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Study on Coexistence between Long Term Evolution and Digital Broadcasting services

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Abstract

Korea has made a plan to transfer from analog television to Digital Television (DTV). Therefore, TV White Spaces (TVWS) are the unused TV broadcast channels which can be available for wireless communication systems. This paper assumes that DTV operates on Channel 34 and Long Term Evolution (LTE) is assumed that it uses Frequency Division Duplexing (FDD), and then upper 4 MHz of Channel 32 and channel 33 are assumed to allocate to LTE Uplink, and channel 35 and lower 4 MHz of channel 36 are assumed to allocate to Downlink. However, the interference effect of LTE on DTV has to be taken into account. Therefore, according to the interference probability of 5% required by DTV receiver and the allowable transmit power of LTE Base Station (BS) and Mobile Station (MS), the protection distance from the reference LTE BS and MS to DTV receiver and the guard band will be analyzed by using Spectrum Engineering Advanced Monte-Carlo Analysis Tool (SEAMCAT).

As a result, in the case that 8 MHz guard band is required and the assumed emission mask of LTE BS is used, the required protection distance between the LTE BS and DTV receiver is about 2 km. In the case of interference between LTE MS and DTV receiver considering the assumed emission mask of LTE MS, the protection distance is negligible above 8 MHz of guard band. The results can be as a guideline and reference in making plan for the coexistence of LTE and DTV.

Keywords: *TV White Spaces (TVWS), Long Term Evolution (LTE), Digital Television (DTV), Guard Band, Protection Distance*

1. Introduction

TV White Spaces (TVWS) are the unused TV broadcast channels which can be available for wireless communication systems. Specially, more available TVWS is freed up after the transition from analog television to digital television. Because TVWS is located in the VHF and UHF bands, it has several important properties that make them highly desirable for wireless communications as following [1]: Ability to penetrate buildings and foliage, non-line of sight connectivity, broadband payload capacity. Therefore, TVWS channels can be used in certain locations by certain devices, such as Long Term Evolution (LTE), Wireless Mobile World Interoperability for Microwave Access (WiMAX), Wireless Microphone and etc.

This paper assumes that LTE is operating on adjacent channels in TVWSs. Also, the specified spectrum emission mask and the assumed spectrum emission mask of LTE Base Station (BS) and Mobile Station (MS) are taken into consideration. The impact of LTE on Digital Television (DTV) is analyzed by using Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) based on the Monte-Carlo simulation method, which was developed within the frame of European Conference of Postal and Telecommunication administrations (CEPT). The protection distance and the guard band are figured out through analysis.

2. System Description

2.1. Interference Link

The 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) is the latest standard in the mobile network technology tree that produced the GSM/EDGE and UMTS/HSPA network technologies [2][3][4]. It is a project of 3GPP, operating under a name trademarked by one of the associations within the partnership, the European Telecommunications Standards Institute (ETSI). The main advantages with LTE are high throughput, low latency, plug and play, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) in the same platform, an improved end-user experience and a simple architecture resulting in low operating costs. LTE will also support seamless passing to cell towers with older network technology such as GSM, UMTS, and CDMA2000. The next step for LTE evolution is LTE Advanced and is currently being standardized in 3GPP Release 10[5]. LTE has introduced a number of new technologies when compared to the previous cellular systems. They enabled LTE to be able to operate more efficiently with respect to the use of spectrum and also to provide the much higher data rates that are being required.

Orthogonal Frequency Division Multiplex (OFDM) technology has been incorporated into LTE because it enables high data bandwidths to be transmitted efficiently while still providing a high degree of resilience to reflections and interference. The access schemes differ between the uplink and downlink. Orthogonal Frequency Division Multiple Access (OFDMA) is used in the downlink. While Single Carrier - Frequency Division Multiple Access (SC-FDMA) is used in the uplink. SC-FDMA is used in view of the fact that its peak to average power ratio is small and the more constant power enables high RF power amplifier efficiency in the mobile handsets - an important factor for battery power equipment [6].

One of the main problems that previous telecommunications systems have encountered is that of multiple signals arising from the many reflections that are encountered. By using MIMO, these additional signal paths can be used to advantage and are able to be used to increase the throughput. When using Multiple Input Multiple Output (MIMO), it is necessary to use multiple antennas to enable the different paths to be distinguished. Accordingly schemes using 2 x 2, 4 x 2, or 4 x 4 antenna matrices can be used. While it is relatively easy to add further antennas to a base station, the same is not true of mobile handsets, where the dimensions of the user equipment limit the number of antennas which should be placed at least a half wavelength apart.

System Architecture Evolution (SAE) with the very high data rate and low latency requirements for 3G LTE, it is necessary to evolve the system architecture to enable the improved performance to be achieved. One change is that a number of the functions previously handled by the core network have been transferred out to the periphery. Essentially this provides a much "flatter" form of network architecture. In this way latency times can be reduced and data can be routed more directly to its destination.

In view of the fact that there are a number of differences between the operation of the uplink and downlink, these naturally differ in the performance they can offer. The LTE specification provides downlink peak rates of at least 100 Mbps, an uplink of at least 50 Mbps and RAN round-trip times of less than 10 ms. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD)[6]. The key parameters of the 3G LTE specification are summarized in Table 1[3][7].

Table 1. The Key Parameters of the LTE

Parameter	Details
Peak downlink speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speeds (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Channel bandwidths (MHz)	1.4, 3, 5, 10, 15, 20
Duplex schemes	FDD and TDD
Mobility	0 - 15 km/h (optimised), 15 - 120 km/h (high performance) 120 ~ 350km/h(Mobility maintained) 350 ~ 500km/h(Under consideration depending on frequency band)
Spectral efficiency	Downlink: 3 - 4 times Rel 6 HSDPA Uplink: 2 -3 x Rel 6 HSUPA
Access schemes	OFDMA (Downlink) SC-FDMA (Uplink)
Cell Range	~ 5 km: Best Throughput, Spectrum Efficiency and mobility ~ 30 km: Mobility as defined above, some degradation in Throughput, Spectrum Efficiency ~ 100 km: Supported, Degradations accepted
Modulation types supported	QPSK, 16QAM, 64QAM (Uplink and downlink)

Main parameters of LTE are summarized in Table 2, Table 3, Table 4, Table 5, Table 6, Table 7 and Table 8, respectively.

Table 2. Parameters of the LTE BS [8][9]

Parameters	Value
BS Maximum Power Amplifier Power	43dBm
BS Antenna Maximum Gain	15 dBi
BS Height	32 m
BS Noise Figure	5 dB
BS RX Sensitivity	-101.5 dBm
ACS[10]	43.5 dB

Table 3. LTE BS Spectrum Emission Limit for 10MHz Bandwidth [11]

Frequency offset from channel edge (MHz)	Minimum requirement (dBm)	Attenuation (dBc)	Measurement bandwidth
0~0.2	-14	-57	30 kHz
1~10	-13	-56	1 MHz
10 ~25	-15	-58	1 MHz

On the basis of specified LTE BS spectrum emission limit in Table 3, the assumed LTE BS Spectrum emission limit is summarized in Table 4.

Table 4. Assumed LTE BS Spectrum Emission Limit

Frequency offset from channel edge (MHz)	Minimum requirement (dBm)	Attenuation (dBc)	Measurement bandwidth
0~0.2	-19	-62	30 kHz
1~2	-18	-61	1 MHz
2 ~3	-23	-66	1 MHz
3~4	-28	-71	1 MHz
4~5	-33	-76	1 MHz
5~15	-38	-81	1 MHz

According to the specified spectrum emission mask in Table 3 and the assumed spectrum emission mask in Table 4, two spectrum emission masks are illustrated in Figure 1.

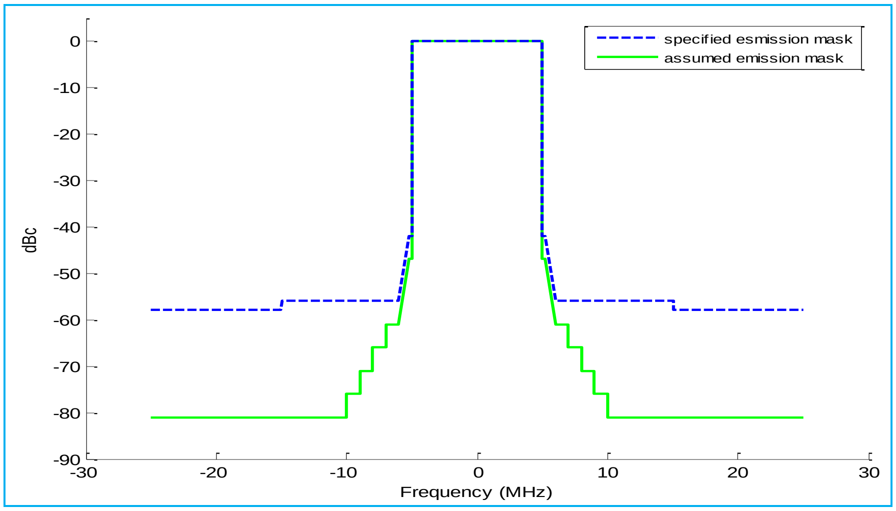

Figure 1. Spectrum Emission Mask of LTE BS

Table 5. . Parameters of the LTE MS

Parameters	Value
MS Antenna Maximum Power Amplifier Power	24 dBm
MS Antenna Minimum Power Amplifier Power	-30 dBm
MS Antenna Gain	0 dBi
MS Height	1.5 m
MS Noise Figure	9 dB
MS RX Sensitivity	-94 dBm
ACS[10]	33 dB

Table 6. LTE MS Spectrum Emission Limit for 10 MHz Bandwidth [11]

Frequency offset from channel edge (MHz)	Minimum requirement (dBm)	Attenuation (dBc)	Measurement bandwidth
0~1	-18	-42	30 kHz
1~5	-10	-34	1 MHz
5~10	-13	-37	1 MHz
10~25	-25	-49	1 MHz

On the basis of specified LTE MS Spectrum emission limit in Table 6, the assumed LTE MS Spectrum emission limit is summarized in Table 7.

Table 7. Assumed LTE MS Spectrum Emission Limit

Frequency offset from channel edge (MHz)	Minimum requirement (dBm)	Attenuation (dBc)	Measurement bandwidth
0~1	-23	-47	30 kHz
1~2	-15	-39	1 MHz
2 ~3	-20	-54	1 MHz
3~4	-25	-59	1 MHz
4~5	-30	-64	1 MHz
5~6	-35	-69	1 MHz
6~7	-40	-74	1 MHz
7~8	-45	-79	1 MHz

According to the specified spectrum emission mask in Table 6 and the assumed spectrum emission mask in Table 7, two spectrum emission masks are illustrated in Figure 2.

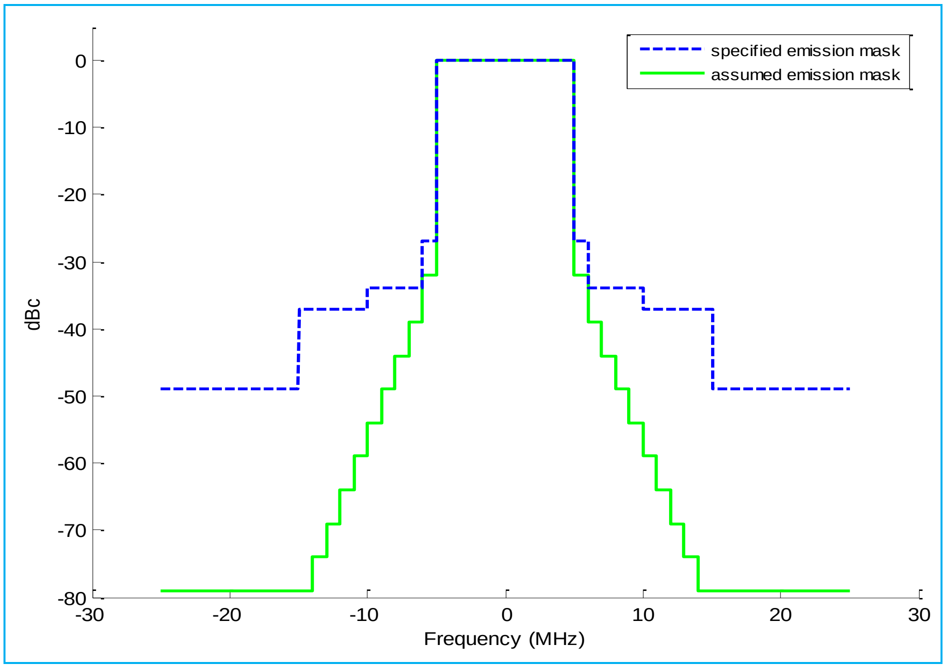

Figure 2. Spectrum Emission Mask of LTE MS

Table 8. Some Necessary Parameters of LTE for Simulation

Parameters	Value
Duplex	FDD
Carrier Frequency	579 MHz
Band Width	10 MHz
Thermal Noise	-174 dBm/Hz
I/N	-10 dB
LTE Link Coverage requirement	95% at the coverage edge[12] Log-normal shadowing=10 dB
Building Penetration Loss	8 dB[13]
Propagation Model	Macro cell propagation model Urban [10]
Coverage Radius	2.8668km
Network Topology	Hexagonal Grid, 19 sites (57 cells) with wrap around.
Inter-Side Distance	4.9654km
Sectorization	Tri- sector antennas
Minimum Coupling Loss	70 dB
Number of Available Resource Blocks (M)	24
Number of Resource Block per UE (N)	1
Number of Active UEs per Cell (K)	24 (K=M/N)
Minimum subcarrier usage per Base Station	assumed full loaded system 100%
Bandwidth of Resource Block	375 kHz (180kHz is the size of resource block later defined, but this has no big impact on the simulation results)
Hand Over (HO) Margin	3 dB
Link Performance Model	Attenuated and truncated form of the Shannon bound

3GPP TR 36.942 V10.1.0 [10] introduced that Macro cell propagation model for urban area is applicable for scenarios in urban and suburban areas outside the high rise core where the buildings are of nearly uniform height:

$$L = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot Dhb) \cdot \log_{10}(R) - 18 \cdot \log_{10}(Dhb) + 21 \cdot \log_{10}(f) + 80dB \quad (1)$$

Where Dhb is the base station antenna height in metres, measured from the average rooftop level and R is the base station separation in kilometers and f is the carrier frequency in MHz. Considering a carrier frequency of 579 MHz and a base station antenna height of 15 metres above average rooftop level, the propagation model is given by the following formula:

$$L = 116.8 + 37.6\log_{10}(R) \tag{2}$$

Here, R is the protection distance between the base station (BS) and mobile station (MS) in kilometers.

After L is calculated, log-normally distributed shadowing (Log(F)) with standard deviation of 10 dB should be added. A Shadowing correlation factor of 0.5 for the shadowing between sites (regardless aggressing or victim system) and of between sectors of the same site shall be used the pathloss is given by the following formula:

$$\text{Pathloss\_macro} = L + \text{Log}(F) \tag{3}$$

2.1. Victim Link

DTV is an advanced broadcasting technology that transmits audio and video by digital signals. In contrast to the analog signals used by analog TV, it has several advantages over analog TV such as requiring less bandwidth, providing high-definition television service, providing multimedia or interactivity [14]. Therefore, many countries are replacing over the air broadcast analog television with digital television to allow other uses of the radio spectrum formerly used for analog TV broadcast. The US DTV standard (ATSC) is used in this paper and the main relevant characteristics of DTV are summarized in Table 9 [15].

Table 9. Characteristics of DTV

Characteristic	Value
Transmit power	4 kW (66 dBm)
Frequency band	587 MHz(Channel 34)
Bandwidth	6 MHz
Tx antenna height	100 m
Tx antenna gain	0 dBi
Rx antenna height	10 m
Rx antenna gain	10 dBi
Noise Figure	10 dB
Sensitivity	-83 dBm
C/I	23 dB
Modulation	FM or QPSK

On the basis of Federal Communications Commission (FCC) emission mask for DTV is illustrated as in Figure 3.

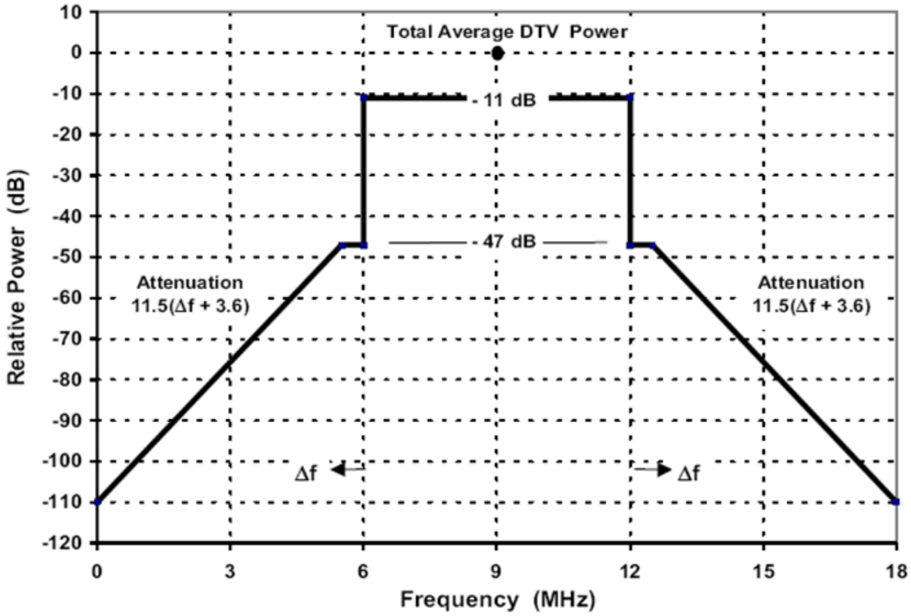

Figure 3. FCC DTV Emission Mask (measurement bandwidth of 500 kHz)

DTV blocking response is defined as in Table 10 by referring to Digital video Broadcasting-Terrestrial (DVB-T) blocking response as the opposite of the protection ratio for DVB-T signal interfered with by emission of Code Division Multiple Access-1X(CDMA-1X) in reference [16].

Table 10. DTV Blocking Response

ΔFrequency (MHz)	-15	-12	-6	-3	0	3	6	12	15
Blocking(dB)	45	38	20	3	-10	3	20	38	45

3. Interference Analysis Method

3.1. Interference Analysis Method (SEAMCAT)

The classical approach such as Minimum Coupling Loss (MCL) appear being too rigid and difficult to implement in many cases, where operation of radiocommunications systems may not be described in static terms, e.g. random nature of operation of user terminals in the mobile systems. While compromise in such cases may be found by making certain (pessimistic) assumptions and simplifications on the operation of the considered systems, this may produce unnecessarily stiff and static interference assessment, which becomes often biased towards one of the considered systems depending on the partiality of assumptions/ simplifications made. However, a Monte Carlo simulation can completely achieve above-mentioned requirements.

Within the frame of the European Conference of Postal and Telecommunications Administrations (CEPT) Working Group Spectrum Engineering, a new statistical simulation model has been developed based on the Monte-Carlo method, named SEAMCAT. This model and its supporting software implementation allow quick yet reliable consideration of spatial and temporal distributions of the received signals and the resulting statistical probability of interference in a wide variety of scenarios. It therefore enables more precise mutual positioning of those considered systems, hence more efficient use of the radio spectrum [17] .

3.2. Main Principles of SEAMCAT

The Monte-Carlo simulation method is based upon the principle of taking samples of random variables, using their defined probability density functions (for simplicity called "distributions" in the SEAMCAT environment). Hence, first a user defines the distributions of possible values of the parameters of considered radiocommunication systems (e.g. antenna heights, powers, operating frequencies, positions of the transceivers, etc.) and then, the SEAMCAT uses those distributions to generate random samples (also called trials or snapshots) of subject parameters. Afterwards for each trial SEAMCAT calculates the strength of the interfering and the desired signals and stores them in data arrays [18][19]. Figure 4 illustrates a typical victim and interferer scenario for a Monte Carlo simulation trial.

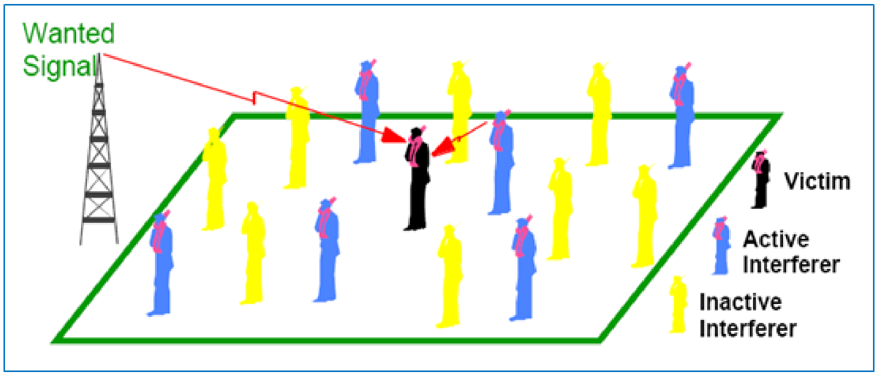

Figure 4. A Typical Scenario of Victim and Interferer

As a final step, the SEAMCAT derives the probability of interference taking into account the quality of the receiver in a known environment, and the calculated signals.

The criterion for interference to occur is for the victim receiver (Vr) to have a carrier to interference ratio (C/I) less than the minimum allowable value. In order to calculate the victim's C/I, it is necessary to establish the victim's desired received signal strength(dRSS) corresponding to the C, as well as the interfering received signal strength (iRSS) corresponding to the I. Figure 5 illustrates the various signal levels. Figure 5 (a) represents the situation when there is no interference and the victim is receiving the desired signal with wanted signal margin. Figure 5 (b) illustrates what happens when interference occurs. The interference adds to the noise floor. The difference between the wanted signal strength and the interference signal is measured in dB, which is defined as the signal to interference ratio. This ratio must be more than the required C/I threshold if interference is to be avoided. The Monte Carlo simulation methodology is used to check for this condition and records whether or not interference is occurring, which is illustrated further in Figure 6.

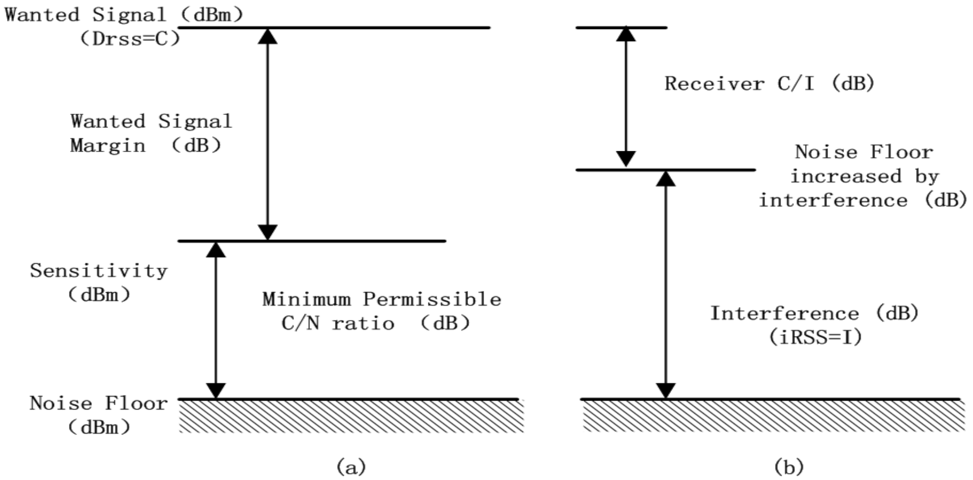

Figure 5. The Signal Levels Used to determine whether or not Interference is Occurring

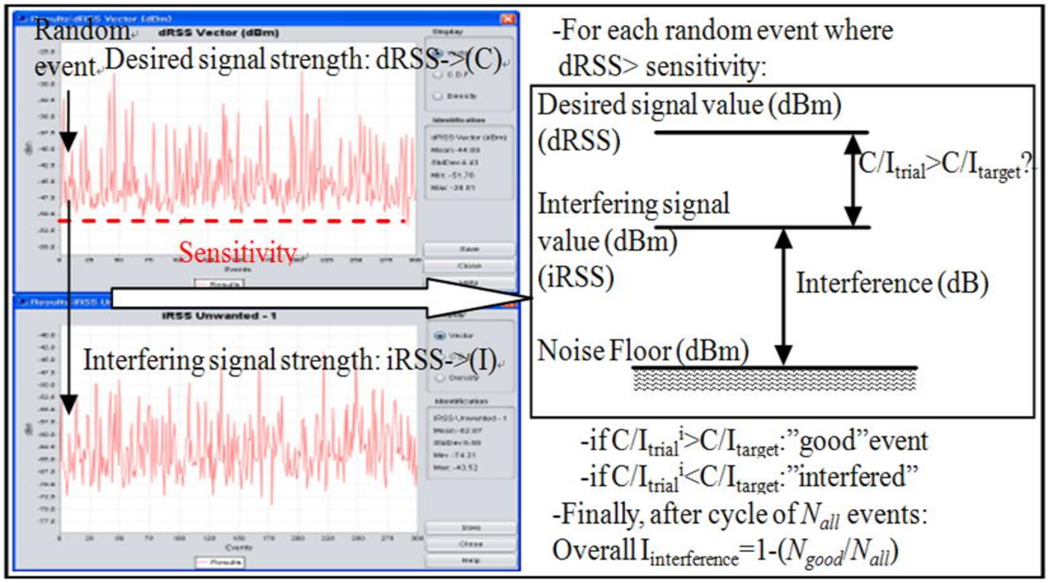

Figure 6. Scenario of LTE Interfering with DTV & Illustrative Summary of the Interference Criteria Computation

SEAMCAT calculates the probability of interference (P_I) of the victim receiver as follows:

$$P_I=1-P_{NI} \tag{4}$$

Here, P_I is the probability of interference in the victim receiver. The P_{NI} is the probability of non interference in victim receiver. When a C/I criteria is considered, P_{NI} is defined as: P

$$P_{NI} = P(\frac{dRSS}{iRSS} > \frac{C}{I}, dRSS > Sensitivity) \tag{5}$$

By definition of P(A|B)=P(A∩B)/P(B), the P_{NI} becomes:

$$P_{NI} = \frac{P\left(\frac{dRSS}{iRSS} > \frac{C}{I}, dRSS > Sensitivity\right)}{P(dRSS > Sensitivity)} \tag{6}$$

In such manner, the SEAMCAT can address virtually all radio interference scenarios in both co-channel (sharing) and adjacent frequency (compatibility) interference studies. This flexibility is achieved by the way the system parameters are defined as variable (or constant) through their distribution functions. It is therefore possible to model even very complex situations by relatively simple elementary functions [17].

3.3. SEAMCAT Architecture

The architecture of SEAMCAT software is composed of the Event Generation Engine (EGE), Interference Calculation Engine (ICE), CDMA/OFDMA Engine, any potential future calculation engine as well as an extended user interface outputs. The data storage is XML-based files. The architecture of SEAMCAT-3 is shown below in Figure 7 [17].

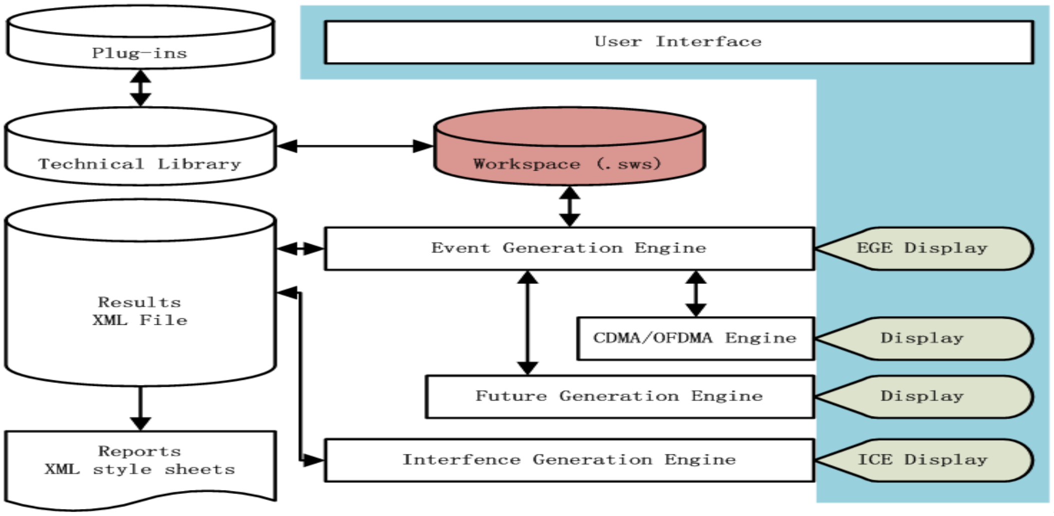

Figure 7. Architecture of SEAMCAT

4. Assumption of frequency allocation and interference scenario

4.1. Assumption of Frequency Allocation for LTE and DTV

Firstly, channel 34 (CH34) in DTV bands is assumed to allocate to DTV. It is assumed that LTE uses Frequency Division Duplexing (FDD), and then upper 4 MHz of Channel 32 (CH32) and channel 33 (CH33) are assumed to allocate to LTE Uplink (UL), and channel 35(CH35) and lower 4 MHz of channel 36 (CH36) are assumed to allocate to Downlink (DL). Figure 8 illustrates the assumption of frequency allocation for LTE and DTV.

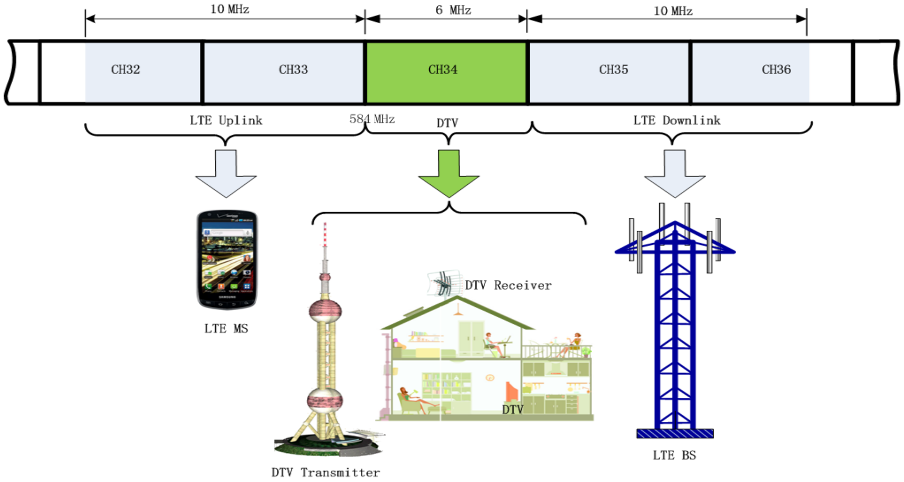

Figure 8. Assumption of Frequency Allocation for LTE and DTV

4.2. Interference Scenario

Figure 9 illustrates scenario of interference impact of LTE on DTV receiver. In the case of LTE potentially interfering with DTV, there are two scenarios to be taken into account ：LTE BS is interferer and DTV receiver is victim and LTE MS is interferer and DTV receiver is victim.

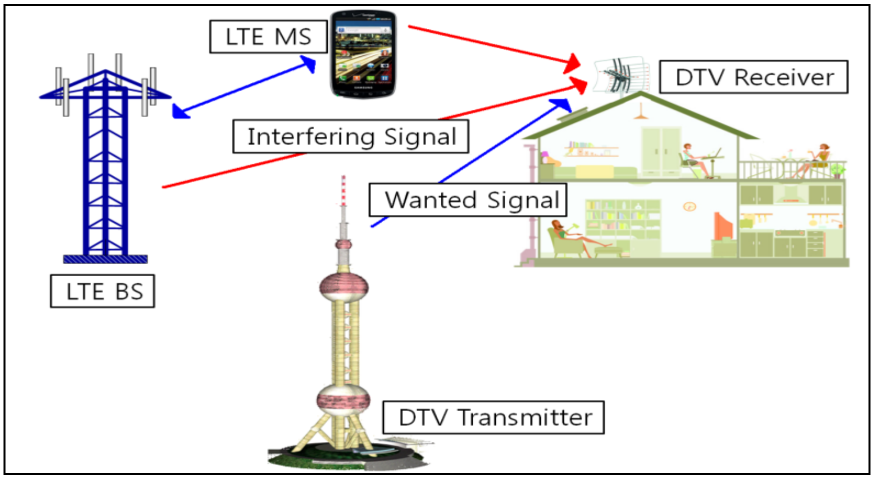

Figure 9. Interference Scenario of LTE Interfering with DTV

4. Simulation Results and Analysis

4.1 The Case of LTE BS Interfering with DTV

In the case of LTE BS interfering with DTV receiver, main parameters such as power, frequency, C/I, and so on are set up for the interference simulation. Therefore, the evaluation of the relationship between the guard band and the protection distance is conducted. One snapshot of simulation status is illustrated Figure 10.

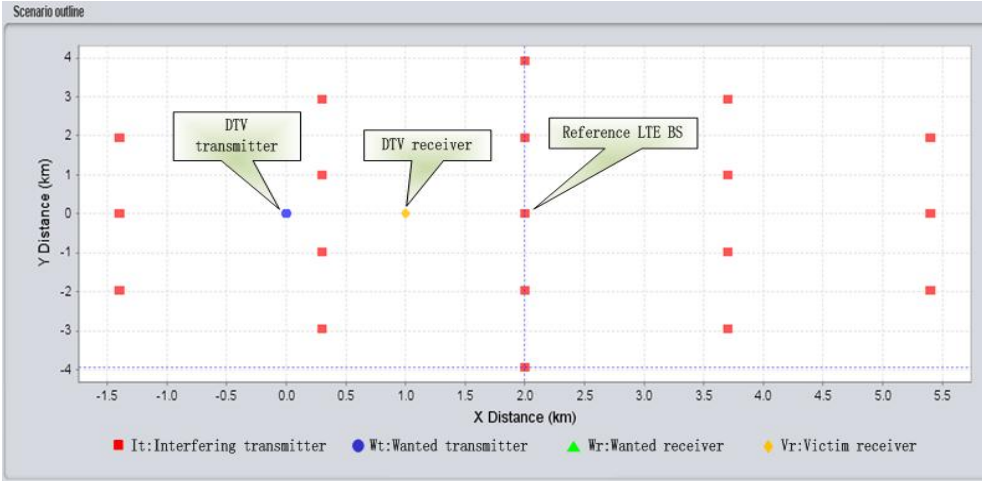

Figure 10. Scenario of LTE BS Interfering with DTV Receiver in SEAMCAT

In order to meet the interference probability of 5% required by DTV receiver and the maximum allowable transmit power of LTE BS, the relationship between the guard band and the protection distance is illustrated in Figure 11, when the specified spectrum emission mask and the assumed spectrum emission mask of LTE BS is used, respectively.

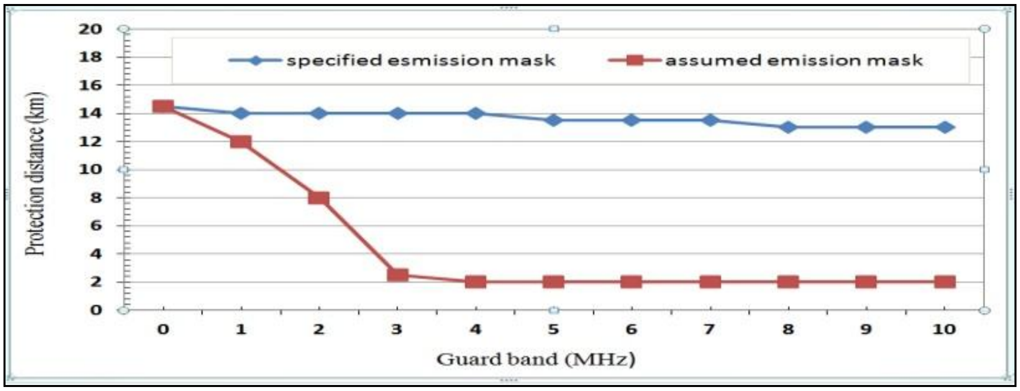

Figure 11. The Relationship between the Guard Band and the Protection Distance in the Case of LTE BS

If 4 MHz of guard band is required, when the specified emission mask of LTE BS is used, the protection distance must be more than 14 km. When the assumed emission mask of LTE BS is used, the protection distance is reduced to 2 km.

4.2 The Case of LTE MS Interfering with DTV

In the case of LTE MS interfering with DTV receiver, main parameters such as power, frequency, C/I, and so on are set up for the interference simulation. One snapshot of simulation status of two systems is illustrated in Figure 12.

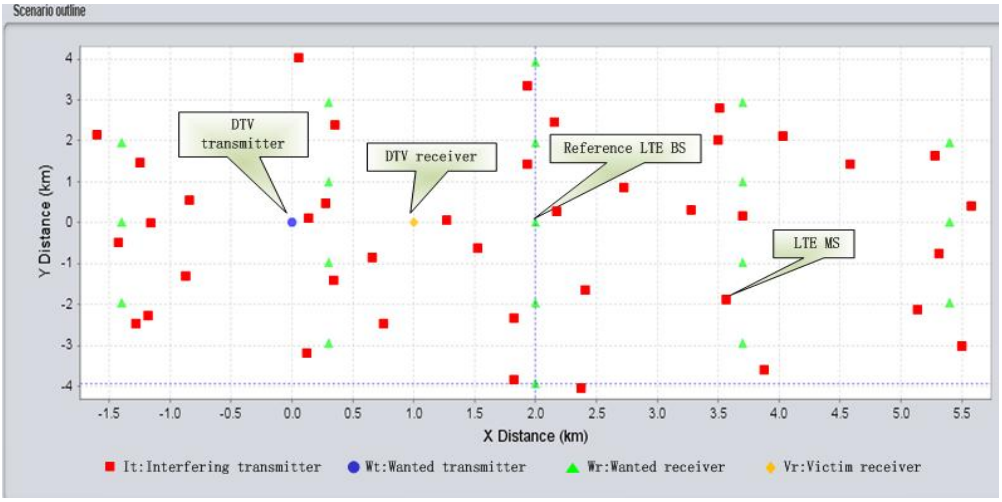

Figure 12. Scenario of LTE MS Interfering with DTV Receiver in SEAMCAT

To meet the interference probability of 5% required by DTV receiver, the relationship between the guard band and the protection distance is shown in Figure 13 The specified spectrum emission mask and the assumed spectrum emission mask of LTE MS are used.

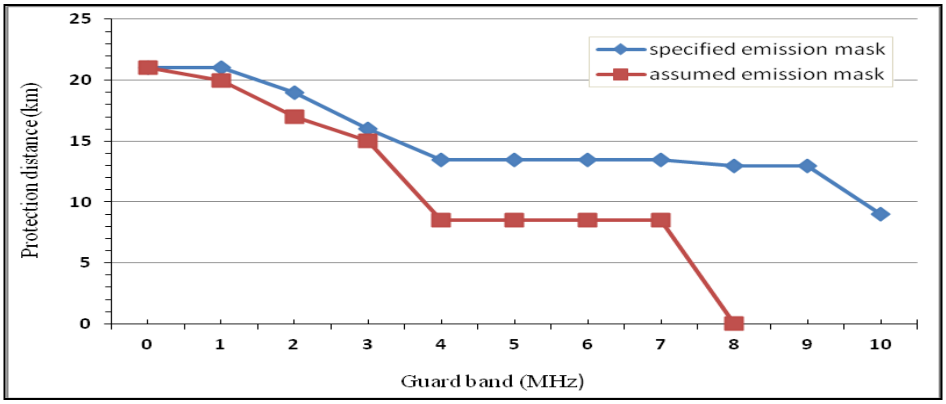

Figure 13. The Relationship between the Guard Band and the Protection Distance in the Case of LTE MS

Figure 13 shows that if 4 MHz of guard band is required, when the specified emission mask of LTE MS is used, the protection distance between the LTE MS and DTV receiver should be at least 13 km. If the assumed emission mask of LTE MS is used, the protection distance should be at least 8.5 km. However, the protection distance is negligible when the guard band is 8 MHz and above.

5. Conclusions

The interference scenario of LTE in TVWS potentially interfering with DTV is assumed. The relationship between the protection distance and the guard band for protecting DTV from interference of LTE is analyzed by using SEAMCAT.

As a result of study, the worst case is taken into account. The 5 % below of interference probability of DTV receiver is required along with maximum allowable transmit power of LTE. In order to meet 4 MHz guard band, the protection distance must be more than 14 km when the specified emission mask of LTE BS is used. But when the assumed emission mask of LTE BS is used, the protection distance is reduced to 2 km. If the specified emission mask of LTE MS is used, the protection distance should be at least 13 km. If the assumed emission mask of LTE MS is used under 8 MHz of guard band, the protection distance is almost negligible. The analysis result may offer a reference and be helpful to resolve the interference problem between DTV and other wireless communication systems.

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