New modus operandis to telecommunication regulation based on propagation mechanism for offshore systems

Opportunity to improve the offshore telecommunication regulation for oil & gas industries.

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Abstract - **The oil and gas industries are expanding their activities in offshore areas to regions that are very far from the coast. The telecommunication systems are, in this context, important actors to provide safe and productive operations. The platforms and ships operate on ocean environment, facing difficult weather conditions, where robust communications are always necessary. Such environment has peculiar aspects and requires new regulatory rules in order to provide facilities and allow a more effective spectrum management. This paper proposes a new regulatory *modus operandis* based on radio wave propagation mechanism to be applied to oil and gas industries for their offshore telecommunication systems.**

Keywords-component; telecommunication; regulatory; offshore; propagation; frequency; spectrum management.

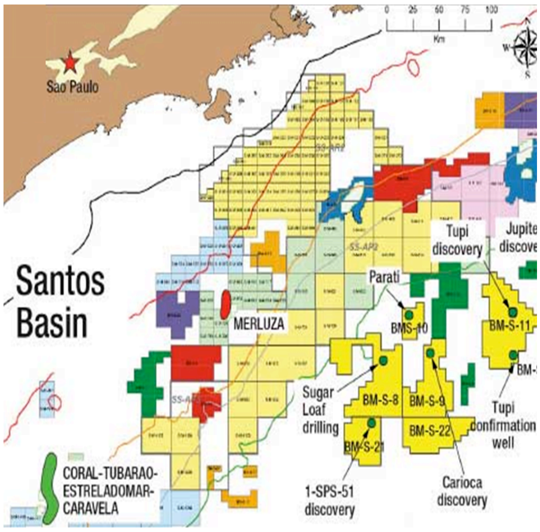
I. Introduction

The telecommunication regulatory rules were developed by national Administrations, guided by the international bureau, focused mainly on onshore systems for a long period, while offshore regions were just considered to attending maritime international agreements, especially to emergency communications. It is clearly acceptable because the regions that are far from coast do not have a high density population to demand sophisticated telecommunications systems, except in some areas around resort islands or others atypical situations. As a consequence, the resolutions that define the telecommunication services and frequency destinations were, in majority, developed to onshore services with specific rules. These rules sometimes do not allow the use of some frequency bands and services on new offshore areas, preventing the efficient spectrum use.

II. New Events

Petrobras, a Brazilian oil and gas company, is a world leader in development of advanced technology in deep-water and ultra-deep water to oil and gas exploitation. Petrobras currently conducts research to explore new offshore fields in order to increase petroleum production. Some new fields were discovered in regions located up to 350 km from the Brazilian coast. It is a new frontier where technology is the key to oil exploitation. Besides this, communication is a strong requirement not only for operational security but also for data, voice and surveillance. The oil discovered on pre-salt (deep-water) is a good example to be mentioned as Tupi oil field, located in the Santos Basin, 250 km (160 miles) from the coast of Rio de Janeiro, Brazil. The Santos Basin region and Tupi field can be seen in figure 1. This field was discovered in a geological formation known as the pre-salt layer, that it is a new petroleum play which is thought to contain significant volumes of oil and natural gas.

Figure 1. Santos basin region. [1]

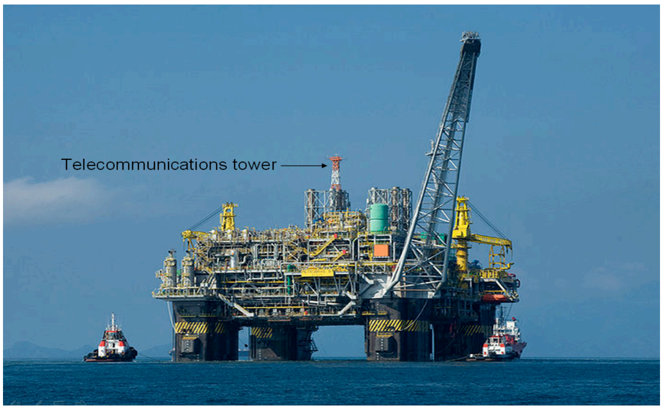


III. Offshore Telecommunication Infrastructure

It is necessary a robust infrastructure to perform the petroleum exploitation in deep-water. There are gas leaked detectors at various locations on the platforms, alarms for increased pressure inside the well and systems for preparing and injecting fluids into its interior. Aeronautical and maritime resources are used to provide people and equipment transportation by ships and helicopters, from coast to platforms and between platforms and survey vessels. All operations are supported by telecommunications systems. The platforms have satellite stations, radio links, optical fibers, automation and control systems, repeaters, trunking, radionavigation aids, aeronautical and maritime communications, Global Maritime

Distress Safety System - GMDSS and portable radios. Therefore, it is essential to have accessibility of modern telecommunication systems to support automation, control, alarms and operational communications. A telecommunication tower of the semi-submersible platform named P 51 is shown on figure 2 as an example. The correct use of telecommunications systems is a challenging task because they need to be approved, certified and legalized by the regulatory authorities, including the Administration of the country that built the platform, international organizations and local aeronautical, maritime and telecommunications authorities. Besides these legal requirements, is not possible to use any desirable frequency bands because some of them have regulatory barriers, although technically the use of these resources in offshore regions does not cause any harmful interference in onshore systems.

Figure 2. Telecommunication tower on P 51 semi-submersible platform. [2]



IV. Geographical Separation to Frequency Reuse

This section establishes a study of geographical separation to frequency reuse that can be applied to terrestrial telecommunication systems (on land and ocean areas). The initial frequency band selected to be considered is 400 MHz. This band is widely used in onshore and offshore regions by oil and gas industries to provide communications on services like voice, data, and to automation purposes as well. Frequencies bellow 400 MHz will have a large coverage and the appropriated distances to apply the co-channel reuse will be bigger than typical distances from coast to the fields, located in deep-water. For this reasons those bands (f < 400 MHz) were not considered in this study. The other frequency bands were selected by the availability of commercial equipments or operational facilities. Based on these arguments, the following frequencies were selected to be studied: 400, 600, 800 MHz, and 2, 5.8, 8, 11, 15, 18 e 23 GHz. The first step was to verify the signal losses along the link path, calculating the attenuation by free space propagation mechanism. The preliminary data is a hypothetical system using an output level of 30 dBm and a transmitting antenna with gain of 25 dBi. Cable and connector losses were considered 2 dB. It is also assumed the level of -90 dBm that is a typical receiver threshold for most systems working on those frequency bands. Figure 3 shows a chart with the frequencies and their respective signal attenuation along the link distances. The horizontal axis is in kilometers in steps of 1 km, from zero to ten and in steps of ten km from ten to 400. The equation used is (1).

$$\text{Level (dBm)} = 30 + 25 - 2 - (32.4 + 20.\text{Log}(d[\text{km}]) + 20.\text{Log}(f[\text{MHz}])) \quad (1)$$

d: Distance (km) / f: Frequency (MHz)

It is assumed the worst scenario in which the transmitter antenna located in the coast is directly pointed into the ocean direction (aligned to an antenna of an offshore system). The purpose is to verify the interference possibilities on offshore areas. The graphic on figure 3 is only to show the radio waves behavior in free space and the distances where the signal decays up to the threshold level, like indicated in table 1.

Figure 3. Attenuation in free space (only the transmitter set parameters).

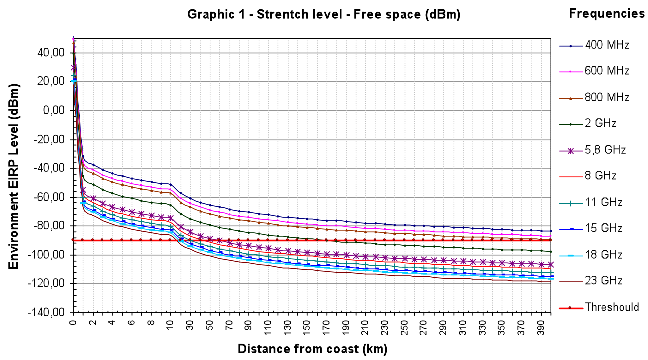


Figure 4. Table 1 – Distance to threshold level (Transmitter set only).

Frequency	Distance	Frequency	Distance
400 MHz	Outside the range of interest.	8 GHz	50 km
600 MHz	Outside the range of interest.	11 GHz	40 km
800 MHz	Outside the range of interest.	15 GHz	30 km
2 GHz	Outside the range of interest.	18 GHz	20 km
5.8 GHz	Outside the range of interest.	23 GHz	20 km

In fact, in order to make an accurate evaluation of the propagation, it is necessary to complete the radio link calculation with the antenna gain and cable loss in the receiver set and considers the additional attenuation due the propagation by spherical Earth diffraction. The calculation is explicated in parts, to make easier the understanding of the analysis. As a second step, the figure 5 shows signal levels, along the link path, detected in the receiver input considering the antenna gain of 25 dBi and the cable/connectors losses equal to 2 dB, represented by equation (2).

$$\text{Receiver input level (dBm)} = 30 + 25 - 2 - (32.4 + 20.\text{Log}(d[\text{km}]) + 20.\text{Log}(f[\text{MHz}])) + 25 - 2 \quad (2)$$

Here the goal of the second step is to show the radio wave behavior of a hypothetical system (considering the transmitter and receiver set) using the ten referred frequencies, just with the free space losses calculated. It is noted that the distances increase significantly to get the threshold level, making the lower frequencies stay out of the interest range, as showed in table 2. After that, the third step is to include the spherical Earth diffraction loss.

Figure 5. Attenuation in free space (transmitter & receiver parameters).

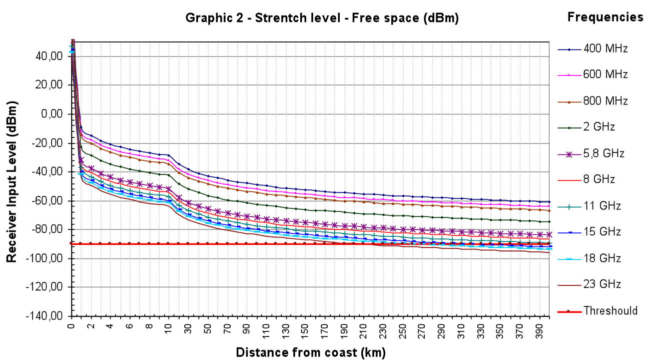


Figure 6. Table 2 – Distance to threshold level (Transmitter & receiver set).

Frequency	Distance	Frequency	Distance
400 MHz	Outside the range of interest	8 GHz	600 km
600 MHz	Outside the range of interest	11 GHz	440 km
800 MHz	Outside the range of interest	15 GHz	320 km
2 GHz	Outside the range of interest	18 GHz	270 km
5.8 GHz	Outside the range of interest	23 GHz	210 km

The additional transmission loss due to diffraction over a spherical Earth can be computed by the classical residue series formula [3]. At long distances over the horizon, only the first term of the residue series is important. This first term can be written as the product of a distance term, *F(X)* (9), and two height gain terms, G_T and G_R. The extent to which the electrical characteristics of the surface of the Earth influence the diffraction loss can be determined by calculating a normalized factor for surface admittance, K, given by the formulae:

$$K_H = \left(\frac{2\pi a_e}{\lambda}\right)^{-1/3} \left[(\varepsilon - 1)^2 + (60\lambda\sigma)^2\right]^{-1/4} \quad (3)$$

$$K_V = K_H \left[\varepsilon^2 + (60\lambda\sigma)^2\right]^{1/2} \quad (4)$$

k_H for horizontal polarization and k_V for vertical polarization

Where a_e : Effective radius of the Earth (km) / ε: Effective relative permittivity = 81 (*to salt water*) / σ : Effective conductivity (S/m) = 5 (*to salt water*) and f: Frequency (MHz).

The diffraction field strength, E, relative to the free-space field strength, E_0, is given by the formula:

$$20\log\frac{E}{E_0} = F(X) + G(Y_1) + G(Y_2) \quad \text{dB} \quad (5)$$

where X is the normalized length of the path between the antennas at normalized heights Y_2 and Y_1 (or G_T and G_R).

$$X = 2.2\beta f^{1/3} a_e^{-2/3}\, d \quad (6)$$

$$Y = 9.6 \times 10^{-3} \beta f^{2/3} a_e^{-1/3}\, h \quad (7)$$

d: path length (km) / a_e: equivalent Earth's radius (km)

h: antenna height (m) / *f*: frequency (MHz).

β is a parameter allowing for the type of ground and for polarization. It is related to K by the following semi-empirical formula:

$$\beta = \frac{1 + 1.6K^2 + 0.75K^4}{1 + 4.5K^2 + 1.35K^4} \quad (8)$$

For horizontal polarization at all frequencies, and for vertical polarization above 20 MHz over land or 300 MHz over sea, β may be taken as equal to 1. For vertical polarization below 20 MHz over land or 300 MHz over sea, β must be calculated as a function of K.

The distance term is given by the formula:

$$F(X) = 11 + 10\ \log(X) - 17.6\,X \quad (9)$$

The height gain term, G(Y) is given by the following formulae: (It is necessary calculate to transmitter and receiver antennae.)

$$G(Y) \cong 17.6\,(Y - 1.1)^{1/2} - 5\log(Y - 1.1) - 8 \quad (10)$$

for $Y > 2$

For $Y < 2$ the value of $G(Y)$ is a function of the value of K computed on (3) or (4).

$$G(Y) \cong 20\log(Y + 0.1Y^3) \quad \text{for } 10\,K < Y < 2 \quad (11)$$

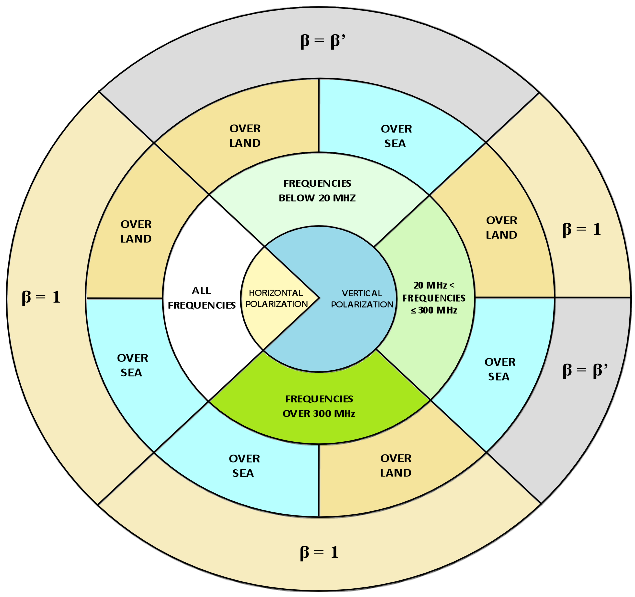
$$G(Y) \cong 2 + 20\log K + 9\log(Y/K)\left[\log(Y/K) + 1\right] \quad (12)$$

for $K/10 < Y < 10\,K$

$$G(Y) \cong 2 + 20\log K \quad \text{for } Y < K/10 \quad (13)$$

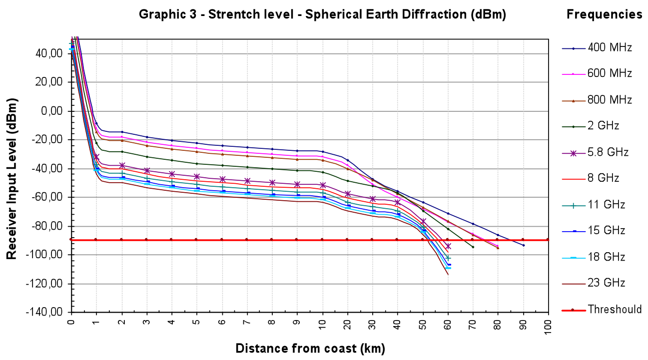
The choice of β can be done by the diagram indicate on figure 7, analyzing the link characteristics from the center to the circle to outside. This diagram was created to make easier the selection of β . The notation β' in the diagram means that β needs to be calculated by equation (8).

Figure 7. β selection diagram.



Finally, the graphic on figure 8 shows a more complete theoretical calculating. Additional losses due to spherical Earth diffraction are included. It is assumed the vertical polarization and heights of 50 and 30 metres to transmitter and receiver respectively. The earth curvature became a real obstacle to radio wave, affecting the frequencies according to the band, offering a better isolation to reuse of higher frequencies.

Figure 8. Attenuation by free space & spherical Earth diffraction.



We can see on table 3 the preliminary calculated distances from coast to acquire threshold level and the approximate region where the diffraction effects probably start to be the predominant propagation mechanism.

Figure 9. Table 3 – Distance to threshold level and diffraction region .

Frequency	Distance	Diffraction efects	Frequency	Distance	Diffraction efects
400 MHz	90 km	20 to 30 km	8 GHz	60 km	40 to 50 km
600 MHz	80 km	20 to 30 km	11 GHz	60 km	40 to 50 km
800 MHz	80 km	20 to 30 km	15 GHz	60 km	40 to 50 km
2 GHz	70 km	30 to 40 km	18 GHz	60 km	40 to 50 km
5.8 GHz	60 km	40 to 50 km	23 GHz	60 km	40 to 50 km

V. Calculator Sheet to Regulatory Proposal

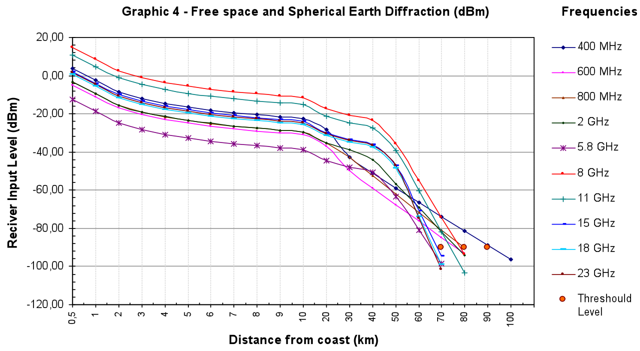
A research was made to select a group of typical telecommunication equipments used by oil and gas industries, privates companies and telecommunication service providers, in order to develop a study to obtain an appropriate geographical separation to propose a frequency reuse that can be applied as a new modus operandis to offshore systems regulation. The parameters that were selected are in table 4.

Figure 10. Table 4 – Systems technichal parameters.

Frequency band	Output level (dBm)	Transmitter antenna gain (dBi)	Receiver antenna gain (dBi)	Losses (dB)	Threshould level
400 MHz	40,00	23,00	23,00	4,00	-90 dBm
600 MHz	35,00	23,00	23,00	4,00	-90 dBm
800 MHz	35,00	25,00	25,00	4,00	-90 dBm
2 GHz	33,00	30,00	30,00	4,00	-86 dBm
5.8 GHz	33,00	30,00	30,00	4,00	-87 dBm
8 GHz	33,00	45,00	45,00	4,00	-94 dBm
11 GHz	33,00	45,00	45,00	5,00	-90 dBm
15 GHz	27,00	45,00	45,00	5,00	-94 dBm
18 GHz	27,00	45,00	45,00	5,00	-93 dBm
23 GHz	30,00	45,00	45,00	5,00	-92 dBm

Therefore, applying the parameters from table 4 and calculating the attenuation by the apropriate propagation mecanisms as indicated in table 3, it was possible to compose the chart shown on figure 11.

Figure 11. Receiver input level considering real parameters.



The graphic above shows the prediction results of radio links, based on telecommunication systems set with typical parameters, in order to simulate real operational conditions. As we can see, the distances to acquire the threshold levels are in the interval from 70 to 100 km, in a regime where the main propagation mechanism is the spherical Earth diffraction. In order to clarify the study, table 5 exposes the calculated values and the intervals where are applied the free space or spherical earth diffraction as the factor of attenuation. Table 6 presents the distances from coast to obtain the threshold level. The distances became smaller by the inclusion of additional loss due to the diffraction.

Figure 12. Table 5 – Results of propagation calculating.

Distance (km)	Frequencies (MHz)									
	400	600	800	2000	5800	8000	11000	15000	18000	23000
0,5	3,58	-4,94	-3,44	-3,40	-12,65	14,56	10,79	2,10	0,52	1,39
1	-2,44	-10,96	-9,46	-9,42	-18,67	8,54	4,77	-3,92	-5,51	-4,63
2	-8,46	-16,98	-15,48	-15,44	-24,69	2,52	-1,25	-9,94	-11,53	-10,66
3	-11,98	-20,51	-19,00	-18,96	-28,21	-1,00	-4,77	-13,46	-15,05	-14,18
4	-14,48	-23,00	-21,50	-21,46	-30,71	-3,50	-7,27	-15,96	-17,55	-16,68
5	-16,42	-24,94	-23,44	-23,40	-32,65	-5,44	-9,21	-17,90	-19,48	-18,61
6	-18,00	-26,53	-25,02	-24,98	-34,23	-7,02	-10,79	-19,48	-21,07	-20,20
7	-19,34	-27,86	-26,36	-26,32	-35,57	-8,36	-12,13	-20,82	-22,41	-21,54
8	-20,50	-29,02	-27,52	-27,48	-36,73	-9,52	-13,29	-21,98	-23,57	-22,70
9	-21,53	-30,05	-28,55	-28,51	-37,75	-10,55	-14,31	-23,01	-24,59	-23,72
10	-22,44	-30,96	-29,46	-29,42	-38,67	-11,46	-15,23	-23,92	-25,51	-24,63
20	-28,46	-36,98	-35,48	-35,44	-44,69	-17,48	-21,25	-29,94	-31,53	-30,66
30	-42,92	-49,70	-42,64	-38,96	-48,21	-21,00	-24,77	-33,46	-35,05	-34,18
40	-51,02	-58,79	-52,52	-44,10	-50,71	-23,50	-27,27	-35,96	-37,55	-36,68
50	-58,84	-67,60	-62,12	-56,78	-63,60	-35,82	-39,06	-47,28	-48,59	-47,36
60	-66,48	-76,23	-71,54	-69,28	-81,09	-55,20	-60,53	-71,00	-73,74	-74,59
70	-74,00	-84,74	-80,84	-81,67	**-98,47**	-74,47	-81,87	**-94,59**	**-98,78**	**-101,70**
80	-81,43	**-93,16**	**-90,05**	**-93,96**		**-93,64**	**-103,13**			
90	-88,79									
100	**-96,10**									

Legend	
Receiver input level below the threshold parameter.	
Receiver input level calculated by sphericalEarth diffraction.	
Receiver input level calculated by free space.	

The distances indicated on table 6 are not enough to reuse the frequencies, because it is still necessary to have a minimum signal/noise ratio to avoid interference in the receiver. This insulation was calculated by increasing the distances up to adding at least a margin of 10 dB, based on spherical Earth diffraction. The results are exposed in the table 7 - Geographical separation to frequency reuse

Figure 13. Table 6 – Distance to acquire the threshold level.

Frequency band	Distance to acquire the threshold level	Frequency band	Distance to acquire the threshold level
400 MHz	100 km	8 GHz	80 km
600 MHz	80 km	11 GHz	80 km
800 MHz	80 km	15 GHz	70 km
2 GHz	80 km	18 GHz	70 km
5.8 GHz	70 km	23 GHz	70 km

Safety frequency reuse can be obtained by application of geographical separation indicate on table 7.

Figure 14. . Table 7 - Geographical separation to frequency reuse.

Frequency band	Geographical separation to frequency reuse	Frequency band	Geographical separation to frequency reuse
400 MHz	110 km	8 GHz	90 km
600 MHz	90 km	11 GHz	90 km
800 MHz	100 km	15 GHz	80 km
2 GHz	90 km	18 GHz	80 km
5.8 GHz	80 km	23 GHz	80 km

VI. COMMENTS

A. *Selecting the diffraction region*

The transition of the propagation from free space to spherical Earth diffraction along the radio link is not a clear boundary at a specific point in the space. It will depend on environment conditions and terrain profile but in this paper the considered link is over the sea with no obstruction. Based on this assumption, the diffraction region was estimate by the theory available on Recommendation ITU-R P. 526-10 “Attenuation by diffraction”. The regions where diffraction acts as a predominant mechanism are indicated in table 3. According to the distances marked on horizontal axis of the graphic (Attenuation by free space & spherical Earth diffraction) in figure 8, the table 3 shows a range between two distances from the coast within which begins to occur the phenomenon of diffraction. In that table the upper limit was selected to start the diffraction calculating, because the occurrence of this phenomenon seems to be more reasonable.

B. *Propagation anomalies*

Although the distances proposed are considered enough to guarantee the interference insulation (from onshore systems to offshore ones), some abnormal environmental conditions can provide anomalous propagation events like tropospheric scatter or ducting and layer reflection/refraction. These events could occur in very small percentage of time and can be neglected in most cases. Nevertheless, complete calculating for specific situations can be obtained by the use of Recommendation ITU-R P.452-14 “Prediction procedure for the evaluation of interference between stations on the surface of the Earth”.

C. *Regions to applying the proposed method*

Platforms located at distances higher than that indicates in table 7 can apply the proposed frequency reuse (co-channel) and utilize telecommunication services with the appropriate insulation against interference. But platforms located at distances shorter than those show in table 6 should have their systems regulated under the same conditions of onshore stations regulation, observing the spectrum bands and conventional destinations, because the geographical separation will not be sufficient to provide adequate insulation to prevent electromagnetic interference.

D. *Need to updated regulation*

In fact there is a new situation to be considered in deep water. The concentration of platforms in offshore region (deep-water) requires a robust telecommunication system to ensure safe and efficient operations. This fact generates new opportunities to modernize regulatory issues and provide a more efficient use of radio spectrum. Therefore, the regulatory authorities need to be a great ally and driver to the use of modern technologies by providing facilities for legalization of the systems used on offshore areas.

E. *Secure boundary to frequency reuse*

In order to guarantee interference insulation, the coordination areas need to be established correctly. Therefore, a secure boundary to frequency reuse has to take into account the threshold level and an additional ratio of signal/noise to guarantee an appropriate protection as indicate in table 7. Due to reciprocity of the antennas the interference cases is investigated from coast to the offshore areas and vice versa.

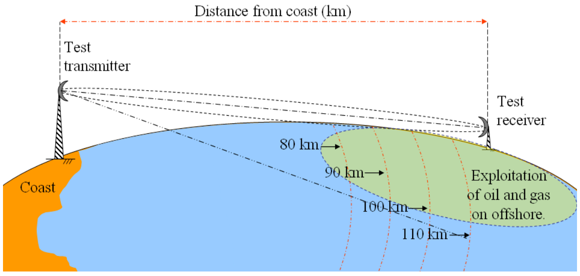
F. *Achievements*

The achievements obtained are based in the typical parameters of telecommunication systems, selected to the calculating of propagation. If other parameters were selected the results will be different. For example, if the antenna height was replaced in the transmitter or in the receiver site, the regions where the propagation by diffraction mechanism was considered the main attenuation factor can be changed too.

VII. CONCLUSION

This paper considers the opportunity shaped by oil and gas exploitation in deep-water that created a high density of communication stations (platforms, ships and vessels) on ocean region. Therefore, it is proposed a new modus operandis for telecommunication regulation to be applied on offshore area, by the use of propagation mechanism (free space plus Spherical Earth diffraction) as a frequency reuse factor. See the geographical separation indicated in table 7 (e.g. in the illustration of figure 15). It is also proposed suppress the legal barriers to private companies (working on oil and gas exploitation) on the use of some frequency bands with the existing destinations specific to telecommunications service providers and others, allowing them to use these resources on offshore areas

Figure 15. Example of geographical separation to frequency reuse.



These barriers prevent the efficient use of radio spectrum. Since there is no harmful interference and also there are no other customers to telecommunications service providers on offshore regions, the oil and gas industries could use the frequencies bands to their own purposes on specific systems and communications.

Some example of advantages to be gained in applying the proposed new modus operandis to the telecommunication regulation based on propagation mechanism for offshore systems, are mentioned in the following items:

a) More efficient spectrum use;

b) Increasing of the density of frequency users in a secure way;

c) More taxes to telecommunication agencies;

d) Better possibilities to oil and gas industries operate their system in oceanic environment with more security and efficiency; and

e) Opportunity to telecommunication industries on provide a list of ready equipments to offshore areas.

Acknowledgment

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