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Evaluation of TV White Space Implementation in Indonesia: A Case Study in Yogyakarta

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Abstract

TV white space is a technology that utilizes unused spectrum owned by primary users, namely TV broadcasters in a particular area and time. There are two main problems related to the use of white space, namely protection of primary users and identification of white space channels. The prohibited, strict, moderate, and loose (PSML) method has previously been proposed, dividing the TV protection area into four zones to model the white space system. Researchers generally use additional protection areas and television coverage areas with a location probability of less than 70% to consider the possibility of overlap between white space and protected areas. However, this method has not been in implementation in the field. In this study, the author implemented the PSML method in the city of Yogyakarta by using the coverage area of TVRI Patuk as a sample. Based on the measurement results, the author discovered that the deviation between the simulation results and the measurement results was 7.32 dB or 1.82 dB higher than ITU's recommendation. This deviation indicates that, based on geographical conditions, Yogyakarta has a higher variation in field strength values than ITU's recommendations.

Keywords: *TVWS, PSML, Field Strength, Deviation Standard.*

1. INTRODUCTION

TV White Space (TVWS) utilizes unused TV spectrum for secondary purposes, namely internet access (Yuan Ma Chen Fu, Wenge Rong, Zhang Xiong, Shuguang Cui, n.d.)(Freyens & Loney, 2013). TVWS is appropriate for rural areas due to its cost-effectiveness (Lessy Sutiyono Aji, Wibisono, & Gunawan, 2017b). In the utilization of TVWS, it is necessary to consider the protection of its primary users, namely existing TV operators. However, local policies of each country occasionally constraints the use of TVWS. For example, in Indonesia, operators cannot apply TVWS because the government does not allow the spectrum use for other purposes. Moreover, the government can only implement TVWS utilization policy after the migration from analog to digital TV is complete.

There are two frameworks used globally regarding the implementation of TVWS, namely the federal communications commission (FCC) framework and the office of communications (OFCOM) framework. The FCC model has demonstrated more excellent performance than ECC in supplying white space channels (Lessy Sutiyono Aji et al., 2017b). Provided that it is located outside the no-talk region, WSD may operate with a maximum EIRP of 4 W (Lessy Sutiyono Aji, Wibisono, & Gunawan, 2017a). Therefore,

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the FCC standard is suitably applied in a large geographic area where the incumbent transmitter is not too dense, such as in Indonesia (Lessy Sutiyono Aji et al., 2017b).

Numerous researchers have attempted to develop the performance of the FCC model to expand its capabilities in areas that are dense with TV transmitters (Beek et al., 2012)(Villardi, Harada, Kojima, & Yano, 2017)(Rosston & Skrzypacz, 2021). A latest study (L S Aji, Juwono, Wibisono, & Gunawan, 2018) has indicated that the PSML method has undergone a series of development. The Villardi method (Villardi et al., 2017; Aji, 2022) proposes to utilize more TV spectrum for TVWS purposes. Improved geolocation performance is obtained by utilizing the DTT coverage area, which has a probability of less than 70% as white space, to produce more white space channels compared to Villardi's research (Villardi et al., 2017) by modifying the mathematical equations in the study (Beek et al., 2012). The study indicated that PSML model may provide 3 (three) more white space channels or equivalent to 24 MHz of channel width when compared to Villardi's model when implemented in transition areas between rural and urban.

The research model in (L S Aji et al., 2018) has not carried out the field measurements, therefore the deviations between the model and the actual conditions are not available. Hence, this research attempts to contribute by implementing the PSML model in the field. This study examined the model implementation in the TV area in Yogyakarta, Indonesia. The TV transmitter belongs to TVRI, a state-owned TV operator that has run simulcast while the migration policy to digital is not in place. The basis for selecting the location is as follows:

- TVRI Patuk has broadcast using digital transmission on channel 29
- COVID-19 pandemic has posed extreme restrictions in the scale of the experiment

This paper chronicles the study as follows: Section II discusses the previously developed PSML system, Section III describes the method of measuring the field strength of digital TV transmitters used in this study, while Section IV describes the results and discussion, and Section V presents the conclusion of the study.

2. MATERIALS AND METHODS

2.1 The PSML Method

The PSML model divides the no-talk area into four zones, namely prohibited zone, strict zone, moderate zone and loose zone. Figure 1 illustrates these four zones. In a prohibited zone, WSD may not operate at all. The prohibited zone represents the DTT coverage area, which has a location probability of higher than 70%. The strict zone utilizes the area within the protection contour with a location probability of lower than 70%. The moderate zone allows white space transmitters to transmit signals using maximum power (4 watts). The loose zone permits maximum transmit power.

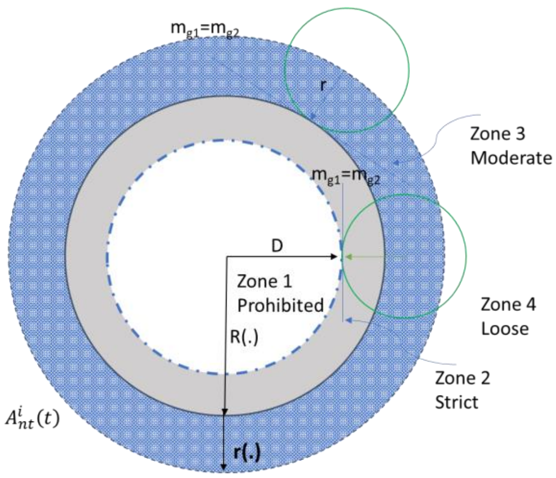


Figure 1. The PSML Method

Source: L S Aji et al., 2018

The following mathematical equation outlines the description of Figure 1 as follows (L S Aji et al., 2018):

$$I_{PSML}(t,f,x) = \begin{cases} 0,\ x \in A^i_{nt}: \|x_i - x\| < D \\ 1|P_{strict},\ x \in A^i_{nt}: D \le \|x_i - x\| < R \\ 1|P_{Mod}, x \in A^i_{nt}: R \le \|x_i - x\| < R + r \\ 1|P_{max}, x \notin A^i_{nt} \end{cases} \quad (1)$$

The notation A^i_{nt} represents the no-talk region of a digital TV transmitter, while $\|x_i - x\|$ describes the distance norm between the TV transmitter (x_i) and the WSD transmitter location (x). Mathematical equation $0,\ x \in A^i_{nt}: \|x_i - x\| < D$ indicates that WSD is in Zone 1. The value of 0 indicates that WSD cannot operate or there is no available white space channel in that particular area. The equation $1|P_{strict},\ x \in A^i_{nt}: D \le \|x_i - x\| < R$ represents that WSD is in Zone 2, while the equation $1|P_{Mod}, x \in A^i_{nt}: R \le \|x_i - x\| < R + r$ indicates that WSD is in Zone 3. The difference between Zone 2 and Zone 3 is in the notation of the transmit power limit. Using the notation $1|P_{strict}$, Zone 2 applies a strict maximum transmit power limit and WSD cannot operate at the maximum transmit power (4 W). Meanwhile, Zone 3 uses the notation $1|P_{Mod}$, denoting a moderate transmission power limitation in the area. Moderate transmission power limitation indicates that WSD is able to transmit a signal with a higher transmit power than Zone 2, and WSD may operate at maximum transmit power certain areas in this zone. Lastly, the WSD outside the no-talk region is symbolized by $1|P_{max}, x \notin A^i_{nt}$. In this area, all WSDs may operate at maximum transmit power (4 W).

The D in equation (1) represents the radius of Zone 1, while R and r denote the radius of the DTT protection contour and the extra protection distance respectively. For radius R, the value of E is equal to the value of E_{min}, while the E_{med} value determines radius D. The E_{med} value is similar to the E_{min} value added with the Cr correction factor obtained using equation (2).

$$Cr = [Z * \sigma |\ Pr\{Z \ge \overline{SNR}\} = 70\%] \quad (2)$$

Equation (2) indicates that the value of Cr is equal to the random probability of the signal to noise ratio (SNR) at the receiver with a value equal to or greater than 70%. (ECC Report 159: Technical and operational requirements for possible operation of cognitive radio systems in the 'white spaces' of the frequency band 470-790 Mhz, 2011; ECC Report 236: Guidance for national implementation of a regulatory framework for TV WSD using geo-location databases, 2015). σ is the standard deviation of the random

SNR, while Z is the ratio of the random signal at a normally distributed receiver. The simulation used a standard deviation value of 5.5 dB as recommended by ITU [28].

The protection value ensures that there is no interference with the DTT when the white space transmitter appears, whereas the protection ratio value determines the maximum permissible field strength value for WSD (E_{MaxWSD}) at the edge of the DTT protection contour. As indicated in equation (3), $\alpha_{f\pm n}$ represents the protection ratio value, which varies depending on the frequency used by the secondary user. This also causes differences in the E_{MaxWSD} value for each frequency used. The n values of 0, 1, and 2 in equation (3) represent co-channel, the first adjacent channel, and the second adjacent channel respectively.

$$E_{max\,WSD}(f) = E_{min\,DTT} - \alpha_{f\pm n}\ dB\mu V/m, n = \{0,1,2\} \quad (3)$$

2.2The Field Strength Measurement Method

The field measurement method determines the amount of field strength. The expected result is the standard deviation between the measurement results and the simulation, which can be used as a correction factor to the standard deviation recommended by ITU. ITU recommends a standard deviation of 5.5 dB to accommodate variations in the field (Method for point-to-area predictions for terrestrial services in the frequency range of 30 MHz to 3 000 MHz, 2013). In the calculation of the E_{med} quantity in equation (2), the standard deviation (σ) used the value of 5.5 dB, multiplied by the normal distribution value (Z) to obtain the value of the correction factor (Cr). The Cr value is subsequently added to the E_{min} value to produce E_{med}. Hence, changes in the σ value will affect the amount of $E_{med.}$ Since the PSML method uses the E_{med} to determine the boundary between zone 1 and 2, determining the value of σ is extremely important.

The author carried out P measurements at 36 points scattered around the TVRI Patuk's transmitter (Figure 2) and 36 denotes the minimum number of N sampling normal distributions (Driels & Shin, 2004; Oberle, 2015). These measurement points are within the service coverage of TVRI Patuk.

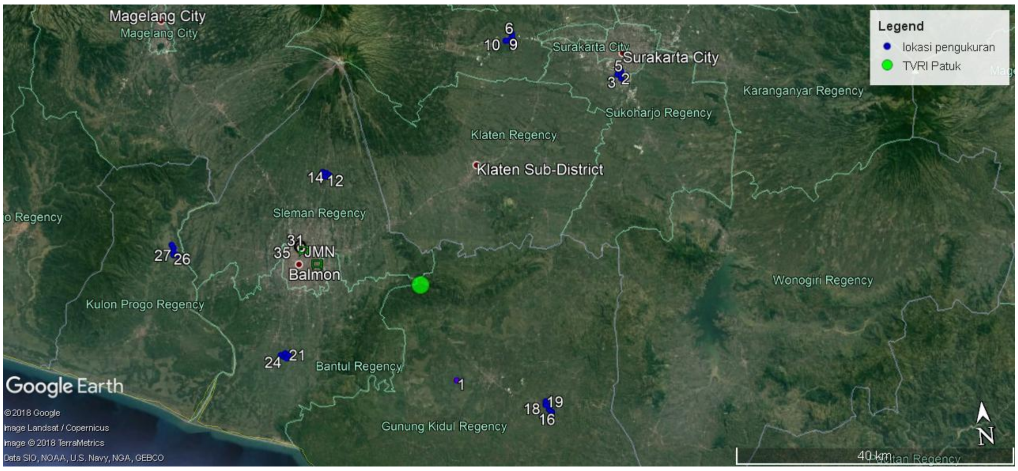
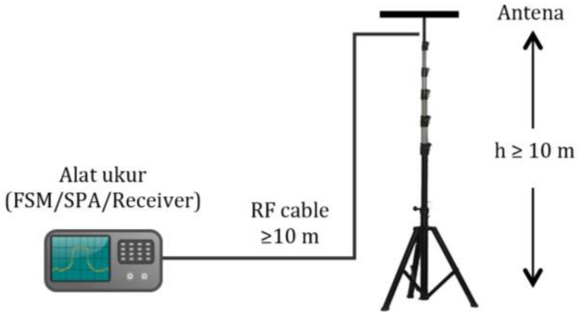


Figure 2. Field Strength Measurement Location

The author used the Rohde & Swartch EFL 240 tool to measure the field strength of the TVRI Patuk transmitter at a predetermined location and Figure 3 illustrates the measurement method. The TV signal receiving antenna was mounted on a tripod and the height of the receiving antenna from the ground varied between 3 m – 10 m. The author recorded field strength values read by the EFL 240 measuring instrument at each measurement point in the logbook for further data processing. The author carried out only one measurement at each location to obtain an overview of the coverage area (ITU, 2011).



a. Measurement Scenario

c. Antenna Setting

b. R&D EFL 240

Figure 3. The Field Strength Measurement Method

3. RESULTS AND DISCUSSION

3.1The PSML Method Implementation

The author conducted a simulation using existing data from TVRI Patuk, indicated in Table 1. Using the equation recommended by ITU (ITU-R, 2014), the E_{min} value was 42.53 dBµV/m. By adding the Cr value of 2.884, the E_{med} value was 45.42 dBµV/m. The E_{min} and E_{med} value represent the threshold values for Zone 1 and Zone 2 in the PSML method. On the other hand, the threshold value for Zone 3 and Zone 4 uses the value of $E_{(R+r)}$, which represents the value of the field strength at a distance of R+r in the PSML method. The ITU-R 1546 method determined the R and D values using the E_{min} dan E_{med} as inputs, and produced 50.36 Km and 41.77 Km for the R and D values respectively. In addition, the author calculated the maximum allowable WSD field strength value “EmaxWSD” using equation (3). Subsequently, the author obtained the value of r for WSD with a transmitter height of 30 m by using the ITU-R 1546 method, which was 20.61 Km. Using the ITU-R 1546 method, the amount of field strength at a distance of R+r (70,4 Km) was 34.74 dBµV/m ($E_{(R+r)}$). After the author determined the values of E_{med}, E_{min} dan $E_{(R+r)}$ s, the PSML method was ready to be implemented with the results indicated in Figure 4.

Table 1. The Specification System of DTT TVRI Patuk

Specification	Value
Modulation	64 QAM
Code Rate	4/5
FFT	16 K
Guard Interval	1/8
Pilot Patern	PP8
FEC	64 K

Figure 4 is a visualization of the implementation of the PSML method in TVRI Patuk's coverage areas. The red color represents the Zone 1 area where WSD may not operate, while the yellow color represents the Zone 2 area that allows WSD to operate with a strict maximum transmit power limit. The green color represents Zone 3 area, where WSD may operate with limited transmit power and the blue color represents Zone 4 area, where WSD may freely operate using the maximum transmit power (4 W).

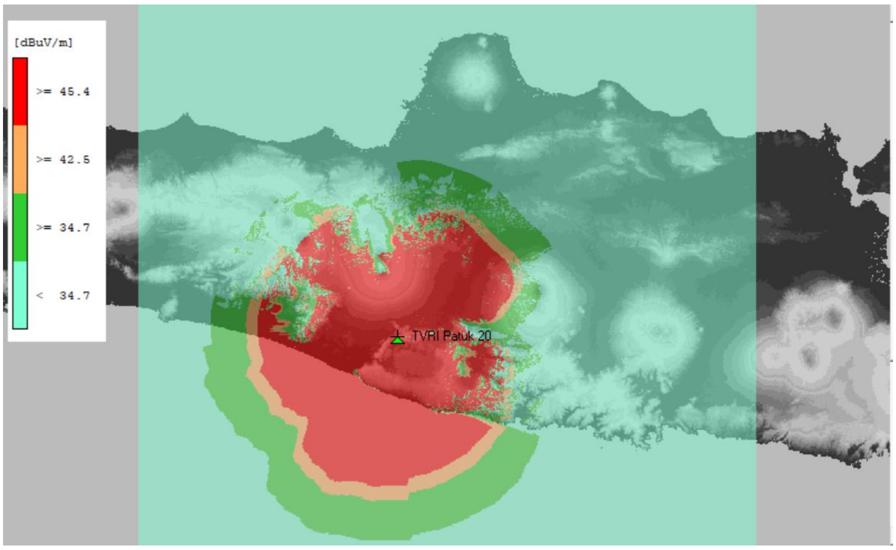


Figure 4. The PSML Model Implementation Simulation on TVRI Patuk’s Coverage Area

Subsequently, the author carried out measurements of the field strength according to data in the field for comparison with simulation results. The author adapted the method from the method described in section III. The measurement points are located in Zone 1, as indicated in Figure 5, since the protected areas are represented in red, while other colors represent white space areas.

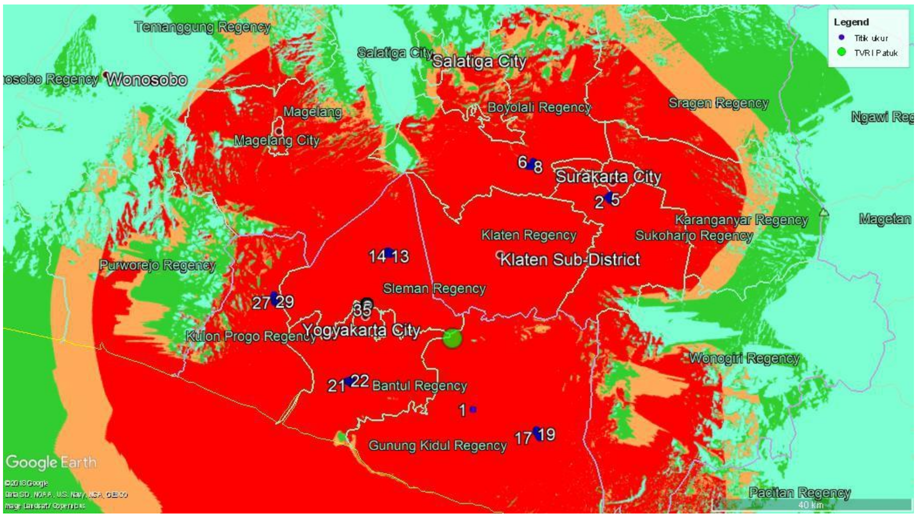


Figure 5. The Location of Measuring Points in the Coverage Area of TVRI Patuk

Figure 6. Example of Measurement Result Parameter

Figure 6 demonstrates an example of measurement results using the EFL 340 tool. The author entered the measurement results of each measuring point into the data entry form and Microsoft Excel for processing.

3.2The Comparison of Field Strength Values based on Simulation with Field Measurement

The author subsequently compared the simulated field strength values at each measurement point using the chirplus_BC simulator with the field measurement results. Table 2 presents the comparison of the simulation results and the field measurement results.

Tabel 2. The Comparison of Simulation and Field Measurement

No.	Field Stength		Difference	No.	Field Stength		Difference
	Simulation	Measurement			Simulation	Measurement	
	dBuV/m	dBuV/m	dB		dBuV/m	dBuV/m	dB
1	60,6	63,73	3,13	19	67,8	82,83	15,03
2	60,7	64,23	3,53	20	67,4	80,63	13,23
3	61,2	74,73	13,53	21	66,9	61,03	-5,87
4	61	67,13	6,13	22	75,3	64,13	-11,17
5	67	68,73	1,73	23	74,9	68,03	-6,87

6	63,8	69,93	6,13	24	75	82,13	7,13
7	64,3	68,63	4,33	25	74,8	68,53	-6,27
8	64,6	64,03	-0,57	26	72,3	75,83	3,53
9	64,7	65,63	0,93	27	72,7	75,83	3,13
10	64,8	73,33	8,53	28	73	70,83	-2,17
11	58,7	68,23	9,53	29	73,3	74,73	1,43
12	77,5	64,13	-13,37	30	72	79,93	7,93
13	77,1	77,73	0,63	31	83,2	77,73	-5,47
14	77,5	74,33	-3,17	32	80,3	72,73	-7,57
15	76,7	62,93	-13,77	33	80,3	78,93	-1,37
16	68	69,43	1,43	34	80,2	78,03	-2,17
17	68,3	76,43	8,13	35	80,5	80,33	-0,17
18	68,3	58,73	-9,57	36	75,3	79,73	4,43

The formulation of the hypothesis of the normality test in this study is as follows:

H_0: The existing data are a normal distribution

H_1: The existing data are not a normal distribution

As depicted in Table 2, the data in the column difference represent the deviation between the simulations and the field measurements. Hence, the author would process the data in the column difference in dB units further. When viewed from the values in the column, the results varied. Therefore, it was necessary to determine the average deviation using the normal distribution approach. Before using the normal approach, it was necessary to ascertain whether the data had a normal distribution. The author used Saphiro Wilk method (Razali, 2011) for normality test. In general, the Saphiro Wilk test follows the below equation:

$$T = \frac{1}{F}\left[\sum_{i=1}^{k} a_i (X_{n-1+i} - X_i)\right]^2 \quad (4)$$

Where,

$$F = \sum_{i=1}^{n} (X_i - \overline{X})^2 \quad (5)$$

F denotes the sum of all sample squares X minus the mean $\overline{X}$, while a_i in equation (4) represents the coefficient of the Saphiro Wilk test that can be determined using the Saphiro Wilk table. In addition, the notation X denotes the tested value for each data i in the total number of samples n.

Using Saphiro Wilk test, the author must sort data set from the smallest to the largest value. Subsequently, the author subtracted each data by the average of the data and squared. The author subsequently added up all the square results to determine the value of F as mentioned in equation (4). Table 3 presents the F value results.

Tabel 3. The F value in the Shapiro Wilk Method

No.	Xi	Xi- Mean	$(Xi\text{-}Mean)^2$	No.	Xi	Xi- Mean	$(Xi\text{-}Mean)^2$
1	-13,77	-14,7139	216,4985	19	1,43	0,4861	0,2363
2	-13,37	-14,3139	204,8874	20	1,73	0,7861	0,6180
3	-11,17	-12,1139	146,7463	21	3,13	2,1861	4,7791

4	-9,57	-10,5139	110,5419	22	3,13	2,1861	4,7791
5	-7,57	-8,5139	72,4863	23	3,53	2,5861	6,6880
6	-6,87	-7,8139	61,0569	24	3,53	2,5861	6,6880
7	-6,27	-7,2139	52,0402	25	4,33	3,3861	11,4657
8	-5,87	-6,8139	46,4291	26	4,43	3,4861	12,1530
9	-5,47	-6,4139	41,1380	27	6,13	5,1861	26,8957
10	-3,17	-4,1139	16,9241	28	6,13	5,1861	26,8957
11	-2,17	-3,1139	9,6963	29	7,13	6,1861	38,2680
12	-2,17	-3,1139	9,6963	30	7,93	6,9861	48,8057
13	-1,37	-2,3139	5,3541	31	8,13	7,1861	51,6402
14	-0,57	-1,5139	2,2919	32	8,53	7,5861	57,5491
15	-0,17	-1,1139	1,2407	33	9,53	8,5861	73,7213
16	0,63	-0,3139	0,0985	34	13,23	12,2861	150,9485
17	0,93	-0,0139	0,0002	35	13,53	12,5861	158,4102
18	1,43	0,4861	0,2363	36	15,03	14,0861	198,4185
			Total		33,98		1876,3231

There are two data groups in the Xi column in Table 3. First, the data in the middle to the last order are denoted as X_{n-i+1}. Second, the data in the middle order to the first data are denoted as X_i. Subsequently, according to equation (3), the next step is to multiply each result (X_{n-i+1} - X_i) by the coefficient a from the table of Saphiro Wilk factors. Table 4 presents the results of the calculations.

Tabel 4. Saphiro Wilk Normality Test

I	X_{n-i+1}	X_i	$X_{n-i+1}-X_i$	a	$a(X_{n-i+1}-X_i)$
1	15,03	-13,77	28,8	0,4068	11,71584
2	13,53	-13,37	26,9	0,2813	7,56697
3	13,23	-11,17	24,4	0,2415	5,8926
4	9,53	-9,57	19,1	0,2121	4,05111
5	8,53	-7,57	16,1	0,1883	3,03163
6	8,13	-6,87	15	0,1678	2,517
7	7,93	-6,27	14,2	0,1496	2,12432
8	7,13	-5,87	13	0,1331	1,7303
9	6,13	-5,47	11,6	0,1179	1,36764
10	6,13	-3,17	9,3	0,1036	0,96348
11	4,43	-2,17	6,6	0,09	0,594
12	4,33	-2,17	6,5	0,077	0,5005
13	3,53	-1,37	4,9	0,0645	0,31605
14	3,53	-0,57	4,1	0,0523	0,21443
15	3,13	-0,17	3,3	0,0404	0,13332

16	3,13	0,63	2,5	0,0287	0,07175
17	1,73	0,93	0,8	0,0172	0,01376
18	1,43	1,43	0	0,0057	0

Equation (3) yields the T value, while Saphiro Wilk table indicates the W value of 0,935 when significance level ρ is 5%. H_0 is acceptable if the T value is greater than W (ρ=5%). With T = 0,976, this value is acceptable since it is greater than 0,935. Hence, the existing data is normally distributed (accept H_0). By grouping the data into five groups (see table 5), Figure 7 illustrates the shape of the data distribution.

Table 5. Data Grouping

Group	Min	Max	Numbers	Relative Frequency	Cumulative Frequency
1	-13	-8	4	11,11%	11,11%
2	-7,9	-2,9	6	16,67%	27,78%
3	-2,8	2,2	10	27,78%	55,56%
4	2,3	7,3	9	25,00%	80,56%
5	7,4	12,4	4	11,11%	91,67%
6	12,5	17,5	3	8,33%	100,00%
Total			36	100,00%	

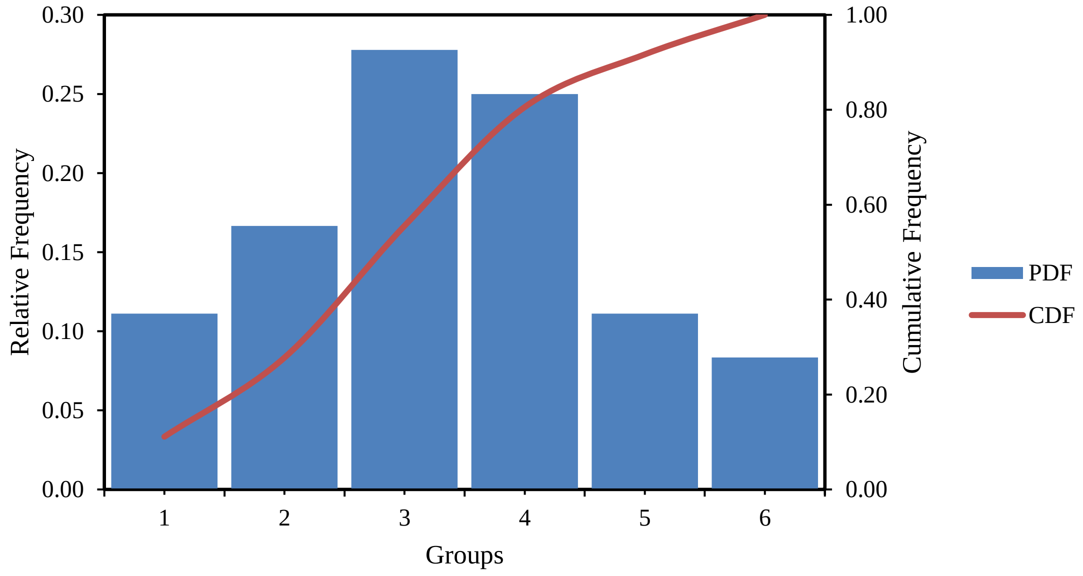


Figure 7. Distribution of Measurement Result Data

Figure 7 indicates that the existing data are normally distributed because they are close to the normal distribution shape, which resembles a bell-shape curve (Gordon, 2006). With the mean value of 0.94 dB and the standard deviation of 7.32 dB, the Z value of the normal distribution can be expressed in equation (5) as follows:

$$Z = N(\mu, \sigma) = N(0.94, 7.32) \quad (5)$$

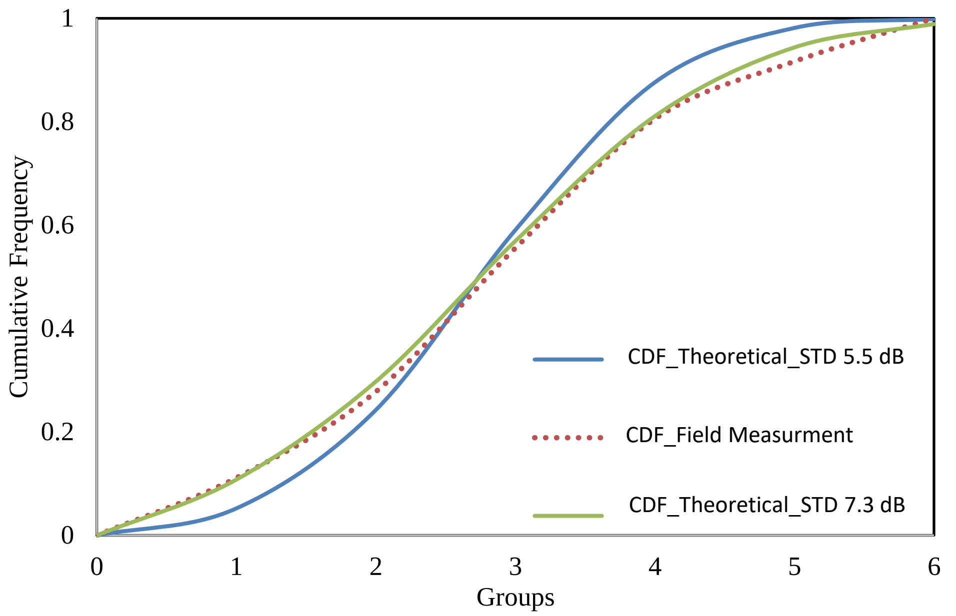


Figure 8. Comparison of Theoretical CDF with Measurement Result CDF (σ = 7,32 dB)

Equation (8) indicates that the standard deviation based on field measurement results is 7.32 dB. In contrast, the amount of standard deviation used during the theoretical calculation is 5.5 dB, referring to the recommendation from ITU (Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands, 2017). A similar study by Arenas et al., n.d. indicated that the shadowing effect caused the difference in standard deviation. Figure 8 demonstrates the comparison of theoretical CDF according to ITU and CDF from field measurements. As indicated, the cumulative probability value of the measured data does not coincide with the theoretical CDF. These differences indicate that the field strength values at the test locations varied by approximately 1.82 dB compared to ITU's test locations . The variations are within the tolerance limit recommended by the ITU, which is 3 dB (ITU-R, 2018). These variations are mainly due to geographical conditions that affect signal propagation from sender to receiver. Therefore, there is a possibility of inaccuracies in the magnitude of the field strength with actual conditions in several locations. The author adjusted the Cr value to bring the simulation results close to the field conditions. By multiplying the value of 0.52 by 7.32 dB according to equation (2), the author obtained the correction factor for Cr at 3.81 dB. Subsequently, the author added the Cr value to the minimum field strength value of TVRI Patuk, E_{min} (42,53 dBµV/m), yielding the E_{med} value of 46,34 dBµV/m. Figure 9 illustrates the comparison of prior Cr value correction and after Cr value correction.

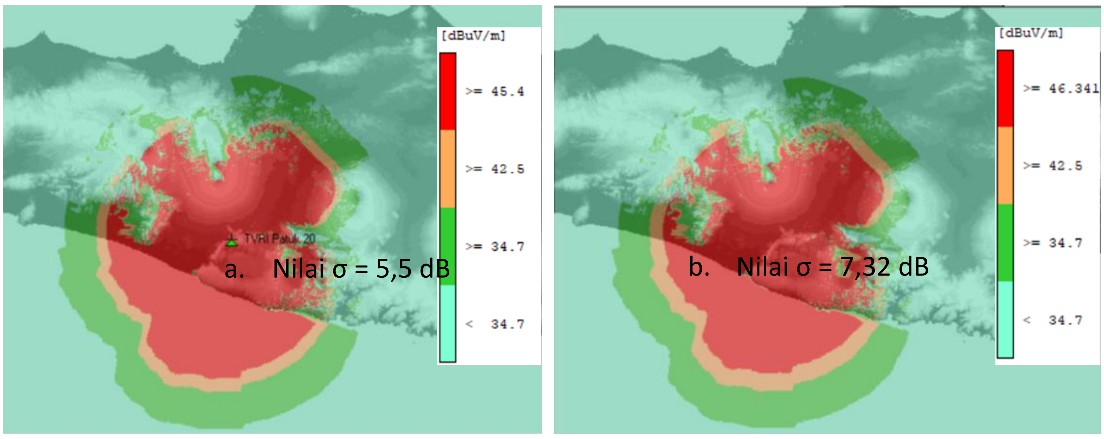


Figure 9. Comparison of coverage area between σ = 5,5 dB with σ = 7,32 dB

There is no significant difference between part a and part b of Figure 9 since the variation between the simulation and theoretical results is merely 0.947 dB. The main difference lies in the Zone 2 area (yellow color), which seems wider in part b of Figure 9. This is to compensate for the increase in the Emed value from 45,4 dBµV/m to 46,34 dBµV/m due to the difference in standard deviation. Based on the analysis results, simulation using chirplus_BC to implement the PSML model can be applied since it does not appear to be significantly different from the measurement results.

Further measurements are necessary to determine the minimum location probability value under the geographical conditions of Indonesia, especially in the border areas between Zone 1 and Zone 2 in the PSML method. These will also enable measurement results to be replicated in other areas as well. It is also necessary to measure continuously or at intervals (normal method) under the recommendations of ITU (ITU, 2011). The difference in the probability value of the location will affect the TV service's coverage area, which will subsequently affect the white space area. Higher location probability value will drive higher white space value, and vice versa. These field measurements are part of the future work that the author intend to carry out to strengthen the PSML method and the results will be published in international publication. It is hoped that the PSML method can be used as an accurate and comprehensive reference on the implementation of white space TV in Indonesia.

4. CONCLUSION

The author had compared the results of the simulation and field measurements to evaluate the implementation of TV White Space using the PSML method. The author had also obtained the variation of field strength value deviation between the simulation results and the measurement results for each test point. The Shapiro Wilk test had helped determine that the distribution of the deviation data was normally distributed with the standard deviation value of 7.32 dB. In comparison, according to the ITU's recommendations, the standard deviation value used in the simulation was 5.5 dB. Therefore, there was a difference of 1.82 dB between the measurement results' standard deviation and the ITU's recommended value. These results indicate that the deviation of the field strength values in Yogyakarta is more varied than the ITU's recommendation. However, according to ITU's recommendation, this variation remains within the tolerance of 3 dB. Hence, the government may still use the value of 5.5 dB as a standard deviation in implementing TV White Space using the PSML method in Indonesia.

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References

Aji, L S, Juwono, F. H., Wibisono, G., & Gunawan, D. (2018). Proposal for Improving White-Space Channel Availability. IEEE Access, 6, 59528–59539. https://doi.org/10.1109/ACCESS.2018.2874590

Aji, Lessy Sutiyono, Wibisono, G., & Gunawan, D. (2017a). Analysis of white space coverage area radius to find the equilibrium point between DVB-T2 and IEEE 802.22 WRAN. In 2017

Int. Conf. on Elect. Eng. and Informatics (ICELTICs), Aceh, Indonesia (pp. 173–178). IEEE. https://doi.org/10.1109/ICELTICS.2017.8253270

Aji, Lessy Sutiyono, Wibisono, G., & Gunawan, D. (2017b). The adoption of TV white space technology as a rural telecommunication solution in Indonesia. In 15th Int. Conf. on Quality in Res. (QiR) 2017, Bali, Indonesia (Vol. 2017-Decem, pp. 479–484). Bali, Indonesia: IEEE. https://doi.org/10.1109/QIR.2017.8168534

Aji, L. S. (2022). Field Measurement Test on Protection Ratio For DVB-T2 Interfered By TV White Space Devices. Syntax Literate; Journal Ilmiah Indonesia, 7(2), 815-829.

Arenas, J., Angueira, P., I. Peña, Gil, U., Fernandez, I., Vélez, M., & Guerra, D. (n.d.). Analysis of the Electric Field Strength Location Variability in the UHF Band for Mobile and Portable Multimedia Broadband Services in SFN Networks. Universidad del País Vasco/Euskal Herriko Unibertsitatea.

Beek, J. van de, Riihijarvi, J., Achtzehn, A., Mahonen, P., van de Beek, J., Riihija, J., … Mahonen, P. (2012). TV White Space in Europe. IEEE Transactions on Mobile Computing, 11(2), 178–188. https://doi.org/10.1109/TMC.2011.203

Driels, M. R. ., & Shin, Y. S. (2004). Determining the number of iterations for Monte Carlo simulations of weapon effectiveness. Naval Postgraduate School Monterey. Retrieved from https://core.ac.uk/download/pdf/36694536.pdf

ECC Report 159: Technical and operational requirements for the possible operation of cognitive radio systems in the ‘white spaces’ of the frequency band 470-790 Mhz. (2011). Eur. Conf. Postal Telecommun. Admin. (CEPT), London, UK. Retrieved from https://www.ecodocdb.dk/download/be051b35-91e9/ECCREP159.PDF

ECC Report 236: Guidance for national implementation of a regulatory framework for TV WSD using geo-location databases. (2015). Eur. Conf. Postal Telecommun. Admin. (CEPT), London, UK. Retrieved from https://www.itu.int/md/D14-SG01-C-0134/en

Freyens, B. P., & Loney, M. (2013). Emerging issues in white space regulation. Telecommunications Policy. https://doi.org/10.1016/j.telpol.2012.06.010

Gordon, S. (2006). The Normal Distribution. University of Sydney.

ITU-R. (2014). Frequency and network planning aspects of DVB-T2 (No. ITU-R BT.2254-2). ITU-R, Geneva, Switzerland. Retrieved from www.itu.int › Home › ITU Publications › Radiocommunication (ITU-R)

ITU-R. (2018). ITU-R SM.378--7: Field-strength measurements at monitoring stations. Geneva.

ITU. (2011). Spectrum Monitoring Handbook. Switzerland, Geneva.

Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. (2013). (No. ITU-R P.1546-5). ITU-R, Geneva, Switzerland.

Oberle, W. (2015). Monte Carlo Simulations: Number of Iterations and Accuracy.

Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands. (2017). (No. BT.1368-8). ITU-R, Geneva, Switzerland. Retrieved from https://www.itu.int/rec/R-REC-BT.1368/en

Razali, N. M. Y. B. W. (2011). Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. Journal of Statistical Modeling and Analytics, Vol.2 No.1(2011), 21–33.

Rosston, G. L., & Skrzypacz, A. (2021). Reclaiming spectrum from incumbents in inefficiently allocated bands: Transaction costs, competition, and flexibility. Telecommunications Policy, 45(7), 102167. https://doi.org/https://doi.org/10.1016/j.telpol.2021.102167

Villardi, G. P., Harada, H., Kojima, F., & Yano, H. (2017). Multilevel Protection to Broadcaster Contour and Its Impact on TV White Space Availability. IEEE Transactions on Vehicular Technology, 66(2), 1393–1407. https://doi.org/10.1109/TVT.2016.2566675

Yuan Ma Chen Fu,Wenge Rong,Zhang Xiong,Shuguang Cui, Y. G. (n.d.). TV White Space Spectrum Analysis Based on Machine Learning. Journal of Communications and Information Networks. Retrieved from http://www.infocomm-journal.com/jcin