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Study the Impact of the Distance Factor on the Optimal Workable Frequencies for the Long Distance Radio Communications

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Abstract

In this research, the influence of the distance factor on the optimal working frequency (FOT) parameter has been studied theoretically for the ionosphere layer over the Middle East Zone. The datasets of the (FOT) parameter have been generated using the (VOACAP) model which considers as one of the recommended modern international communication models that used to calculate the ionosphere parameters. The calculations have been made for the connection links between the capital Baghdad and many other locations that distributed on different distances and directions over the Middle East region. The years (2011-2013) of the solar cycle 24 have been adopted to study the influence of the distance factor on the FOT parameter. The results of the conducted study showed that the distance factor has a clear influence on the values of the FOT parameter, also the day/night effect is more significant in the long distance HF links (i.e. more than a 500 Km).

Keywords: Optimal Workable Frequency (FOT), HF communication, Ionospheric Parameters.

دراسة تأثير عامل المسافة على قيم الترددات العاملة المثلى للاتصالات الراديوية بعيدة المدى

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الخلاصـــة

تم في هذا البحث إجراء دراسة نظرية لحساب تأثير عامل المسافة على معامل التردد المستخدم الأمثل (FOT) لطبقة الأيونسفير فوق منطقة الشرق الأوسط. تم استخدام نموذج الاتصالات العالمي الـ VOACAPالذي يعد واحد من أفضل النماذج العالمية المعتمدة لحساب المعاملات الأيونسفيرية. لقد تم أجراء حساب قيم معامل الـ FOT لوصلات الاتصال بين العاصمة بغداد والعديد من المواقع الموزعة على مسافات واتجاهات مختلفة فوق منطقة الشرق الأوسط. كما تم أختيار الأعوام (2011، 2012 و 2013) والتي تقع ضمن الدورة الشمسية (24) لأجراء أختبار تأثير عوامل الاتجاه، المسافةعلى الـ (FOT). أظهرت النتائج أن لعامل المسافة تأثير واضح على قيم معامل الـFOT كما أوضحت الدراسة أيضاً أن تأثير تغاير النهار/الليل قد ظهر بشكل ملحوظ على وصلات الاتصالات بعيدة المدى (أي المسافة الأكثر من 500 كيلومتر).

Introduction

The history of radio wave propagation that represents a great part of our understanding of the ionosphere began almost in the year 1864 when *J. C. Maxwell* proposed his theory of electromagnetic waves, he observed theoretically that an electromagnetic disturbance travels in free space with the speed of light [1].

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Sunlight is a familiar form of electromagnetic radiation. Only the visible radiation and parts of the infrared and radio regions penetrate the atmosphere completely. Electromagnetic radiation travels outward from its source as waves (pulses) or photons (packets) of energy. The speed of EM wave in a vacuum is the same no matter how much energy it carries. All electromagnetic waves travel at the speed of light (*c*) which equal (299,792,456 m/sec) [2]

The continuum of the electromagnetic frequency spectrum useful for communications range from the Extremely Low Frequency (ELF) (designated 30-300 hertz) to the Extremely High Frequency (EHF) (designated 30-300 GHz) millimeter waves [3].

High Frequency (HF) radio transmission is defined to be the frequency range 3-30 MHz, although frequencies down to 1.5 MHz are often considered part of the HF band. HF is used substantially for long distance communications. It is an extremely cost effective (inexpensive widely available technology) radio frequency for implementing long-range communications. Propagation is by direct, ground and sky wave [3].

The Radio signals affects by the ionosphere in different ways depending on their frequencies. On frequencies below about 30 MHz the ionosphere may act as an efficient reflector, allowing radio communication to distances of many thousands of kilometers. Radio signals on frequencies above 30 MHz usually penetrate the ionosphere and, therefore, are useful for ground-to-space communications [4].

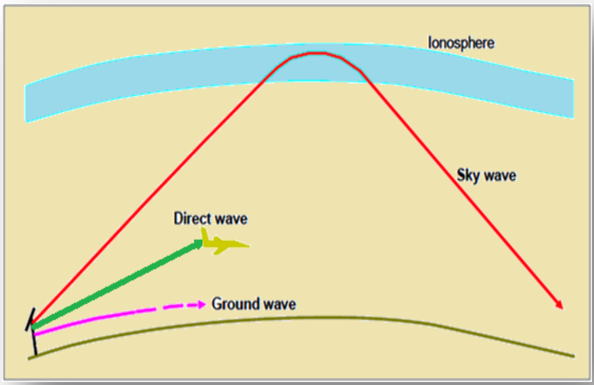


Figure 1- Types of high frequency propagation [6].

Radio waves flow from the transmitter’s antenna to the receiver's antenna, but not always directly. Because radio waves travel in a variety of ways to the receiver. High frequency (3 to 30 MHz) radio signals can propagate to a distant receiver, via the following methods as shown in figure -1 [5]:

1. Direct wave
2. Ground wave
3. Sky wave.

The ionosphere is defined as that part of the upper atmosphere that is extended from 60 km upwards over the surface of the Earth to 1000 km. It’s produced by ionizing radiation from the sun, resulting in free electrons and ions. The ionization levels in this near-Earth space plasma layer are controlled by solar extreme ultraviolet (EUV) radiation and particle precipitation [7].

Generally, the ionosphere is a highly variable and complex physical system where sufficient ionization can exist to affect the propagation of radio communication over large distances by making use of one or more ionospheric reflections. During the day there may be four regions present called the D, E, F1 and F2 regions. At night the D, E and F1 regions become very much depleted of free electrons, leaving only the F2 region available for communications [7].

Ionospheric Propagation Parameters

The ionospheric propagation parameters describe the acceptable operation frequencies of a radio service between giving terminals. It's affected by the primary factors influence (electron density of ionization), so these parameters will be increased with higher ionization density and decrease with lower ionization density [8]. The ionospheric parameters can be described as follows:-

- **Maximum Usable Frequency (MUF):** the highest frequency that will be reflected back to earth by the ionized layers. Above this frequency there is no reflection. MUF depends on the layer that is responsible for refraction/reflection and so contact between two stations relying on skip will depend on the amount of sunspot activity, the time of day, time of year, latitude of the two stations, and antenna transmission angle. The median value of MUF parameter is only 50% of the time [9].
- **Lowest Useable Frequency (LUF):** is the lowest radio frequency that can propagate through ionosphere layer between two terminals on the surface of the earth. It is exceeded by the operational MUF on 10% of the specified period [9].
- **Frequency of Optimum (Workable) Transmission (FOT):** is the highest effective (i.e. workable) frequency that is predicted to be usable for a specified path and time for 90% of the days of the month [9]. The predicted values of the MUF, LUF and FOT change in regular way due to the variations of the ionospheric factors over the day, the year and the 11-year sunspot cycle. Also, the ionospheric parameter values change progressively in the D, E and F layers depending on maximum electron density for each layer and the angle of incidence of the emitted radio wave [10] as shown in figure -2.

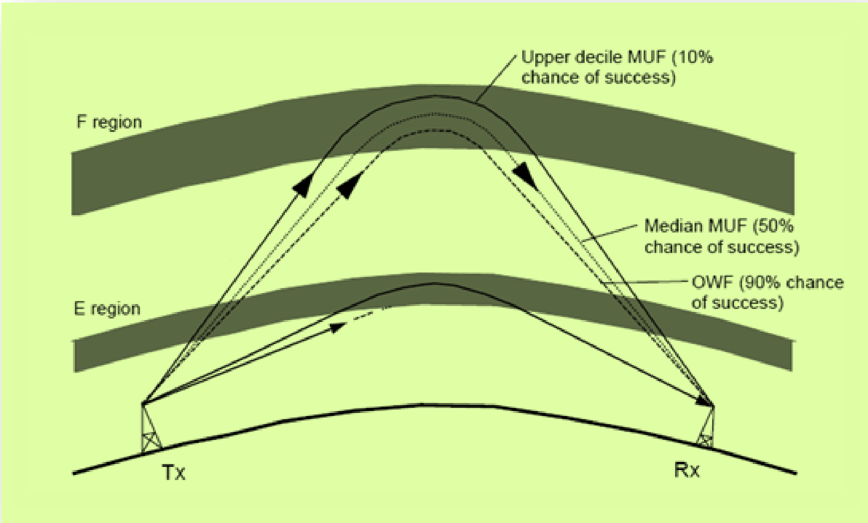


Figure 2- Range of operation usable frequencies [6].

The adopted International model

In this research the VOACAP International Communication Model has been adopted to be the model that will be used to get the date set of the studied parameter for the specific transmitter and receiver station locations.

VOACAP stands for the Voice of America Coverage Analysis Program. It is an ionospheric model predicting the expected performance of HF transmissions. It takes into account tens of parameters to support the planning and operation of long distance traffic or broadcast transmissions. VOACAP is a "Point-to-Point" analysis tool [11].

The VOACAP model contains two main windows, the input and output windows. The input window contains many parameters as well as the output window contains the sets of the calculated parameters.

Calculations and Results

In the present work, an analytical study had been made to investigate the behavior and influence of the distance factors on FOT parameter during the years (2011- 2013) for the region over the Middle East zone.

The VOACAP communication model that represents one of the best recommended international HF communication models has been adopted to calculate the dataset values of the FOT ionospheric parameter. Method 26 of the VOACAP model has been chosen to calculate the FOT parameter, because this method achieves the requirements of this study.

Also, the years (2011-2013) have been selected to be the studied time period, to show the variation of the solar activity which represented by the sunspots number during the three consecutive years on the ionospheric parameter (FOT). The monthly-observed sunspots number (SSN) had been picked. Figure -3 illustrates the variation of the monthly values of the observed sunspots [12].

Fig. (3): Behavior of the observed sunspots number for years (2011- 2013), respectively.

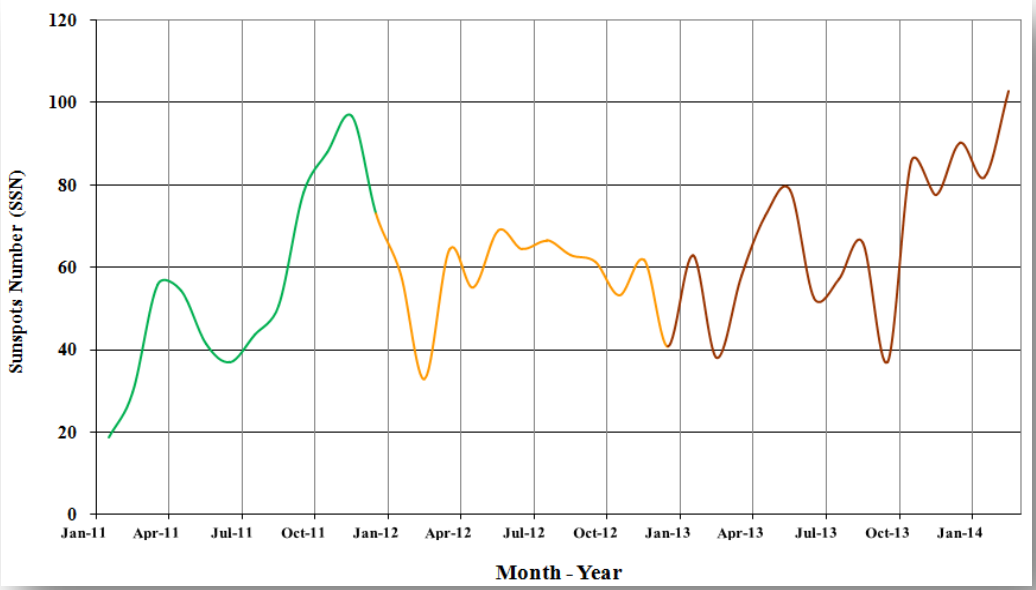


Figure. 3- Behavior of the observed sunspots number for years (2011- 2013), respectively.

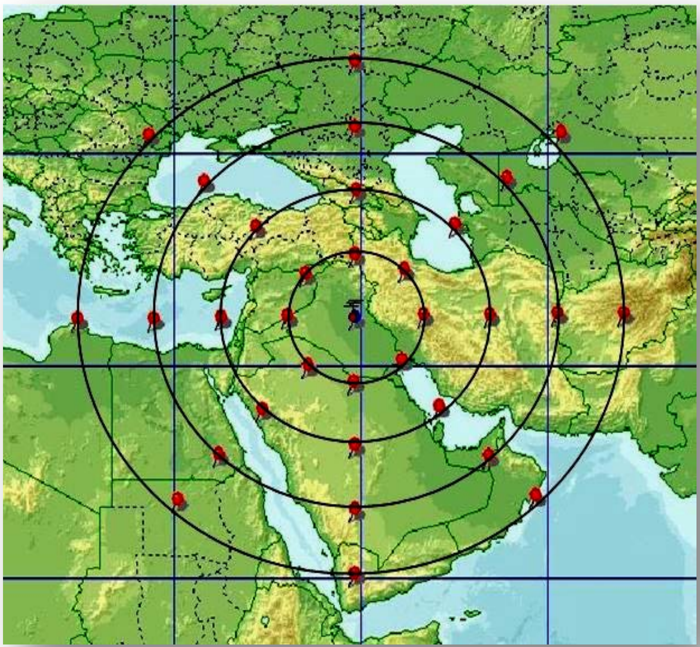


Figure 4- Distribution of the selected transmitter and receiveing stations over Middle East region.

In this study, The Middle East Region which is laid within the longitudes range of (22.89ºE – 65.87ºE) and latitudes (15.26ºN – 51.44ºN) has been considered as the studied area. The capital "Baghdad" which is located at geographical coordinates (44.42ºE & 33.32ºN) had been selected to represent as a transmitter station and thirty-two different locations which are distributed around the transmitter station over the Middle East region in eight directions and four certain distances have been represented as receiving stations, as in figure -4.

The geographic location (longitude and latitude) and the distance between transmitting and receiving stations for the selected receiving satiations have been listed in Table-1.

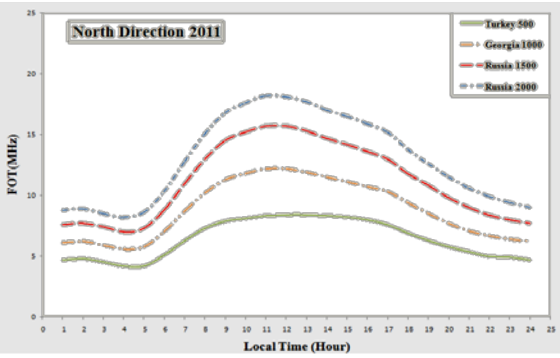
Table 1- The geographic locations and distance between transmitting and receiving stations: Where N=North; NE=Northern East; E=East; SE=Southern East;S=South; SW=Southern West; W=West; NW=Northern West.

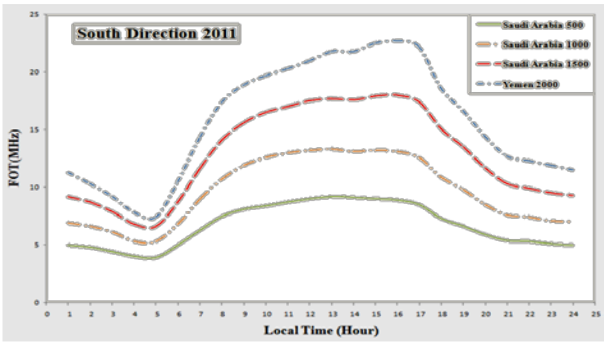
Name		Longitude (Degree)	Latitude (Degree)	Distance (Km)
N	Turkey	44.38	37.87	500
	Georgia		42.39	1000
	Russia		46.92	1500
	Russia		51.44	2000
NE	Iran	48.24	36.55	500
	Caspian Sea	52.25	39.75	1000
	Uzbekistan	56.43	42.95	1500
	Kazakhstan	60.8	46.14	2000
E	Iran	49.75	33.35	500
	Iran	55.12		1000
	Iran	60.5		1500
	Afghanistan	65.87		2000
SE	Kuwait	48.1	30.15	500
	Saudi Arabia	51.7	26.95	1000
	Emirates	55.19	23.76	1500
	Oman	58.89	20.56	2000
S	Saudi Arabia	44.38	28.83	500
	Saudi Arabia		24.3	1000
	Saudi Arabia		19.78	1500
	Yemen		15.26	2000
SW	Saudi Arabia	40.66	30.15	500
	Saudi Arabia	37.06	26.95	1000
	Egypt	33.57	23.76	1500
	Sudan	30.17	20.56	2000
W	Iraq	39.01	33.35	500
	Med. Sea	33.64		1000
	Med. Sea	28.27		1500
	Med. Sea	22.89		2000
NW	Syria	40.52	36.55	500
	Turkey	36.51	39.75	1000
	Black Sea	32.33	42.95	1500
	Rumania	27.95	46.14	2000
*Med. Sea=Mediterranean Sea				

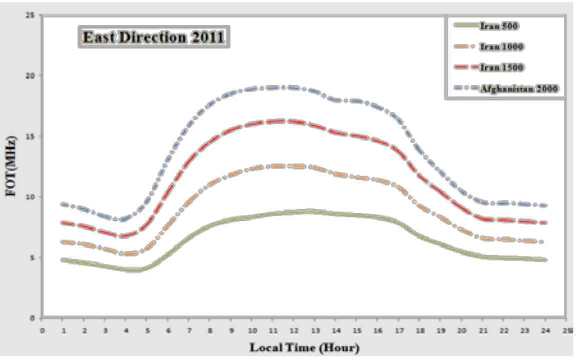
Table 2-shows a sample of the calculated FOT parameter using the VOACAP international model for the 2000 Km around the capital Baghdad for the link (Baghdad-Yemen / South Direction).

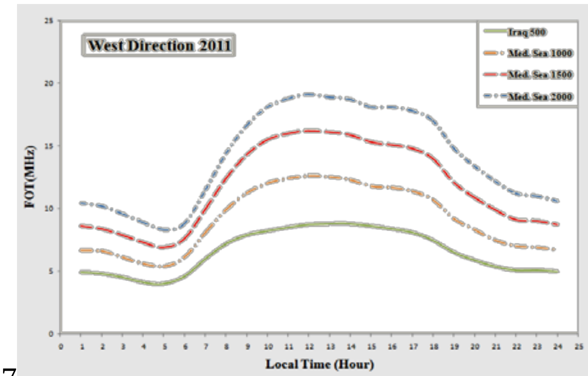
Baghdad - Yemen / South Direction, 2000 km, (2013)													
LMT	FOT(Jan.)	FOT(Feb.)	FOT(Mar.)	FOT(Apr.)	FOT(May)	FOT(Jun.)	FOT(Jul.)	FOT(Aug.)	FOT(Sep.)	FOT(Oct.)	FOT(Nov.)	FOT(Dec.)	Annual Time (2013)
1	9.09	9.26	12.48	14.61	13.26	11.44	11.35	11.35	9.95	13.44	11.43	12.82	11.7
2	8.36	7.96	11.42	13	12.44	9.96	9.91	9.91	9.41	11.83	10.43	11.53	10.5
3	7.22	7.26	10.13	11.47	11.67	9.38	9.36	9.37	8.5	9.84	8.73	9.57	9.4
4	5.53	5.7	8.34	9.97	10.71	8.62	8.67	8.65	7.5	7.76	6.57	6.98	7.9
5	4.78	4.67	7.53	9.59	10.48	8.57	8.62	8.58	7.91	7.47	6.09	5.95	7.5
6	7.63	7.67	10.82	13.09	13.57	11.24	11.23	11.32	11.6	11.83	10.35	9.62	10.8
7	12.23	12.2	15.6	16.57	15.71	13.19	13.15	13.66	15.19	17.29	16.5	15.17	14.7
8	17.36	17	19.8	18.88	16.72	13.99	13.98	14.7	17.05	21.62	21.9	20.9	17.8
9	20.73	19.83	21.59	19.42	16.66	14.87	14.74	14.73	17.12	23.41	24.23	24.12	19.3
10	21.23	18.24	23.15	20.58	17.46	16.42	16.41	16.53	17.05	24.66	25.06	23.94	20.1
11	21.12	18.63	24.25	22.12	18.91	17.43	17.52	17.77	18.15	25.29	24.68	23.13	20.8
12	20.95	19.12	25.81	24.37	21.07	17.84	17.96	18.24	19.98	26.2	24.91	22.21	21.6
13	21.48	19.63	26.89	26.15	22.85	17.58	17.62	18.78	21.76	27.42	25.9	22.29	22.4
14	22.13	20.94	25.36	25.02	22.36	17.6	17.06	18.77	23.76	26.4	25.38	22.92	22.3
15	22.84	21.74	25.3	25.04	23.03	18.26	17.74	19.58	24.62	27.02	26.39	24	23.0
16	22.68	22.2	25.15	25.04	23.44	18.98	18.39	20.25	24.92	26.95	26.24	24.18	23.2
17	21.56	21.25	24.27	24.76	23.44	19.42	18.71	20.73	24.21	25.84	24.71	23.26	22.7
18	18.26	19.37	19.03	20.12	19.13	18.05	17.32	19.11	18.38	20.2	19.03	20.16	19.0
19	16.32	16.54	16.83	18.18	17.24	16.63	15.98	17.55	15.52	18.06	17.02	18.86	17.1
20	14.48	14.17	14.74	16	14.96	14.23	13.7	14.93	12.32	16.23	15.33	17.74	14.9
21	12.91	12.46	13.34	14.54	13.31	12.15	11.61	12.36	9.97	15.14	13.98	16.7	13.2
22	11.25	11.04	13.82	15.4	13.81	11.82	11.24	11.53	9.97	15.83	13.93	15.19	12.9
23	10.12	10.04	13.51	15.57	13.75	11.67	11.23	11.24	9.78	15.23	12.79	14.11	12.4
24	9.37	9.4	13.06	15.4	13.59	11.61	11.4	11.37	9.89	14.39	11.92	13.28	12.1

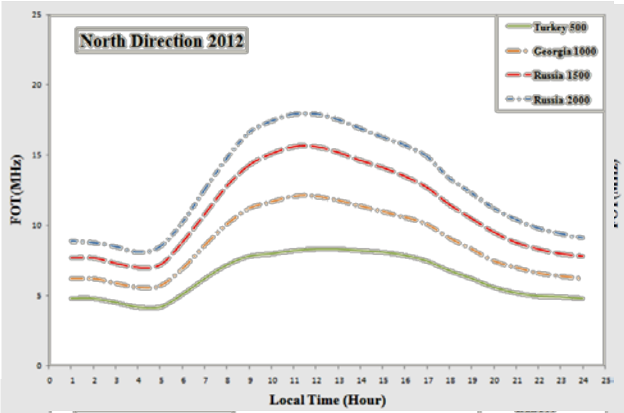
This research has been conducted to investigate the affection of the distance factor on the FOT parameter. The study has been made for the distances (500, 1000, 1500 & 2000) km from a transmitter station "Baghdad". So, each tested point is located at a specific distance (four distances) and direction (eight directions) around a transmitter station. Figure -5, show the result of the variation of the distance factor on the FOT values on each direction for the years 2011,2012 and 2013.

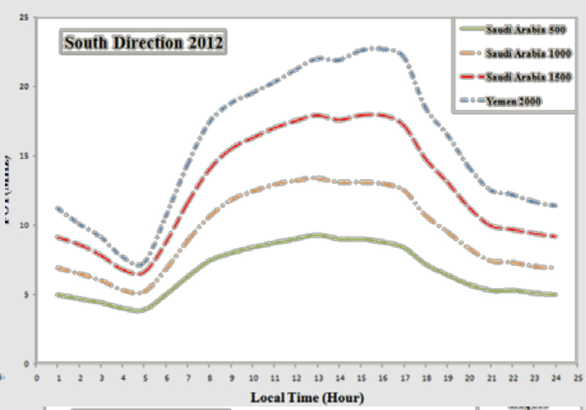


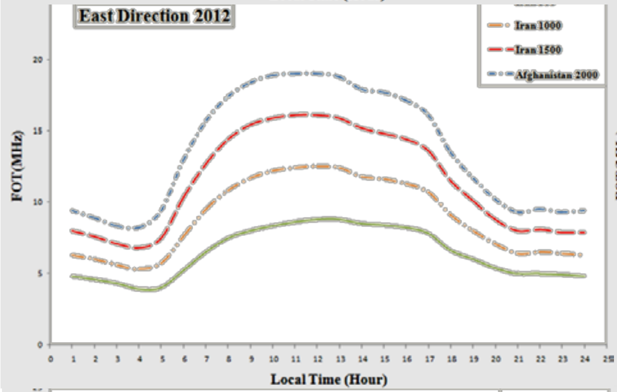


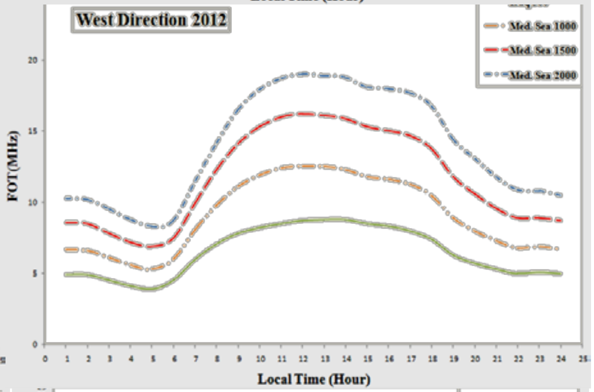


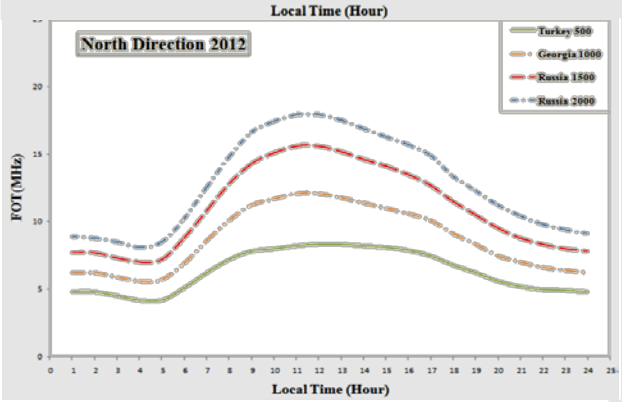


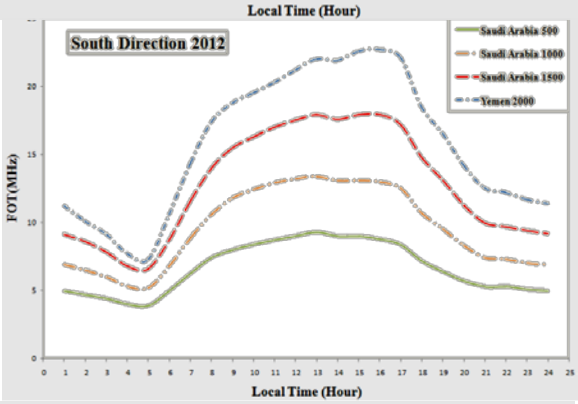

North Direction 2012
Turkey 500
Georgia 1000
Russia 1500
Russia 2000
FOT(MHz)
Local Time (Hour)

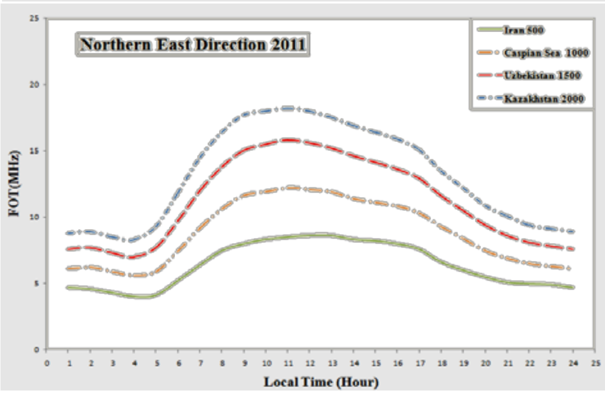

South Direction 2012
Saudi Arabia 500
Saudi Arabia 1000
Saudi Arabia 1500
Yemen 2000
Local Time (Hour)

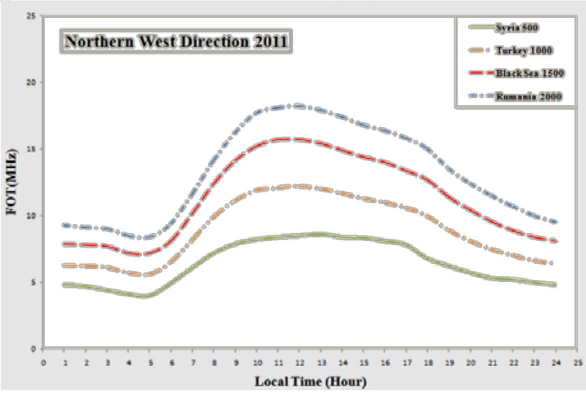

East Direction 2012
Iran 1000
Iran 1500
Afghanistan 2000
FOT(MHz)
Local Time (Hour)

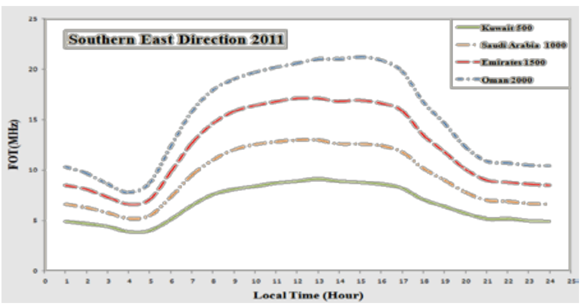

West Direction 2012
Med. Sea 1000
Med. Sea 1500
Med. Sea 2000
FOT(MHz)
Local Time (Hour)

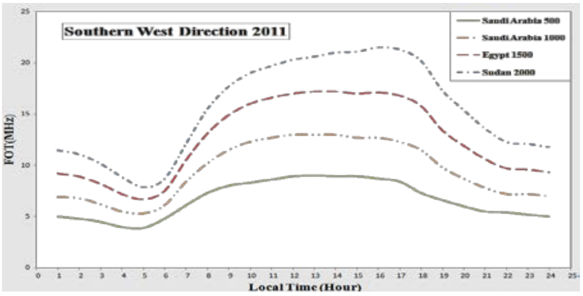

North Direction 2012
Turkey 500
Georgia 1000
Russia 1500
Russia 2000
FOT(MHz)
Local Time (Hour)


South Direction 2012
Saudi Arabia 500
Saudi Arabia 1000
Saudi Arabia 1500
Yemen 2000
FOT(MHz)
Local Time (Hour)


Northern East Direction 2011
Iran 500
Caspian Sea 1000
Uzbekistan 1500
Kazakhstan 2000
FOT(MHz)
Local Time (Hour)


Northern West Direction 2011
Syria 500
Turkey 1000
Black Sea 1500
Rumania 2000
FOT(MHz)
Local Time (Hour)


Southern East Direction 2011
Kuwait 500
Saudi Arabia 1000
Emirates 1500
Oman 2000
FOT(MHz)
Local Time (Hour)


Southern West Direction 2011
Saudi Arabia 500
Saudi Arabia 1000
Egypt 1500
Sudan 2000
FOT(MHz)
Local Time (Hour)

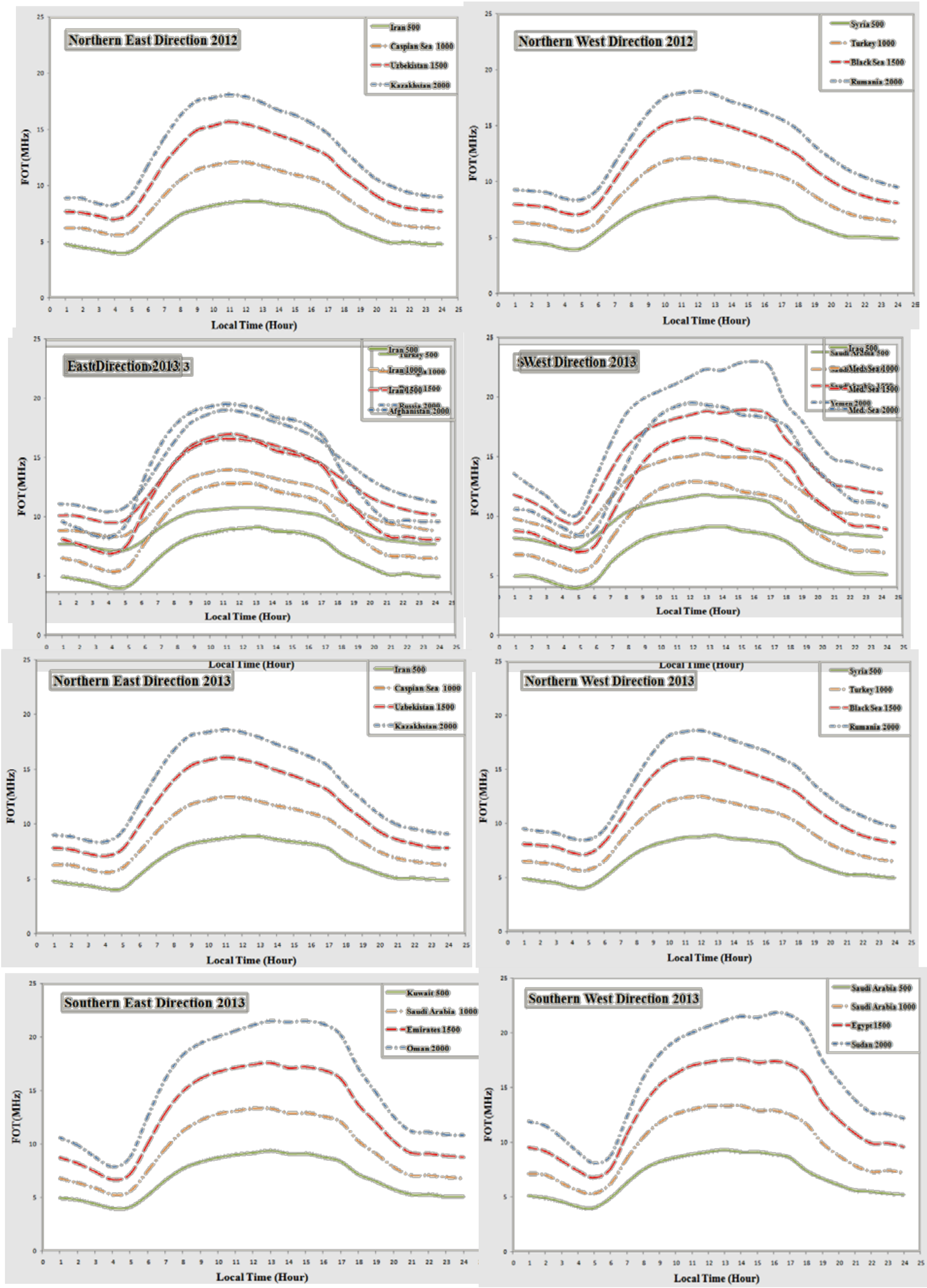


Figure 5- The influence of Distance factor on FOT parameter.

Conclusions

The affection of the distance factor for the distances (500, 1000, 1500, and 2000) km on the FOT parameter has been studied. Figure (5); shows The results of this study that illustrated the influence of the distance factor on the FOT values for each distance. It's noticeable that: the FOT values were increased with increasing the distance from the transmitter station.

In another mean, the study of the affection of the distance factor on the FOT parameter presents that there is a direct correlation between the FOT parameter and the distance factor, the FOT values are increased by getting away from the transmitter station. The affection of the distance factor shows a more complicated variation on the behavior of a FOT parameter, practically for those in the south and southern west locations.

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