Determination of the Annual Optimal Reliable Frequency for Different Transmitter/Receiver Stations Distributed over the Iraqi Territory

Samar A. Thabit[1*], Khalid A. Hadi[1], Loay E. George[2]

[1]Department of Astronomy & Space, College of Science, University of Baghdad, Baghdad, Iraq
[2]University of Information Technology & Communication, Baghdad, Iraq

Abstract

This paper aimed to determine the Optimal Reliable Frequency (ORF) that can maintain certain connection link between different transmitter/receiver stations laid over the Iraqi territory. Three different transmitting sites were chosen as tested stations located in the northern, central, and southern regions of Iraq. These sites are Mosul, Baghdad, and Basra, respectively. In this study, the years 2009 and 2014, which represent the minimum and maximum years of solar cycle 24, were chosen to examine the effect of low and high solar activity on the determined ORF. The datasets of the Best Usable Frequency (BUF) were calculated using the ASAPS international communication model. An analytical study was made on the generated BUF parameter dataset of the annual time for the adopted years. Also, an analytical simulation was made for the suggested ORF parameter depending on the BUF parameter datasets. The results of this simulation showed that the suggested ORF parameter can be represented by polynomial equation of different orders. The suggested formula was determined depending on different tested parameters (path length, bearing, time (day) and BUF values). For this purpose, a certain program was built using a visual basic programing language (VB6). The suggested ORF parameter was investigated for the annual time for the three sites of the years 2009 and 2014.

Keywords: Ionospheric Parameters, BUF, HF Communication, ORF, Ionospheric Simulation

<div dir="rtl">

أستقبال مختلفة موزعة فوق الاراضي /حساب قيم التردد الموثوق السنوي الأمثل لمحطات أرسال العراقية

سمر عبد الكريم ثابت*[1]، خالد عبد الكريم هادي[1]، لؤي ادورد جورج[2]

[1]قسم الفلك والفضاء، كلية العلوم، جامعة بغداد، بغداد، العراق

[2]جامعة تكنولوجيا المعلومات والاتصالات، بغداد، العراق

الخلاصة

يهدف هذا البحث إلى حساب التردد الموثوق الأمثل (ORF) الذي يمكن أن يحافظ على ارتباط اتصال معين بين محطات الإرسال / الاستقبال المختلفة الموجودة فوق الأراضي العراقية. تم اختيار ثلاثة مواقع إرسال مختلفة كمحطات اختبار تقع في المناطق الشمالية والوسطى والجنوبية من المنطقة العراقية ، وهذه المواقع هي الموصل وبغداد والبصرة على التوالي. في هذه الدراسة ، تم اختيار عامي 2009 و2014 اللذان يمثلان الحد الأدنى والأقصى لسنوات الدورة الشمسية 24 لأختبار تأثير النشاط الشمسي المنخفض والعالي

</div>

_____

*Email: Samarthabit89@yahoo.com

<div dir="rtl">

على قيم التردد المحسوبة. تم حساب مجموعة البيانات الخاصة بأفضل تردد مستخدم (BUF) باستخدام نموذج الاتصال الدوليASAPS. تم إجراء دراسة تحليلية على مجموعة بيانات معامل BUF للفترة السنوية للأعوام المعتمدة في الدراسة. كما تم إجراء محاكاة تحليلية لمعلمة ORF المقترحة اعتمادًا على مجموعات بيانات معلمة BUF. أظهرت نتائج هذه المحاكاة أنه يمكن تمثيل معلمة ORF المقترحة بمعادلة متعددة الحدود ذات أسس مختلفة. تم تحديد الصيغة المقترحة اعتمادًا على معلمات مختلفة تم أختبارها (طول المسار ، الزاوية، الوقت (اليوم) وقيم التردد الأمثل). لهذا الغرض، تم بناء برنامج معين باستخدام لغة البرمجة فجول بيسك (VB6). تم التحقق من معامل ORF المقترح للفترة السنوية للمواقع الثلاثة المنتخبة وللعامين 2009 و2014.

</div>

Introduction

    The ionosphere is the upper part of the atmosphere that extends at 60-450 Km. It is a highly ionized region due to the Sun UV radiation [1]. The ionosphere consists of different layers because of different wavelengths in the Sun UV spectrum [2]. Layers of the ionosphere are different during day and night, as illustrated in Figure-1, which reflect or refract the wave depending on the wave frequency. Each layer may reflect properly a specific band frequency [1]. The radio waves at high frequency band (HF-band 3-30 MHz) represent the primary communication resources that are back to Earth at distance from the transmitting station [3]. The ionosphere may act as an effective reflector on frequencies below 30 MHz. It allows radio wave propagation to distances of many thousands of kilometers, while the radio signals of frequencies above 30 MHz usually penetrate the ionosphere [1]. Sky wave propagation method can propagate signals over a great distance; and usually the high frequency (HF) band is used for sky wave propagation [4].
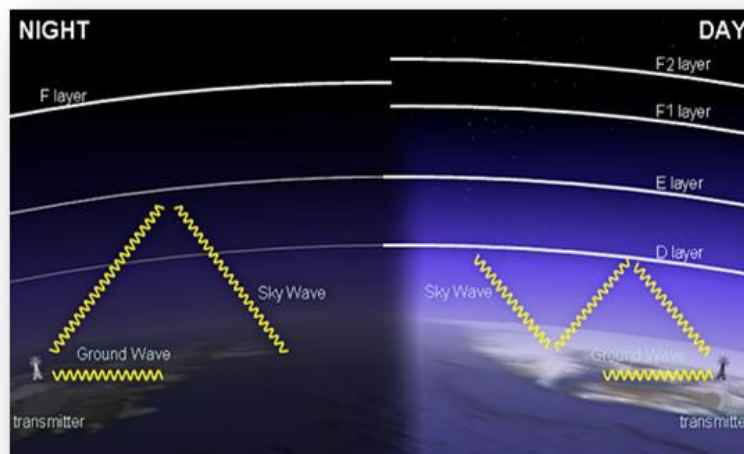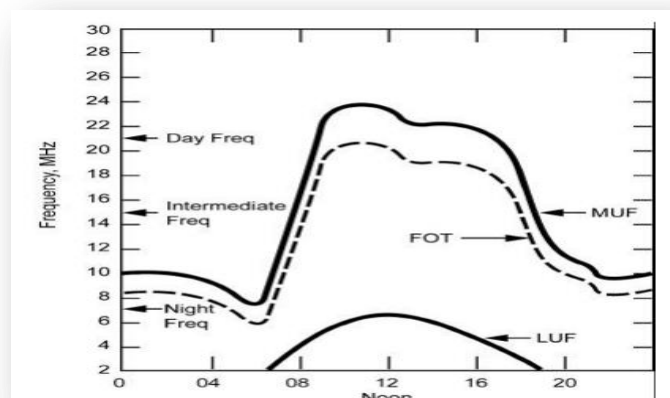

Figure 1- The structure of the ionosphere [5].

Figure 2- The ionospheric parameters [6].

Ionospheric Communication Parameters

The ionospheric parameters represent important parameters in HF communications to determine the best range of reliable frequencies that are reflected from the ionospheric layers between two terminals at specific time [7], as shown in Figure-2. The MUF, LUF, FOT and BUF parameters represent the main ionospheric parameters that can determine the best communication frequencies [3]. The ionospheric parameters can be defined as follows

1. The Maximum Usable Frequency (MUF): The highest frequency at which radio wave is returned to Earth by reflection from the ionosphere, which can be used to transmit over a particular path under given ionospheric conditions at a specific time, the median value of MUF working 50% of the time [8].

2. The Optimum Working Frequency (OWF): Also called the Optimum Traffic Frequency (FOT), which is the most practical operating frequency that one can rely on to have the least number of problems. The OWF is about 85% of the MUF [9].

3. The Lowest Usable Frequency (LUF): The lower frequency that allows reliable long-range HF radio communication between two stations by ionospheric refraction. It is exceeded by the operational MUF on 10% of the specified period [9].

4. The Best Usable Frequency (BUF): The frequency from the specified set with the maximum signal to noise ratio (S/N), which also satisfies the specified minimum take-off angle, the required S/N ratio, and the probability level. The BUF graph for each hour is selected by the frequency set user and determined on the   basis of ionospheric conditions and the user-specified system details [10].
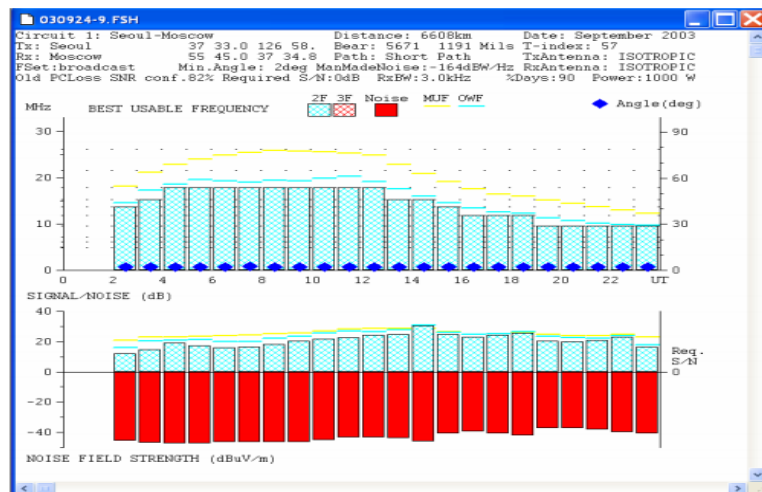

Figure 3- Base to base BUF frequency [10].

ASAPS HF Propagation Model

Many organizations have developed HF ionospheric communication models in order to provide more accurate usable frequencies that are maintained between transmitter and receiver stations over long distances. The performance of HF communication models has been developed progressively, starting in the 1930's with studies by radio scientists and engineers in some countries [3]. The Australian government's IPS Radio and Space Services HF propagation prediction method is known as the Advanced Stand Alone Prediction System (ASAPS). ASAPS is able to predict sky wave radio communications for the HF and VHF radio spectrum. ASAPS represents the development of the IPS Radio and Space Services of the Australian Bureau of Meteorology, merging the features of the original IPS method with the ITU-R / International Radio Consultative Committee (CCIR) models [11]. ASAPS prediction is more accurate than that of other systems and is especially accurate when driven from the T index, because this index is used to quantify the response of the ionosphere to solar activity.

Test and Results

In the present work, a study was made to determine the OTF value that can maintain a certain communication link between different transmitter/receiver stations laid over the Iraqi territory. The selected sites are Mosul (43.119°E, 36.335°N), Baghdad (44.401°E, 33.341°N), and Basra (47.780°

E, 30.508˚N), which are distributed respectively on the northern, central, and southern regions of the study area. The selected sites were selected to represent transmitter stations. Eighty different locations were selected for each station (8 directions and 10 distances) to represent receiver stations. The calculation of the geographic coordinates was performed by building a program using Matlab programming language. The calculations were made depending on the values of the geodesic parameters which were adopted in this research (path length (100, 200, 300, …, 1000) km and bearing (0, 45, 90, …, 315) degree), calculated using equations (1) and (2). Samples of the geographical coordinates (latitude and longitude) for the locations of the receiving stations distributed over the studied area are illustrated in Table-1.

$$\lambda = \frac{\Delta x}{\Delta \text{ long.}} + \lambda_\circ \tag{1}$$

$$\varphi = \frac{\Delta y}{\Delta \text{ Lat.}} + \varphi_\circ \tag{2}$$

$$\Delta y = \text{Path length} * \cos(B) \tag{3}$$

$$\Delta x = \text{Path length} * \sin(B) \tag{4}$$

$$\Delta \text{ Lat} = \frac{2\pi R}{360} \tag{5}$$

$$\Delta \text{ Long} = \frac{2\pi R}{360} \cos(\varphi_\circ) \tag{6}$$

where (λ, $\lambda_\circ$) and (φ, $\varphi_\circ$) are the longitude and the latitude values of the receiver and transmitting stations, respectively, Δy is the distance between two points along a vertical of latitude, and Δx is the distance between two points along a parallel of longitude; B: Bearing; R: Radius of Earth.

Table 1- Samples of geographical coordinates (latitude and longitude), path length, and bearing for the receiving stations distributed around the transmitting stations

Path length (Km)	Bearing (Degree)	Latitude (Degree)	Longitude (Degree)	Station Name (R_x)
Mosul (T_x)				
100	0	37.234	43.119	Duhok, Zakho
	45	36.971	43.908	Duhok, Aqrah
	90	36.335	44.235	Erbil, Shaqlawa
	135	35.699	43.908	Kirkuk, Makhmur
	180	35.436	43.119	Saladin, Al-Shirqat
	225	35.699	42.330	Nineveh, Hatra
	270	36.335	42.003	Nineveh, Sinjar
	315	36.971	42.330	Nineveh, Tel Afar
200	0	38.134	43.119	Turkey, Çatak Van
	45	37.607	44.698	Iran, West Azerbaijan,Urmia
	90	36.335	45.352	Iran, West Azerbaijan
	135	35.063	44.698	Sulaymaniyah, Chamchamal
	180	34.536	43.119	Saladin, Baiji
	225	35.063	41.540	Nineveh, Al-Ba'aj
	270	36.335	40.886	Syria, Al-Hasakah
	315	37.607	41.54	Turkey, Ardıç Köyü
Baghdad (T_x)				
100	0	34.240	44.401	Saladin, Al-Daur
	45	33.977	45.162	Diyala, Muqdadiyah
	90	33.341	45.477	Diyala, Baladrooz
	135	32.705	45.162	Wasit, Al-Suwaira
	180	32.442	44.401	Babylon, Hilla
	225	32.705	43.640	Al Anbar, Razazza Lake
	270	33.341	43.325	Al Anbar, Ramadi

	315	33.977	43.640	Saladin, Samarra
	0	35.140	44.401	Kirkuk, Daquq
	45	34.613	45.923	Iran, Kermanshah
	90	33.341	46.554	Iran, Ilam
200	135	32.069	45.923	Wasit, Al-Hayy
	180	31.542	44.401	AlQadisiya, Hamza
	225	32.069	42.879	Al Anbar, Ar Rutba
	270	33.341	42.248	Al Anbar, Ar Rutba
	315	34.613	42.879	Saladin, Baiji
Basra (T_x)				
	0	31.407	47.780	Iran
	45	31.144	48.518	Iran, Khuzestan
	90	30.508	48.824	Iran, Khuzestan
100	**135**	29.872	48.518	Arabian Gulf
	180	29.609	47.780	Kuwait, Al Jahra
	225	29.872	47.042	Basra, Al-Zubair
	270	30.508	46.736	Basra, Al-Zubair
	315	31.144	47.042	Thi Qar, GIBAYSH
	0	32.307	47.780	Iran, Khuzestan
	45	31.780	49.256	Iran, Khuzestan
	90	30.508	49.868	Iran, Omidiyeh
200	**135**	29.236	49.256	Arabian Gulf
	180	28.709	47.780	Kuwait
	225	29.236	46.304	Al Muthanna, Al-Salman
	270	30.508	45.692	Al Muthanna, Al-Salman
	315	31.780	46.304	Thi Qar, Rifai

The ASAPS communication model, which represents one of the best recommended international HF communication models, was adopted to calculate the dataset values of the BUF parameter. The years 2009 and 2014 were selected as the tested time period. These two bounding years represent the minimum and maximum of the solar cycle 24. Table-2 illustrates the monthly T-Index values of the selected years of solar cycle 24.

Table 2- T-index values for the solar cycle 24

Month	**2009**	**2014**
January	-2	91
February	-1	108
March	-2	130
April	0	114
May	2	96
June	-3	84
July	-4	86
August	-7	81
September	-2	90
October	-3	94
November	-3	98
December	-2	103

In this work, the values of the BUF parameter were studied statistically by analyzing the generated dataset from the ASAPS model for the annual time period of the selected years of solar cycle 24.
The effects of path length (100-1000) km, bearing (0^0-315°), day time (0-23), and BUF parameter are represented using a simple mathematical model for the annual variation. The datasets of the ionospheric parameter ORF were generated for minimum and maximum years of the solar cycle 24 by program which was built up (implemented) using visual basic programing language (VB6). The annual expressions that describe the relations between the parameter (ORF) and the time, path, season, and bearing are

$$ORF(d.t.B.M) = \left(\sum_{i=0}^{n1} a_i d^i\right) \times \left(b_0 + \sum_{k=1}^{n2} b_{2k-1} \cos\left(\frac{2\pi kB}{360}\right) + b_{2k} \sin\left(\frac{2\pi kB}{360}\right)\right)$$

$$\times \left(c_0 + \sum_{j=1}^{n3} c_{2j-1} \cos\left(\frac{2\pi jt}{24}\right) + c_{2j} \sin\left(\frac{2\pi jt}{24}\right)\right) \qquad \text{........ (7)}$$

where d: Path Length (Km), B: Bearing (Degree), t: Time (UT), and n: The polynomial order.
Many tests have been performed to determine the orders (n_1, n_2, n_3) of the polynomial equation (7). These tests include the calculations of squared correlation coefficient (R^2), mean difference (MD), mean square deviation (MSD), and mean absolute deviation (MAD) between the BUF and ORF ionospheric parameters. Depending upon the calculation result, the suitable polynomial coefficients set that reflects a close behavior of BUF and ORF is attained to be in the of order of n_1=2, n_2=2, n_3=10. Figures- (4-6) present sample results of the calculated ORF ionospheric parameter as compared to the BUF parameter for Mosul, Baghdad, and Basra transmitting stations for different path length and bearing values for the annual time of 2009 and 2014.
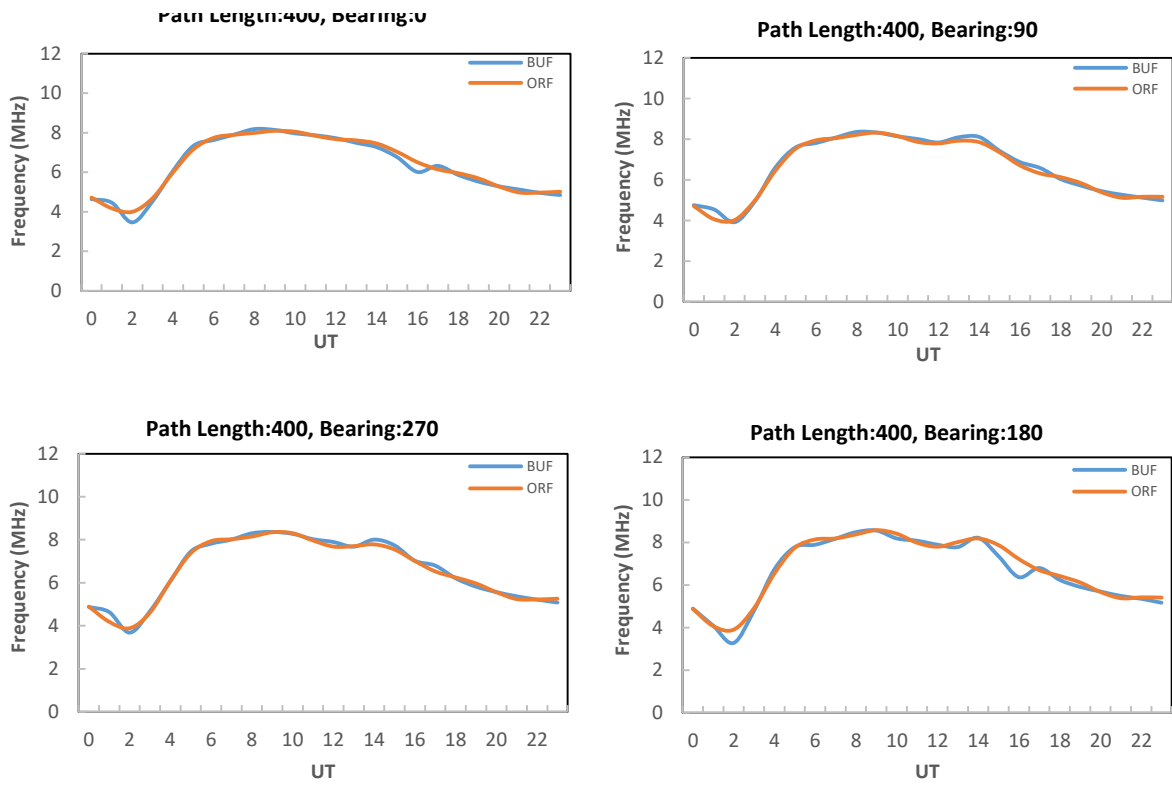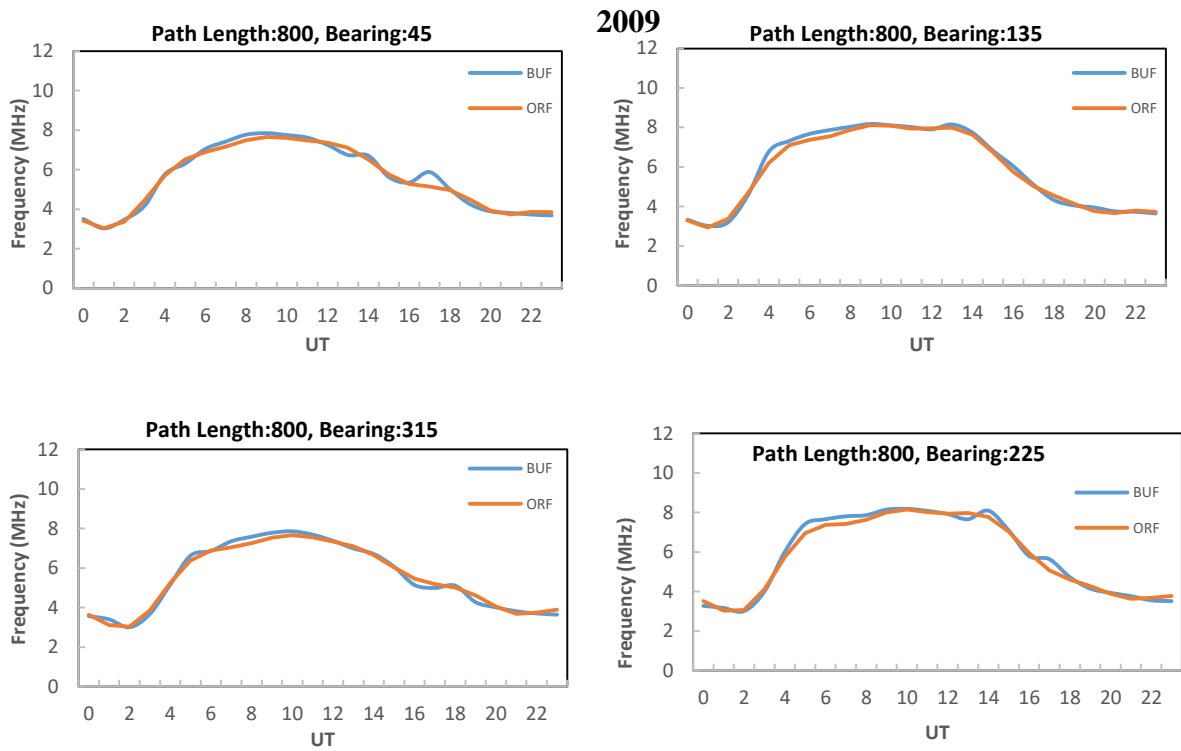
2009
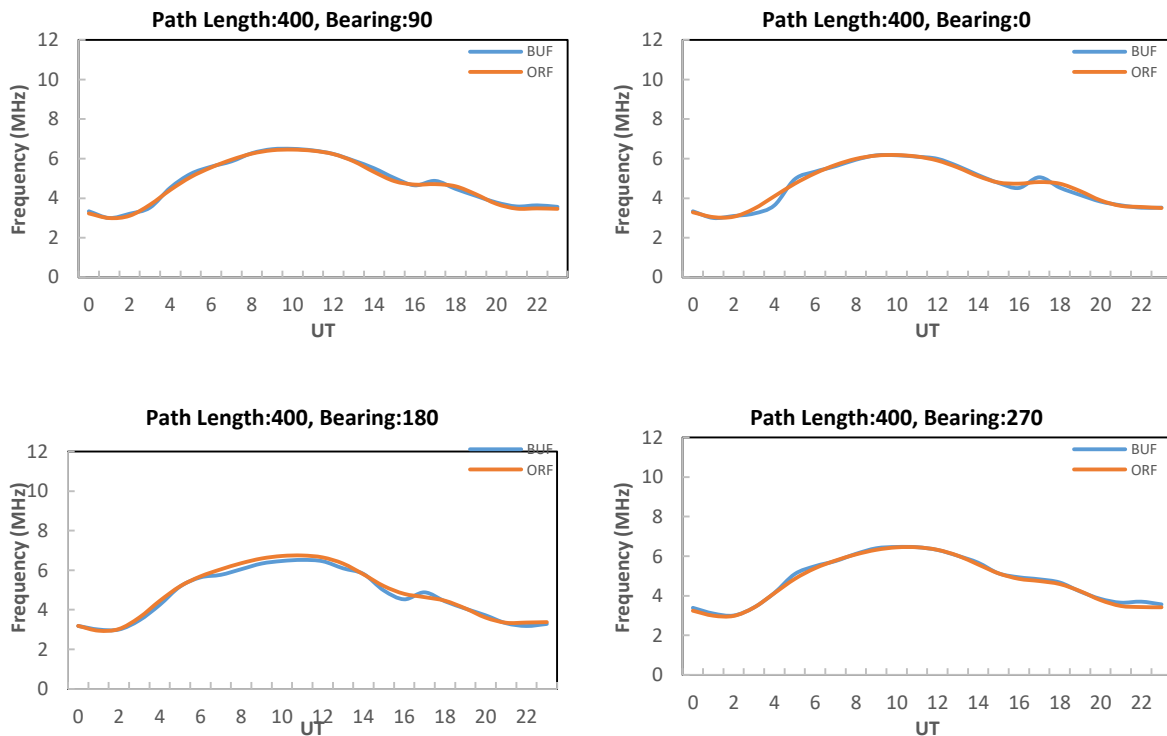
2014

Figure 4- Annul variation of ORF parameter for Mosul station compared to BUF parameter at different path length and bearing values for the years 2009 and 2014.
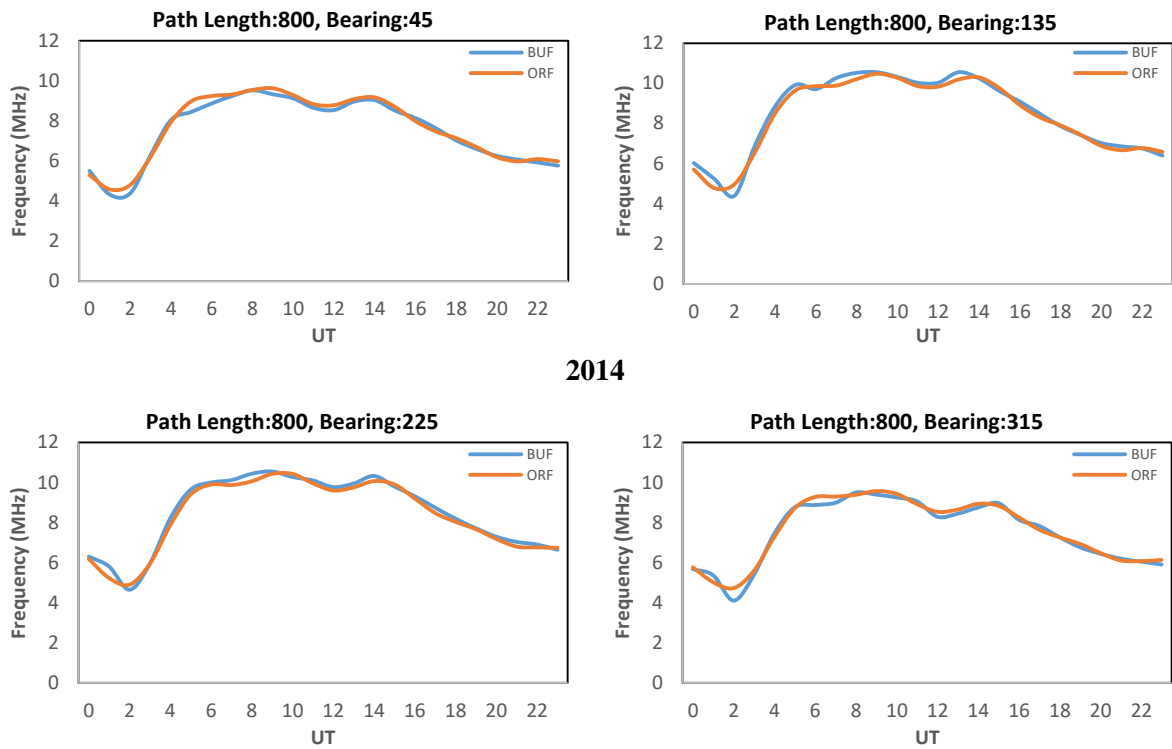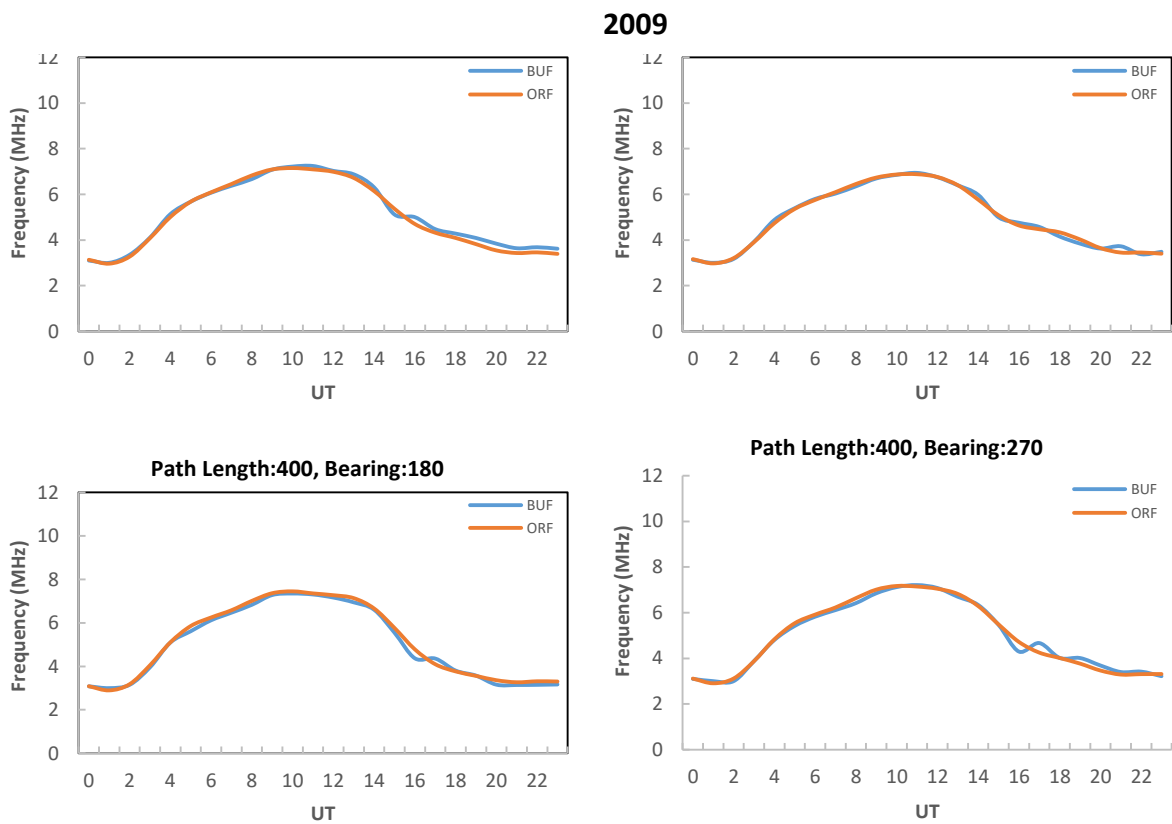
2014

Figure 5- Annul variation of ORF parameter for Baghdad station compared to BUF parameter at different path length and bearing values for the years 2009 and 2014.
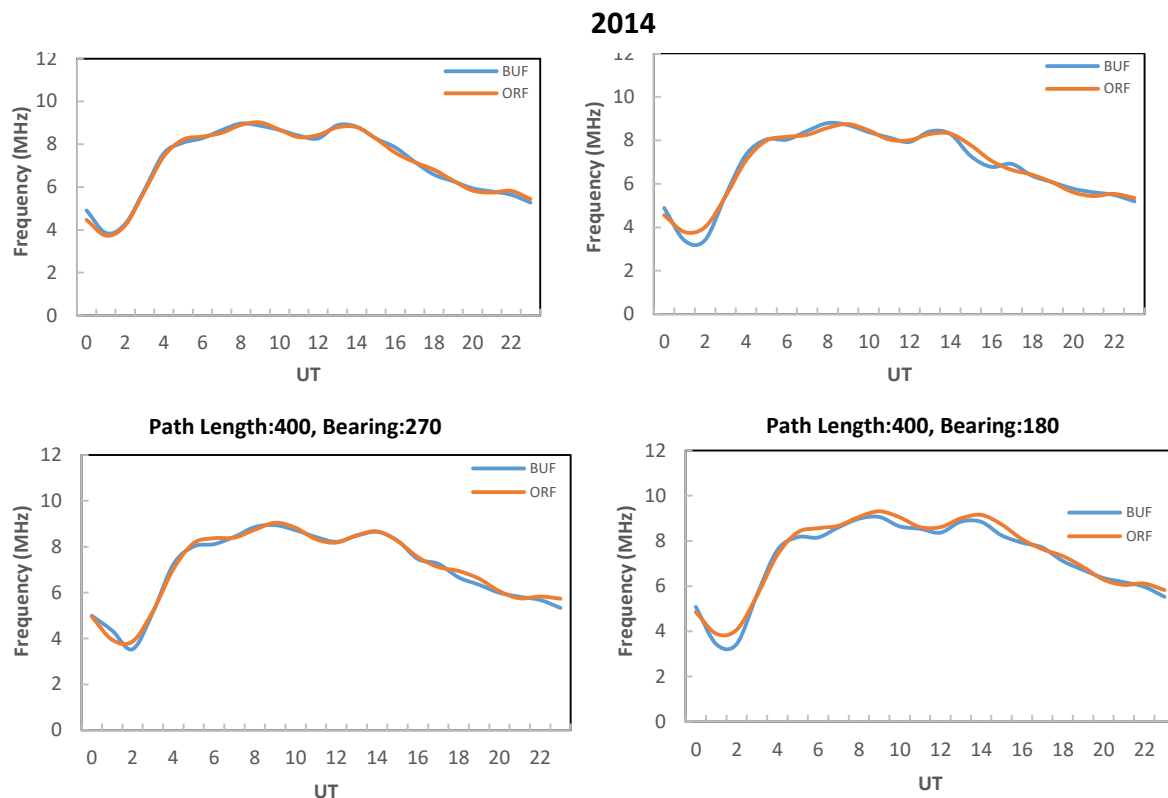
2009

Figure 6- Annul variation of ORF parameter for Basra station compared to BUF parameter at different path length and bearing values for the years 2009 and 2014.

Discussion and Conclusions

In this work, an analytical simulation for the ORF parameter behavior was achieved over the Iraqi territory for an annual period of the years 2009 and 2014. The results of the ORF parameter for Mosul station for the year 2009, as shown in Figures-4, reveal values that vary with the path length parameter; the ORF values were increased with increasing the path length value, reflecting a directly proportional relationship, reaching a maximum value at 1000 km. The highest ORF values occurred at noontime, then they started to decline until reaching their minimum values at sunset. This might be due to the changes in the electron density of the ionosphere layers. Also, was noticed that the ORF parameter showed differences in behavior at different bearing angles, possibly due to the effect of the sunrise and sunset phenomena. The variation of the ORF parameter at different bearing angles had its highest value at (180°), may be because of the impact of thermal and geographical equators on the structure of the ionosphere layer at this bearing value. For Baghdad station (central region) in the year 2009 and the minimum solar cycle 24, it was observed, as shown in Figure-5, that the ORF parameter had approximately the same behavior and variation as that shown for Mosul station, except that it showed higher values. It was also noted from the results of the minimum solar cycle for the year 2009 for Basra transmission station (the southern region), shown in Figure-6, that the behavior of the ORF parameter had the same behavior in general for the stations of Baghdad and Mosul, with slightly higher value. This might be attributed to the effect of the proximity of the city of Basra to the thermal and geographical equator, compared to the locations of Mosul and Baghdad.

The results of the variation values of the ORF parameter in the maximum solar cycle for the year 2014, illustrated in Figures- (4-6), showed almost the same behavior as that for the year 2009, but with more fluctuations and higher values. This might be due to the effect of high solar activity on the behavior and structure of the ionosphere layer.

Based on the previous discussion, it was noted that 2009 showed a more stable variation than that observed in 2014. The ORF parameter showed higher values in the southern region (Basra site) and these values decreased towards the northern region (Mosul site). The higher ORF parameter values for the three tested sites at the annual time of the minimum and maximum years 2009 and 2014 of solar

cycle 24 were 8.656 and 11.475 for Mosul station, 8.963 and 11.922 for Baghdad station, and 9.918 and 12.493 for Basra station, respectively.

According to the above discussion, our conclusions are summarized in the followings:

1.   Radio wave communications depend on different parameters, including path length, bearing angle between the transmitting and receiver stations, time of the day, and minimum and maximum of the solar cycle.

2.   The values of the ORF ionospheric parameter increase with the increase of path length (distance) between the transmitting and receiving stations.

3.   The value of the ORF parameter varies with the bearing between the transmitting and receiving stations. This behavior may be due to the geographical location and closeness to the thermal and geographical equators.

4.   The ORF values were higher at the maximum solar cycle (2014) than the minimum solar cycle (2009), while the year 2009 (minimum solar cycle) showed more stable variation than the year 2014 (maximum solar cycle).

5.   The results of the annual variation of the optimum reliable frequency showed almost the same behavior with different values during various path length, bearing, and solar activity.

6.   The values of the ORF parameter increase in the morning time, during sunrise, until they reach their highest values at midday (in the afternoon time), then they start to decrease at sunset due to the decrease in the electron density of the ionosphere layer.

7.   The ORF values increase as the equator approaches, since the ORF parameter values in Basra station (southern region) were higher than those for Baghdad (central region) and Mosul (northern region) stations.

References

1. K. Saha. **2008**. The Earth's Atmosphere. Ph.D. Thesis, Library of Congress Control Number: 2008925553, ISBN: 978-3-540-78426-5, University of Park, USA.

2. T. D. Carozzi. **2000**. Radio Waves in the Ionosphere: Propagation, Generation, and Detection. Ph.D. Thesis, ISSN: 0284-1703, Uppsala University, Sweden.

A. Z. Aziz, K. A. Hadi. **2013**. Determination of Ionospheric Parameters over Iraqi Zone, *Iraqi Journal of Science*, **54**: 475-484.

3. Introduction to HF radio propagation. **2000.** IPS Radio and Space Service, Australian Government.

4. The Structure of Ionosphere https://sidstation.loudet.org/ionosphere-en.xhtml

5. G. Lane. **2005**. Improved Guidelines for Automatic Link Establishment Operations, *Preprint paper to 3B-4*, Ionospheric Effects Symposium, Alexandria VA USA.

6. K. A. Hadi, L. E. Goerge. 2011. A Simplified Mathematical Model to Calculate the Maximum Usable Frequencies Over Iraqi Territory. Journal of Daily Journal for pure science, 7(4).

7. G. E. Gearhard. **2001**. Antenna Construction and Propagation of Radio Waves. *Marine Corps Institute.*

8. J. Douglas, D. M. Boore. **2011**. High-frequency filtering of strong-motion records. *Journal of Bulletin Earthquake Engineering,* **9**: 395-409.

9. Space Weather Services, Australian Government Bureau of Metrology. https://www .sws. bom.gov. au /Products_and_Services/1/2

10. C. Mudzingwa, A. Chawanda. **2018**. Radio Propagation Prediction for HF Communications. *science publishing Group*, **6**(1): 5-12.

11. ASAPS international HF communication model. https://www.sws.bom.gov.au/Products_and_Services/1/2