PROPAGATION OF ELECTROMAGNETIC WAVES IN SOME PUBLIC BUILDINGS IN CROSS RIVER STATES, NIGERIA

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Abstract

A Digital Community-Access (or Cable) Television (CATV) Analyzer with 24 channel spectrum 46 – 870MHz have been used to measured the received signal strength level, RxLev in four buildings (two office buildings and two residential buildings) in Calabar city at 519.25MHz. The results obtained indicated an average penetration loss of approximately 6dB with a standard deviation of 2dB. This is in accordance with several other studies done on this subject. In general, an increase has been found in the average signal strength when the receiver is moved upward in a building, the worst case situation being at ground floor.

Keywords: Electromagnetic waves, digital community-access (or cable) television analyzer, received signal strength level, average penetration loss and correlation coefficient

1.0 Introduction

Over the years, in personal wireless communication systems, a great deal of the radio coverage inside buildings have been provided with the use of base stations located outside the buildings (Martijn, 2000). At both the base station and the mobile station, the received signal is a combination of multiple radio waves arriving from different directions and with different magnitudes and phases (Rappaport, 1996). The mobile station of the user inside the building received radio waves affected by both the outdoor as well as the indoor environment. In addition to the properties of the outdoor radio channel, the mobile station will experience extra attenuation and the effects of indoor multipath propagation. This will deteriorate the signal to noise ratio even more and may limit the maximum achievable data due to delayed radio arrivals.

The phrase "interaction between the source (base station) and the receiver (mobile station)" means that when the source is turned on, or somehow modified, a change is observed in the receiver. This change does not occur instantaneously but, rather, after an interval of time that is consistent with the interpretation that something has travelled from the source to the receiver with the very great velocity c = 186,300 miles per second (3×10^8 m/s). This propagation in free space with a single velocity is one property common to all electromagnetic phenomena from gamma rays to low frequency electromagnetic waves (Johnston and Bahr, 1995). The propagation of radio wave is generally described by three basic mechanisms; these are reflection, diffraction and scattering. The aim of this paper is to gain good understanding of the fundamental propagation mechanism involved in radio wave propagation from outside into building and to obtain statistical data of the signal strength outside and inside buildings in order to draw conclusions about the building penetration loss. The correlation coefficients between the outdoor and indoor measured signal strengths used for the penetration loss calculations will be reviewed. The data were collected on the downlink with the base station as the transmitter and the mobile station as the receiver.

2.0 Methodology:

2.1 The transverse electromagnetic waves experiment

Measurements were taken in two office buildings and two residential buildings in Calabar city. The main objective have been to obtain statistical data of the signal strength outside and inside the buildings in order to be able to draw conclusions about the building penetration loss. The measurements were carried out using the digital community-access (cable) television (CATV) analyzer with 24 channel spectrum 46 – 870MHz.

2.1.1 Digital community-access (or Cable) television analyzer

Digital community-access (or Cable) television (CATV) analyzer with 24 channel spectrum, model “DLM3-T”, operates over a frequency range of 46 – 870MHz. It is specially designed to provide a spectrum view of the available off-air channels and provide a relative strength reading, which assist in alignment of directional antenna. It can measure signal level of 0 – 100dB and has internal rechargeable batteries which lend power to an antenna pre-amp to give an accurate set-up location. Test data and TV images are displayed simultaneously, conveniently and efficiently (BM/E Magazine, 1973).

2.1.2 Charge-coupled device camera

The most widely used image pickup device is the charge-coupled device (CCD). The CCD camera is used in many applications such as broadcasting, imaging, security and military applications. A CCD is an integrated circuit etched onto a silicon surface forming light sensitive elements called pixels. Photon incident on this surface generate charge that can be read by electronics and turned into a digital copy of the light patterns falling on the device. Although, CCDs are not the only technology to allow for light detection, it is often used where high quality image data are required as in this case (Beasley and Miller, 2010).

2.2 Measurement method

The measurement was done by a single person walking round the rooms and carrying the mobile station for data acquisition. The digital CATV analyzer was carried into the rooms and mounted in different positions and measurements were taken. The approximate mounting height was 1.5m; this method roughly resembles the positioning of television set in our homes.

2.3 Site descriptions

The measurements were carried out in four different buildings illuminated by the transmitter from the first floor of the CRBC buildings. The building information is given in Table 1. The exact types of building material for the buildings CCC, ADC and NTA are made up of reinforced concrete and normal (not coated) glass while that of CAP building is made up of brick and coated glass.

TABLE 1: Building information

Building	Height(m)	Number of floors	Position	Internal Description
CCC	10	5	LOS with some vegetation in front of the rooms oriented towards the transmitter.	Ground floor and floor 1 is mainly office rooms. Main bowl is the normal acoustic theatre.
ADC	16	4	NLOS at street level with direct path to transmitter being obstructed by a building at roundabout. LOS at higher floor levels.	The measured room is a large room on the entire front side, at some floors (1, 2 & 3) divided by partitions.
NTA	4	1	LOS with vegetation in front of the rooms at the front area. NLOS for the other sides of the building. There is a tall building obstructing to the left of the direct path.	Mainly office rooms, studio and some rooms containing equipment.
CAP	12	3	NLOS at street level. One obstructing building with height about 11m. LOS on floor 2.	Normal residential rooms.

CRBC: Cross River Broadcasting Corporation, IBB Way. The transmitter location.
CCC: Cultural Centre Complex, Cultural Centre Road, Calabar.
ADC: Advance Computer Building, 111 Calabar Road, Calabar.
NTA: Nigerian Television Authority, Murtala Mohammed Highway, Calabar.
CAP: CAPITAL House, 8 Mile, Calabar.

3.0 Experimental results and discussion

3.1 Results in Cultural Centre Complex (CCC) building

The RxLev distribution curve for all the floors and outdoor is plotted in Figure 1. The first aspects noticed when comparing the received signal strength level in the building with the level outdoor in the vicinity are the extra attenuation and spreading introduced by the building structure and interior. Another aspect is increase in measured RxLev values with increasing floor level.

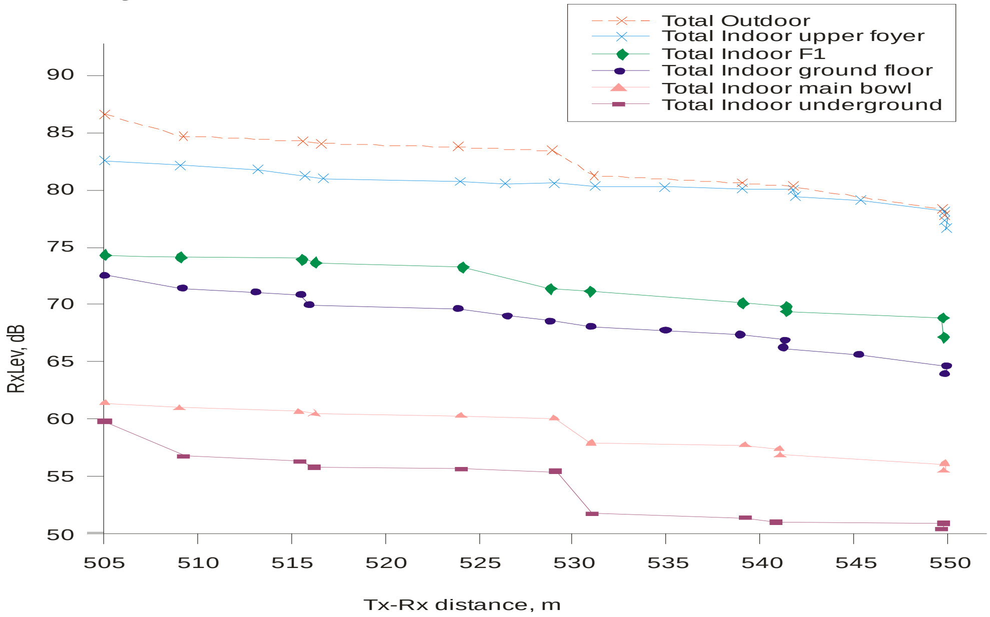

FIGURE 1: RxLev distribution curve for mean ReLev of all the floors and total outdoor.

At the upper foyer, the measured RxLev values were higher than the outdoor values at street level. The approximate increases in signal strength between the floors are caused by the antenna radiation pattern. The differences on the lower floors are not caused by the radiation pattern, however on the higher floors the effect is much.

3.2 Results in advance computer (ADC) building

In Figure 2, the same observation as in section 3.1 of CCC building can be made. The measured values increase with increasing floor height. The difference is that here the explanation cannot be given by means of the radiation pattern of the antenna rather there must be another effect taking place. This effect can be referred to as that of the occurrence of diffraction. The radio waves arriving at street level in the front area are diffracted at the edge of a building at 800m from the transmitter before the ADC building as shown in Figure 3.

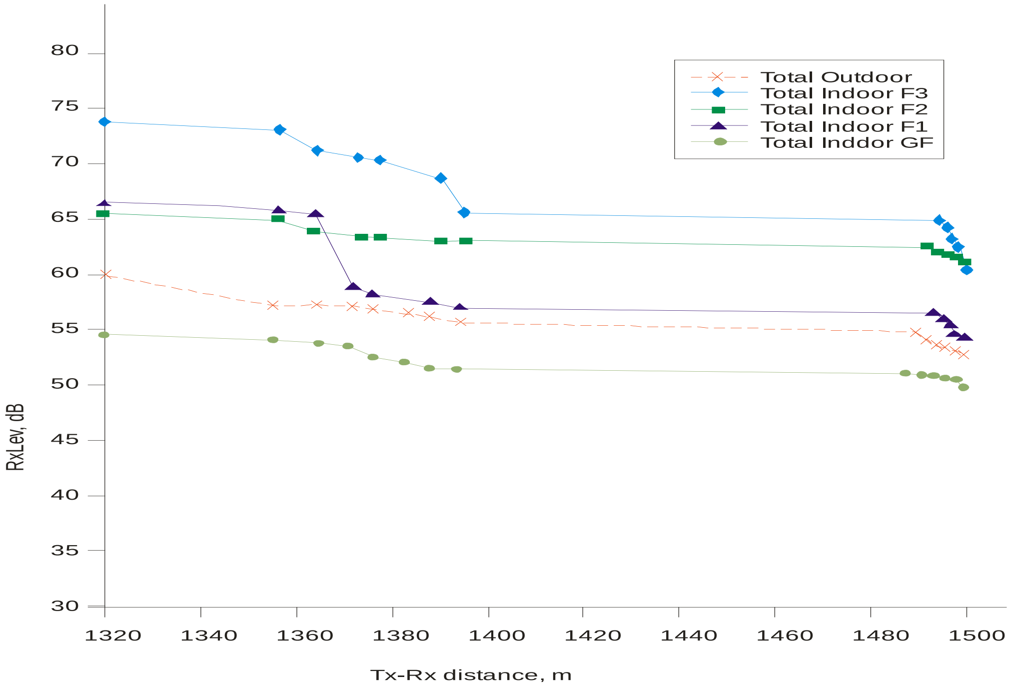

FIGURE 2: RxLev distribution curve for ADC building outdoor and all floors.

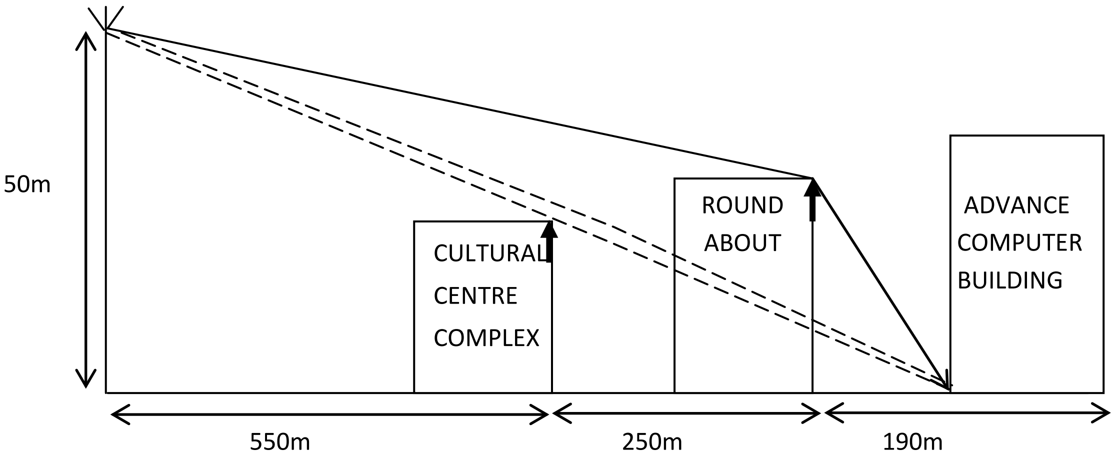

FIGURE 3: Propagation of radio waves at street level in ADC building

Again, it should be noted that the values at higher floors are higher than those at street level and more at LOS than at NLOS areas.

3.3 Results in Nigerian Television Authority (NTA) building

All measured RxLev around the NTA building and indoor are plotted in Figure 4. The right area has a higher outdoor level than the left area. The explanation here is that of a 'tunneling' effect caused by the neighbouring building on the right side of the NTA building.

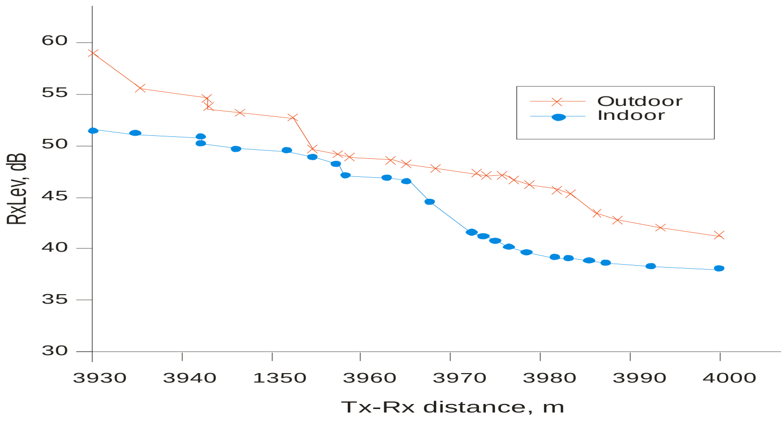

FIGURE 4: RxLev distribution curve for total NTA building.

Again, the loss toward the end of the right area is the largest. One possible explanation is that toward the end, the previous tunneling still has an effect causing a high outdoor level. However, the neighbouring building is not long enough to act as a reflector for this area.

3.4 Overall experimental results

Table 2 show an overview of the four buildings given for each measured floor. The mean RxLev measured both inside and outside, and the standard deviation calculated over the entire floor are given. From the mean RxLevs per room, both inside and outside the room losses has been calculated. Also, the building loss and its standard deviation, and floor-height factor has been calculated over the mean values of all the room losses on the ground floor of the buildings. The factor can be given in dB per metre; however, since all the buildings have approximately the same floor height the value was given in dB per floor.

TABLE 2: Overall results per floor of the measured buildings

Building	Floor	Mean RxLev outs	SD RxLev outs	Mean RxLev ins	SD RxLev ins	Building loss (dB)	SD building Loss (dB)	Floor height factor (dB/floor)	Approx. distance Tx-Rx (m)	Building Height (m)
CCC	Under-ground			54.0	2.9				530	
	Main bowl			59.2	2.1			5.2		
	GF	82.0	2.0	68.1	2.3	13.9	1.3	8.9		

	F1			71.2	2.3			3.1		
	Upper foyer			82.2	2.1			11.0		10
ADC	GF	55.4	2.0	51.9	1.3	3.4	0.8		1420	
	F1			58.7	4.2			6.8		
	F2			64.2	0.6			5.5		
	F3			67.5	4.2			3.3		16
NTA	GF	48.6	4.5	44.3	4.8	4.2	3.2	-	3970	4
CAP	GF	30.8	3.4	27.2	0.6	3.6	3.9		5920	
	F1			31.6	0.4			4.4		
	F2			35.8	1.2			4.2		12

3.4.1 Building penetration loss

The buildings ADC, NTA and CAP have building penetration losses around 3-4dB and CCC has building loss of approximately 14dB. In the previous sections, explanation was given for low losses in ADC building to be as a result of the difference in outdoor path loss between the ground floor and street level. For CAP building, a similar situation arose; the building is situated at approximate distance of 5.9km and is also obstructed by a building of height 11m. The first floor however lies at approximately 8m height and therefore encounters less outdoor path loss. In the CCC building, there is not much difference in the antenna radiation pattern for the street level and ground floor, therefore it can be concluded that the building loss measured here is close to the loss that would have been measured on the first floor. In NTA building, the measurements were carried out at ground floor and are therefore valid for building loss calculation.

From the above, it can be concluded that the average building loss for measurements taken in some public buildings in Calabar city with transmitter of height 50m is approximately 6.3dB with a standard deviation of 2.3dB. These results are in accordance with the results of some other studies done at 1800MHz. After extensive measurements in an urban area with transmitter above rooftop, Turkmani and de Toledo (1991) found for 1800MHz an average penetration loss of 13.4dB with a standard deviation of 7.6dB.

3.4.2 Correlation

To measure the relationship between the mean RxLev measured outside in the streets adjacent to each rooms and the mean RxLev measured in the room, the correlation coefficient was calculated. The overall computed correlation coefficient was 0.8. This means that there is a close relation between the RxLev measured in a room and the RxLev measured just outside the room.

3.4.3 Effects of horizontal sun shields

The effect of aluminum sun shields was measured in rooms in CCC and NTA buildings. First the signal strength was measured with all the sun shields removed from the windows and then with all the sun shields closed. Table 3 gives the results of these measurements. From the Table, a loss of 3.8dB is observed between the mean RxLev with shields and without shields. It can then be concluded that sun shields causes an additional attenuation. In Horikoshi et al (1986), an additional attenuation of 7dB for windows with aluminum sun shields were reported.

TABLE 3: Results of measurements with and without sun shields

Building & floor	Condition	Mean RxLev without shields	Mean RxLev with shields	Extra loss (dB)
ADC F3	LOS	73.2	69.8	3.4
NTA GF	LOS	51.2	47.1	4.1

4.0 Conclusion

In this paper, experiments have been carried out to characterize the propagation of radio waves into some public buildings. Results from measurements taken in two office buildings and two residential buildings situated in Calabar city, Nigeria indicated an average penetration loss of approximately 6dB with a standard deviation of 2dB. The correlation between the outdoor and indoor measured signal strengths used for the penetration loss calculations showed that there is a close relation between the signal strength measured in a room and the signal strength measured just outside the room.

In general, there is an increase in the average signal strength when the receiver is moved upward in a building, the worst case situation is at ground floor. This is in accordance with several other studies done on this subject. The observed increase has been found to be dependent on factors such as the antenna radiation pattern in buildings close to the transmitter [with (partial) line-of-sight],building structure, interiors and the local urban clutter. Conclusively, there is more variability in the indoor average received signal strength compared to the outdoor average received signal strength.

References:

Beasley, J. S. and Miller, G. M. Modern Electronic Communication (9th ed.). New Jersey: Pearson Prentice Hall, pp 627 – 629, 2010.

Editors of BM/E Magazine. Broadcast Antenna Systems Handbook (2nd ed.). New York: Tab Books, pp 117 – 124, 1973.

Horikoshi, J., Tanaka, K. and Moringa, T. 1.2GHz Band Wave Propagation Measurements in Concrete Building for Indoor Radio Communications.

Institute of Electrical and Electronics Engineers (IEEE) Transaction on Vehicular Technology. *35* (4), pp 73 – 77, 1986.

Johnston, B. and Bahr, L. Collier's Encyclopedia. Ontario: P.F. Collier and Son, pp 772 – 773, 1995.

Martijn, E. F. T. Characterization of Radio Waves Propagation into Buildings at 1800MHz. The Netherlands: M.Sc Thesis, Eindhoven University of Technology, Eindhoven, pp 9, 2000.

Rappaport, T. S. Wireless Communications. New Jersey: Pearson Prentice Hall, pp 495 – 502, 1996.

Turkmani, A. M. D. and de Toledo, A. F. Radio Transmission at 1800MHz into and within Multistory Buildings. *Institute of Electrical and Electronics Engineers (IEEE) Proceedings*. *138* (6), pp 76 – 83, 1991.

APPENDICES

MEASUREMENT RESULTS PER ROOM OF ALL FLOORS IN THE FOUR BUILDINGS

The average of the measured RxLev is given for outdoor and all measured rooms of the four measured buildings CCC, ADC, NTA and CAP. Also the room losses, transmitter-receiver distances for rooms on the ground floor (Tx-Rx distance) and floor height factors are given. Finally, the building loss, standard deviation and correlation coefficient are given in the gray sections.

Mean RxLev per room for building CCC									
Room	Outdoor	Underground	Main bowl	Ground floor	Floor 1	Upper foyer	Room loss(dB)	Tx-Rx distance (m)	Floor height factor (dB/Floor)
K1	83.1	51.1	61.6	69.6	70.3	86.4	13.5	529	5.2
K2	82.9	50.9	60.9	67.5	68. 5	83.6	15.4	527	8.9
K3	83.2	51.0	61.1	70.7	72.4	83.7	12.5	524	3.1
K4	83.5	51.5	61.2	69.7	73 .1	83.2	13.8	516	11.0
K5	83.0	51.8	57.2	67.4	69.7	83.0	15.6	532	
K6	82.9	51.6	61.3	68.0	69.9	84.9	14.9	535	
K7	82.8	56.4	61.5	67.3	66.9	80.4	15.5	542	
K8	82.7	55.9	57.5	66.7	70.5	80.1	16.0	550	
K9	83.6	56.0	57.3	72.4	70.0	79.9	11.2	505	
K10	83.1	59.9	56.7	71.1	73.9	80.2	12.0	508	
K11	83.3	56.1	56.9	70.2	74.2	80.5	13.1	513	
K12	83.0	56.3	57.1	68.6	74.5	80.0	14.4	517	
K13	79.6			65.5			14.1	539	
K14	78.8			65.8			13.0	542	
K15	78.3			64.6			13.7	546	
K16	77.9			64.3			13.6	550	
Average	82.0	54.0	59.2	68.1	71.2	82.2	Building Loss(dB)		13.9
SD	2.0	2.9	2.1	2.3	2.3	2.1	SD(dB)	1.3	
							R	0.8	

Mean RxLev per room for building ADC								
Room	Outdoor	Ground Floor	Floor 1	Floor 2	Floor 3	Room loss(dB)	Tx-Rx distance (m)	Floor height factor (dB/Floor)
K1	60.0	54.4	57.2	63.9	71.2	5.6	1320	6.8
K2	56.7	53.2	58.2	64.5	70.9	3.5	1365	5.5
K3	56.5	52.5	57.7	65.1	74.0	4.0	1377	3.3
K4	56.3	52.2	65.4	65.4	70.2	4.1	1384	
K5	55.7	51.9	66.0	65.0	73.3	3.8	1393	
K6	53.8	51.4	65.7	64.5	65.2	2.4	1491	
K7	53.1	50.7	55.3	64.6	68.5	2.4	1499	
K8	52.7	49.5	54.8	63.3	63.3	3.2	1500	
K9	52.9	50.2	56.4	64.4	65.0	2.7	1496	
K10	53.8	50.8	55.9	62.9	64.7	2.7	1490	
K11	54.8	51.8	57.5	64.0	62.9	3.0	1493	
K12	56.1	51.9	54.6	63.9	60.5	4.2	1388	
K13	56.4	52.8				3.6	1371	
K14	56.7	53.8				2.9	1358	
Average	55.4	51.9	58.7	64.2	67.5	Building Loss(dB)		3.4
SD	2.0	1.3	4.2	6.0	4.2	SD(dB)	0.8	
						R	0.9	

Mean RxLev per room for building NTA

Room	Outdoor	Ground Floor	Room Loss (dB)	Tx-Rx Distance (m)
K1	58.5	50.9	7.6	3930
K2	55.6	50.7	4.9	3943
K3	54.9	50.4	4.5	3946
K4	54.5	50.1	4.4	3955
K5	53.9	49.4	4.5	3957
K6	49.3	48.7	0.6	3963
K7	48.3	46.3	2.0	3973
K8	47.6	46.8	0.8	3974
K9	47.4	41.4	6.0	3979
K10	47.1	40.3	6.8	3982
K11	45.7	39.1	6.6	3984
K12	43.0	39.4	3.6	3989
K13	42.0	38.7	3.3	4000
K14	42.4	38.9	3.5	3992
K15	42.7	39.0	3.7	3986
K16	45.5	39.7	5.8	3977
K17	46.6	39.4	7.2	3976
K18	46.8	40.0	6.8	3969
K19	47.3	40.6	6.7	3967
K20	47.1	47.0	0.1	3959
K21	48.3	44.8	3.5	3952
K22	48.5	48.2	0.3	3935
K23	54.1	49.6	4.5	3943
Average	48.6	44.3	Building Loss(dB)	4.2
SD	4.5	4.8	SD(dB)	3.2
			R	0.9

Mean RxLev per room for building CAP

Room	Outdoor	Ground Floor	Floor 1	Floor 2	Room Loss (dB)	Tx-Rx Distance (m)	Floor Height Factor (dB/Floor)
K1	35.2	28.5	32.0	34.0	6.7	6000	4.4
K2	34.3	27.9	32.3	34.2	6.4	5990	4.2
K3	34.5	27.2	31.5	33.9	7.3	5991	
K4	35.0	26.7	31.4	34.7	8.3	5996	
K5	34.8	26.9	31.6	36.9	7.9	5999	
K6	27.7	27.0	31.9	37.1	0.7	5858	
K7	28.2	26.8	32.0	36.5	1.4	5893	
K8	26.4	26.3	31.7	36.3	0.1	5821	
K9	28.3	27.5	31.3	36.6	0.8	5888	
K10	29.0	27.1	31.0	36.7	1.9	5884	
K11	27.8	26.6	31.1	37.2	1.2	5871	
K12	28.4	28.0	31.2	35.5	0.4	5877	
Average	30.8	27.2	31.6	35.8	Building Loss(dB)		3.6
SD	3.4	0.6	0.4	1.2	SD(dB)	3.9	
					R	0.4	