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Analytical Study for an International Model of Long Distance Radio Wave Propagation

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Abstract: In this research an analytical study had been made for one of the modern international models which are used to predict the behavior of transferring radio waves among the stations and of affection of these waves by the atmosphere. In this study, Iraq has been adopted generally, whereas, Baghdad was taken specially to be represented as an axial point. Since, the capital Baghdad has been adopted to be as a transmitting/receiving station with many stations lying within Iraqi cities and some surrounded Arabian and foreign capitals that place within the Middle East zone. The analytical study of the application of one of the international theoretical models on Iraq and its neighbors has been made in order to reach for the conclusions that enable us to forecast the frequencies that maintain the reliable semi-permanent connection between the transmitting and receiving stations.

Keywords: Long distance communication, HF radio propagation, wireless communication, Ionospheric.

Introduction

The long distance radio wave propagation [High Frequency Band (3-30 MHz)] is conside-red as one of the vital strategic wireless comm-unication systems, which is adopted by many establishments in their work for transferring their information among distant geographical locations. Many of these establishments suffer from a problem of inability to maintain the connection between their stations due to the changes that effect on the atmosphere layers. The atmosphere layers represented by the iono-sphere layer which plays a role of a reflector of transmitted radio waves between different stations. That is because of the inexistence of the studies related to our country, so it is important to achieve such a type of research to understand the nature of changes that happen in the atmosphere above the country.

Radio Waves Propagation Methods

Since the surface of the earth is approximately spherical and because the electromagnetic waves in a uniform atmosphere travel in straight lines, long-distance radio communication is made possible by the reflection of radio waves from the ionosphere (i.e. the upper part of the Earth's atmosphere). The ionosphere affects radio signals in different ways depending on their frequencies. Radio signals with frequencies above 30 MHz like VHF, UHF, SHF, or EHF usually penetrate the ionosphere and, therefore, are useful for ground-to-space communications. While radio waves with frequencies below 30 MHz are designated as high frequencies (HF), the ionosphere may act as an efficient reflector, allowing radio communication to distances of many thousands of kilometers [1].

There are a number of ways by which an HF radio wave may travel. The radio wave may propagate via the ionosphere (sky wave propagation) or it may travel directly to the receiver by line-of-sight (ground wave or sideband transmission).
The ground wave is designated as short to medium distance communications, typically up to 500km). Sky wave or long distance propagation depends upon the configuration of the ionospheric layer, which is in turn depends on the solar activity (solar cycle or sunspot number), the time (annual, seasonal, and diurnal), and propagation direction (orientation). Sky wave can offer global coverage under optimum conditions; although it is susceptible to many disturbances which will make the coverage not always reliable [2].

HF Propagation Models

Current methodologies for HF performance prediction evolved gradually, beginning with uncoordinated studies by workers from many countries and organizations. Serious work to establish prediction methods began in earnest during World War-II because of the obvious military communication requirements. The earliest methods by the Allies, Germany, and Japan were of the graphical type to speed analysis, because computer methods were not available. The long-distance methods used by Germany and those used by the Allies [IRPL, 1943][3] form an interesting contrast. The Interagency Radio Propagation Laboratory (IRPL) was a forerunner to the Central Radio Propagation Laboratory (CRPL) now it is named the Institute for Telecommunication Sciences (ITS) at Boulder, Colorado.

Fundamental to all efficient HF computer prediction programs are the synoptic numerical coefficient representations of the ionospheric characteristics. These were first developed by ITSA and first published in 1960 [4]. Models that stem from methods were developed by the Department of Commerce scientists at Boulder, Colorado, include ITSA-1, ITS-78, HFMUFES-4, IONCAP, RADARC, and, more recently, ICEPAC, VOACAP and REC533. These methods have influenced the design of other prediction models. The CCIR (currently the ITU-R) has developed methods for estimating field strength and transmission loss based upon empirical data, and a computer method for propagation prediction was developed for the WARC-HFBC under the aegis of the International Frequency Registration Board (IFRB) now the Radio Regulations Board (RRB), an organ of the ITU. The followings are synopsis of some computer models: ITSA-1 [5], ITS-78 (HFMUFES) [6, 7], IONCAP [8, 9], RADARC [10, 11, 12], FTZ: [13], CCIR 252-2 [14], CCIR 252-2 Supplement [15], CCIR 894-1 [16], HFBC84: [17], AMBCOM: [18], VOACAP, ICEPAC, REC 533 [19]

The Adopted REC533 International Model

In this research work, the REC533 international model had been selected as an international model for the analysis of HF-links performance over Iraq. The selection of the REC533 model is due to the fact that this model represents one of the last best common HF communication prediction models and this model meets the current study requirements and purpose. As mentioned before the REC533 model is a PC/Windows based implementation of the International Telecommunication Union's (ITU) propagation model (Recommendation ITU-R). It predicts the expected performance of high frequency (HF) systems and in doing so it is useful in the planning and operation of HF transmissions for the four seasons, different sunspot activities, hours of the day, and geographic location. Monthly median basic MUF, incident sky-wave field strength, and available receiving power from a lossless receiving antenna of giving gain are determined. Signal strengths are standardized against a CCIR measurement data bank. The method requires the determination of a number of ionospheric characteristics and propagation parameters at specified, "control points".

Test and Analysis Results

The aim of the analytical study for the REC533 international HF propagation model is to conduct some test examples which are sufficient to derive the required conclusions that can give the ability to predict the frequencies which can ensure the most reliable HF-link between the transmitting and receiving stations. The probability of successful transmission between the transmitting and receiving stations depends on the probability that the transmitted frequency is below the critical frequency (i.e. the maximum frequency for reflection) and the probability that the available signal-to-noise ratio (S/N) is above certain level. The optimum working frequency (OWF) is generally thought to be a system performance parameter. The OWF is the highest frequency for which the successful link depends on the level of a signal-to-noise ratio.
Since the REC533 model has the ability to calculate the values of S/N for each link frequency, then the probability of the successful communication for the longest period of time can be determined.

In the present study, the output results of the international model REC533 were used to determine, the reliable optimum frequency, by calculating the probability that the signal-to-noise ratio for each operational frequency is above a specific threshold value.
The probability of a reliable operating frequency has been calculated by using a computer program (APIPM), which was designed and implemented (using Borland C programming language) for this purpose. The written analysis program was designed to be able to do different logical tracing and statistical analysis on the output data file of the REC533 Model. The program flow could be illustrated in the form of a block diagram, as shown in figure (1) :

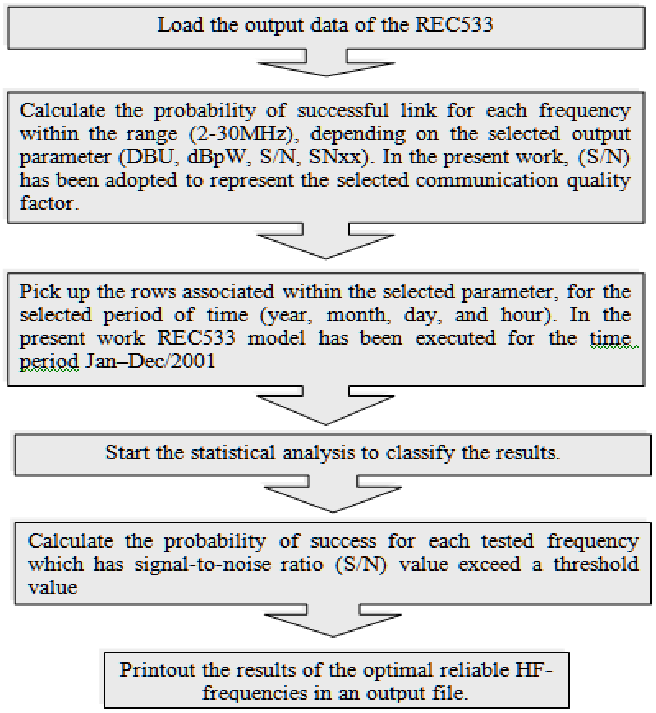

Fig. (1) A Block diagram illustrates the flow steps of the analysis program.

Also, The analysis program has the ability to classify the data according to the seasonal (winter, spring, autumn and summer), diurnal (sunrise, day, sunset and night) and annual percentage probability. The output data file of the program is illustrated in figure (2).

(S/N) - Signal to Noise Ratio (dB) (Baghdad - AL-RUTBA) Threshold Value - 73

	MUF	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
	4.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
Winter -- Winter -- Winter (December - January - February) Winter -- Winter -- Winter — Sunrise-(6-7)AM. , Daytime-(7-17) , Sunset-(17-18)PM. , Night-(15-6)											
Sunrise:	100.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Daytime:	100.0%	76.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.7%
Sunset :	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	66.7%	66.7%
Night :	100.0%	80.6%	100.0%	100.0%	100.0%	100.0%	97.2%	86.1%	83.3%	61.1%	50.0%
SeasPSN:	100.0%	76.4%	100.0%	100.0%	100.0%	100.0%	98.6%	93.1%	91.7%	79.2%	72.2%
Spring -- Spring -- Spring (March - April - May) Spring -- Spring -- Spring — Sunrise-(5-7)AM. , Daytime-(7-17) , Sunset-(17-19)PM. , Night-(19-5)											
Sunrise:	100.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Daytime:	100.0%	63.3%	80.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sunset :	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Night :	100.0%	80.0%	90.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.7%
SeasPSN:	100.0%	68.1%	79.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	98.6%
Summer -- Summer -- Summer (June - July - August) Summer -- Summer -- Summer — Sunrise-(5-6)AM. , Daytime-(6-19) , Sunset-(19-20)PM. , Night-(20-5)											
Sunrise:	100.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Daytime:	100.0%	61.5%	76.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sunset :	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Night :	100.0%	66.7%	88.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
SeasPSN:	100.0%	62.5%	79.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Autumn -- Autumn -- Autumn (September - October - November) Autumn -- Autumn -- Autumn — Sunrise-(5-6)AM. , Daytime-(6-19) , Sunset-(19-20)PM. , Night-(20-5)											
Sunrise:	100.0%	0.0%	50.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Daytime:	100.0%	73.3%	90.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sunset :	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Night :	100.0%	86.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.7%	93.3%	83.3%
SeasPSN:	100.0%	75.0%	91.7%	100.0%	100.0%	100.0%	100.0%	100.0%	98.6%	97.2%	93.1%
Annual :	100.0%	70.5%	87.5%	100.0%	100.0%	100.0%	99.7%	98.3%	97.6%	94.1%	91.0%

Fig. (2) A sample of the print out file of the analytical program, where the probability of successful link for the frequency range (2-11) that has S/N exceeding the threshold value (73 dB) was computed.

Farther more, the analysis program is capable to calculate and printout the path geometry parameters (path length, bearing of transmitter to receiver and receiver to transmitter (vice versa), and the distance between the transmitter and receiver stations), some samples of these calculations are illustrated in table (1).

Table (1) Sample of the output data of the analysis program illustrate the calculations of the path length, distance, bearing of transmitter to receiver and vise versa

```
      The Bearing - Pathlength - Distance Between The Transmiter and Receiver
---------------------------------------------------------------------------------

The Transmitre's longitude & latitude :  44.38  33.35     ( Iraq - Baghdad )
The Reciever's longitude & latitude   :  40.35  33.05     ( AL-RUTBA )

---------------------------------------------------------------------------------

The Path Length = 0.059084    Rarians
The distance    = 376.834961  Kilometers

---------------------------------------------------------------------------------

          Bearing's Mode                  Mathod.1.     Mathod.2.     Avargae
--------------------------------------  ----------   ----------   ---------------
The Bearing of Transmitter to Receiver :  264.916168   264.912964  264.914551 Deg.
The Bearing of Receiver to Transmetter :   84.916161    84.930420   84.923294 Deg.
```

For the study purposes, many parameters have been determined, these parameters are related to the considered link specification, such as the transmitting and receiving station locations, the distance between these stations, the link orientation and the date and time.
This study was concentrated on the Iraq territory and its surrounded region. The capital Baghdad was considered as an axial communication point or a central station to transmit/receive radio waves to/from with other locations and some of the neighbor Arabian and foreign capitals and cities that lie within the region of the Middle East zone which are taken as the other sites of the link. So, depending on the distances and the geographical locations, the analytical study has been classified into two communication zones, these are the local and regional zones.

1. The Local Zone:

A study has been made to calculate the reliable operational frequencies between Baghdad (which represents the first station) and some other Iraqi cities (each one is considered as a second station in the link). For the local zone, about 30 HF-links have been made to cover the Iraq territory from north (Zakhow) to south (Al-Basrah) and from east (Mandely) to west (Al-Rutbah). The selected link locations used in the local communications study are illustrated in figure (3).

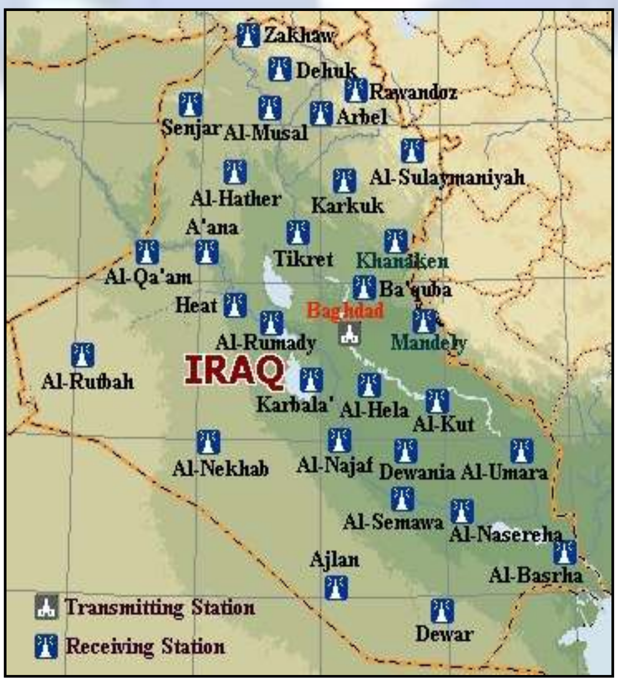

Fig. (3). The local transmitting and receiving stations.

The distances and bearings between the transmitting station (Baghdad) and receiving stations had been calculated and tabulated besides to the geographical locations (longitude, latitude) for each studied site, as shown in table (2).

Table (2) Longitude, latitude, distance and bearing between the transmitting and receiving stations.

Regional Communications		Location		Distance (KM)	Bearing (degree)
		Longitude (E)	Latitude (N)		
BAGHDAD	Al-Musal	43.13	36.33	350	341
	Sulaymaniyah	45.48	35.5	259	22
	Mandely	45.60	33.73	120	69
	Al-Basrah	47.78	30.50	145	134
	Al-Semawah	45.25	31.30	242	160
	Al-Nekheab	42.27	32.15	238	235
	Al-Rutbah	40.17	33.1	393	265
	Al-Qa'im	42.05	34.37	243	297
	Dehuk	43.00	36.85	409	342
	Zakhow	42.70	37.30	465	340
	Arbel	44.52	36.18	315	2
	Karkuk	44.38	35.47	235	0
	Sinjar	41.68	36.33	413	323
	Tikret	43.66	34.58	152	334
	Al-Rumady	43.30	33.42	100	274
	Ba'aquba	44.64	33.74	49	29
	Khanaken	45.38	34.8	185	29
	Karbala'a	44.03	32.60	89	201
	Al-Hela	44.44	32.51	93	176
	Al-Kute	45.82	32.53	162	124
	Al-Umara	47.17	31.86	309	122
	Al-Dewania	44.94	31.99	160	160
	Al-Najaf	44.33	31.98	152	181
	Ajlan	44.27	30.04	368	181
	Al-Nasereha	46.27	31.06	310	145
	Al-Hather	43.72	35.58	255	346
	A'ana	41.92	34.39	255	296
	Dewer	45.49	39.85	403	164
	Heat	42.80	33.63	149	282
	Rawandouz	44.55	36.61	363	2

The calculations of the optimal workable frequencies have been made to search for the more reliable frequencies; the calculations for the probability that the signal-to-noise ratio of the considered link exceeds a threshold value were performed, as shown in figure (4). Figure (4) presents some charts, which illustrate the results of the analytical study for the local zone.

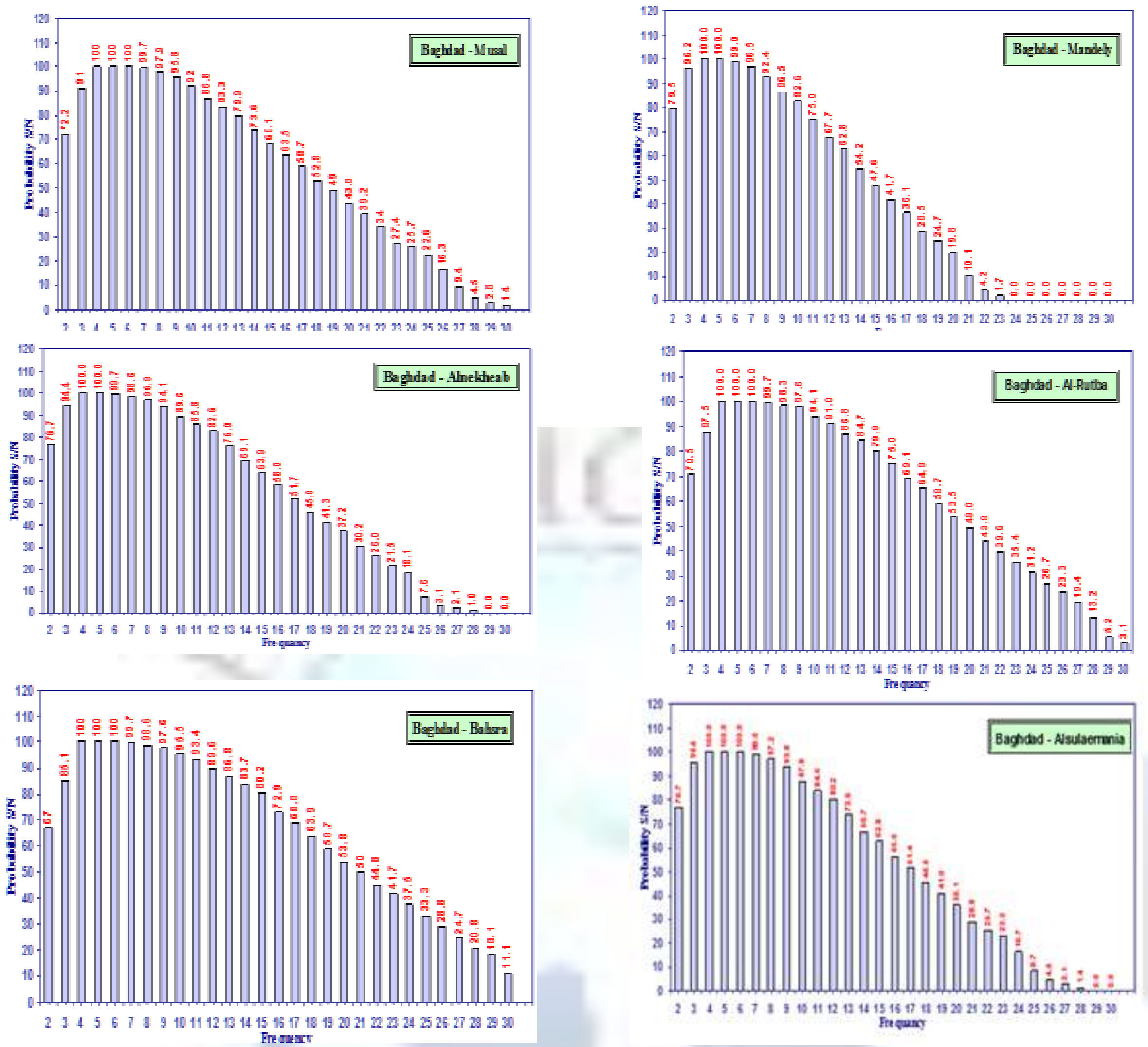

Fig. (4) Some charts illustrate the results of the analytical study that had made for the local zone.

Finally, the reliable HF-frequencies for each link were allocated by electing the frequencies that show probability of successful link that exceeds 95%. The selected frequencies for the local communication links have been plotted using the contour graphical representation. Figure (5), illustrates the contours of the reliable optimum frequencies working within the local zone, taking into consideration that the analyzed data are predications of the REC533 international model.

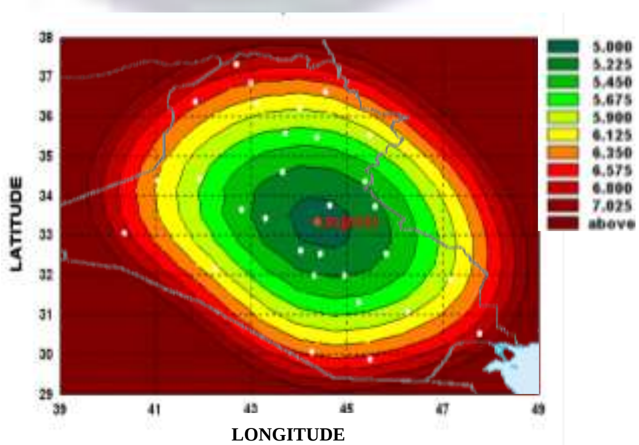

Fig. (5) The contour diagram of the reliable optimum frequencies for the local communications zone.

W232q2. The Regional Zone

For the regional zone, the calculations have been done between the Iraqi capital-Baghdad (as a first station) and another neighbor Arabian and foreign capitals and cities (as second stations). Most of the considered capitals lay in the region of the Middle East zone. The goal of the regional communications study is to determine the reliable frequencies, which shows the ability to maintain a permanent HF-link connection between Baghdad and the other considered city in the Middle East zone for the period (year 2001) and under different ionospheric and solar conditions. The considered transmitting and receiving locations taken in our study are clarified in figure (6). The name of the considered cities, their geographical location coordinates (longitude & latitude), the distance between the transmitting station and receiving stations, and the bearing from Baghdad to the studied counties and cities have been shown in table (3) The analysis procedure adopted for the regional zone was similar to that used in the local zone. Figure (7), shows some charts which illustrate the results of the analysis operation of the regional zone.

Fig. (6) The regional transmitting/receiving stations. locations.

Table (3) Location names, longitude, latitude, distance and bearing from the transmitting to receiving stations for the regional communications zone

Regional Communications			Location		Distance (KM)	Bearing (degree)
			Longitude (E)	Latitude (N)		
BAGHDAD	Turkey	*Arzurum*	41.28	39.92	781	339
		Malatya	38.32	38.35	779	315
		Van	43.36	38.55	586	350
		Batman	41.12	37.87	583	329
	Jordan	*Amman*	35.93	31.95	806	285
		Al-Jufur	38.23	32.53	581	260
		Ba'ar	36.68	30.78	780	248
		Al-Aqabah	35.00	29.52	987	244
	Iran	*Qum*	50.90	34.65	618	76
		Tehran	51.43	35.67	696	68
		Ixfahan	51.63	32.67	680	96
		Shiraz	52.53	29.60	878	118
		Hamadan	48.50	34.80	412	66
		Ardabil	48.30	38.25	650	32
		Tabriz	46.30	38.08	554	18
		Mahabad	45.70	36.72	393	17
		Karmanshah	47.07	34.32	271	66
		Masjed Sul.	49.51	31.98	504	107
	K.S.A	*Al-Riyadh*	46.72	24.63	996	166
		Al-Jawf	39.87	29.86	577	227
		Ar'ar	41.00	30.95	415	230
		Tayma'a	35.73	27.50	1054	231
		Ha'il	41.70	27.55	694	201
		Buraydah	43.98	26.33	782	182
		Al-Hufuf	49.57	25.37	1020	150
		Al-Fanea	48.70	28.10	715	144
		Tabuk	36.58	28.38	927	233
	Syria	*Dayr AlZawr*	40.15	35.33	446	299
		Tadmur	38.25	34.60	582	283
		Damascus	36.25	33.50	755	271
		Al-Raqqah	39.02	35.93	568	300
		Al-Haxakah	40.75	36.48	480	316
		Halab	37.17	36.22	732	295
		Hamah	36.75	35.13	729	285
	Palestine	*Al-Quds*	35.25	31.76	874	258
	Lebanon	*Batrut*	35.50	33.88	825	274
	Azerbaijan	*Paravan*	42.33	40.10	773	346
	Bahran	*Al-Manama*	50.58	26.22	993	142
	Qatar	*Al-Dawhah*	51.53	25.28	1134	142

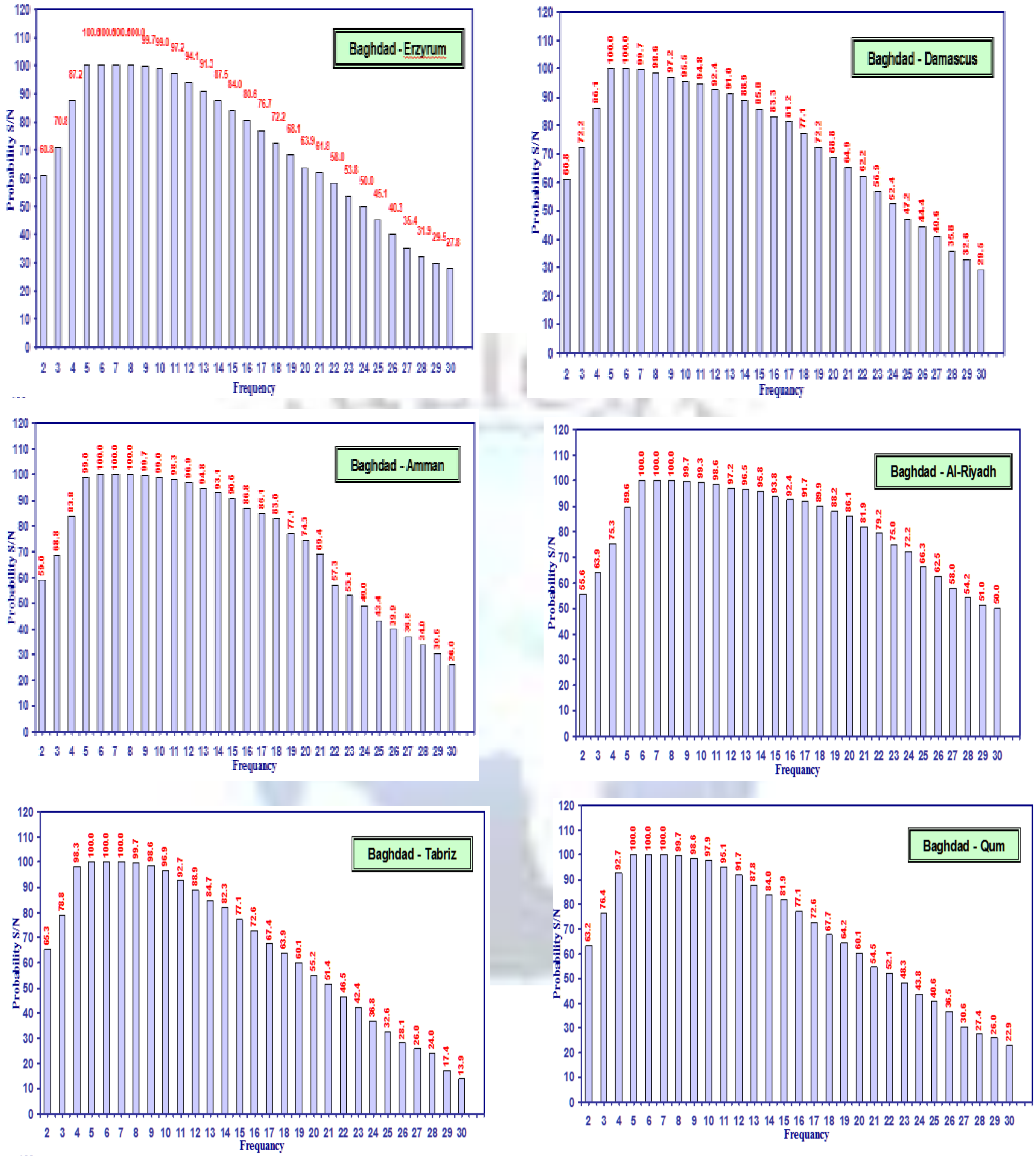

Fig. (7) Some charts illustrate the results of the analytical study that had made for the Regional zone.

The selected optimal reliable frequencies for the Middle East zone are presented in figure (8). Figure (8) presents the contour diagram of the frequencies that have a probability of successful link exceeding 95%.

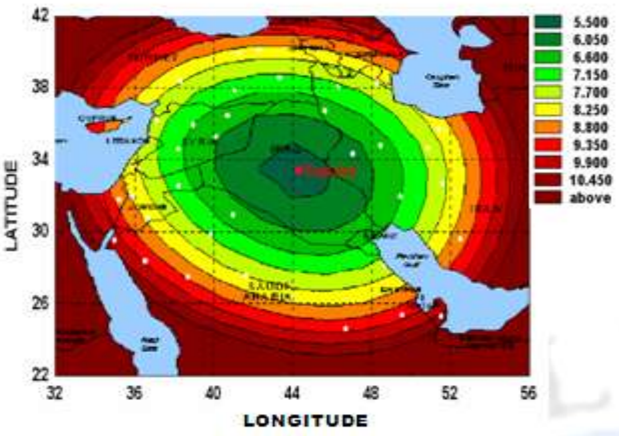

Fig. (8) The contour diagram of the reliable optimum frequencies for the regional communications zone.

Discussion and Conclusions

In this research, an analytical study for the REC533 international propagation model has been made for the Middle East region. The frequency predictions have been made using REC533, then the annual probability communication link success for each frequency was determined, the criteria of communication link success was "the S/N ratio must exceed a threshold value". The most reliable frequency calculations for the Middle East region according to that model have been divided into two zones depending on their distances from the capital Baghdad, which has been adopted to represent a central transmitting/receiving station for the HF-radio waves.

Iraq territory has been adopted to represent the first studied zone, which was called the local zone. This study was aimed to allocate those HF-frequencies which have the ability to maintain reliable permanent connections between Baghdad and thirty different locations distributed above the Iraq territory. The results of this study have been clarified in terms of contour diagram, as shown in figure (5). Figure (5) represents the values of the predicted frequencies extracted from the results of REC533 international model. From the figure; it is possible to perceive that the calculated most reliable frequencies lay within the frequency range (4-7MHz). The calculated frequency range is compatible with the results of other prediction models, which indicate that the workable frequencies for the Iraqi area should be restricted in the frequency range (2-10MHz). In addition, figure (5) declare that the frequency contour distribution has a semi-oval shape, where the frequency increases gradually with the increment of the distance between Baghdad (the first transmitting /receiving station) and the other HF station. The oval frequency distribution shape has a major axis approximately parallel to the longitude and minor axis parallel to the latitude, this shape may due to the effect of the sunrise and sunset phenomenon. These phenomena affect the workable frequencies on the regions located approximately on the same latitude (different longitude), while this effect is relatively lesser on the regions located in the same longitude, because they will suffer from the same influence at the same time (simultaneously). The semi-oval shape has a small dent on the western-south part of the diagram this may due to the scarcity of the studied samples in this region.

The second studied zone has covered some of the Middle East countries that surround Iraq from the four directions, and their distance may far about 1000Km from the capital Baghdad, as illustrate in figure (6). This region was called the regional zone. The same analysis procedure has been applied to select the most reliable frequencies from the predictions of the REC533 international propagation model for sixty nine different locations placed on capitals and cities distributed within the Iraq surrounded countries. The calculated most reliable frequencies have been clarified in figure (8), which illustrates the contour distribution of these frequencies within the studied zone. From this figure, it is noticeable that the calculated frequencies are restricted in the frequency range (4-11MHz), which is similar to the range of the predicted OWF in the same zone area. The diagram of the frequency contour distribution shows a semi-circular shape, where the reliable frequency values increase as we move farther from the center, it is obvious that this increment becomes sharper as the distance increase between the transmitting and receiving stations. Also, in the figure it is remarkable that there is simple inflation in the southern part of the diagram, which may due to fact that the southern part is very close to the thermal equator line, which can significantly affect the structure of the ionosphere layer, and in turn affect the values of the workable frequencies between Baghdad and the countries placed on the Arabian Gulf. According to the above discussions concerned with the results of the international HF-communication predictions model, the following conclusions have been derived:

1. The success of high distance radio wave communications depends upon different parameters, the most important factors are; the distance between the transmitting and receiving stations, the connection direction (orientation), the connection time, and the solar activity.
2. It has been concluded that on specific conditions for the time and solar activity parameters, the reliable frequency depends primarily on the distance between the transmitting and receiving stations, this dependence can be represented as a direct relation (between the reliable frequencies and the distance between the transmitting and receiving stations).
3. The influence of the azimuthal direction parameter on the communication frequency values was detected, and it is mainly due to the sunrise and sunset phenomena, and to effect of spatial variation in the ionospheric plasma in the regions near the thermal equator.
4. The most reliable frequencies for the Iraq territory zone lay within the frequency range (4 – 7 MHz).
5. The most reliable frequencies for the regional zone are restricted in the frequency range (4 – 11 MHz).

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