

ANTENNA CHARACTERIZATION AND DETERMINATION OF PATH LOSS EXPONENTS FOR 677 MHz CHANNEL USING FIXED AND PORTABLE DIGITAL TERRESTRIAL TELEVISION

F. S. Caluyo¹ and J. C. Dela Cruz^{1,2,*}

¹Department of EECE, Mapua Institute of Technology, Philippines

²College of Engineering, DeLa Salle University, Manila, Philippines

Abstract—This paper presents propagation measurements results using Integrated Services Digital Broadcast-Terrestrial (ISDB-T) to investigate the characteristics of 6 MHz wideband Digital Terrestrial Television channel at 677 MHz for fixed and portable reception. Empirical measurements were done at predetermined measurement points consisting of 21 radials for a total of 92 locations extending to 20 kilometers around the National Broadcasting Network (NBN) digital transmitter. Characterizations were conducted using antenna heights of 9 m (fixed reception), 3 m (fixed reception), and 1.5 m (portable reception). Modulation Error Rate (MER), power received, field strength and delay profiles were captured to help characterize the channel in an urban area in and around Metro Manila at day time for temperatures ranging from 26°C to 32°C. Measured field strength was compared to NTC F(50,90) curves. Polynomial fit using least square errors was used to plot the field strength coverage of NBN. For large-scale fading, it is observed that signal power conforms to Log Normal distribution. The study helped identify problem sites within the coverage. These are locations within the coverage area or at the outskirts of the coverage area where DTV signal is not received at all. A more accurate description of the DTT channel will lead to a better design of the parts of the Digital Television system from the network to transmitting system and receiving equipment. Path loss exponents computed for the three antenna heights can be helpful in developing empirical prediction models.

Received 26 March 2012, Accepted 9 May 2012, Scheduled 18 May 2012

* Corresponding author: Jennifer C. Dela Cruz (jennycdc@yahoo.com).

1. INTRODUCTION

The broadcast industry is undergoing transition from analog terrestrial broadcast to digital terrestrial broadcast. The Philippines, being a developing nation situated in the tropical region, needs to undertake a verification and improvement of existing methodologies/techniques in the prediction of the coverage area. Currently, outdoor measurement models available were derived from studies by developed nations located above and below the tropics. These are Okumura Hata and Cost 231 models to name a few [1].

It is assumed that a tailored approach for a unique distribution of urban and rural dwellings needs to be considered in the establishment of a technical coverage prediction. This study will lead to outdoor model development through antenna characterization and path loss exponent determination. Studies were done by Masa-Campos et al. [2] to develop an indoor model based on Log Distance Path Loss and Rayleigh Fading. These are mathematical models based on empirical measurements. In the Philippines, ISDB-T standard has been chosen as the Digital Terrestrial Television (DTT) Standard to the various reception modes of fixed outdoor, mobile and portable reception. In the delivery of video services in such varied modes of reception, the relevance of maintaining sufficient carrier to noise levels is crucial to maintaining the stability and availability of the broadcast service. In this respect, a study has been commissioned to validate the effects of varying tropical conditions, terrain, urban and rural dwelling from the prediction and transmission of digital TV services.

For large scale outdoor propagation models, several studies were noted at UHF band or frequencies for field tests purposes and eventual adoption of DTV standards. ISDB-T system tests in Brazil initially done last 2001 were repeated in 2003–2004 using new receivers. This enables carrier to noise, minimum signal, impulse noise interference, Doppler effect and multipath interference measurements to be carried out to validate receiver performance [3, 4]. An improvement was noted in terms of performance in the presence of rigorous multipath and impulse noise interference and robustness in Doppler Effect noticeably increased. Similar studies using DVB-T standards for field trials and coverage measurements and analysis of portable outdoor reception were both done in Spain [5, 6].

Other field testing done for the launching of DTV standards was conducted in Mauritius [7, 8]. This was done to analyze and compare existing Path Loss Models that will be used as a suitable prediction tool to model regions in the north and south of Mauritius. Another measurement campaign was done in Indonesia prior to the roll out of

DTV [9]. For mobile DTV reception, Ong [10] consider height gain measurements in built-up areas in Singapore. The study confirmed that height-gain is different in different locations and depends on the local scatterer, ground reflection and the radiation pattern of the transmitting antenna. Also, for ATSC in the United States, mobile channel measurements were conducted by Semmar et al. [11,12].

Measurement campaign performed in this study relied on the live broadcast of NBN. Its transmitter is located at Visayas Avenue, Quezon City of the National Capital Region. As can be seen in Figure 1, service coverage was measured using 16 radials plus 5 more radials at the major lobe. Grid distances of 1.6 km, 3 km, 5 km, 7.5 km, 10 km, 15 km and 20 km were used covering 92 test sites. Measurements were categorized as perfect, intermittent and failed receptions. A decision was made in determining the acceptability of the measured data based on the successful establishment of reception. In general, all measured data are taken as valid even if reception failure is experienced. This establishes the receiving conditions in the defined test point if the signal levels are within the desired levels. In each test point, several measurement samples were made with varying antenna elevations. The cluster of test points was based in an area of 9 m^2 per test point [13]. Large deviations in cluster measurements are determining factors to repeat the measurements.

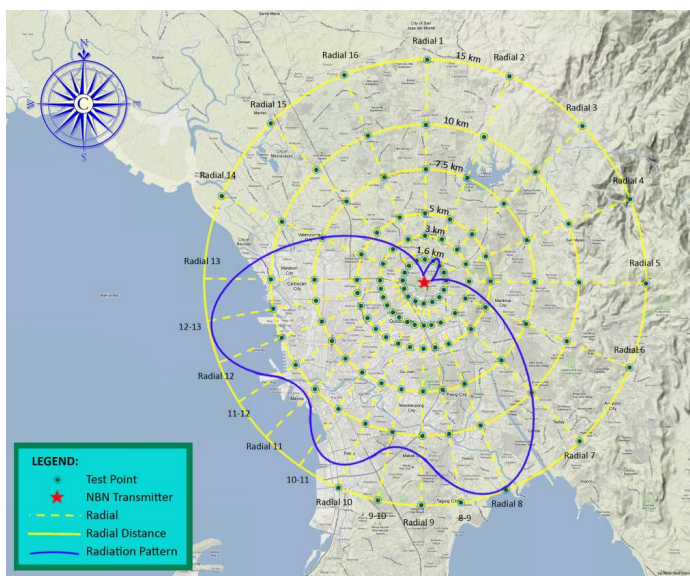


Figure 1. NBN radiation pattern and radial plots.

Table 1. Transmitter parameters.

Parameter	Value
Mode 3	8 K
Modulation	64 QAM SD, QPSK, 1 seg
Guard Interval	1/8
Convolutional Encoding	3/4 SD, 2/3 1 seg
UHF Channel	48
Frequency	674–680 MHz (677.142 MHz)
Bit rate	5 Mbps — SD, 256 kbps 1 seg

Data obtained from measurements conducted helps determine the service coverage for a given network configuration. Predicting the coverage will also help identify the proper location of repeater stations known as Single Frequency Networks (SFN) in Digital Television to accommodate areas located at the outskirts of the main coverage. Likewise, for more accurate network planning, predicting the location where reception is null will identify the optimum location of gap fillers that also serve as repeaters in analog and digital TV.

2. MEASUREMENT PROCEDURE

NBN is one of the pioneers in Digital Television. It is located at Visayas Avenue, Quezon City transmitting a 1 kW power and operating at UHF Channel 48 (677 MHz). It has a system gain of 10.77 dB using a horizontally polarized PHP4B Broadband UHF panel antenna. It is a two bay panel antenna using two faces horizontally polarized antenna located at a height of 120 m. Table 1 shows the ISDB-T Transmitter parameters used in the conduct of the study.

The instrumentation diagram shown in Figure 2 was used to carry out the measurements needed. It consists of a horizontally polarized log periodic antenna with 7.25 dB gain. Signal is amplified by AU40S MASPRO, towards the ANRITSU spectrum analyzer where details of C/N, power received, field strength and delay profiles were captured and recorded. Visual monitoring is achieved using analog TV with ISDB-T 1st generation set top box to classify received signal as perfect, intermittent or failure.

Equipment and procedures were based on Guidelines and Techniques for the Evaluation of Digital Terrestrial Television Broadcasting Systems ITU-R BT 2035-1 [13] including data collection and recording. Identified test site routes were planned and visited on

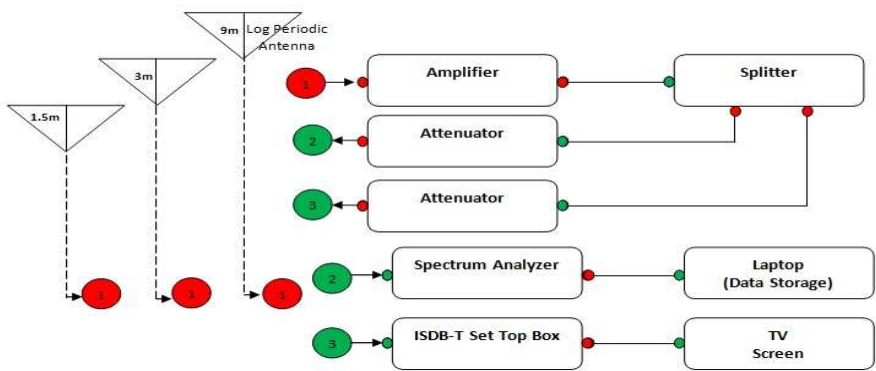


Figure 2. Measurement instrumentation.

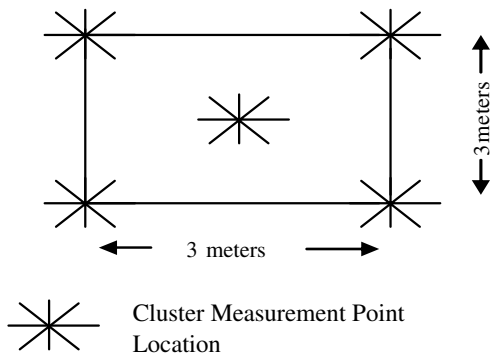


Figure 3. Cluster measurement point arrangements.

a daily basis that lasted for about 40 days at an average of 2–3 sites per day. Setting up and dismantling of equipment takes around 30 minutes and characterization at antenna heights of 9 m, 3 m and 1.5 m were done one after another.

Cluster measurement was adopted for this purpose as specified in Figure 3. Typically, cluster measurements require a minimum of five evenly distributed measurement points to capture data over an area of approximately 9 square wavelengths (3m on each side). For 92 test points a total of 460 measurements were taken for outdoor characterization at a particular antenna height, i.e., total of approximately 1380 measurements for 9m, 3m and 1.5m antenna heights. A laptop for data acquisition and a camera to record test site and surroundings were used.

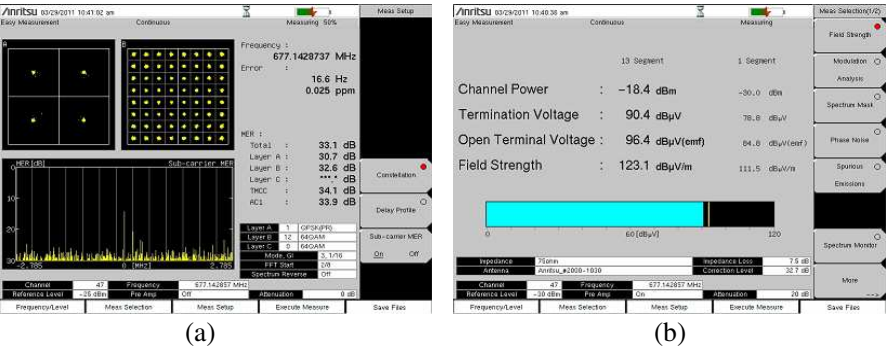


Figure 4. Spectrum analyzer display using a 9 m antenna of test site 1.6 km of Radial 7, (a) constellation, (b) field strength and power received.

3. MEASUREMENT RESULTS

Cluster measurements at every test point were tabulated and site description, test conditions, coordinates, elevation, temperature and time of the day were recorded. Spectrum analyzer display of the test site located inside Claret school is shown at Figure 4. Figure 4(a) represents the actual constellation of received outdoor signal recorded from the spectrum analyzer at an antenna height of 9 meters. This is an example of a perfect signal with an MER of 33.1 dB. Modulation Error Rate is a single figure of merit for the signal quality that includes noise, inter modulation and other corruptions of the signal. At the cliff edge, the MER equals this threshold value, being approximately 20.8 dB for modulation of 64QAM with a FEC of 2/3 or 3/4. Figure 4(b) indicates a received power of -18.4 dBm and field strength of $123.1\text{ }\mu\text{V/m}$. The distance of this site from NBN is about 1.6 kms at an elevation of 61.89 m with outside temperature at 25°C . A perfect signal was achieved owing to its close distance from the transmitter. The corresponding picture captured on this site can be seen at Figure 5.

3.1. Signal Condition

Signal condition at a given test point was monitored and recorded using an analog TV connected to an ISDB-T set top box. Table 2 is the summary of the signal condition statistics for the 92 sites (460 test points) at three antenna heights. Perfect reception resulted to 77.17% (355/460) for a 9 m antenna height due to near line of sight propagation. For portable receiver or 1.5 m antenna height, only



Figure 5. Sample pictures at Claret school of antenna and equipment installation. Notice the vegetation around test sites.

Table 2. Summary of the number of perfect, intermittent and fail reception for 92 sites.

Antenna Height (m)	Perfect	Intermittent	Fail	Total
1.5 (portable)	243	76	141	460
3 (fixed)	294	36	130	460
9 (fixed)	355	19	86	460
Total	64.64%	9.49%	25.87%	1380

52.83% (243/460) of the visited sites render perfect reception for the 360° radial coverage. Due to multipath reception that causes reflection, diffraction and refraction with buildings, establishments, houses, vegetation and other high structures present along the test sites affects the measured signal. This resulted to the inability of 1.5 m antenna to receive DTV signal at shadowed area.

3.2. Service Coverage

Figures 6(a) and 6(b) show the distribution of field strength for fixed and portable antennas. For the 9 m antenna, range of 56.79 dBμ/m to 123.48 dBμ/m was recorded at various radial distances represented by symbols and shapes in the graph. A standard deviation of 7.98 dB was calculated. Refer to Table 3 for all measurement summaries. For the 1.5 m antenna (portable), range of 45.41 dBμ/m to 110.07 dBμ/m was observed and recorded at various radial distances represented by

Table 3. Summary of measured field strength, power received and signal to noise ratio with the computed standard deviation.

Antenna Height (m)	FS dBμ/m (Mean)	σ (dB)	Pr dBm (Mean)	σ (dB)	MER dB (Mean)	σ (dB)
1.5 (portable)	87.21	6.77	−45.53	6.98	23.05	25.14
3 (fixed)	96.66	12.81	−31.71	9.27	24.04	26
9 (fixed)	100.16	7.98	−32.29	6.49	26.77	27.91

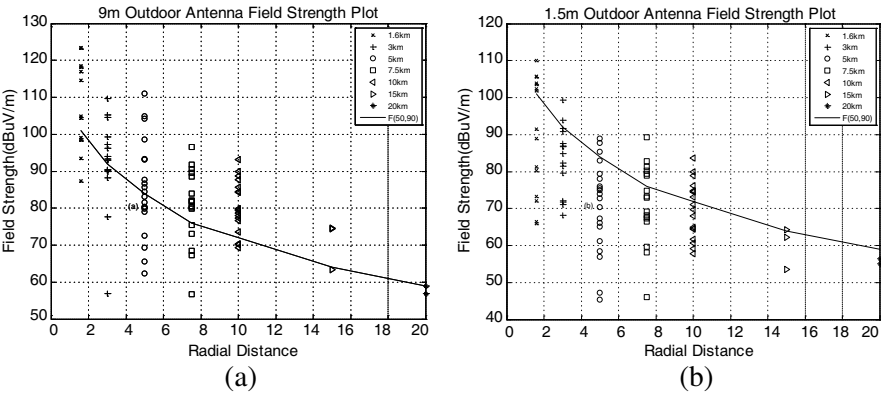


Figure 6. Plots of measured field strength and F(50, 90) values for (a) 9 m fixed antenna, (b) 1.5 m portable antenna.

symbols and shapes in the graph. This resulted to a standard deviation of 6.77 dB.

Notice the variation of field strength per radial distance at Figure 6. This can be attributed to multipath fading and attenuation present in most of the test sites. In evaluating the minimum field strength value for perfect reception per radial, values of 65.99 dBuV/m to 90.86 dBuV/m were observed which is much higher than the reference of 51 dBuV/m.

The FCC propagation curves F(50, 90) was used to compare the approximate/predicted values to actual mean measured values. A percent difference of 0.45% to 15.61% was computed.

For the sample field strength coverage of 9m fixed antenna and 1.5m mobile antenna, please refer to Figures 7 and 8. Polynomial fit was used to determine the coverage of NBN. A lower order polynomial

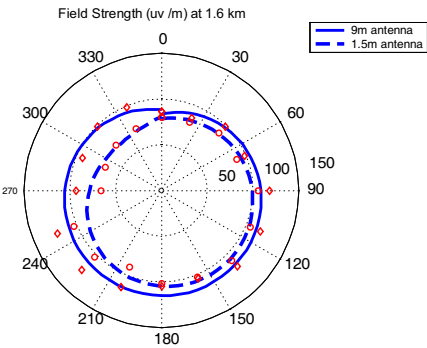


Figure 7. Field strength coverage at 1.6 km around NBN for fixed (9 m) and portable (1.5 m) antenna heights.

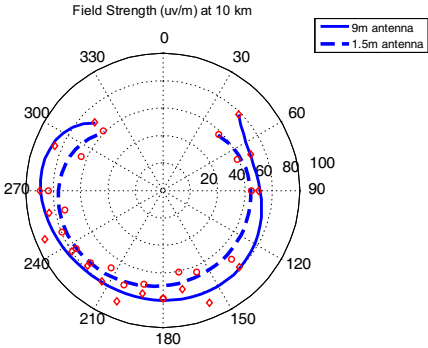


Figure 8. Field strength coverage at 10 km around NBN for fixed (9 m) and portable (1.5 m) antenna heights.

Table 4. MSE, variance and standard deviation for polynomial fit of 1.5 meter antenna height.

Order of polynomial	$\sum_{i=1}^N e_i^2$	σ^2	σ
3	1166.3	72.8936	8.5378
5	770.9461	48.1841	6.9415
7	689.2445	43.0778	6.5634

with 5 constraints was chosen for smoother curve. Fifth order polynomial has lower MSE of 770 and lower standard deviation of 6.9. Please refer to Table 4. The plot describes the concentration of the radiation pattern at 60°–300° of the polar plot and resembles the antenna radiation pattern of NBN. This represents the location of the major lobe of the antenna radiation pattern. Reception of fixed antenna at 9 m and 3 m is possible up to 20 km and portable reception can be up to 15 km. The radiation pattern of NBN using 2 bay panel antennas is focused on SW direction covering radials 8–13. Most of the failed receptions were located at the back lobe of NBN or at radials 1–7 and 14–16.

The data gathered were fit to a normal or Gaussian distribution. By computing the probability density function (PDF) of the measured data for field strength, power received and MER, the Gaussian curves were obtained for antenna heights 9 m, 3 m and 1.5 m. Please see Figure 9.

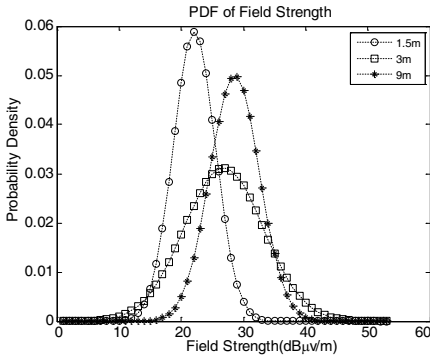


Figure 9. PDF of field strength for 1.5 m, 3 m and 9 m antenna.

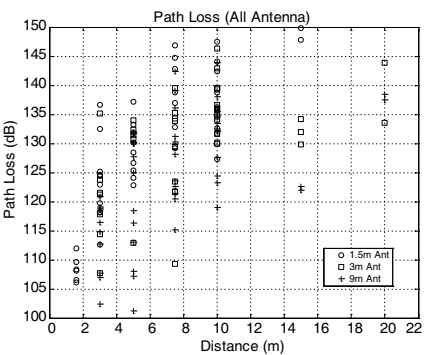


Figure 10. Measured path loss for all antenna heights.

Table 5. Path loss exponents for the three antenna heights.

Antenna Height (m)	Path Loss Exponent n	σ (dB)
1.5	4.26	7.92
3	3.65	7.24
9	2.87	9.36

3.3. Path Loss Exponents

For a total of 92 sites, 57 of which is located at the major lobe of the radiation pattern. These measurement results were used to compute for the path loss and path loss exponents of the outdoor channel using 1.6 km as the reference distance from the transmitter. Path loss was computed using Equation (1). Figure 10 shows the plot of the collected path losses from all antenna heights.

$$PL = P_t \text{ (dBm)} - P_r \text{ (dBm)} \tag{1}$$

Using Log Distance Path Loss Model, path loss exponent n for all antenna heights were determined.

$$PL(d)[\text{dB}] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n \log \left(\frac{a}{d_0} \right) + X_\sigma \tag{2}$$

Minimum mean square error (MMSE) was used to estimate path loss exponent's n using the sum of squared errors between the measured and estimated received power.

$$J(n) = \sum_{r=1}^k \left(P_r - \widehat{P_r}(n) \right)^2 \tag{3}$$

Table 5 shows the resulting path loss exponent values and its corresponding standard deviations.

4. CONCLUSION AND RECOMMENDATION

The service coverage of DTV transmission of NBN using ISDB-T Mode 3 was measured and analyzed using field strength data. With the transmitter parameters of 64 QAM for SDTV and QPSK for one segment mobile reception, field strength, power received and MER at 677 MHz UHF Channel 48 were measured, recorded and plotted. For fixed reception using 9 m and 3 m antenna, the standard deviation of field strength values resulted to 7.98 dB and 12.81 dB respectively. A large standard deviation from rooftop level or 9 m antenna to a lower antenna height of 3 m is expected due to the presence of obstructions higher than the receiving antenna. The same observation was obtained for power levels in dBm received at fixed receivers 9 m and 3 m antenna. Standard deviations of 6.49 dB and 9.27 dB were calculated and this shows how the signal level values spread around 360° radial measurement. For portable reception using 1.5 m antenna, field strength and power received values decreases with 6.77 dB and 6.98 dB standard deviations respectively. Overall, measured signal strengths are above the reference level of 51 dB μ /m during perfect reception.

In digital TV, field strength can no longer serve as the basis for perfect reception and good video quality. Several cases in the measurement campaign conducted proved that a high field strength value does not necessarily result to a successful reception. The value of signal to noise ratio or MER must be closely monitored and must not be below 20 dB. However, the standard deviations measured for MER are 25.14 dB, 26 dB and 27.91 dB for 1.5 m, 3 m and 9 m antenna respectively. The high standard deviations for MER contributes to the number of fail and intermittent measurements encountered at 1380 measurement points. A total of 35.36% of the total test points failed and only 64.64% was considered a perfect reception. Majority of data with perfect signal is close or near to 20.8 dB. Data above 20 dB has an average of 57.14% that lies in the major lobe of antenna radiation pattern. Values below 20 dB which corresponds to 42.86% fall at the back lobe or beyond 15–20 kms.

Path loss exponents' n for the three antenna heights were computed and presented. The 9 meter antenna has the lowest path loss exponent of 2.87 due to its height where signal will most likely not to be obstructed. This resulted to a standard deviation of 9.36 dB. Line of sight can still be expected on some test locations. Although sites

visited were located in major cities, the building heights, billboards and vegetation contribute to the increase in path loss exponent from free space value of 2. Antenna height of 3 m has a path loss exponent of 3.65 and standard deviation of 7.24 dB owing to the decrease in antenna height. The lowest path loss exponent was obtained using a 1.5 m antenna of 4.26 and standard deviation of 7.92 dB.

Collected path loss values were compared to outdoor path loss models and they are in good agreement with Okumura Hata and Cost 231 models. Its regression is evident in accordance to antenna heights. Same conclusion was arrived when measured field strength values were plotted in $F(50,90)$ curves. These outdoor prediction models were proven to be a reliable tool in estimating outdoor power levels. Path loss exponents were proven to be inversely proportional to antenna height. These path loss exponent values can be used in developing outdoor models in estimating radio path loss. Authors are now in the process of modeling radio path loss from outdoor to indoor. Further measurements are performed to gather more data samples in developing and validating the outdoor to indoor model.

It is recommended that NBN should install additional bay panel antenna to increase their service coverage. It must be directed anywhere at radials 1–7 and radials 13–16. Transmitter power must be correspondingly adjusted as well as the antenna orientation and elevation. Further measurement campaigns must be conducted to test and investigate receiver sensitivity of the new generation set top box.

ACKNOWLEDGMENT

This work was supported by the ERDT program of the Department of Science and Technology, NBN, DLSU and Mapua Institute of Technology.

REFERENCES

1. Rappaport, T. S., *Wireless Communications — Principles & Practice*, 2nd Edition, 2002.
2. Masa-Campos, J. L., J. M. Lalueza-Mayordomo, and B. Taha-Ahmed, "RF propagation in indoor environment at WIMAX band of 3.5 GHz," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 17–18, 2495–2508, 2010.
3. Bedicks, Jr., G., F. Yamada, F. Sukys, C. E. S. Dantas, L. T. M. Raunheite, and C. Akamine, "Results of the ISDB-T system tests, as part of digital TV study carried out in Brazil," *IEEE Transactions on Broadcasting*, Vol. 52, 38–44, 2006.

4. Da Silva Mello, L. A. R., R. S. L. de Souza, P. V. G. Castellanos, and C. E. S. Dantas, "Measurements of propagation loss and multipath delay profiles at 593 MHz in a dense urban area in Brazil," *IEEE Conference on Antennas and Propagation*, 1–3, 2008.
5. Arrinda, A., M. M. Velez, P. Angueira, D. de la Vega, and J. L. Ordiales, "Digital terrestrial television (COFDM 8K system) field trials and coverage measurements in Spain," *IEEE Transactions on Broadcasting*, Vol. 45, 171–176, 1999.
6. Angueira, P., M. M. Velez, D. de La Vega, A. Arrinda, I. Landa, J. L. Ordiales, and G. Prieto, "DTV (COFDM) SFN signal variation field tests in urban environments for portable outdoor reception," *IEEE Transaction on Broadcasting*, Vol. 49, 81–86, 2003.
7. Armoogum, V., K. M. S. Soyjaudah, N. Mohamudally, and T. Fogarty, "Comparative study of path loss using existing models for digital television broadcasting for summer season in the north of mauritius," *IEEE Advanced International Conference on Telecommunications*, 34–34, 2007.
8. Armoogum, V., K. M. S. Soyjaudah, N. Mohamudally, and T. Fogarty, "Path loss analysis between the north and the south of mauritius with some existing models for digital television broadcasting for summer season at UHF bands," *AFRICON 2007*, 1–6, 2007.
9. Hendranto, G., A. Ruffyanto, S. Dharmanto, and B. H. Tjahjono, "Urban radio propagation measurement for digital TV broadcast in Jakarta, Indonesia," *IEEE Broadcast Technology Newsletter*, 2007.
10. Ong, J. T., S. V. B. Rao, Y. Hong, and G. Shanmugam, "Height gain measurements for DTV reception in Singapore," *IEEE Transactions on Broadcasting*, Vol. 50, 396–398, 2004.
11. Semmar, A., J. Y. Chouinard, V. H. Pham, X. Wang, Y. Wu, and S. Lafleche, "Digital broadcasting television channel measurements and characterization for SIMO mobile reception," *IEEE Transactions on Broadcasting*, Vol. 52, 450–463, 2006.
12. Semmar, A., V. H. Pham, J. Y. Chouinard, S. Lafleche, X. Wang, and Y. Wu, "UHF wideband mobile channel measurements and characterization using ATSC signals and diversity antennas," *IEEE Conference on Broadcasting*, 2004.
13. Union, I. T., "Guidelines and techniques for the evaluation of digital terrestrial television broadcasting systems," ITU-R BT 2035-1, 2007.