Investigation in Communication Behavior of Ionosphere Regions

Kareem AbdulAmeer Difar
Department of Telecommunication Engineering
Faculty of Electronic Telecommunication and
Information Technology
Politehnica University of Bucharest
Bucharest, Romania
e-mail: Kaad1983@gmail.com

Antonio Sorin Tasu
Department E119
Faculty of Electronics and Telecommunications
Maritime University of Constanta
Bucharest, Romania
e-mail: sorin.tasu@gmail.com

Abstract—**The Ionosphere is the region from 80 to 1000 km altitude above the Earth and it contains free electrons and ions that disturb the electromagnetic waves when the waves pass through it. The larger electrons density in the Ionosphere disturbs the GPS (Global Position System) signal that passes through it. The Ionosphere is a variable medium and its frequency behaviour cannot be predicted accurately. One issue arises because the Ionosphere near the equatorial region causes more electromagnetic signal errors compared to the North and South Poles. In this article, it has been proved that the GPS signals transmitted in equatorial regions are more refracted than the ones crossing the Ionosphere in the North and South Poles regions. The refraction index will decrease as the electron density increases. This subject is important, because if, for instance, a satellite is not working in military events, then there is an alternative communication solution, which employs Ionosphere as a reflector for long-distance terrestrial communication around the world. The free electrons in the Ionosphere create a high conductivity layer, which could be used as a perfect reflector for short waves in long-distance terrestrial communication. Two models, namely IRI (The International Reference Ionosphere)-Plas 2017 model and VOACAP model (The Voice of America Coverage Analysis Program), have been used in our simulations. These models were used to evaluate the quality of the Ionosphere in different regions for reflecting shortwaves frequencies and the perturbations for GPS signals. The selected regions for the simulations were Iraq, Romania, and Ukraine. The conclusion was that the Ionosphere efficiency of reflecting frequencies for Iraq region is better than the one for Romania and Ukraine regions.**

Keywords- IRI-Plas 2017; VOACAP; Refraction index.

I. INTRODUCTION

The Ionosphere is the region between 80km to 1000km of the Earth's atmosphere. The attentiveness in this region of free electrons is so great that it affects radio waves [1]. The Ionosphere was discovered when it was detected that radio waves can transmit over great spaces and therefore one then must adopt the existence of an electrically conductive layer in the upper atmosphere which could reflect the waves [2][3]. The electrically conductive region extends from about 50km to 500km above the ground and the10^6 m^3 at 50km to a maximum of 10^{12} particles per m^3 at 250-300 km [3][4]. The challenges of our work were the mathematical equations that cover the derivatives of these equations compatible with the three regions studied in this paper: Iraq, Romania and Ukraine. We had chosen five parameters together: phase and group velocity, plasma frequency, and error distance for the first and second order. All these parameters together prove that the equatorial region has an influence on the GPS signal more than other places on Earth, like the North Pole. In this paper, we have focused on evaluating the disturbances of the lower and upper regions of the Ionosphere from 80km to 1000km. Section II explains the state of art of this paper. In Section III, the related work is presented. In Section IV, the adopted model is described. Section V presents the effects of Ionosphere on the microwave signal with extended numerical examples in Section VI, including approaches for Ionosphere disturbances. The simulation and analysis of the refraction index of the GPS signal are illustrated in Section VII. Finally, Section VIII concludes and hints to future work.

II. STATE OF ART

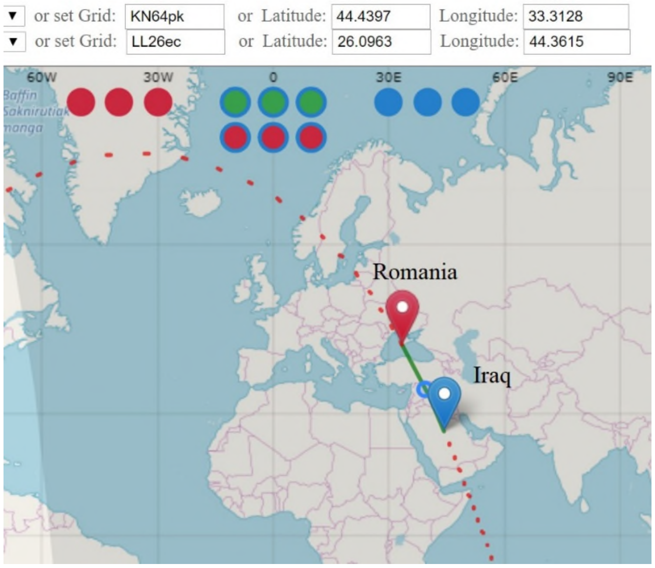
In [5], the distance error of GPS signal that propagates through the Ionosphere at equatorial is computed by using total electron content (TEC) which disturbs the radio wave propagation. In [6], two models, IRI-Plas 2017 and NeQuick, are used for computing the discrepancies of the Ionosphere. Here, the Ionosphere disturbance at high latitudes was investigated. The output parameters of these models are electron density and total electron content. The electron density is like TEC which disturb the radio wave propagation. In our paper, we used IRI-Plas 2017 model and we computed the refraction index that represents the strength of the signal in the Ionosphere medium depending on the electron density, for both Iraq and Romania regions. This parameter could be used as an indicator of the reflection capabilities of Ionosphere for long distance communications. VOACAP model was used by us provided by free professional high-frequency (HF) propagation prediction software to determine the quality for long distance communications, using the Ionosphere as a reflector [7]. This model is based on frequency. The parameter frequency is used to evaluate the Ionosphere disturbance at low and high latitudes by using VOACAP model. The range of reflected frequencies that can be used for long distance communication provided by VOACAP online model gives an indicator about Ionosphere capacity to reflect the communication signals.

ISBN: 978-1-61208-695-8

VOACAP provides the observer with more accurate results than IRI-Plas 2017 and NeQuick models, determining the highest usable frequency for the long-distance communications, using the Ionosphere as a reflector.

III. RELATED WORK

In Gsponer [8] showed that Maxwell equations can be used for many applications in Ionosphere for electron density, or another component in the atom that constitutes the plasma frequency. In M. K. Mardan and K. A. Hadi [3] used Baghdad, the capital of Iraq, to test the Ionosphere features, like the energy of an electron. In this paper, the group velocity of the signal that gives the accurate description of the medium of the disturbance of Ionosphere at Iraq space and Romania space was computed. By using VOACAP as in Fig. 1, several different latitudes have been chosen and compared from the point of view of real plasma frequency, instead of electron density. The VOACAP model provides us with the best frequencies reflected from Ionosphere which have good SNR. Based on these frequencies, it is possible to determine the Ionosphere disturbance can be evaluated.



or set Grid: KN64pk	or Latitude: 44.4397	Longitude: 33.3128
or set Grid: LL26ec	or Latitude: 26.0963	Longitude: 44.3615

Figure 1. The coordinates of Romania and Iraq [5]

IV. THE APPLETON–HARTREE EQUATION

IRI-Plas 2017 model has been used in the Appleton–Hartree equation (13). This is a general formula for the Appleton–Hartree equation that comprises all the effects in Ionosphere that could happen and affect the electrometric signal and may disturb the transmission [9].

$$n^2 = f(variables) general\, formula \tag{1}$$

$$n^2 = 1 - \frac{X}{1 - jZ - \frac{Y_T^2}{2(1-X-jZ)} \pm \left(\frac{Y_T^4}{4(1-X-jZ)^2} + Y_L^2\right)^{\frac{1}{2}}} \tag{2}$$

$$X = \frac{\omega_0^2}{\omega^2} \tag{3}$$

$$Y = \frac{\omega_H}{\omega} \tag{4}$$

$$Z = \frac{\nu}{\omega} \tag{5}$$

$$\omega_0 = 2\pi\, f_0 = \sqrt{\frac{N_e\, e^2}{\varepsilon_0\, m_e}} \tag{6}$$

$$\omega_H = 2\pi\, f_H = \frac{B_0\, e}{m_e} \tag{7}$$

TABLE I. ALL CONSTANTS ARE ILLUSTRATED BY THEIR MEANING

θ	Angle between the direction of propagation and the magnetic field.
Ne	Electron density.
$\omega = 2\pi f$	(Radial frequency).
f	Wave frequency.
ω_0	Electron plasma frequency.
ω_H	Electron gyrofrequency.
ε_0	Permittivity of free space.
B_0	Magnitude of the magnetic field vector.
m_e	Mass of electron.
ν	Collision frequency.

By neglecting the frictional force, assuming that we are in a cold, collisionless, magnetized plasma such as the Ionosphere, the refractive index for the carrier phase, n_P, can be expressed by the Appleton expression, for both ordinary (upper sign) and extraordinary (lower sign) waves.

Equation (2) can be simplified by neglecting the parameter Z that represents the ratio between the collision frequency and signal frequency, being dimensionless.

$$n_P^2 = 1 - \frac{X}{1 - \frac{Y_T^2}{2(1-X)} \pm \left(\frac{Y_T^4}{4(1-X)^2} + Y_L^2\right)^{\frac{1}{2}}} \tag{8}$$

V. EFFECTS OF IONOSPHERE IN MICROWAVE SIGNAL

For signals with frequencies ω >> ω_P (and hence ω >>ω_g), as in satellite communication for higher frequencies, equation (2) could be represented into a second-order Taylor approach which can be obtained in terms only up to (f^-4), similarly to [10].

$$n_P^2 = 1 - \frac{1}{2}X \pm XY_L - \frac{1}{8}X^2 - \frac{1}{4}X.Y^2(1 + \cos^2\theta) \tag{9}$$

$$Y^2 = Y_L^2 + Y_T^2 = (\frac{\omega_g}{\omega})^2 \tag{10}$$

$$Y_L = -\frac{\omega_g}{\omega}\cos\theta \tag{11}$$

$$Y_T = -\frac{\omega_g}{\omega} \sin\theta \tag{12}$$

Here, the positive sign signifies ordinary wave and the minus sign extraordinary wave. It is possible to identify the equation (8) by real parameters that describe the Ionosphere state in:

$$n_P^2 = 1 - \frac{a_1}{f^2} - \frac{a_2}{f^3} - \frac{a_3}{f^4} \tag{13}$$

Wherea_1, a_2, $a_3$and a_4 are constants. All these constants comprise the physical constants m_e, q, ϵ_0 , their units being in SI. The simulated data are provided by [7][11].

VI. NUMERICAL APPROACHES FOR IONOSPHERE DISTURBANCES

After inserting the physical contents and proceed with numerical calculations, the constants $a_1, a_2, and\ a_3$ can be expressed as follows:

$$a_1 = 40.3 \int_{T_X}^{R_X} N_e \, dl \tag{14}$$

$$a_2 = 1.1284.10^{12} \int_{T_X}^{R_X} N_e \, B \, \cos\theta \, d \tag{15}$$

$$a_3 = 812.42 \int_{T_X}^{R_X} {N_e}^2 + 1.5793.10^{22} \int_{T_X}^{R_X} B^2 \, N_e \, (1 + \cos^2\theta) dl \tag{16}$$

n_P^2 , Y^2 ,a_1 ,a_2 ,a_3 and n_P as shown in [9][12][13]

These parameters $a_1, a_2, and\ a_3$ will determine the error distance for all electromagnetic waves that propagate in the Ionosphere. In this paper it has been used GPS signals. The GPS signals are in microwaves frequencies. These waves usually refract tens of meters in the ionosphere. But shortwaves will be refract hundreds of meters. The free electrons and ions are responsible of these error distance and especially the free electrons because they are lighter than ions. This error distance is significant in the Equatorial region because they highly concentrated there. The most important parameters is a1 because it depends mainly on the electron density and no other factor. The second parameter depends on magnetic field that is very weak in Equatorial regions and mid-latitudes. But in the Poles the magnetic field is very large. This work is specifically employed for low latitudes that comprises Iraq region and mid latitude that comprises Romania and Ukraine.

VII. SIMULATIONS AND ANALYSIS

A. The simulations and analyses in Iraq and Romania regions by using IRI-Plas 2017 model.

Fig. 2 and Fig. 3 show that the refraction index in Iraq is smaller than the one in Romania. In Fig. 4 and Fig. 5, the group velocity of GPS signals for Romania region is larger than in the Iraq region. The results are mentioned in Table II and Table III.

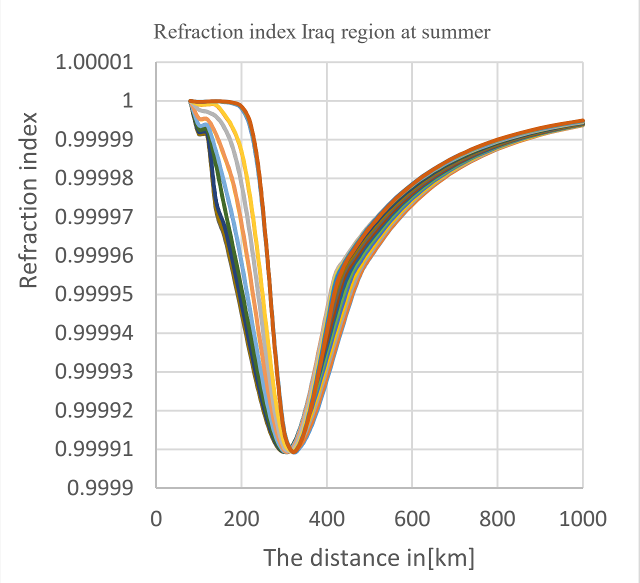


Figure 2. Refraction index Iraq region at summer

TABLE II. REFRACTION INDEX IN IRAQ REGION AT SUMMER.

Index	Refraction index distance [km]	value
1	350	0.99991
2	400	0.99992
3	600	0.99997
4	1000	1.00000

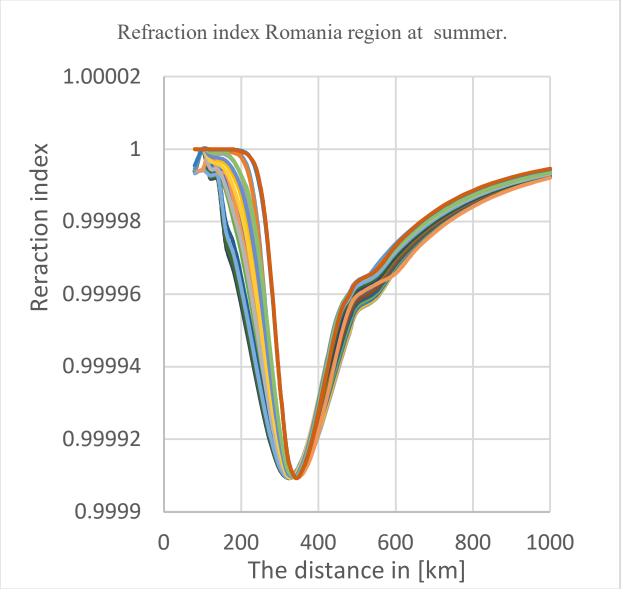


Figure 3. Refraction index Romania region at summer.

The curves in Fig.2 and Fig.3 represent all the hours in one day. These results have shown higher refraction index for Romania, compared to the Iraqi region. Higher refraction index means low perturbations in the Ionosphere region. It is definitely clear that Iraq region is a better place for reflecting higher frequency, by using Ionosphere as a reflector. The Romanian region is a better place for GPS signal, penetrating the Ionosphere with low error-distance.

TABLE III. REFRACTION INDEX ROMANIA REGION AT SUMMER.

Index	**Refraction index distance [km]**	**value**
1	350	0.999925
2	400	0.99992
3	600	0.999975
4	1000	1.000000

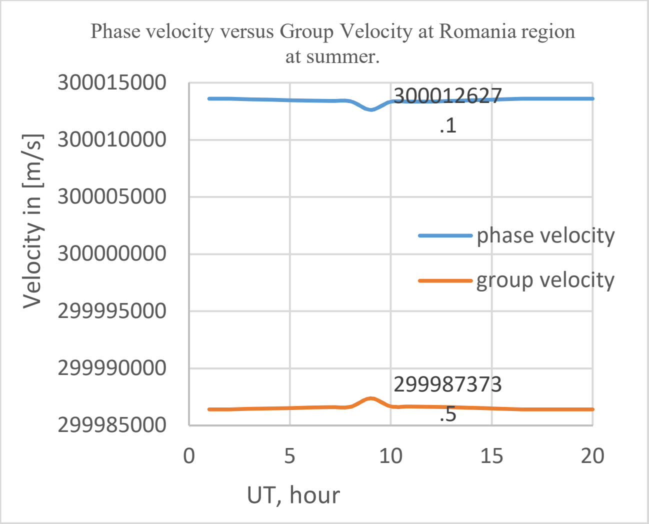


Figure 4. Phase velocity versus Group Velocity at Romania region.

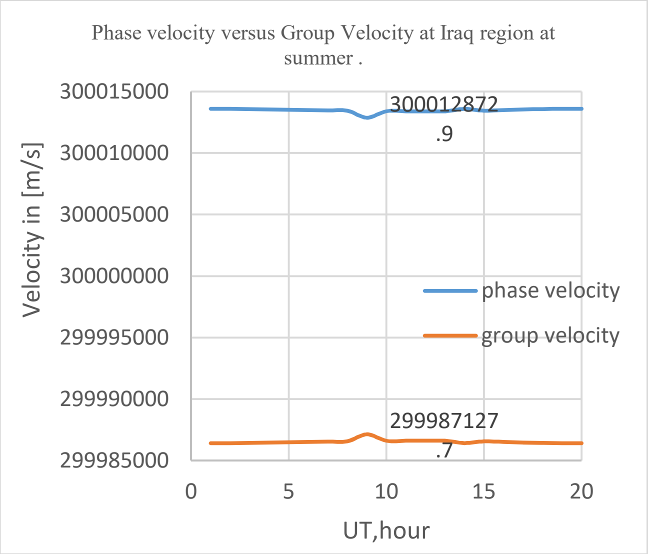


Figure 5. Phase velocity versus Group Velocity at Iraq region.

TABLE IV. COMPARISON BETWEEN ROMANIA AND IRAQ.

	Iraq		**Romania**	
1	***Phase velocity [m/s]***	***group velocity [m/s]***	***phase velocity [m/s]***	***group velocity[m/s]***
2	300012872.9	299987127.7	300012627.1	299987373.5

In this section, the refraction index is determined by simulations using a GPS signal. This refraction index shows the disturbance of Ionosphere. Higher disturbance means good reflection medium for higher frequencies. This results could be used as an estimate for the quality of the signal for long communications around the world, using reflection on Ionosphere.

B. *The simulations and analyses for Iraq, Romania and Ukraine regions by using VOACAP model.*

In this section, a VOACAP model is used to predict the high-frequency propagation in communications, using Ionosphere as a reflector. The quality of the Ionosphere space reflection was evaluated for two scenarios. One scenario assumed a long communication channel between Iraq and Romania, and the second scenario used a communication between Romania and Ukraine, which takes place at higher latitude. The results obtained for the reflection quality on Ionosphere were correlated with the results provided by the IRI- Plas 2017 model on refraction index and electron density.

By using online data of VOACAP model in 2018, the highest usable frequency for the communication link between Iraq and Romania was obtained. The results are presented in Fig. 6; the three curves represent the best signals with the highest SNR, maintained for at least half a day. The results demonstrate that the highest usable frequency reached up to 20 MHz, for the best signal that has the highest SNR. In Fig. 7, the highest usable frequency for the communication link between Romania and Ukraine was obtained. Romania and Ukraine have higher latitudes than Romania and Iraq. The results are shown here demonstrate that the highest frequency reached up to 7 MHz for the best signal that has the highest SNR. The comparison between Fig. 6 and Fig. 7 is shown in Fig.8, by using the mean values of the three frequencies from Fig. 6 and Fig. 7. Now, it is very clear that the Ionosphere disturbance at the space between Iraq and Romania is higher than that of Ukraine and Romania, because they have low latitudes and highest plasma frequency, as shown in Table V. Based on the previous results, it is definitely clear that low latitudes have higher disturbance than higher latitudes.

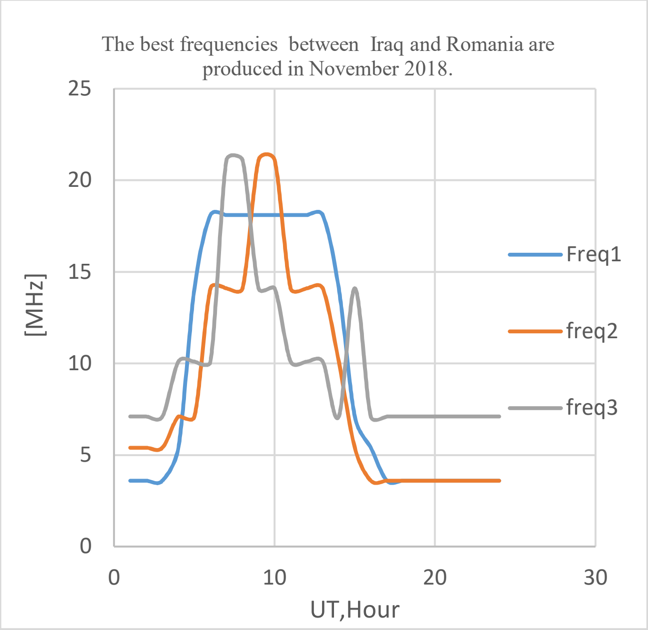


Figure 6. The best frequencies between Iraq and Romania are produced in November 2018.

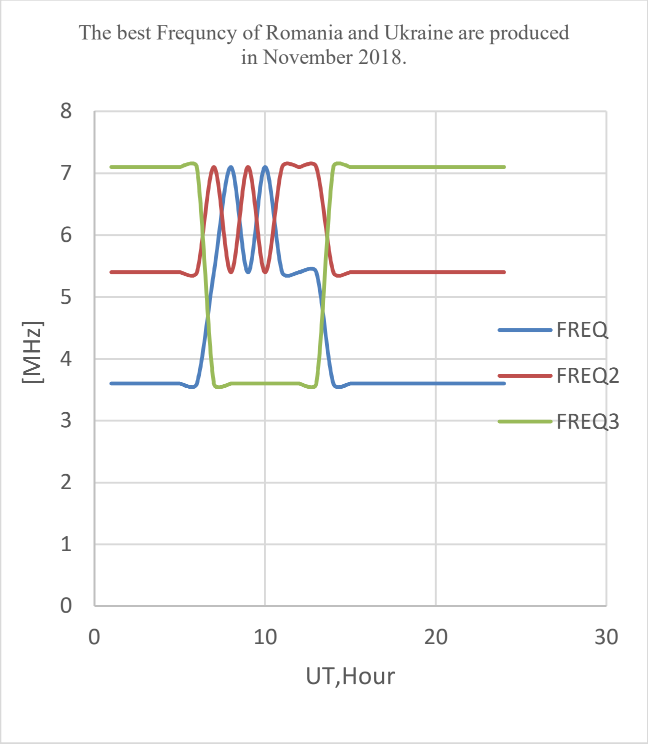


Figure 7. The best Frequency of Romania and Ukraine are produced in November 2018.

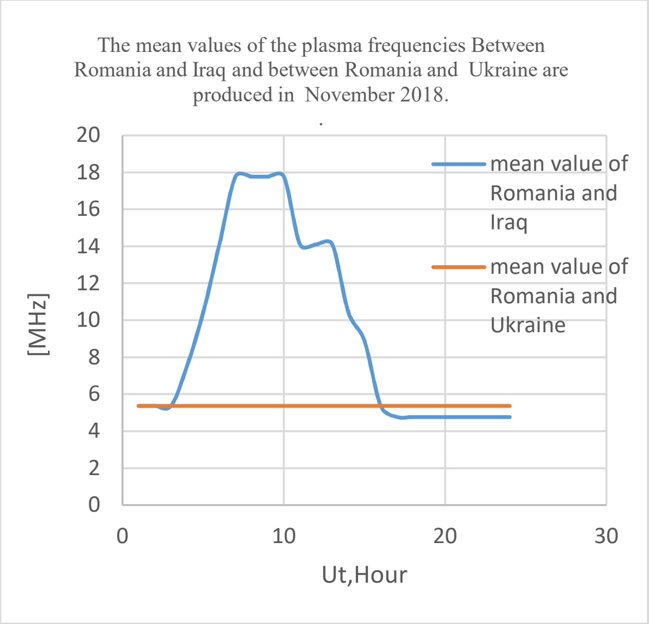


Figure 8. The mean values of the plasma frequencies Between Romania and Iraq and between Romania and Ukraine are produced in November 2018.

TABLE V. THE REFLECTED FREQUENCIES FOR LOW AND HIGH LATITUDES.

Regions	**Iraq and Romania**	**Ukraine and Romania**
time	***The mean value frequencies in [MHz]***	***The mean value frequencies in [MHz]***
10 A.M	18	5
15 P.M	10	5

VIII. CONCLUSION AND FUTURE WORK

In this paper, Iraq, Romania and Ukraine regions were investigated for the Ionosphere perturbations. The results that are based on IRI-Plas 2017 model show that Iraq has a lower refraction index than Romania in the Ionosphere. The refraction index is decreased because the electron density is higher around the equatorial region, which is closer to Iraq than Romania. As a consequence, the group velocity in Iraq region is lower compared to Romania region, as shown in Table IV. From these results, it is expected to have a higher reflection Ionosphere medium in Iraq, because Iraq is located at low latitudes compared with Romania and Ukraine. VOACAP model depends on the frequencies that are reflected directly from the Ionosphere. The results produced by VOACAP model have confirmed this conclusion, but they have also provided a better picture of the Ionosphere reflection capabilities by producing an indication of the frequency range that is usable for long distance communication. We plan to investigate the phenomenon of creating artificial Ionosphere that reflects broader bandwidth and frequencies for poor reflected frequencies region in the Ionosphere.

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