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Coexistence between Wireless Fidelity and Wireless Microphone in TV Band

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Abstract

Wireless Fidelity (WiFi) and Wireless microphone are assumed to operate on adjacent channels in TV White Spaces（TVWS）. The Scenario of WiFi potentially interfering with Wireless microphone is analyzed through Minimum Coupling Loss (MCL) and Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) based on the Monte-Carlo simulation method. In the case of single WiFi interfering with Wireless microphone, the protection distance between WiFi and the Wireless microphone should be at least 25.12 m to avoid WiFi impact on Wireless microphone. When the active number of WiFi is 12, the guard band between WiFi and Wireless microphone should not be less than 4.97 MHz to guarantee that WiFi does not interfere with the Wireless microphone.

Keywords: WiFi, wireless microphone, TVWS, MCL, SEAMCAT, protection distance, guard band

A preliminary version of this paper was presented in JCICT & YES-ICuC 2011, August 17-20, Shandong University at Weihai, China. This version includes more detailed interference analysis results between Wireless Fidelity and Wireless Microphone with more than 30 percent substantial contributions.

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1. Introduction

TV White Spaces (TVWS) are unused TV broadcast channels which can be available to wireless communication systems. In specific, more available TVWSs can be freed up after the transition from analog to digital TV. Due to the fact that TVWSs are located in the VHF and UHF bands, there are several important properties that make them highly desirable for wireless communications. Therefore, TVWS channels can be used in certain locations by certain devices, such as Wireless Fidelity (WiFi), Wireless Mobile World Interoperability for Microwave Access (WiMAX), Wireless microphone, Long Term Evolution (LTE). In general, the cognitive technology (CR) is necessary to guarantee the coexistence of various wireless services in TVWS [1]. Prior to CR technology, it is required that interference analysis should be carried out. In this trend, this paper assumes that WiFi and Wireless microphone are operating on adjacent channels in TVWSs. As a matter of fact, WiFi frequency is located in Industria, Scientific and Medica (ISM) band. Therefore, the WiFi can be can be considered as a candidate service for TVWS in the near future. As a result , it is assumed that WiFi can be used in the TVWS to solve data traffic problems in the future.

The impact of WiFi potentially interfering with Wireless microphone is analyzed by using Minimum Coupling Loss (MCL) and 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 SEAMCAT is used widely in the field of spectrum engineering. The characteristics of WiFi and Wireless Microphone are described in section 2 and the interference analysis processs is explained in section 3. The simulation results of interference analysis on the basis of the assumed interference scenario are presented in section 4 and then concluded in section 5.

2. Characteristics Description of WiFi and Wireless Microphone.

Before carry out the interference analysis with SEAMCAT, the system parameters of WiFi and Wireless Microphone will be reviewed. The WiFi term for certain types of wireless local area network (WLAN) uses specifications within the 802.11 family. The definition of WiFi typically is the extention of an existing wired local area network. WiFi is built by attaching a device called the access point (AP) to the edge of the wired network. Clients communicate with the AP using a wireless network adapter similar in function to a traditional Ethernet adapter. WiFi has gained acceptance in coffee shops like Starbucks, bookstores, offices, airport terminals, schools, hotels, communities, and other public places. The main parameters of WiFi are summarized in **Table 1** [2].

Table 1. Main parameters of WiFi

Parameter	Value
Frequency	573MHz(Channel 31~32)
Reception Bandwidth	22,000 kHz
Receiver Sensitivity	-55.33 dBm

Modulation	OFDM
Interference Criteria(C/I)	10 dB
Noise Floor	-90.41 dB
Antenna Height	Rx 1.5/Tx 2.5 m
Antenna Azimuth	0~360 Degree
Antenna Peak Gain	6 dBi
Antenna Pattern	Omni-directional
Output Power	23 dBm

Emission limit for WiFi is illustrated in **Table 2** [3].

Table 2. WiFi emission limit

Frequency offset from center frequency[MHz]	**Attenuation [dBc]**	**Reference Bandwidth [kHz]**
0~11	0	22,000
11~22	-30	22,000
22~33	-50	22,000
33~44	-60	22,000

The emission mask of WiFi transmitter is shown in **Fig. 1.**

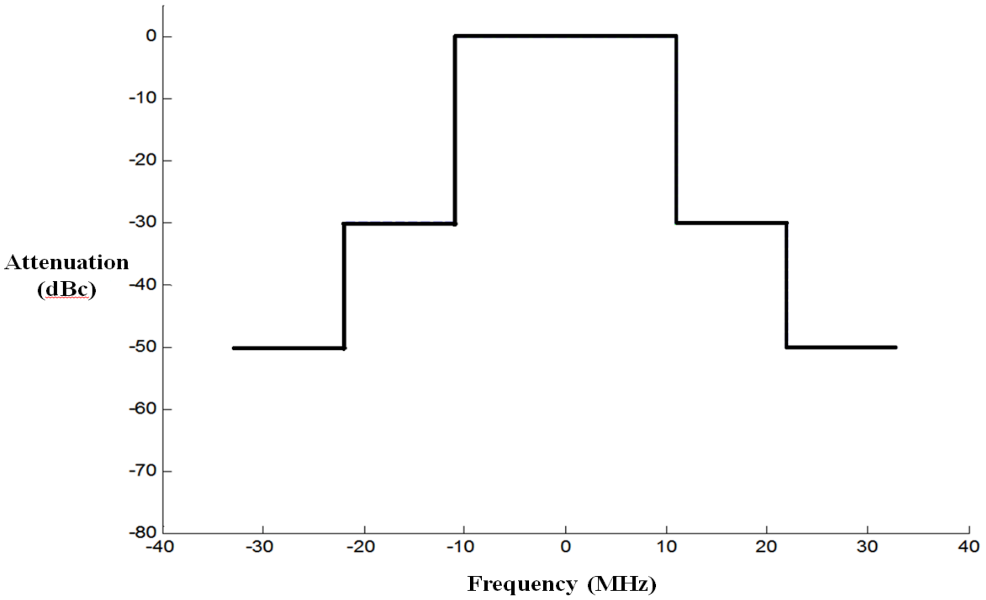

Fig. 1. Emission mask of WiFi transmitter

A Wireless microphone is mainly used in theatres, concert halls, outside broadcast or electronic news gathering between a location and the studio [4]. Relevant characteristics of wireless microphone are summarized in Table 3.

Table 3. Relevant characteristics of Wireless microphone

Characteristic	Value
Transmit power	17 dBm (50 mW ERP) [5]
Frequency band	578 MHz~590 MHz(Channel 33~34)
Antenna (transmit and receive) Bandwidth	Omnidirectional (0 dB gain) 200 kHz
Typical range	100 m
Noise Floor	-116 dBm
Noise Figure	4 dB
Sensitivity	-68 dBm
Modulation	FM
C/I	32.4 dB

Blocking response of Wireless microphone receiver is assumed as in **Fig. 2** [6]. The power attenuation (dB) versus frequency difference from center frequency (kHz) is also described in the **Fig. 2**.

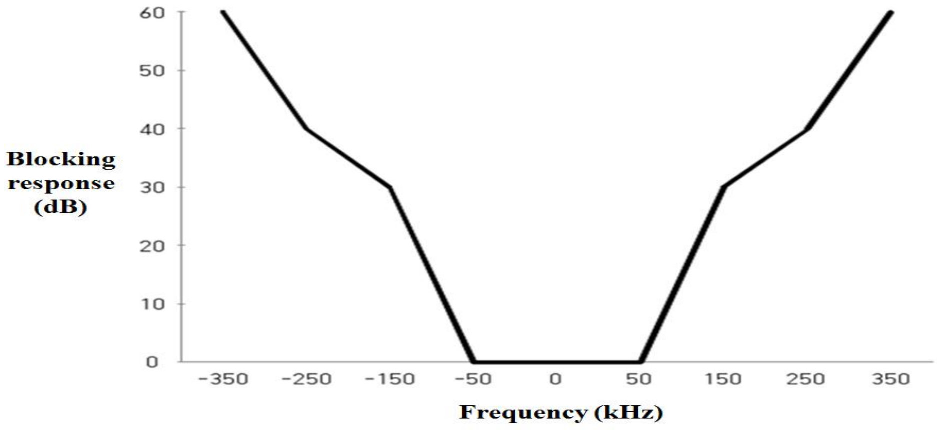

Fig. 2. Blocking response of Wireless microphone receiver

3. Interference Analysis Method

3.1 Minimum Coupling Loss (MCL) Method

The most common assessment method is based on the minimum coupling loss (MCL) required between the two systems to avoid interference. Generally, the MCL is calculated and then converted to an interference distance using an appropriate propagation model. This method produces an accurate interference distance when the interference scenario is well defined [7].

The MCL method is useful for an initial assessment of frequency sharing, and is suitable for fairly “static” interference situations (e.g. fixed links vs mobile base stations) but it is difficult to judge the overall magnitude of the problem from the study of a single interference scenario. MCL between interfering transmitter (It) and a victim receiver (Vr) is defined as follows [8].

$$\text{MCL} = \text{It power (dBm/Ref.BW)} + \text{dBBW} + \text{It antenna gain (dBi)} + \text{Vr antenna gain (dBi)} - \text{Vr interference threshold (dBm/Ref.BW)} \quad (1)$$

Here the dBBW is the bandwidth conversion factor between interferer and victim.

In the case of calculating minimum protection distance (Dmin) [9], free-space path loss equation is used as follows [10].

$$L_P = 20\log_{10}(F) + 20\log_{10}(D) - 27.5 \quad (2)$$

When the L_P (dB) is free-space propagation path loss, F (MHz) is frequency and D (meters) is propagation path length. Thus the minimum protection distance (Dmin) can be calculated.

The most important characteristics of the MCL method are summarized below: the result generated is the isolation in dB, which may be converted into a physical separation if an appropriate path loss formula is chosen. It is assumed that the victim receiver is operating at 3 dB above reference sensitivity. A single interferer transmitting at fixed (usually the maximum) power will be examined.

3.2 SEAMCAT (Spectrum Engineering Advanced Monte-Carlo Analysis Tool)

The Monte-Carlo simulation method is based on 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 radio communication systems (e.g. antenna heights, power, 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. For each trial, SEAMCAT calculates the strength of the interfering and the desired signals and stores them in data arrays [11][12][13]. **Fig. 3** illustrates a typical victim and interferer scenario for a Monte Carlo simulation trial.

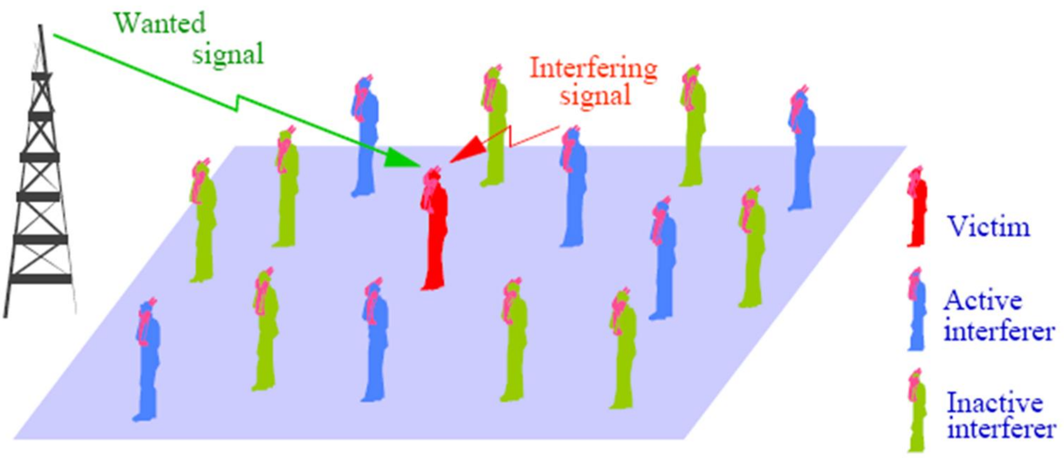

Fig. 3. A typical scenario of victim and interferer

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. **Fig. 4** illustrates the various signal levels. **Fig. 4-(a)** represents the situation when there is no interference and the victim is receiving the desired signal with wanted signal margin. **Fig. 4-(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 **Fig. 5**.

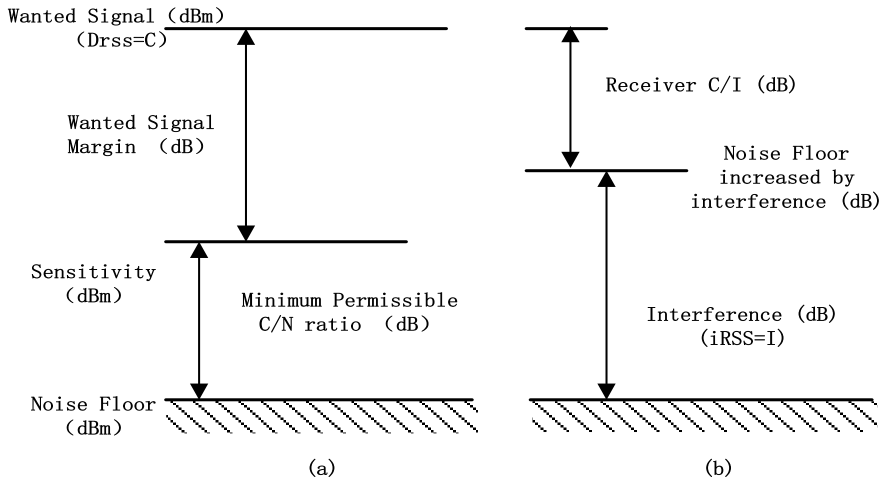

Fig. 4. The signal levels used to determine whether or not interference is occurring

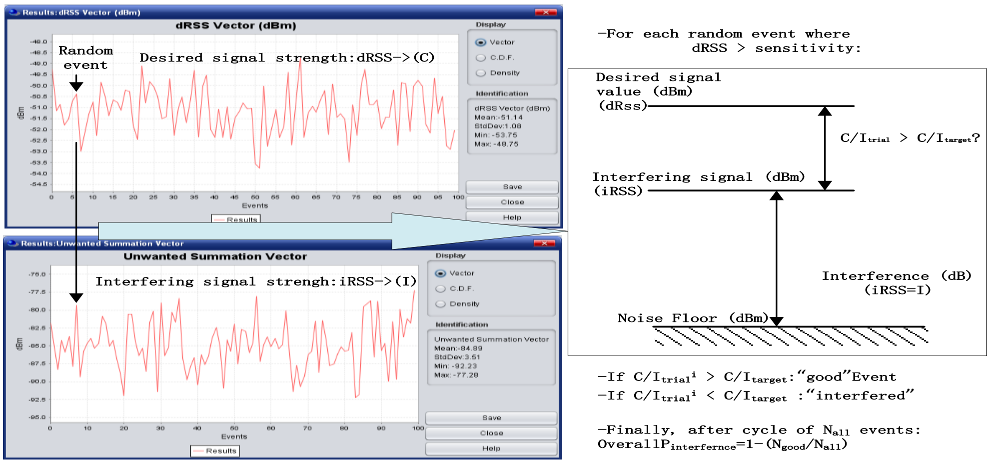

Fig. 5. Illustrative summary of the interference criteria computation

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

$$P_I=1-P_{NI} \tag{3}$$

Where P_I is the probability of interference in the victim receiver, P_{NI} is the probability of Non Interference ($_{NI}$) of the victim receiver.
P_{NI} is defined as follows:

$$P_{NI} = P\left(\frac{dRSS}{iRSS_{\text{comp}}} > \frac{C}{I} \middle| dRSS > Sensitivity\right) \tag{4}$$

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

$$P_{NI} = \frac{P\left(\dfrac{dRSS}{iRSS_{\text{comp}}} > \dfrac{C}{I}, dRSS > Sensitivity\right)}{P(dRSS > Sensitivity)} \tag{5}$$

With $iRSS_{\text{comp}} = \sum_{j=1}^{P} iRSS_j$ where P is the number of interferers (i.e. active transmitters).

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 [13].

A number of various radio communications services can be modeled using SEAMCAT, such as Broadcasting (terrestrial systems and ground components of satellite systems), Mobile (terrestrial systems and ground components of satellite systems), Point-to-point fixed, Point-to-multipoint fixed.

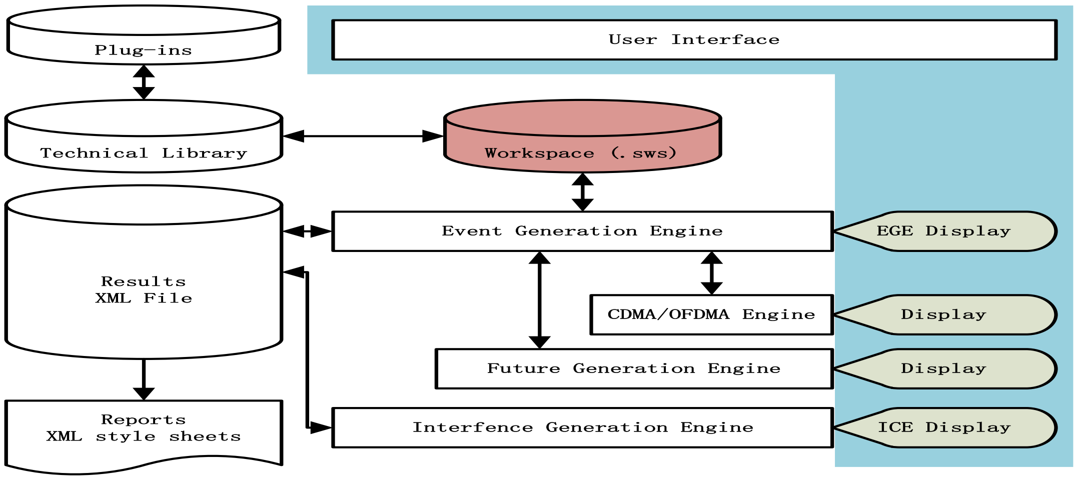

Fig. 6. Architecture of SEAMCAT

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 in **Fig. 6** [13].

4. Simulation and Results

4.1 Interference scenario

An interference scenario is illustrated in **Fig. 7**. Wireless microphone receiver is the victim, whereas a laptop with WiFi is the interferer. Wireless microphones can be either handheldor lavalier microphones. The interference scenario is described as follows: There is a Wireless microphone on channel 33 attempting to transmit signal to Wireless microphone receiver. At the same time, single or multiple laptop with WiFi on channel 31~32 are producing power, which is out of band. Therefore, WiFi will potentially interfere with Wireless microphone.

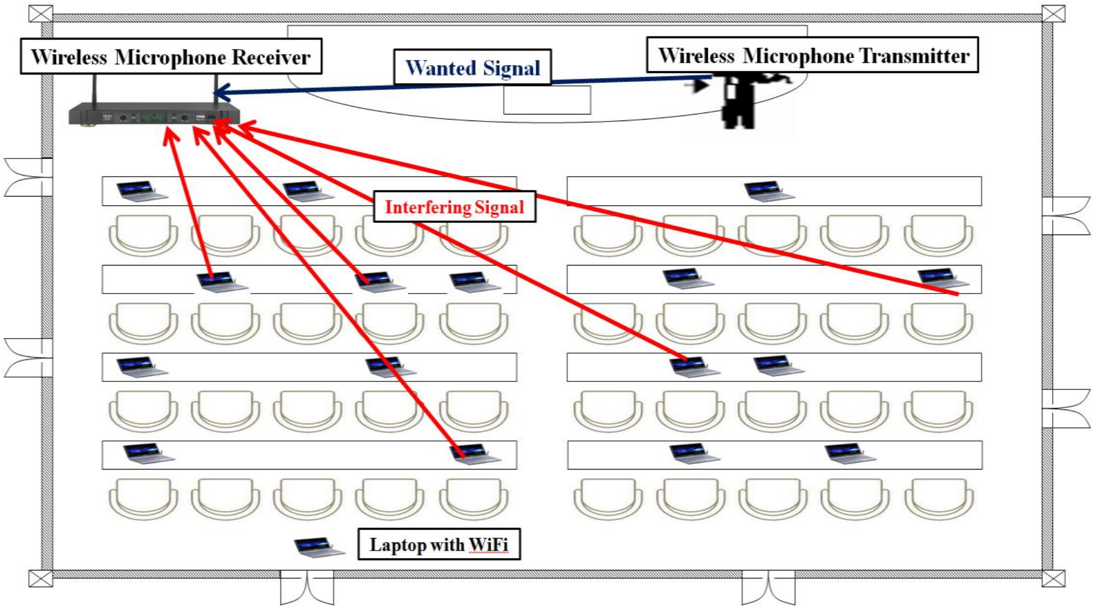

Fig. 7. Interference scenario of Wireless microphone and WiFi operating

4.2 Single WiFi Interference with Wireless Microphone

In the case of a single WiFi interference with Wireless microphone, the protection distance from the laptop with WiFi to the Wireless microphone receiver is subsequently analyzed by using the MCL method.

With the maximum allowable interferer signal level, the protection distance between the laptop with WiFi and the Wireless microphone receiver can be calculated. Knowing the distances involved, considering the worst case, the free space propagation model is used as follows:

$$\text{Free space loss (dB)} = 20\log_{10}(\text{distance}) + 20\log_{10}(\text{frequency}) - 27.56 \quad (6)$$

The signal strength at the Wireless microphone receiver, assuming that it has a unity gain antenna, is given by subtracting the free space loss (1) from the transmit power.

$$\text{Rx signal} = 17\text{dBm} - \{20\log_{10}(100) + 20\log_{10}(581) - 27.56\} = -50.72 \text{ dBm} \quad (7)$$

Note that this paper uses the centre of channel 33 (581 MHz) as the frequency in this calculation.

The interferer signal level needs to be below -50.72 dBm by the carrier to the interference ratio (C/I). If 12 dB of C/I is chosen as the ratio of full signal power to interference, it is necessary to adjust the 12 dB of C/I mandated by 20.4 dB, where 20.4 dB is calculated as follows : $10\log_{10}$(22 MHz of WiFi signal / 0.2 MHz of Wireless microphone signal) [4].

The implied 'same bandwidth C/I' is therefore 12 dB + 20.4 dB = 32.4 dB. The interference signal must be 32.4 dB below the wanted signal calculated by using (8).

$$\text{Interference signal} < -50.72\text{dBm} - 32.4\text{dB} = -83.12 \text{ dBm} \quad (8)$$

Thus the interference signal in the relevant 200 kHz bandwidth must be below -83.12 dBm. The required protection distance (PD) can now be calculated from the free space loss formula (9).

$$PD = 10\text{^}\{[P_{\text{WiFi out-of-band}} - P_{\text{interference}} + 27.56 - 20\log_{10}(f)]/20\} \quad (9)$$

Using the emission levels in **Table 2**, the required protection distances for the situation where the Wireless microphone transmitter is 100 m away from the Wireless microphone receiver are given as in **Table 4**. In addition, the calculations are repeated for more typical operating distances of 50 m, 20 m, 10 m. **Fig. 8** describes the relationship between protection distance and the operating frequency of Wireless Microphone.

Table 4. The minimum protection distances for Wireless microphone

Frequency of Wireless microphone (MHz)	The protection distance (m)			
	Range of Wireless microphone (m)			
	100	50	20	10
578.1	25.12	12.56	5.02	2.51
589	25.12	12.56	5.02	2.51
589.1	2.51	1.25	0.5	0.25
600	2.51	1.25	0.5	0.25
600.1	0.79	0.4	0.16	0.08

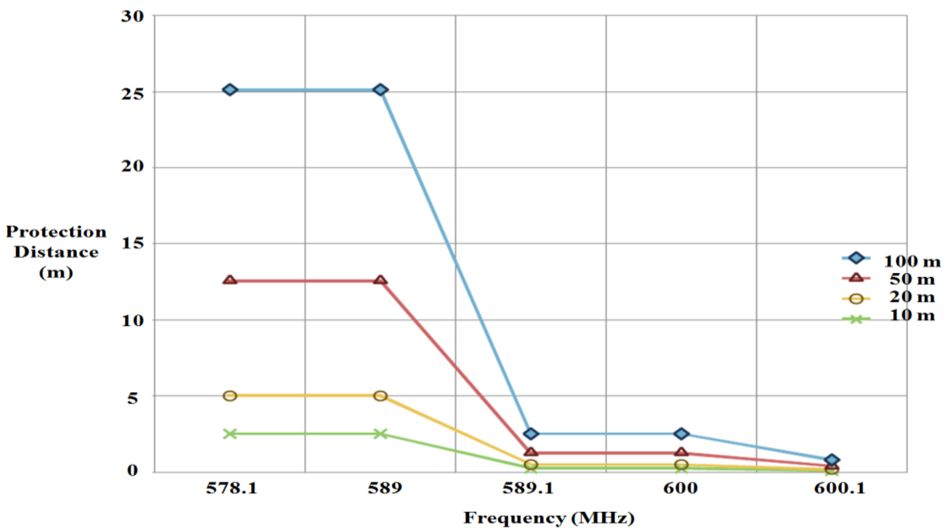

Fig. 8. The minimum protection distances for Wireless microphone

Table 4 shows the interference from WiFi to Wireless microphone is the worst case when Wireless microphone range is 100 m and operates at frequency of 578.1 MHz namely without guard band. Consequently, the protection distance between WiFi and Wireless microphone receiver should not be less than 25.12 m.

4.3 Multiple WiFis Interference with Wireless Microphone

Since the MCL method is relatively straight forward, it can provide a static result which guards against the worst case scenario. However, SEAMCAT based on Monte Carlo method is a statistical technique which models a victim receiver's probability of interference when situated amongst a randomly generated population of interferers [11]. Therefore, SEAMCAT is used to determine the guard band between WiFi and Wireless microphone in the case of multiple WiFis interfering with the Wireless microphone.

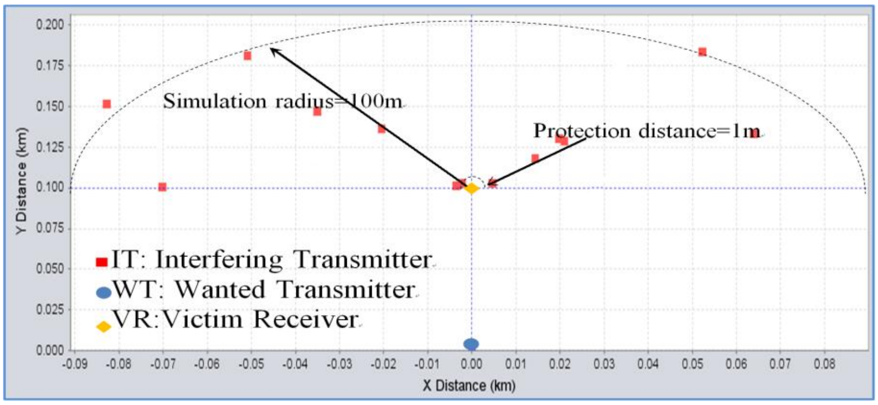

Fig. 9. One snapshot of simulations

Simulation parameters are as follows: Simulation radius is 100 m, the number of active WiFi is 3, 5, 12, respectively. The protection distance is 1 m and the Wireless microphone range of 100 m is selected. Once free space is chosen as propagation model, the WiFi and Wireless microphone will be set up in SEAMCAT according to the parameters of WiFi and Wireless microphone. **Fig. 9** is one snapshot when the number of active WiFi is12. Simulation results are summarized in **Table 5**.

Table 5. The relationship between frequency of Wireless microphone and interference probability

Frequency of Wireless microphone (MHz)	Interference probability		
	The number of active WiFi		
	3	5	12
578.1	16.01%	83.38%	100%
580	16.32%	83.14%	100%
585	15.63%	83%	100%
589	0.04%	4.39%	96.7%
589.001	-	-	96.36%
589.01	-	-	91.82%
589.05	-	-	16.22%

589.07	-	-	0.16%
589.1	-	-	0%

Table 5 indicates that the interference from WiFi to Wireless microphone is the worst case when Wireless microphone range is 100 m and the number of active WiFi is 12. If interference probability of 5% is acceptable, the guard band for avoiding WiFi interfering with Wireless microphone should be at least 4.97 MHz since the frequency of wireless microphone was required with 589.07 MHz ± 100 kHz when the WiFi frequency of 573 MHz ± 11 MHz is chosen for simulation.

5. Conclusions

The interference scenario of WiFi potentially interfering with Wireless microphone is assumed in TVWSs environments. The protection distance and the guard band for protecting Wireless microphone from interference of WiFi are analyzed by using MCL and SEAMCAT, respectively.

As a result, in the case of a single WiFi interfering with Wireless microphone, the protection distance between WiFi and Wireless microphone should be at least 25.12 m to guarantee that WiFi does not impact Wireless microphone. When the active numbers of WiFi is12, the guard band should be at least 4.97 MHz to avoid WiFi interfering with Wireless microphone. The results can be used as a guideline and as a reference for the implementation of WiFi and Wireless microphone in TVWSs. For more practical interference analysis results, the multi-path behavior and various interference sources of WiFi should be considered in further studies.

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