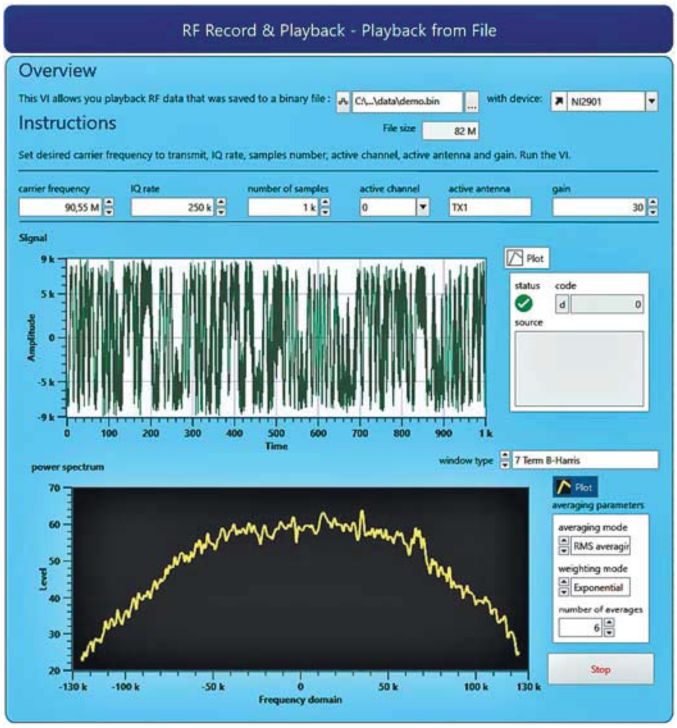

Figure 5. Virtual device to playback the *IQ*-samples from a file

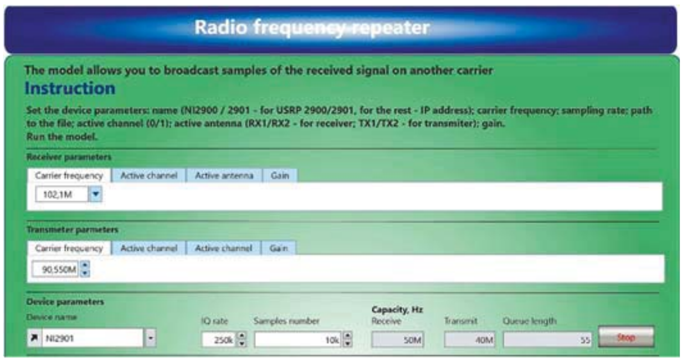

Figure 6. The control part of the front panel of the prototype of the virtual device-repeater

The main part of the front panel of the modified virtual instrument-repeater is shown in Figure 7.

We list a number of key features of this implementation. Firstly, it is the convenience of operational management of the choice of content source. At the same time, the association between the stations name and the broadcasting frequency is not lost – the device contains a linear scale of broadcasting frequencies, which can be used independently. The second feature, as mentioned above, is the ability to monitor the peak signal level.

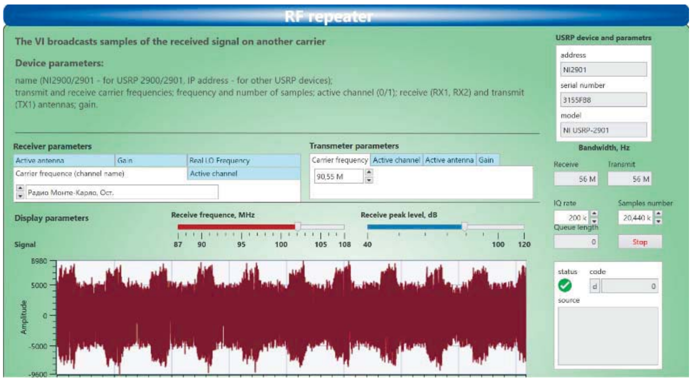

Figure 7. The main part of the front panel of the modified virtual instrument-repeater

This "seamless" switching is implemented by LabVIEW software, more precisely, by a queuing mechanism that allows signal samples to be written to and read from the queue asynchronously for playback by another channel of the USRP 2901 device. Of course, the queue parameters must be consistent with the type of signal samples, but they must simultaneously correspond to the technical capabilities of the computer that implements the software part of the complex. One of the indication elements of this correspondence is placed on the front panel of the device.

3.3. Development of virtual instruments to playback the file multimedia content and transmit the voice information using the FM radio standard

The general basis to create the virtual instruments are similar solutions, in particular, those described in [25]. Analogues are not complete solutions; therefore, they required significant processing. The created virtual instruments are equipped with the necessary settings that allow you to select the source of the acoustic signal, control the quality of the broadcast signal by selecting the sampling frequency, frequency modulation parameters and broadcast frequency. On Figure 8 shows the front panel of a virtual instrument that provides signal transmission, the source of which is a microphone.

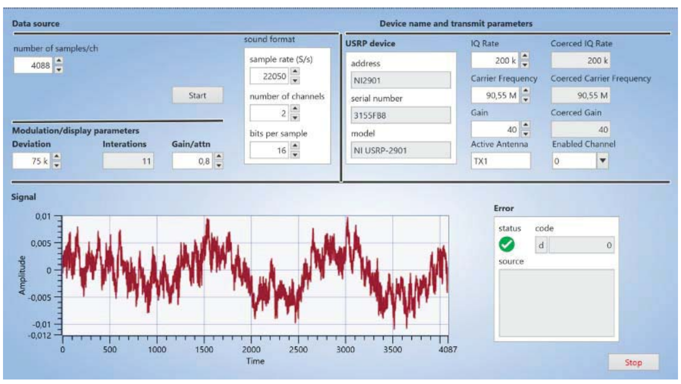

Figure 8. The part of the front panel of the virtual instrument-transmitter, the signal source of which is a microphone

The signal source for the virtual instrument shown in Figure 9 is a prepared multimedia (for example, music) file. Note that this instrument is capable of resampling (up- or down-sampling) while optimizing the quality of the transmitted content and the size of the source file.

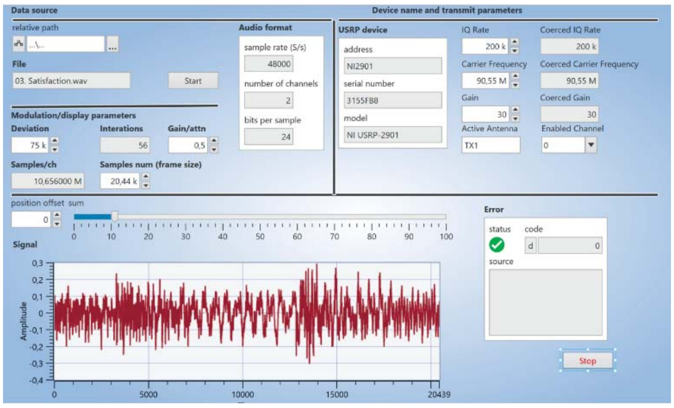

Figure 9. The part of the front panel of the virtual instrument-transmitter, the signal source of which is a file music content

4. Discussion

The given parameters of the virtual instrument to scan the frequency range shown in Fig. 1 match the capabilities of the NI USRP 2901 device. It is important that the device is dual channel. We also note that the performance of the complex depends very much on the selected computer equipment, the characteristics of the interface for interaction with USRP devices, the number and type of displayed parameters. Particularly demanding for computer equipment are tasks that require spectral analysis of a signal in a wide frequency band.

In the NI USRP 2901 device, the USB interface is most often criticized instead of the 1 Gbps Ethernet interface in the USRP 2920 devices and other more advanced and expensive devices. At the moment, there is no clear information about the conditions under which you can expect to achieve the maximum throughput of the USB version 3.0 interface - 5 Gbps. Of course, this is due to certain technical difficulties, however, work in this direction continues. In particular, D-Link announces the release of a new DUB-E250 USB-C 2.5G Ethernet adapter (Consumer Electronics Show 2021 - CES 2021), providing 2.5 times the bandwidth compared to 1 Gbps Ethernet.

We did not have the opportunity to experimentally test the capabilities and characteristics of this device together with the USRP 2901 device as part of a hardware-software system, however, undoubtedly, it is worth being critical of the claimed shortcomings of the modern USB interface in relation to at least the 1 Gbps Ethernet interface. In this regard, one of the most interesting tasks of studying the potential characteristics of this type of hardware and software systems is the experimental verification and comparison of the performance characteristics of USB interfaces versions 3.0, 3.1, 1 Gbps and 10 Gbps Ethernet. This, however, is beyond the scope of this work. We only note that the difference in the implementations of the USB interfaces in modern computers (both desktop and mobile) that participated in the experimental studies of the authors demonstrated a very strong influence of this factor on the performance of hardware and software systems of this type.

Of course, full optimization of the complex is impossible, and the best available solution for experimental research at the moment turned out to be a computer with the following main characteristics: Intel Core i7 processor; 16 GB RAM and disk memory on a PCIe SSD.

Comparative estimates: objective – based on the analysis of the spectra presented in Figures 2, 3, and subjective – based on listening to the recorded signal samples - showed that the choice of sampling frequencies above 200 kHz does not lead to a noticeable increase in the playback quality, but significantly increases the recorded files size. The experiment showed that the created virtual instruments provide the needs for solving the stated range of tasks of cognitive radio.

It is useful to compare estimates of the required bandwidth of the frequency modulated signal obtained analytically and experimentally. The most well-known method of analytical evaluation is the Carson rule, one of the forms of which looks like this:

$$B = 2F_m(1+\beta) \quad (1)$$

where

B – bandwidth of the frequency modulated signal;

F_m – modulating harmonic frequency;

$\beta = \frac{\Delta F}{F_m}$ – modulation index, где ΔF – frequency deviation.

The real modulating signal is not harmonic, however, by replacing F_m in (1) to the maximum frequency $F_{\max}$ in the spectrum of the real modulating signal, you can get a refined value of the required frequency band:

$$B = 2F_{\max}(1+\beta) \quad (2)$$

For the content in question, it is generally accepted that $F_{\max}$ = 15 kHz, and in accordance with FM radio standards, the recommended frequency deviation value is ΔF = 75 kHz, from which we obtain an estimate of the signal bandwidth B = 180 kHz, which is usually rounded up to 200 kHz with a margin. This estimate determines the choice of sampling rate and is in good agreement with the prototyping results described above. In [29], a similar comparison of estimates was made, but the simulation model was used in the experiment, which, however, had almost no effect on the result of the comparison.

Note that in the developed virtual instruments, the "Sample rate" parameter is chosen somewhat higher than the value sufficient for their reliable operation. This is due to the fact that according to the rules of practical application of the sampling theorem conclusions, the modulating signal with information content must be subjected to high-quality low-frequency filtering with a cutoff frequency $F_{\max}$. This is usually done in conjunction with the "upsampling" and "downsampling" procedures to improve the filtering quality. In the developed prototypes, these procedures are omitted for simplicity.

The practice of operating modern analog receivers shows that manufacturers control the quality of signal reception in different ways. One of the control parameters is the threshold signal level, which determines the specified reception quality. The developed virtual repeater device (Figure 7) has the ability to evaluate the threshold level of reliable reception used by the manufacturer, on the one hand, and ensure station detection, on the other hand. The last circumstance, from the standpoint of CR, is important for making a reliable decision about the presence of a free frequency part. This property can also be useful for the design of conventional digital receivers, since, as a rule, in devices of wide application it is often impossible to select a channel whose signal level is below the threshold level chosen by the receiver designers.

5. Conclusions

1. A number of applied task of cognitive radio are considered, aimed at expanding the functionality of information support for bus travel and tourism in general, as well as at achieving efficiency and flexibility in delivering various information content to travelers. These applied tasks impose special requirements on the methods and means of their implementation. The analysis of the requirements for the functional composition and characteristics of the software and hardware environment that implements the applications of cognitive radio technologies is carried out. The use of the USRP architecture and the LabVIEW software environment to solve a number of applied problems of cognitive radio is substantiated. In order to reduce the cost of systems, the USRP 2901 device, the youngest of the NI USRP device line, was selected for implementation.

In fact, the conducted research significantly expands the field of practical application of this type of devices, which is one of the main results of the work.

2. It is shown that in order to solve the considered CR problems, it is necessary to solve the following problems:

- perform a scan of the selected frequency range in order to determine the least loaded and sufficient, in terms of playback quality, part of the frequency range;
- perform a scan of the selected frequency range (for example, the FM radio range) in order to select a channel with the desired information content;
- perform reception, processing and writing to a file of digitized samples of a radio signal at a selected frequency with a given quality;
- perform real-time rebroadcasting of the selected content in the specified frequency range without quality loss;
- transfer file multimedia content in the FM radio standard in the selected frequency range with the specified quality;
- perform real-time transmission of speech information in the FM radio standard in the selected frequency range with the specified quality.

3. A set of virtual instruments has been developed that operate in a unified software and hardware environment (LabVIEW-USRP), which provides a systematic solution of current and future applied problems of cognitive radio. A feature of the developed virtual instruments is a rich variety of settings and indication parameters, which allows them to be used for educational and research purposes, including in the context of a distance educational process.

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ПРИМЕНЕНИЕ ТЕХНОЛОГИЙ КОГНИТИВНОГО РАДИО ДЛЯ ИНФОРМАЦИОННОЙ ПОДДЕРЖКИ АВТОБУСНЫХ ПУТЕШЕСТВИЙ

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Аннотация

Цель работы. Текущие задачи информационного сопровождения автобусных путешествий ограничиваются общей информацией о путешествии и экскурсиях, например, в виде цели и продолжительности тура в целом и отдельных поездок к объектам тура, плана и стоимости экскурсий. Во время основной части достаточно длительной поездки квалифицированный гид или сопровождающее лицо дает стандартную информацию об истории и достопримечательностях посещаемых или проезжаемых пунктов маршрута. На обратном пути к месту постоянной или временной дислокации путешественникам, как правило, предлагается посмотреть фильм из стандартной коллекции или просто отдохнуть. Главная проблема здесь – недостаточная функциональность, гибкость и оперативность формирования информационного контента, ограниченность каналов его доставки. Одним из вариантов решения данной проблемы является локальное радиовещание с использованием разнообразных источников информации и применение технологий когнитивного радио для доставки информации. Подразумевается, что подготовка информационного контента может выполняться и в реальном времени. Исследование эффективности данного предложения является целью данной работы. Обоснование возможности и оценка эффективности применения технологий когнитивного радио выполнено методом прототипирования программно-аппаратных устройств с использованием устройств USRP совместно с программным комплексом LabVIEW. *Результаты работы.* Сформулированы и решены следующие задачи прототипирования: сканирование частотного диапазона для определения свободного участка, достаточного для качественного воспроизведения; сканирование частотного диапазона для выбора канала FM радио с искомым информационным контентом; прием и запись в файл оцифрованных выборок радиосигнала с заданным качеством; ретрансляция в реальном времени найденного контента в выбранном участке диапазона частот; передача файлового мультимедийного контента в стандарте FM радио в выбранном участке диапазона частот с заданным качеством; передача в реальном времени речевой информации в стандарте FM радио в выбранном участке диапазона частот с заданным качеством. Обосновано применение устройств USRP совместно с программным комплексом LabVIEW для решения ряда прикладных задач когнитивного радио. Обоснован выбор устройства NI USRP 2901 с целью снижения стоимости создаваемого прототипа. Актуальность исследования обусловлена необходимостью повышения функциональности, гибкости и оперативности формирования и распространения информационного контента. В связи с этим, данная статья направлена на обоснование необходимости и возможности решения актуальных задач информационного обслуживания с применением технологий когнитивного радио. Для этого выполнен анализ проблем разработки устройств на основе парадигмы прототипирования; разработаны прототипы программно-аппаратных устройств для информационной поддержки автобусных путешествий; выполнена оценка эффективности предлагаемых решений; произведена экспериментальная проверка функциональности и качества разработанных прототипов. Материалы статьи, благодаря богатому набору параметров настройки и индикации разработанных прототипов программно-аппаратных устройств, позволяет использовать созданные виртуальные приборы не только для информационной поддержки любых путешествий, но и в учебно-исследовательских целях, в том числе, в условиях дистанционного образовательного процесса.

Ключевые слова: *когнитивное радио, FM-радио, автобусные путешествия, информационная поддержка, USRP, LabVIEW.*

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