Using SDR Technology in Mobile TroposcatterCommunication Systems

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***Abstract*—The paper analyzes the possible concept of practical implementation of modern mobile universal radio relay and troposcatter communication system with adaptation time, frequency, spatial and polarization parameters. The results choise communication protocols of universal radio relay - troposcatter communications system and preliminary open path testing this communication system are discussed.**

Keywords—Radio Relay and Troposcatter Communications Systems, SDR Technology, Adaptive Modulation, Wireless Interfaces and Communications Protocols.

I. Introduction

Last time, when need to create networks for special and commercial users with distance more than 100 km, interest in the troposphere over-horizon communication systems has increased again. In commercial networks using of troposcatter systems in some cases may be more economically feasible than satellite applications. Due to greater length of inter station intervals, the lines of troposcatter communication have an advantage over line-of-sight links, especially in connection with hard-to-reach areas, as well as in case of emergencies [1-5].

Specificity of physico-geographical conditions of Ukraine determines special role of the troposcatter communications, taking into account the favorable conditions of distant troposphere propagation of radio waves and the spatial selectivity of antennas. However, the equipment of the old park is not oriented to work in modern multiservice networks with the transmission of video data and speech, does not provide traffic for all the growing needs, is characterized by significant mass-dimensional parameters and power consumption.

The paper formulates proposals for construction mobile universal radio relay and troposphere communication system based of using Software Defined Radio (SDR) - technologies. Adaptation of parameters is provided: choice of central frequency and channel width, modulation circuits, threshold SNR, interval of periodic signal calibration, noise immunity, frame protection mode, preamble type and security interval, increased intelligence, interference protection, remote on a safe distance control [2, 4-6].

II. Requirements To Technical Characteristics Of Tropospheric Communication Systems

The energy balance equation for the line of over-horizon troposcatter communications has the form [1,3]

$$P_{RX\,[dB]} = P_{TX} + G_{TX} + G_{RX} + \eta_{TX} + \eta_{RX} - W_p - W_{pTR}$$

where W_p is free space pass losses. The troposphere pass losses W_{pTR} includes various components : climate correction W_{cl}, corrections taking into account terrain W_{ter} features, loss of antenna gain W_{al}, the presence of fast ΔW_{fast} and slow fading W_{slow} etc. Total value W_{pTR}, depending on the parameters of the troposphere channel interval, can reach 60…120 dB. Therefore, when justifying the requirements for the technical characteristics of the mobile universal radio relay – troposcatter communication system, it is advisable to focus on its operation in the most complex – troposcatter mode [3].

Calculations showed that at typical sensitivity of the receiver in the 6-cm band, to ensure communication reliability 95…98% at a distance up to *100km* and date rate up to 2 Mb/s, the equivalent isotropic radiated power should exceed *47...56dB*. This is ensured with output transmitter power $P_{TX} \approx$ *50…100W* and gain of parabolic antenna $G_{TX(RX)} \approx$ *30…36dB,* which corresponds to the diameter of the parabolic reflector of the antenna *90...140cm*. Such stations can be made portable or transported by small vehicles.

The main task in the development is to select the diversity parameters, the type and position of the digital modulation, the methods of noise-immune coding and digital signal processing in which the reliability of the communication is not less than the specified. Naturally, the SDR technology should be used as the basis for implementing such systems.

III. RECOMMENDATIONS FOR CONSTRUCTION UNIVERSAL MOBILE RADIO RELAY - TROPOSPHERIC COMMUNICATION SYSTEM

Noticeable increase in the ratio of the received signal to the threshold, and hence the reliability of communication in the troposphere mode, can be achieved by the joint use of: spatial diversity; adaptive choice of modulation parameters in the time and frequency domains, the method and speed of noise-immune encoding; optimize the processing of received signals. Therefore, the main task in the development of such a system is to adaptively select the diversity parameters, the type and position of the digital modulation, methods of noise-immune coding and digital signal processing in which reliable communication is not less than the specified.

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Spatial diversity gives a gain of up *to 3…6dB*. It is using error correction codes, for example Reed-Solomon or turbo codes, yields a gain of *5* to *8dB*. Gain up to *6dB* gives convolutional coding. Additional significant benefits are provided by the use of adaptive modulation in time and frequency domains, as well as optimization of processing methods. Due to the combined use of these methods, a total gain in energy up to 15...20dB can be achieved [4 ... 6]. It should be noted that when using SDR technology all these features are implemented programmatically and can be updated and expanded quickly.

Software-defined radio is reconfigurable radio platform that allows you to flexibly change radio frequency parameters on the fly. SDR systems have many advantages over traditional radio systems, including the possibility of software configuration and management, improving the system's performance, reducing its size, and minimizing design risks and time from concept development to the release of the finished product. Currently, there are many SDR platforms on the market. Characteristics of the one last most common are presented in Table 1 [7]. The table shows the noticeable advantages of SDR platform Lime SDR (Fig.1). This project is attractive low cost with very high technical characteristics.

The Lime SDR uses: a 12-bit A/D converter with

F_d *= 160 MHz* and a 12-bit DAC with F_d *= 640 MHz*; 2x2 MIMO; FPGA: Altera Cyclone IV EP4CE40F23; memory 2Gbit DDR2; USB 3.0 interface for communication with PC. The platform is based on Lime Microsystems LMS7002M radio chip, which contains LNA, receiver and transmitter mixers, receiver and transmitter filters, receiver gain control scheme, transmitter power control circuit, ADC and DAC.

The disadvantage Lime SDR is a relatively low upper operating frequency of 3800 MHz, which limits its use in L and S bands. However, the presence on the market of a wide band inexpensive transverters C, X and K bands removes this problem.

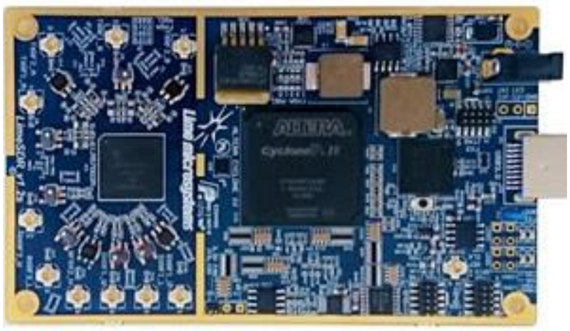

Fig. 1. Hardware platform Lime SDR

A convenient alternative to the SDR of the Lime SDR platform is the access radio access module - the Router Board hardware platform from MikroTik RB912uag-5HnD [8] also implemented on the basis of the SDR concept (see Fig.2 -router board) and Fig. 3 - an external radio module R11e-5HnD).

Structure laboratory sample of mobile radio relay – troposcatter communication system with adaptation in time, frequency, spatial, polarization is shown in Fig.4.

TABLE I. TABLE 1. COMPARATIVE CHARACTERISTICS OF SDR PLATFORMS

Parameter	SDR platforms					
	Hack RF One	Ettus B200	Ettus B210	Blade RF	RTL-SDR	Lime SDR
Frequency band, MHz	1 -6000	70 - 6000	70 – 6000	300 - 3800	22 - 2200	0.1- 3800
Bandwidth, MHz	20	61.44	61.44	40	3.2	61.44
ADC / DAC resolution	8 bit	12 bit	12 bit	12 bit	8 bit	12 bit
Sampling frequency, MHz	20	61.44	61.44	40	3.2	61.44 (limited speed USB 3.0)
The number of transmitting channels	1	1	2	1	0	2
Number of receiving channels	1	1	2	1	1	2
Operating modes	half-duplex	duplex	duplex	duplex	only reception	duplex
Interface	USB 2.0	USB 3.0	USB 3.0	USB 3.0	USB 2.0	USB 3.0
FPGA capacity	64 cells CPLD	75k	100k	40k (115k)	—	40k
Radio chip	MAX5864, MAX2837, RFFC5072	AD9364	AD9361	LMS6002M	RTL2832U	LMS7002M
Source code availability	Full	Only the scheme and software	Only the scheme and software	Only the scheme and software	—	Full
Frequency stability of the reference oscillator	±20ppm	±2ppm	±2ppm	±1ppm	—	±1ppm initial, ±4ppm stable
Output power	-10dBm+ (15dBm @ 2.4GHz)	10dBm +	10dBm +	6dBm	—	From 0 to10dBm (depending on frequency)
Cost	$299	$686	$1119	$420 ($650)	~$10	$299

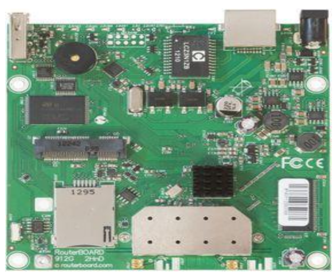

Fig. 2. R/modem MikroTik

Fig. 3. External r/modul

In case of troposphere radio waves propagation, the attenuation factor, unlike line-of-sight microwave links, does not depend on polarization. At the same time, in the over-horizon troposphere communication lines, as in radio-relay line of sight, the polarization plane (depolarization) of radio waves changes. Therefore, from the point of view of reducing the polarization fading in the mobile universal radio relay- troposcatter communication system being developed, it is expedient to use circular polarization.

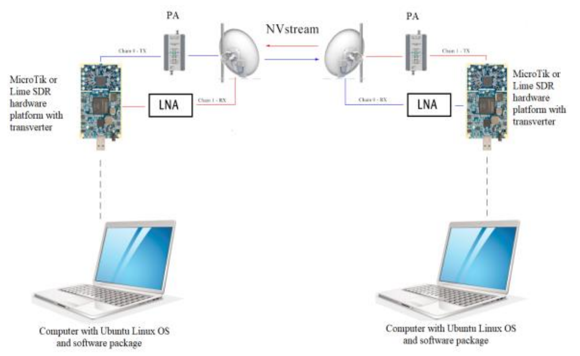

Fig. 4. Structure laboratory sample of universal mobile radio relay - troposcatter communication system

a) b)

Fig. 5. Features of feed horn with circularly polarization

It is important to note that in this case, in each half-set, signals with orthogonal circular polarizations (counter-rotating electric field vectors) are used for transmission and reception, which provides isolation of the receiving and transmitting paths up to 25 dB even without using complex and expensive duplexers. This eliminates inevitable losses in duplexers and, as a result, provides a gain in the noise ratio of each receiving path to 1 ... 1.5dB and the same approximately reduction in losses in the transmission paths of each half-set.

Each half-set can work in one of two modes:

- in the radio relay at open line-of-sight intervals, when only the *Lime SDR* or *Mikrotik RB912 uag-5hpnd* radio modem is used with an integrated radio module and an external radio module R11e-5HnD;
- in the mode of over-horizon troposcatter communica-tion, in which the transmission path is supplemented by a powerful solid-state amplifier with forced air cooling.

Transition from one mode to another is carried out by simple reconfiguration of half-sets - by connecting or disconnecting the output power amplifier of the transmitting path. The amplifying unit is connected by simple switching only if it is necessary to increase the communication range troposphere mode to *80...100km.*

At relatively small distances - less than 30..40km and the presence of an open interval, it is advisable to switch to a very economical high-speed microwave relay mode. With the use of *90cm* parabolic antennas, the output powers of up to 30 dBm and the sensitivity better than -110 dBm of the radio modules of the Mikro Tik hardware platforms are sufficient to provide reliable high-speed (up to *30...50Mbps*) communications in radio relay mode at open intervals.

In the proposed communication system, it is possible to flexibly change the data transfer protocol depending on the communication mode. In the microwave mode, the NV2 protocol is used, which realizes multiple access with time division TDMA, and in the troposcattering mode - *Nstreme-dual-slave* [2,3]. At the same time, the parameters of the radio modem are adjusted: the center frequency and the channel width are *2.5 / 5/10/20MHz* in the operating ranges of *5GHz* or *2.4GHz*, modulation types, SNR threshold, interval signal calibration interval, noise immunity, frame protection mode, preamble type and the value of the guard interval.

A very important feature of this protocol, which should be noted separately is the possibility of working with two radio cards - the *Nstreme* protocol. *Nstreme* protocol allows you to work in three modes:

- "*point-to-point*", when in the mode of connection from each side of the communication channel, one radio module is used;
- "*double point-to-point*" or Nstreme dual, in which two radio modules are used on each side of the radio channel - one transmitting, and the second receiving one;
- "*point - multipoint*", when there is one base station and several clients. In this mode, polling technology is implemented, similar to the *TokenRing* technology, which uses a special three-byte marker frame, moving around the ring and giving the owner the right to transfer information.

The difference in the system of communication in the troposphere mode is the use of an additional powerful output stage of the transmitter and a more stable non-stationary conditions of the tropospheric scattering of the *Nstreeme* communication protocol in the special mode - *Nstreme-dual-slave*, which allows to realize duplex communication using two spaced-apart by frequency (from tens to hundreds *MHz)* of radio channels. In order to optimize the bandwidth, it is envisaged to regulate the time access period within the limits of 1 ... 10 ms. In this case, it is possible to transmit data at a range up to 200km. The main advantages of this protocol in solving the problems of troposphere communication are:

- practical absence of restrictions on the range;
- no dependence of speed on connection distance;
- dynamically adjusting the protocol depending on the type of data transmitted and the resources used;
- poll of the base station by the client.

An important feature of this protocol is the ability to work with two radio cards. One radio card, for example, is more powerful integrated, works on transmission, and the second less powerful external, which is installed in a special jack, works on reception. This allows you to increase the bandwidth of the wireless channel by almost 2 times

IV. RESULTS OF EXPERIMENTS

The experiments were repeatedly conducted during Ukrainian VHF/SHF "Field Day" competitions by organizing amateur radio communications in 3 and 6 cm band. In addition, a large amount of observations were made in Kharkiv by receivering signals from the radio amateur beacons of 6 cm band with power about *0.2W* and panel antenna (*Ga≈16dB*), mounted in Pavlograd (distance approximately 180km). For reception SDR hardware platform MikroTik was used. The real profile of trace between beacon in Pavlograd and reception points in Kharkiv is shown in Fig.6.

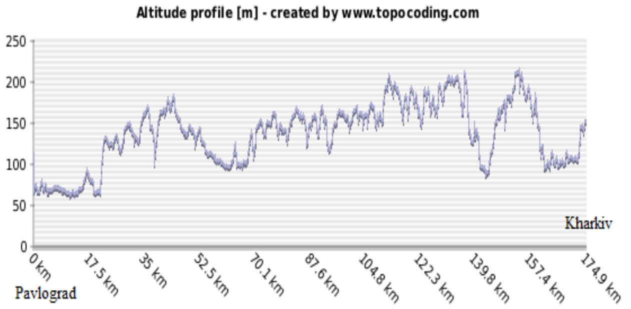

Fig. 6. Real trace profile

The trace, as seen from the graph in Fig. 6, is closed and the signal propagation was provided, mainly, due to their scattering by inhomogeneities in the troposphere. In Kharkiv there are offset parabolic antennas with a diameter 90 cm. The noise factor of the receivers was about 1.5 dB. Figure 7 shows the screenshot of the ASK signal received in Kharkiv. The signal-to-noise ratio reached 20 dB. Special methods to fighting with fading and noise - immune coding have not been used.

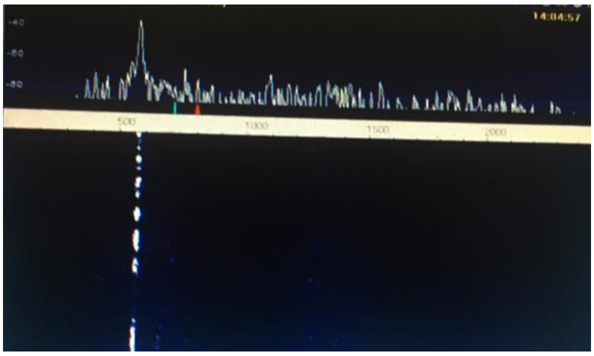

Fig. 7. Signal screenshot

The recording of the beacon signal level during June-July 2018 was carried out daily 10...14 times a day. In this case, no times when signal was not observed. Thus, the possibility of a stable signal reception at limited energy potential due to use tropospheric dispersion was experimentally confirmed. To check the operation of the communication system in the radio relay mode of video transmission with Mikro Tik hardware platform the *Team Talk* program was used. Figure 8 shows a screenshot of the window of the program *Team Talk*, when working in the videoconference mode.

With half-closed path and distance about 40 km, the signal levels at the inputs of both half-sets were about *-80dBm* and the maximum transmission rate was *36Mbit/s.*

V. Conclusions

1. On the basis analysis of demands to technical characteristics to troposcatter communication systemshave been formulated proposals practical implementation such systems on the basis SDR-technology and exchange the information by using modern adaptive communication protocols.

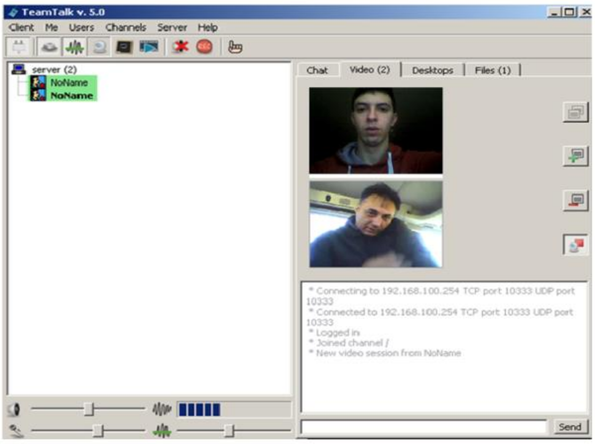

Fig. 8. Screenshot of the *Team Talk* window in video conferencing mode

2. The conception of universal radio-relay- troposcatter communication system with provision flexible change of data transmission protocol depending on the communication regime and adaptation of its parameters to real propagation conditions is proposed.

3. The possibility of stable reception of a signal at a distance up to 180 km with a limited energy potential due to use troposphere dispersion has been experimentally confirmed. In radio relay mode, with a half-closed route and a range of about 40 km in the transmission of video traffic, the transmission speed was 36 Mbit/s.

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