Assessment of IMT-Advanced Downlink Interference to Ship-Based Radar C Using Monte Carlo Technique

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ABSTRACT

In order to support the growing number of mobile users and satisfy their quest for more broadband mobile services, additional spectrum needs to be allocated to the International Mobile Telecommunication (IMT), which is the international standard for mobile communication. However, the radio spectrum being a natural resource cannot be manufactured or reproduced. At the moment there is no empty spectrum to allocate to IMT. This is why the International Telecommunication Union (ITU), plans to enable IMT to share some frequency bands with other existing radio services. One of such bands is 3300 – 3400 MHz, which is currently being used by radiolocation services in all parts of the world on a primary basis. For co-existence in this band to be possible, it is required that IMT services and radiolocation services should not to cause harmful co-channel interference to each other. This work used Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) to study the interference scenario to determine the probability of interference from IMT-Advanced base station to ship-based C radar. The results show that in 85% of the time, IMT-Advanced systems will harmfully interfere with the ship-based radar system. This means that IMT-Advanced base station and ship-based radar C cannot share 3300 – 3400 MHz band without application of interference mitigation technique.

KEYWORDS: Radio Spectrum, IMT-Advanced, Micro Cell, Radiolocation, Ship-Based Radar, Coexistence, Monte-Carlo

INTRODUCTION

Mobile communications have become closely integrated into the daily life of the whole society [1]. And as the population of the world grows, the number of mobile users also grows. Moreover, in the last few decades, there has been increasing demand for wide area mobile broadband applications and services among the mobile users [2]. This has led to the evolution of mobile technology from International Mobile Telecommunication-2000 (IMT-2000) to International Mobile Telecommunication-Advanced (IMT-A) and now IMT 2020. IMT-Advanced which is marketed as 4G technology is meant to go beyond the IMT-2000 requirements and accommodate new services like High-Definition Television (HDTV), roaming with wireless local networks and interact with digital video broadcasting systems. It offers high quality of service for multimedia support, seamless connectivity and global roaming across multiple networks with smooth handovers, high spectral efficiency. To achieve all these requirements additional spectrum is required [3].

However, the radio spectrum which is very essential to the stable operations of all radio communication systems and applications is a natural resource like land, water and oil. Among many distinguishing features, this radio spectrum cannot be reproduced or exported [4]. It can only be optimized for efficient utilization. That is why the international Telecommunication Union (ITU) was formed by the United Nations to ensure the rational, equitable, efficient and economical use of this radio-frequency spectrum by all radio-communication services [5]. Since, radio waves propagate in a contiguous manner such that it knows no boundaries or borders, there is therefore the need to carefully break up the spectrum into smaller chunks so that different radio services and applications can utilize the spectrum simultaneously without causing interference to one another. This has to be done on a global basis for it to work because of the contiguous nature of radio wave propagation, otherwise, radio services in one country might interfere with radio services in another country. ITU has therefore broken up the usable radio spectrum into smaller chunks and allocated them to different radio-communication services and applications. So, at the moment there are no emptier usable spectrum [6]. The bands allocated to fixed and mobile services (IMT Services) have been used up due to the growing demand for more broadband wireless services and applications. This demand has continued to grow and that was why at the World Radio Conference of 2015 (WRC-15), in resolution 223, ITU identified 3300 – 3400 MHz band and some other bands for IMT [7].

However, the 3300-3400 MHz band is currently allocated to radiolocation services in all regions of the world on primary basis [7]. So, IMT-advanced systems are expected to share this band with radiolocation services. Radiolocation service involves using radars to detect the presence, direction, and speed of aircrafts, ships and other objects [8]. And since it is the primary service on that band, IMT-Advanced systems are expected not to cause destructive interferences to it [9]. Therefore, before IMT-Advanced systems can be deployed in that band, studies need to be carried out to investigate the possibility of IMT-Advanced systems sharing the band with radiolocation systems without interference. For this reason, in resolution 223, of the World Radio Conference of 2015 (WRC-15), ITU-R which is a sector of ITU that manages the international radio-frequency spectrum and satellite orbit resources was called upon “to further study operational measures to enable the coexistence of IMT and radiolocation services in the frequency band 3 300-3 400 MHz”. Figure 1 gives a pictorial idea of co-existence in the same band.

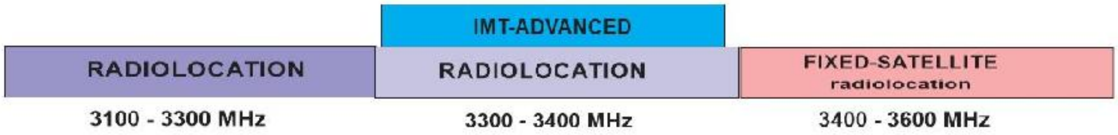


Figure 1: Illustration of co-existence between IMT-Advanced and Radiolocation services

Nigeria is a member of African Telecommunication Union (ATU) which is ITU’s regional group for African countries and is known to operate a ship-based radar in Lagos. Therefore, this study is important to Nigeria and other African countries because 33 out of the 45 countries in which the band 3300 – 3400 is identified for IMT are from African region [10], [14] and [15]. This work is peculiar to Nigeria and it was focused on co-channel analysis between IMT-Advanced systems and Ship-based radar C using Monte-Carlo Method which is implemented on SEAMCAT.

Efforts have been made by different industries and groups in response to the demands mentioned above and that is why cellular network technology has continued to advance from 1st generation to 4th generation and tentatively 5th generation [4]. Each advancement needs more bandwidth to achieve more capabilities than the previous generation. But bandwidth cannot be manufactured because it is a natural resource and other radio services need bandwidth too. This is why spectrum sharing has become very necessary.

RADIOLOCATION SERVICES

Radiolocation is the process of locating objects through the use of radio waves. It involves mainly the use of radars. A radar is a system for detecting the presence, direction, and speed of aircrafts, ships, etc., by sending out pulses of radio waves which are reflected off the object back to the source [8]. Radars are generally grouped into three based on where they operate, namely: Land-Based radars, Ship-Based radars and Air-Based radars. Each of these radars is further divided into types. There are for example ship-based A, ship-based B and ship-based C radars. The difference between them is in their parameters.

In all ITU regions, 3300 – 3400 MHz band is allocated to radiolocation service on a primary basis, but now radars would have to share that band with IMT services in order to improve spectrum efficiency if the sharing studies yield positive results.

SPECTRUM SHARING

An important sharing condition is that co-primary services are not allowed to cause harmful interference to the other primary services. So, before IMT services could be deployed in that band, feasibility studies have to be done in order to determine the sharing conditions or rules. The two methods used in determining the sharing rules are Minimum Coupling Loss (MCL) method and Monte-Carlo method.

The Minimum Coupling Loss (MCL) method calculates the isolation required between a single interferer and a single victim to ensure that there is no interference. The method is analytical, simple to use and does not require a computer for implementation. The primary drawback is that it is a worst-case analysis and produces a spectrally inefficient result for scenarios of a statistical nature [6]. It is usually only used for international coordination threshold [11], [12].

Monte Carlo method is a statistical technique based upon the consideration of many independent events in time, space and frequency. For each event, or simulation trial, a scenario is built up using a number of different random variables that define the systems to be simulated (i.e. where the interferers are with respect to the victim, how strong the victim's wanted signal strength is, which channels the victim and interferer are using etc.). If a sufficient number of simulation trials are considered then the probability of a certain event occurring can be evaluated with a high level of accuracy [13].

RELATED WORKS

A significant amount of work has been carried out at the ITU-R to study the coexistence of IMT systems with many other radio services in an effort to identify more spectrum for IMT services [7]. [8] was the first work done to study the co-existence of IMT and radiolocation in 3300 to 3400 MHz band. Minimum Coupling Loss method was used with many assumed parameters and it concluded that sharing was not possible in co-channel for IMT and radiolocation without some mitigation techniques. Furthers studies that would use accurate system parameters were encouraged. Many preliminary studies have been done in [10], [14], [15] and [16] as working documents and appropriate system parameters were used in these recent works but all of them still adopted Minimum coupling loss method which is not suited for systems like IMT systems that have a statistical nature. In [5] Monte-Carlo approach was adopted but the study involved IMT-Advanced systems and geostationary satellite networks. IMT-Advanced system has also improved tremendously over the years, that is why most recent studies; [10], [14] and [16], unlike earlier studies did not study scenarios where IMT-Advanced systems are the victims because IMT-Advanced system (LTE) now has a technique known as Hybrid-Automatic Repeat reQuest (HARQ) with Chase combining which enables it to still perform well in the presence of the interference from radar system due to the short-period impulse nature of such interferences. In this work, we used Mont-Carlo technique implemented on SEAMCAT to determine the likelihood of interference from IMT-Advanced Base station into ship-based C radar.

METHODOLOGY

Monte Carlo method is a statistical methodology to simulate processes by randomly taking values from a distribution. A Monte Carlo simulation is a statistical technique based upon the consideration of many independent events in time, space and frequency. For each event, or simulation trial, a scenario is built up using a number of different random variables that define the systems to be simulated (i.e. where the interferers are with respect to the victim, how strong the victim's wanted signal strength is, which channels the victim and interferer are using etc.). If a sufficient number of simulation trials are considered then the probability of a certain event occurring can be evaluated with a high level of accuracy.

Figure 2 shows a typical model of a Monte Carlo technique which involves a repeated random generation of interferers and their parameters like power, position, time, activity (idle/active) etc., such that after many trials, not only unfavourable, but also favourable cases will be accounted for, the resulting rules of operation made from the outcome will be less stringent and therefore enable more optimal use of the spectrum. This is quite unlike the Minimum coupling loss method that considers only a single interferer and a single victim operating at exactly the worst-case scenario. Figure 3 illustrates the typical scenario for a Minimum Coupling Loss analysis. However, such worst-case assumption will not be permanent during normal operation and therefore sharing rules might be unnecessarily stringent. That is why the Monte Carlo method is most preferable in analysing systems that have a statistical nature.

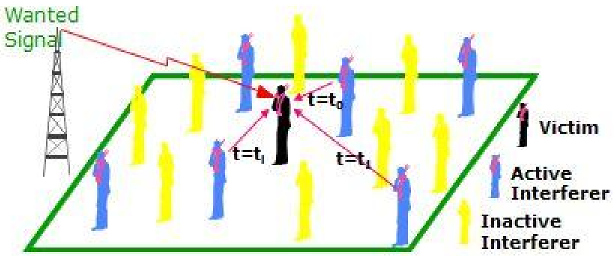


Figure 2: Illustration of the Scenario for Monte-Carlo method

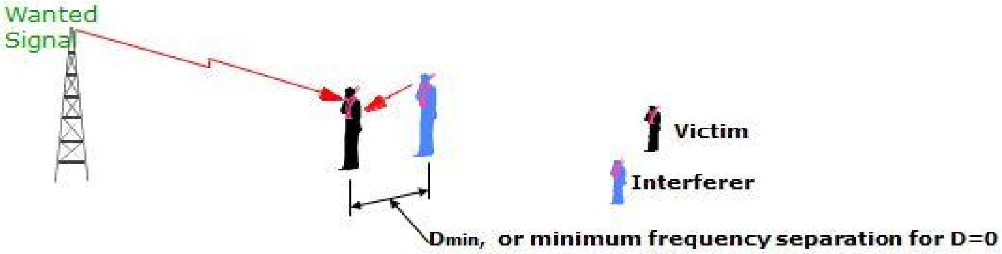


Figure 3: Illustration of the Minimum Coupling loss scenario.

Simulation Parameters

The Parameters of the IMT-Advanced System and Ship-Based radar system were gotten from in-force ITU Recommendations. This is very necessary because different study groups in ITU are continuously working to improve on the parameters used for sharing and compatibility studies. Using parameters from a superseded Recommendation would produce an out of date result. Table 1 and 2 show the parameters of IMT Base Station and User Equipment respectively. OFDMA module is used in the work because it (OFDMA) has been designed for a Long-Term Evolution (LTE) network which is the standard implemented in IMT-Advanced and IMT 2020 systems [13]. Table 3 gives the spectrum emission mask for a 100MHz IMT Base station adopted from 3GPP TS 36.104 release 13, while Table 4 shows the parameters of the ship-based radar used. Noise floor and Radar receiver's sensitivity are calculated using equations 1 and 2. The parameters are inputs to SEAMCAT and all the parameters have to be consistent otherwise there would be inconsistency error which would either flaw the result or hinder the simulation.

$$Noise\ floor = -173.98 + 10log_{10}(frequency) + Noise\ figure \tag{1}$$

$$Sensitivity = Noise\ floor + Protection\ Ratio \tag{2}$$

Table 1: Parameters of the IMT Advanced Base Station

Parameter	**Small cell outdoor/Micro urban**	**Source**
Cell radius/Deployment density	1-3 per urban macro cell <1 per suburban macro site	[18]
Antenna height	6 m	[18]

Parameter	**Small cell outdoor/Micro urban**	**Source**
Frequency Range (MHz)	3300 – 3400	
Frequency reuse	1	[18]
Below rooftop base station antenna deployment	100%	[18]
Maximum base station output power (5/10)	24 dBm	[18]
Maximum base station antenna gain	5 dBi	[18]
Maximum base station output power/sector (EIRP)	29 dBm	[18]
Noise Figure	10 dB	[18]
Protection criterion (I/N)	–6 dB	[18]
Maximum RBs per Base Station	500	Standard
Number of RBs per Mobil Station	25	Standard
Handover Margin	6 dB	[5]
Minimum Coupling loss	53 dB	[17]
System Bandwidth	100 MHz	3300 to 3400MHz
Resource Block Bandwidth	0.18 MHz	Standard
Emission bandwidth	90 MHz	[17]

Table 2: Parameters of IMT advanced User terminal

Parameter	Small cell outdoor/Micro urban	Source
Indoor user terminal usage	70%	[18]
Antenna Height	1.5 M	[18]
Indoor user terminal penetration loss	20 Db	[18]
User terminal density in active mode to be used in sharing studies	3/5 MHz/km2	[18]
Maximum user terminal output power	23 dBm	[18]
Average user terminal output power	−9 dBm	[18]
Typical antenna *gain* for user terminals	−4 dBi	[18]
Body loss	4 dB	[18]
Protection criterion (I/N)	−6 dB	[18]
Noise Figure	9 dB	[18]

Table 3: Spectrum Emission Mask of the IMT-Advanced Base Station

Offset (MHz)	**Mask (dBc)**	**Ref. bandwidth (KHz)**
-65	-61	1000
-55	-61	100
-54.9	-60	100

Offset (MHz)	**Mask (dBc)**	**Ref. bandwidth (KHz)**
-50	-60	100
-45.1	-53.001	100
-45	0	100000
45	0	100000
45.1	-53.001	100
50	-60	100
54.9	-60	100
55	-61	1000
65	-61	100

Table 4: Parameters of Ship-Based Radar C

Parameter	Ship-Based Radar C	Source
Antenna height above ground	20m	[10]
Tuning range	3.1-3.5 GHz	[19]
Tx power into antenna (Peak)	60-200 kW	[19]
Tx bandwidth (–3 dB)	25 MHz	[20]
Antenna gain	40 dBi	[20]
Rx sensitivity	–92.5 dBm	Calculated
Rx noise figure	1.5 dB	[20]
Noise floor	-99.5dBm	Calculated
Rx IF bandwidth (–3 dB)	20 MHz	[20]
Protection criterion (I/N)	–6 dB	[20]
Deployment area	Worldwide	[20]
Coverage radius	30km	[10]
Propagation model	Free-space	[10]

Interference Scenario

The simulated scenario has IMT-Advanced base station as the interferer while the ship-based radar C is the victim. Figure 4 shows a scenario of one event. The victim system transmitter (Green) represents the ship-based radar C, the victim link receiver (Blue) represents the object the radar is detecting while the Interfering link transmitter (Red) is the IMT Base station transmitter. The interfering system receiver (Yellow) is the mobile user which is typically located within the footprint of the base station and therefore is not visible. For each event SEAMCAT calculates the desired Received Signal Strength (dRSS) which is the signal received by the radar from the target and Interfering Received Signal Strength (iRSS) which is signal received by the radar from IMT-Advanced base station. This action is repeated according to the number of events selected in the simulation. Each event is different from every other event in terms of the position of the base station and the antenna radiation configuration between the base station and the radar system. SEAMCAT uses the values of the dRSS and iRSS calculated for each event to compute the probability of interference from the IMT-Advanced base station into ship-based radar C system. dRSS and iRSS are calculated using equation 3 and 4 respectively.

$$dRSS = P_R + (G_R)^2 - L \tag{3}$$

Where P_R is the power transmitted by the radar, G_R is the gain of the radar antenna while L is the propagation loss between the radar and the object being detected.

$$iRSS = P_{IMT} + G_{IMT} + G_R - L \tag{4}$$

Where P_{IMT} is the power transmitted by the IMT-Advanced Base station, G_{IMT} is the gain of the IMT-Advanced Base station antenna, G_R is the gain of the radar antenna while L is the propagation loss between the radar and the IMT-Advanced Base station.

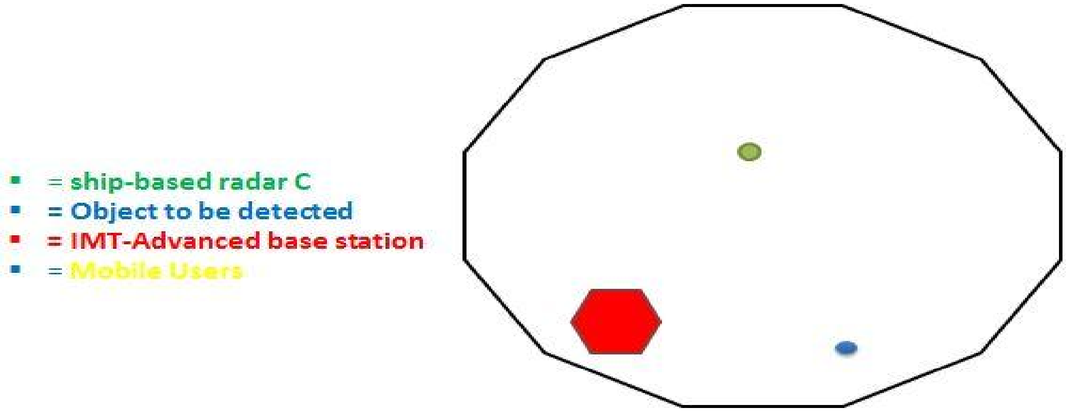


Figure 4: Outline of a single event

The scenario where IMT-Advanced User equipment is the interferer was not studied as it is not necessary. This is because the EIRP of IMT-Advanced User equipment is much lower than that of an IMT-Advanced Base station and IMT-Advanced User Equipment also has power control functionality. So, interference would come much more from the Base station [10], [14], [15] and [16].

Propagation Model

The propagation model between the Base Station and the Ship-Based Radar C is from Recommendation ITU-R P.452-14 [10]. Table 5 shows the values used for the different components of the model. Free Space model was adopted for the radar system while Recommendation ITU-R.452-14 was also used for IMT- Advanced system [10]. The propagation loss equation for free space model is given in equation 5.

$$L = 32.5 + 10\log\left(\left(\frac{(h_{radar} - h_{target})}{1000}\right)^2 + d^2\right) + 20log f \tag{5}$$

Where h_{radar} and h_{target} are the antenna heights of the radar and target respectively, d is the distance between the transmitter and the receiver, while f is the centre frequency of the system.

The basic propagation loss equation for Recommendation ITU-R P.452-14 is given in equation 6.

$$L = 190 + L_f + 20logd + 0.573\theta - 0.15N_0 + L_c + A_g - 10.1(-\log(p/20))^{0.7} \qquad (6)$$

Where L_f is the frequency dependent loss, d is the distance between the transmitter and the receiver, θ is the Path angular distance, N_0 is the sea-level surface refractivity, L_c is the aperture to medium coupling loss while A_g is the gaseous absorption. Some of the other parameters are inputs into propagation panel in SEAMCAT.

Table 5: Propagation Model parameters

Water concentration	3 g/m^2
Refractive index gradient	51.9 1/km
Location (Lagos)	Latitude: 6.45306 deg
Sea level surface refractivity	379.2
Time percentage	20%
Additional clutter loss at the Tx	18dB
Additional clutter loss at the Rx	0dB

INTERFERNCE CALCULATION

The iRSS and dRSS calculated for each event are used by SEAMCAT to compute the probability of interference. The probability of interference $(p_I(i))$ for an ith single event is computed as follows:

$$\left(\frac{iRSS(i)}{N} < \frac{I}{N}\right)|dRSS > Sensitivity \qquad (7)$$

where

$dRSS(i)$ is the desired receive signal strength at the radar receiver during the ith trial

$iRSS(i)$ is the interfering receive signal strength at the radar receiver during the ith trial

$\frac{I}{N}$ is the interference to noise ratio.

$IRSS_{composite} = \sum_{j=1}^{k} iRSS(j)$, k is the number of interfering Base stations per event

Therefore, the probability of interference over all trials is given by:

$$P_I = \frac{\sum_{i=1} 1 \times \left(\frac{}{N} \quad \frac{}{N} \right)}{1\,000\,000} \qquad (8)$$

where

$$1_{\{condition\}} = \begin{Bmatrix} 1\ if\ dRSS\ > Sensitivity \\ 0\ else \end{Bmatrix}$$

RESULTS AND DISCUSSION

The simulation was done using version 5.2.0 rev 8cd03c07e of SEAMCAT. One million events were simulated as accuracy is improved based on the number of events selected [21]. Figure 5 below shows the outline of the simulation events.

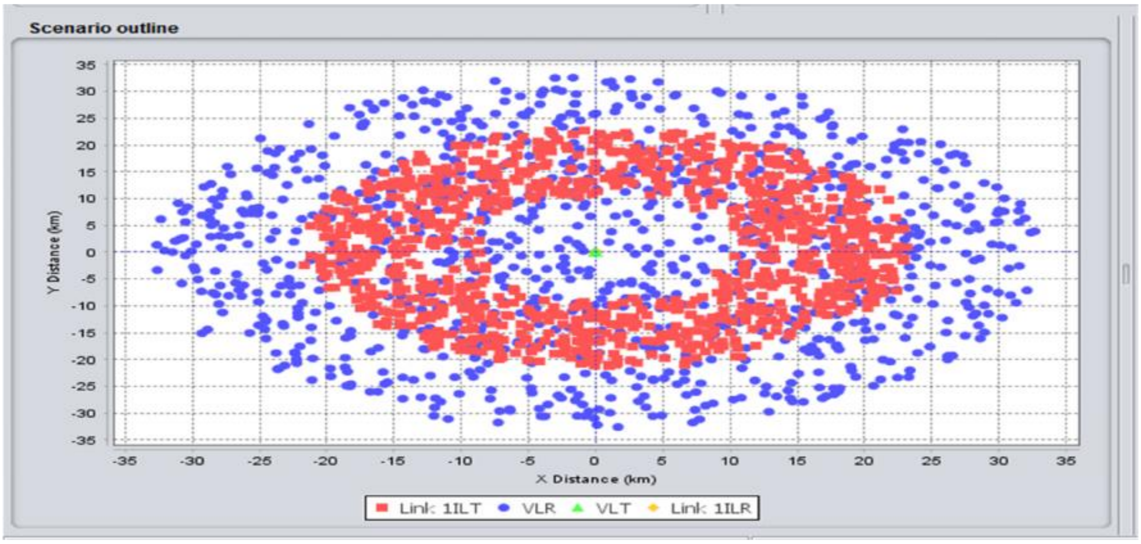
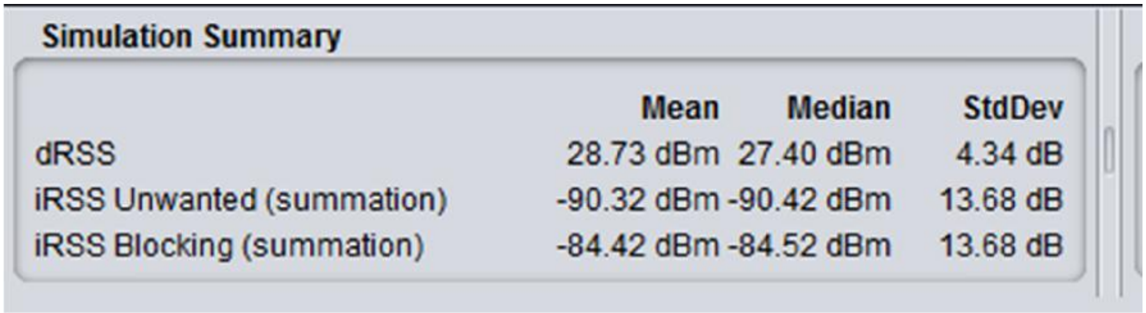


Figure 5: Simulation outline

The green dot at the middle is the victim link transmitter (VLT) which represents the Ship based Radar C, the blue dot is the victim link receiver (VLR) which represents the target that the radar is expected to detect, the red dot is the interfering link transmitter (ILT) which represents the IMT-Advanced Base station while interfering link receiver (ILR) which is not visible in the outline represents the mobile users. The mobile users do not appear because they are expected to be within the footprint of their serving base station which is represented by the red dot.

The radar is located at the middle because it is expected to detect objects that are within its coverage radius. A protection distance of 22km was adopted from [10] meaning that IMT-Advanced base stations are not to be located at any distance less than 22km from the ship-based radar in any of the events. In all trials therefore, the IMT-Advanced base station can only appear in the circular area between the protection distance and the simulation radius. This is clearly seen in the simulation outline.

Each simulation trial or event produces an outcome. The outcome is in terms of the dRSS and iRSS (Unwanted) and iRSS (Blocking). Figure 6 shows for all the trials, the mean, median and standard deviation of the desired received signal strength (dRSS), interference received signal strength ($\mathrm{iRSS_{unwanted}}$) due to unwanted emission and the interference received signal strength ($\mathrm{iRSS_{blocking}}$) due to blocking of the receiver.



Simulation Summary

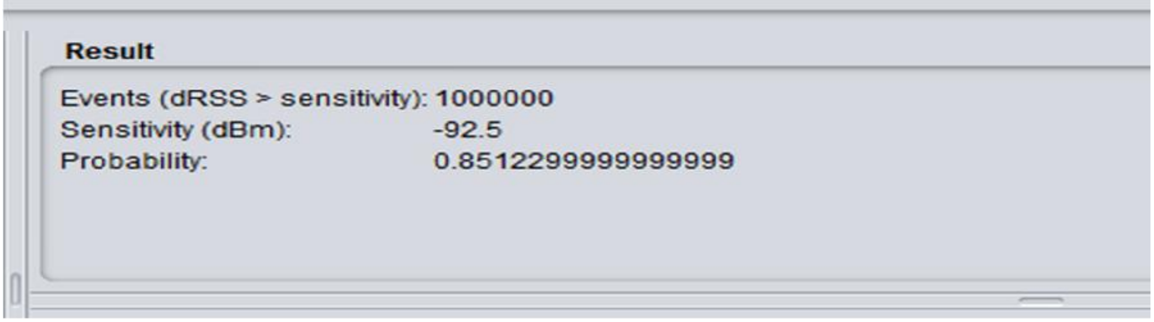
	Mean	Median	StdDev
dRSS	28.73 dBm	27.40 dBm	4.34 dB
iRSS Unwanted (summation)	-90.32 dBm	-90.42 dBm	13.68 dB
iRSS Blocking (summation)	-84.42 dBm	-84.52 dBm	13.68 dB

Figure 6: Summary of the signals.

The dRSS is the strength of the signal received by the radar from the target. This is because it is the radar that emits the signals and then receives them back after being reflected off the target. $\mathrm{iRSS}_{\mathrm{unwanted}}$ is the interference signal power due to unwanted emissions from the IMT-Advanced base station, this kind of interference can only be reduced at the transmitter. $\mathrm{iRSS}_{\mathrm{blocking}}$ comes from the radar receiver due to its selectivity imperfection. The mean dRSS as shown in figure 6 is much greater than the sensitivity of -95.5dBm. This means that a lot of events would meet the condition in equation 7.

Figure 8 shows the probability of interference from IMT-Advanced Base station to ship-based C radar for a total of 1million events in which the dRSS is greater than the sensitivity of the radar receiver.

According to equation 7, for an interference to occur in an event the ratio of the iRSS to Noise has to be less than the radar receiver's protection ratio of -6 dB. While equation is 8 is now used to compute the overall probability of interference. The number of events simulated determines the accuracy of the probability result. As seen in figure 9, one million events were simulated and therefore the result can be trusted.


Result

Events (dRSS > sensitivity): 1000000
Sensitivity (dBm): -92.5
Probability: 0.8512299999999999

Figure 8: Output of the interference calculation engine

The result in figure 9 shows that out of one million events in which the dRSS is greater than sensitivity of -95.5dBm, 85% of the events did not yield an Interference (iRSS) to Noise ratio that is greater than -6dB (24dBm), while only 15% did.

CONCLUSION

This work investigated the co-existence of IMT-Advanced systems and ship-based radar C in the frequency band 3300 – 3400 MHz, SEAMCAT, a Monte Carlo analysis tool was used for the simulations. Standard system parameters documented by ITU-R, were used. The results of the simulation show that the probability of IMT-Advanced base station causing co-channel interference to a ship-based radar C is 85%. This means that IMT-Advanced system cannot share 3300 – 3400 MHz band with radiolocation without the addition of certain mitigation techniques that would reduce the co-channel interference to a level where co-existence with ship-based radars is possible.

REFERENCES

[1] ITU-R, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond", Recommendation ITU-R M.2083-0, 2015.

[2] Arturas, M. & István, B. "Spectrum Management Trends: towards 2020", 2013.

[3] ITU-R, "Requirements related to technical performance for IMT-

Advanced radio interface(s)" Report ITU-R M.2134, 2008.

[4] Madhuri, K. "4G Wireless and International Mobile Telecommunication (IMT) Advanced", IEEE, 2008.

[5] ITU-R, "Sharing studies between International Mobile Telecommunication-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 MHz and 4500-4800 MHz frequency bands in the WRC study cycle leading to WRC-15", Report ITU-R S.2368-0, 2015.

[6] Jean-Philippe Kermoal, "Introduction to SEAMCAT", European Communications Office, 2010.

[7] ITU, "Radio Regulations", 2016.

[8] ITU-R, "Sharing studies between IMT-Advanced and the radiolocation service in the 3400-3700 MHz bands", Report ITU-R M.2111, 2007.

[9] National Frequency Management Council of the Federal Republic of Nigeria, "National Frequency Allocation Table", 2014.

[10] ITU-R, Thales, "Proposed updates on the working document towards a preliminary draft new report itu-r m.[radar&imt-advanced sharing]", Document 5D/609-E, 2017.

[11] ITU-R, France, "Coexistence between radiolocation and IMT systems within 1375-1400" MHZ band", Document 4-5-6-7/-E, 2014.

[12] ITU-R, Telecom New Zealand Ltd and Telstra Corporation Ltd "Study into the coexistence of IMT-Advanced systems and radiolocation systems in the band 1300-1400 MHz", Document 4-5-6-7/510-E, 2014.

[13] European Communications Office, "SEAMCAT Handbook", 2016.

[14] ITU-R, Australia, "Working document towards a preliminary draft new report ITU-R.M. [radar & IMT-advanced sharing]", Document 5D/575-E, 2017.

[15] ITU-R, USA, "Input on the Working Document toward a Preliminary Draft New Report ITU-R M. [Radar & IMT-Advanced Sharing]", Document 5D/583-E, 2017.

[16] ITU-R, Cameroon et al, "In band and adjacent band coexistence and compatibility studies between IMT-Advanced systems in 3 300-3 400 MHz and radiolocation systems in 3100-3400 MHz", Document 5D/632-E, 2017.

[17] ETSI, "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception" (3GPP TS 36.104 version 13.5.0 Release 13)

[18] ITU-R, "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses", Report ITU-R M.2292-0, 2017.

[19] ITU-R, "Characteristics of and protection criteria for radars operating in the Radio-determination service in the frequency range 3 100-3 700 MHz", Recommendation ITU-R M.1465-2, 2015.

[20] ITU-R, "Characteristics of and protection criteria for radars operating in the Radio-determination service in the frequency range 3 100-3 700 MHz", Annex 8 to Document 5B/305-E, 2017.

[21] ITU-R, "Confidence in Monte Carlo simulations", Document 4-5-6-7/560-E, 2014.