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Assessment of Diurnal Signal Strength Penetration of Mobile Signals through Ceiling Materials

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Abstract
Communication has been much easier since the onset of the global system for mobile communication (GSM). However, despite the advancement and several upgrades been deployed in GSM communication, it is also a known fact that signal loss is still being experienced in some buildings due to the different materials utilized in their construction including those of the roofing and ceiling. Hence, this work was aimed at analyzing the Mobile network signal strength penetration through three (3) of the most commonly used ceiling materials (POP, Hardboard and Glass) and the free Air column as control in Nigeria. An In-situ signal strength software installed on an android phone was used for signal strength measurement on the signal reception in buildings during the 09th, 12th, 15th, and 18th communication hours for twelve consecutive days. The data obtained were modelled using the Log distance model for path loss in wireless communication to estimate the pathloss exponent (n) of the signal and the penetration signal (attenuation) loss through for all the ceiling materials. The GSM service providers operating at frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively were used for analysis. The results showed the penetration loss and Path loss exponent (n) for Glass; a maximum value of 9.25 dB and n of 3.61 for 09HR, 3.92dB and n of3.63 for 12HR, 12.22dB and n of 3.40 for 15HR and 0.91dB and n of 3.52, for POP; a maximum value of 13.15 dB and n of 3.68 for 09HR,3.96 dB and n of 3.57 for 12HR, 14.82dB and n of 3.70 for 15HR and 6.07dB and n of 3.79 , for Hardboard; a maximum value of 11.38 dB and n of 3.58 for 09HR, 3.01dB and n of 3.61 for 12HR, 13.41dB and n of 3.79 for 15HR and 4.21 dB and n of 3.60 for frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively. The mean penetration loss obtained for glass was lowest at 18HR 12HR, and high at 09HR and 15HR, with value 0.63dB, 3.04dB and 3.41dB and 3.81 dB, POP with value 2.54dB, 2.547dB and 4.68dB and 6.25 dB and hardboard with value 1.93dB, 2.26dB and 4.90dB and 6.1081 dB respectively. It could be concluded that for all ceiling materials 18HR and12HR were best time to roam calls and to prevent data packet loss during the day.

Key words: Mobile communication, signal loss, signal reception, penetration loss, signal propagation

1. Introduction

The arrival of Global System for Mobile Communication (GSM) in Nigeria has brought about a revolution in telecommunication services including positive and negative effect on the Nigeria society [1-4]. However, most networks in the world uses a frequency of either 900 MHz or 1800 MHz, with the 1800 MHz having more capability than that of the 900 MHz in terms of the number of users it can accommodate [5]. Nevertheless, mobile phone signal strengths are classified within the range of -120 dBm to -50 dBm (i.e., from extremely poor signals to very strong signals).

The closer the number is to zero, the stronger the mobile phone signal. Thus, signal strengths of less than -120 dBm are of extremely poor signal (i.e., dead zone), while those within the range of -120 to -110 dBm (0 – 1 bar) are of very poor signals. Also, those within -109 to -100 dBm (1 – 2 bars) are of poor signals and those within the range -99 to -90 dBm (2 – 3 bars) are of average signals. Moreover, those from -89 to -80 dBm (3 – 4 bars) are of good signals and those within -79 to -50 dBm (4 – 5 bars) are of very strong signals [6]. However, mobile phones experience certain inconsistencies in service including weak signal

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reception when their signal strength is less than -100 dBm. Thus, a mobile phone booster may be required for a signal strength lower than -100 dBm.

In Nigeria, the allotment of transmitting frequencies to GSM network service providers is the sole responsibility of the Nigerian Communications Commission (NCC) [7]. However, since the invention of GSM, there has been series of evolution of signal network leading to the enormous growth of telecommunication companies which have brought about communication revolution through the development of new products and services for diverse usage [8].

The early telephones utilized the push-to-talk system which allow only single channel for sending and receiving telephone signals. But in order to allow users to talk and receive signals at the same time the push-to-talk system was ameliorated through the Improved Mobile Telephone System (IMTS) which has two channels for both transmission and reception. However, in order to further transform the telecommunication systems private companies also began to develop their own telecommunication system called the first generation (1G) wireless cellular technology (mobile telecommunications). This 1G analog telecommunications which was introduced in the 1980s support more users of about 5 to 10 times than that of IMTS [9], but still has its own limitations which included the inability to do roaming. Thus, in order to be able to implement roaming, individual organizations started working under one umbrella called European Telecommunications Standard Institute (ETSI) which subsequently led to the development of the digitalized second-generation (2G) cellular network [10,11].

The 2G cellular networks have several benefits over the 1G telecommunication system. Amongst these benefits are the digital encryption of phone conversations, more significant spectrum efficiency and greater mobile phone penetration level. Also, the 2G telecommunication networks introduced data services for mobile communication through the usage of Short Message Service (SMS) text messages. However, in order to achieve a higher data rate in the 2G communication, the General Packet Radio Service (GPRS) was developed which could transmit data up to 114 kbps. Moreover, an update to the GPRS called an Enhanced Data Rate for GSM Evolution (EDGE) was also introduced specifically for data transfer on GSM networks.

This EDGE features a packet capability, Enhanced General Packet Radio Service (EGPRS), and a circuit switched capability known as Enhanced Circuit Switched Data (ESCD). Through it an Eight Phase Shift Keying (8-PSK) modulation could deliver data at a rate of about 500 kbps [12]. As the internet becomes more universal and phones started supporting web browsing including multimedia services and streaming, the third generation (3G) wireless mobile telecommunication technology was introduced.

However, as technological development improves, telecommunication services also started expanding their products by not been restricted to voice and SMS text messages only. Thus, the fourth generation (4G) cellular communications also known as Long Term Evolution (LTE) which improved spectral efficiency, reduced cost per byte including delays for both connections establishment and transmission latency was introduced. However, despite all these recent merits in telecommunication as a result of technological advancement, GSM subscribers are still been faced by diverse challenges including their inability to receive uninterrupted flow of communication as a result of signal fade and call drop [13].

2.0 Related Works

The recent migration of most GSM service providers' networks from 3G to 4G in Nigeria, and in anticipation of the 5G technology deployment in the country, the 4G GSM network's mobility and coverage within the micro cells in-between Base Stations and Mobile stations in Ibadan were re-examined [14]. Nevertheless, despite that there have been several studies that furthermore investigated signal strength penetration through buildings [15-17], yet those on the signal strength and their penetration loss (i.e., signal strength reduction) through ceiling materials are sparse. Path loss (L) refers to the loss or attenuation a propagating electromagnetic signal (or wave) encounters along its path from transmitter to the receiver. As a result of path loss, the received signal power level is several orders below the transmitted power level. Various environments have been used in the design path loss propagation models and there were many models such as: Free Space Path Loss Model, Okumura HATA Path Loss Model, COST 231 Extended Hata Model, Hata – Okumura Extended Model, Ericson Model *and* Log-distance model [18].

2.1 Free Space Path Loss Model was developed to predict signal strength received when from receiver and transmitter in have a clear line of sight path space within them as given inequation1.0 The Satellite communication and microwave system line of sight radio uses free space propagation,

$$P(dBm) = -77 + 20\log(E) - 20\log(f) \qquad (1.0)$$

Where s is the signal strength, E is the Electrical Field strength and frequency in MHz.

2.2 Okumura HATA Path Loss Model

This model is used for spectrum band between 150MHz to 1500MH, mobile station antenna height between 1 m and 3 m, base station antenna height, between 30 m and 100 m, and for link distance between 1 km and 100 km. This model is the commonly used in urban area.

2.3 COST 231 Extended Hata Model

Cost 231model is been used to date. And it is an extension of the Okumura-Hata model designed to cover more range of frequencies between up to 2 GHz, and is used for medium to small cities.

2.4 Hata – Okumura Extended Model

This model was designed for the Ultra High Frequency (UHF) band, and according to recent recommendations of International Telecommunication Union-Radio communication (ITU-R), it uses up to 3.5GHz.

2.5 Ericson Model

Ericsson model is also used for an indoor signal strength estimation for wireless network planner. The model used the modified Okumura-Hata model parameters for it use in differing propagation environments.

2.6 Log-distance model

This is a model developed for the transmitter whose distances is x from the receiver at a microcell consideration and we consider a micro cell for this study for sub urban environment which fits the study area chosen. L_0 is the path loss at a distance $x > x_0$ meters from the transmitter. The path loss L at an arbitrary. Distance is given for microcell x_0 is 1m to 10m and for a large cell x_0 is 1km. This model validate the path loss exponent in various environment as given in equation 1.1

$$L(dBm) = L_0(x_0) + 10n\log\frac{x}{x_0} + c \qquad (1.1)$$

Where l is the signal strength,
l_0 *is the reference path loss and n is path loss exponent,*
x is the distance of transmitter to the ceiling, and
x_0 *is the distance within the ceiling*

The penetration loss with is the difference between the signal strength measured inside and outside the ceiling for the received signal and was given by equation 1.2

$$PenetrationLoss(dB) = (l_{outside} - l_{inside})(dB) \quad (1.2)$$

Where $l_{outside}$ *and were the signal strength the ceiling material used*

In essence, this work is an attempt to assess the GSM signal strength and their penetration loss through three (3) of the commonly used ceiling materials in Nigeria, namely: POP, Hardboard and Glass so as to be able to provide significant information on signal strength penetration through them when used as roof ceiling materials.

2.7 Pathloss Exponent n

Path loss exponent values for various environment was reported by [18] stated the value of Path loss for different environments which was used to validate the result obtained in our study area. The Path loss in-Free Space environment has a value of 2 according to [18], Urban Area has a value ranges between 2.7 to 3.5, Shadowed urban has a value of between 3 to 5 and in building in line of sight ,it has a value between 1.6 to 1.8.

3.0 Materials and methods

3.1 Data Sources

The characteristics of the selected ceiling materials are that of an insulator, in which their thermal conductivity and diffusion rate impact on refraction of signal in within their column was investigated. The data to examine the effect is the signal strength and the metrics to report this impact are the penetration loss and path loss exponent n in mobile communication.

3.2 Methodology

Signal strength penetration measurements were carried using an In-situ signal strength software installed on an android into 4GLTE enabled mobile phones (Tecno Camon 16CE7j) (As shown in Figure 1), with a view to understanding their effect on signal reception when used in the ceiling materials selected buildings during the 09th, 12th, 15th, and 18th communication hours for twelve consecutive days. Three (3) of the most commonly used ceiling materials (i.e., Plaster of Paris (POP), Hardboard and Glass) in Nigeria, and five (5) 4GLTE Subscriber Identification Module (SIM) cards with frequencies: 2120 MHz (2), 2130 MHz (1), 2140 MHz (1) and 2150 MHz (1) were selected.

These ceiling materials were attached to the open sided components of a cubicle shaped box (As shown in Figure 2) of dimension 600 mm by 300 mm (top and bottom) and 900 mm by 300 mm (remaining four sides) with a tolerance allowance of 6mm for sliding in the ceiling materials. One of the two SIM cards (2120 MHz) inserted into the Tecno camon 16CE7j iPhone placed outside of the cubicle shaped box was utilized in making calls roaming for several seconds at an average interval of 3 minutes during the 09Hr, 12Hr, 15Hr, and 18Hr on a daily basis for twelve (12) consecutive days so as to be able to ascertain the average

Moreover, control measurements were also carried out by making and receiving calls outside the cubicle (air column) to ascertain if signal losses actually occur through the ceiling materials when calls are made.

The data obtained were modelled using the Log distance model for path loss in wireless communication to estimate the pathloss exponent (n) of the signal and the penetration signal (attenuation) loss was also evaluated for all the ceiling materials. This evaluation was done for the GSM service providers operating at frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively.

SIM status (SIM slot 1)

Network
MTN NG

Phone number on SIM
Unknown

Mobile network state
Disconnected

Service state
In Service

Signal strength
-81 dBm 39 asu

Mobile voice network type
UMTS

Mobile data network type
Unknown

Roaming
Not Roaming

Figure 1: Tecno Camon 16CE7j Android iPhone for signal strength measurement

Figure 2: Ceiling materials cubicle used as simulation for house ceilings for house ceilings

4.0 Results and discussion

The penetration loss at various hours of the day 09HR, 12HR,15HR and 18HR and for different ceiling materials Glass, POP, and Hardboard for GSM Mobile frequency band operating at 2120 MHz,2130 MHz, 2140MHz and 2150MHz was presented using equations 1.1 and 1.2.

4.1 Glass ceiling material at 2120 MHz, 2130 MHz, 2140MHz and 2150MHz

The penetration loss at 2120MHz was about 3.9dB at 09HR of the day, 9.0dB for 2130MHz at 09HR, 1.0dB at 2140MHz and 0.1dB respectively. At 12HR, all tested frequencies penetration loss was fairly low value less than 5dB. This can be attributed to the reflection of signal and low thermal diffusion of glass material as ceiling during the time. At 15HR the penetration loss was fairly low of a value less than 2dB except for 2140MHz that has 12dB. At 18HR, the penetration loss was very low of value less than 1dB for all frequencies examined, and it was also attributed to low refraction at this cool weather as presented in Table 1.

4.2 POP ceiling material at 2120 MHz, 2130 MHz, 2140MHz and 2150MHz

At 09HR the penetration loss was 4dB for 2120 MHz, 13dB for 2130 MHz, 0.1dB for 2140MHz and 1dB for 2150MHz respectively. At 12HR the penetration loss was relatively low of between 1dB and 4dB because the thermal diffusion rate for all frequencies considered. At 15HR the penetration loss was as low as0.1dB for 2120MHz, 9dB for 2130MHz, 15dB for 2140MHz and 0.9dB for 2150MHz. Bu tat 18HR, the penetration loss was relatively low at (0-6) dB. This can also be attributed to the cooling down of air column and low refraction of signal that can attenuate the signal as presented in Table 2.

4.3 Hardboard ceiling material at 2120 MHz, 2130 MHz, 2140MHz and 2150MHz

At 09HR the penetration loss was about 5dB for 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively. At 12HR the penetration loss was relatively low of between 1dB and 3dB because the thermal diffusion rate for all frequencies considered. At 15HR the penetration loss was as low as0.1dB for 2120MHz, 9dB for 2130MHz, 13dB for 2140MHz and 1.8dB for 2150MHz. But at 18HR, the penetration loss was relatively low at (0-4) dB. This can also be attributed to the cooling down of air column and low refraction of signal that can attenuate the signal as presented in Table 3.

Table1: The penetration loss, signal strength and path loss exponent (n) for Glass Ceiling Material

9TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**GLASS (dBm)**	**Penetration Loss(dB)**	**n**
2120	-63.9875	-67.4263	3.4388	3.2865
2130	-62.4230	-71.6712	9.2482	3.4933
2140	-73.3690	-74.1947	0.8257	3.6162
2150	-66.5820	-66.4513	0.1307	3.2390
12TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**GLASS (dBm)**	**Penetration Loss(dB)**	**n**
2120	-68.3518	-70.8955	2.5436	3.4555
2130	-71.1070	-73.3982	2.3000	3.5774
2140	-71.0215	-74.9480	3.9265	3.6528
2150	-65.0650	-68.4593	3.3943	3.3368
15TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**GLASS (dBm)**	**Penetration Loss(dB)**	**n**
2120	-65.0263	-66.793	1.7667	3.2556
2130	-68.1043	-68.8163	0.7120	3.3542
2140	-57.6170	-69.8402	12.2232	3.4041
2150	-63.8870	-63.3528	0.5342	3.0881
18TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**GLASS (dBm)**	**Penetration Loss(dB)**	**n**
2120	-66.1957	-66.7633	0.5677	3.2542
2130	-71.8745	-71.0703	0.8042	3.4640
2140	-71.9795	-72.2050	0.2255	3.5193
2150	-65.4845	-66.3895	0.9050	3.2360

Table 2: The penetration loss, signal strength and path loss exponent (n) for POP ceiling Material

9TH HOUR				
Frequency (MHz)	**AIR (dBm)**	**POP(dBm)**	**Penetration Loss(dB)**	**n**
2120	-63.9875	-68.1543	4.1668	3.3219
2130	-62.4230	-75.5828	13.1598	3.6838
2140	-73.3690	-73.3927	0.0237	3.5771
2150	-66.5820	-67.9610	1.3790	3.3125
12TH HOUR				
Frequency (MHz)	**AIR (dBm)**	**POP(dBm)**	**Penetration Loss(dB)**	**n**
2120	-68.3518	-70.7692	2.4173	3.4493
2130	-71.1070	-72.4855	1.4334	3.5329
2140	-71.0215	-73.3927	2.3712	3.5771
2150	-65.0650	-69.0338	3.9688	3.3648
15TH HOUR				
Frequency (MHz)	**AIR (dBm)**	**POP(dBm)**	**Penetration Loss(dB)**	**n**
2120	-65.0263	-65.2518	0.2255	3.1806
2130	-68.1043	-77.0568	8.9525	3.7556
2140	-57.6170	-72.4417	14.8247	3.5307
2150	-63.8870	-62.8513	1.0357	3.0637
18TH HOUR				
Frequency (MHz)	**AIR (dBm)**	**POP(dBm)**	**Penetration Loss(dB)**	**n**
2120	-66.1957	-64.0588	2.1368	3.1225
2130	-71.8745	-77.9395	6.0650	3.7986
2140	-71.9795	-73.8637	1.8842	3.6001
2150	-65.4845	-65.3998	0.0847	3.1878

Table 3: The penetration loss, signal strength and path loss exponent (n) for hardboard ceiling Material

Frequency (MHz)	**AIR(dBm)**	**HARDBOARD (dBm)**	**Penetration Loss(dB)**	**n**
2120	-63.9875	-69.7000	5.7125	3.3979
2130	-62.4230	-73.8015	11.3785	3.5974
2140	-73.3690	-73.3927	0.0237	3.5773
2150	-66.5820	-64.1123	2.4697	3.1254
12TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**HARDBOARD (dBm)**	**Penetration Loss(dB)**	**n**
2120	-68.3518	-70.9660	2.6142	3.4589
2130	-71.1070	-74.0647	3.0100	3.6098
2140	-71.0215	-74.0325	3.0110	3.6083
2150	-65.0650	-65.4708	0.4058	3.1913
15TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**HARDBOARD (dBm)**	**Penetration Loss(dB)**	**n**
2120	-65.0263	-64.9738	0.0525	3.1670
2130	-68.1043	-77.7363	9.6320	3.7886
2140	-57.6170	-71.028	13.4110	3.4619
2150	-66.4570	-65.1722	1.2852	3.1767
18TH HOUR				
Frequency (MHz)	**AIR(dBm)**	**HARDBOARD (dBm)**	**Penetration Loss(dB)**	**n**
2120	-66.1957	-70.4035	4.2078	3.4315
2130	-71.8745	-73.8625	1.988	3.5999
2140	-71.9795	-71.0630	0.9165	3.4636
2150	-65.4845	-64.8570	0.6275	3.1614

The result also showed the penetration loss and Path loss exponent (n) for Glass ranges from (0.13 to 9.25) dB and n from3.23 to 3.61 for 09HR, (2.3 to3.92)dB and n 3.34 to3.63 for 12HR, (0.53 to 12.22)dB and n from 3.09 to3.40 for 15HR and (0.23 to 0.91)dB and n 3.23 to 3.52 for frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively. For POP penetration loss and Path loss exponent ranges from (0.24 to 13.15) dB and n from3.31 to 3.68 for 09HR, (1.43 to3.96) dB and n 3.44 to3.57 for 12HR, (0.23 to 14.82) dB and n from 3.06 to3.70 for 15HR and (0.09 to 6.07) dB and n 3.12 to 3.79 for frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively.

For Hardboard, penetration loss and Path loss exponent ranges from (0.02 to 11.38) dB and n from3.13 to 3.58 for 09HR, (0.41 to3.01) dB and n 3.19 to3.61 for 12HR, (0.05 to 13.41) dB and n from 3.17 to3.79 for 15HR and (0.62 to 4.21) dB and n 3.16 to 3.60 for frequencies 2120 MHz, 2130 MHz, 2140MHz and 2150MHz respectively.

The mean penetration loss obtained for glass was lowest at 18HR 12HR, and high at 09HR and 15HR with value 0.63dB, 3.04dB and 3.41dB and 3.81 dB respectively. For POP was lowest at 18HR, 12HR, and high at 09HR and 15HR with value 2.54dB, 2.547dB and 4.68dB and 6.25 dB respectively. For hardboard was lowest at 18HR 12HR, and high at 09HR and 15HR with value 1.93dB, 2.26dB and 4.90dB and 6.1081 dB respectively. It could be concluded that for all ceiling materials 18HR and12HR were best time to roam calls and to prevent data packet loss during the day as presented in Tables1 to 3.

It was observed that ceiling material used such as glass, POP and hardboard showed generally a fairly decreased trend in penetration loss from 09HR to 18HR this because of refraction of signal (Electromagnet waves) when the temperature of ceiling was high produced more penetration loss than when the temperature had cooled down at 18HR and also at 12HR it was observed that the penetration loss becomes low due thermal diffusion and the refraction before temperature builds up. However, there was sharp increase in penetration loss in 09HR that can be attributed to other conditional losses from service providers as presented in Figure 3 to 5 and Table 4.

Table 4: Diurnal penetration loss for Glass, POP and Hardboard materials at various frequencies

Frequency (MHz)	**9HR L(dB)**	**12HR L(dB)**	**15HR L(dB)**	**18HR L(dB)**
2120	3.4388	2.5437	1.7667	0.5677
2130	9.2482	2.3000	0.7120	0.8042
2140	0.8257	3.9265	12.2232	0.2255
2150	0.1307	3.3943	0.5342	0.9050
MEAN	3.410833	3.041125	3.809	0.625583
POP				
Frequency (MHz)	**9HR L(dB)**	**12HR L(dB)**	**15HR L(dB)**	**18HR L(dB)**
2120	4.1668	2.4173	0.2255	2.1368
2130	13.1598	1.4334	8.9525	6.0650
2140	0.0237	2.3712	14.8246	1.8842
2150	1.3790	3.9688	1.0357	0.0847
MEAN	4.682333	2.547683	6.259583	2.542667
HARDBOARD				
Frequency (MHz)	**9HR L(dB)**	**12HR L(dB)**	**15HR L(dB)**	**18HR L(dB)**
2120	5.7125	2.6142	0.0525	4.2078
2130	11.3785	3.0100	9.6320	1.9880
2140	0.0237	3.0110	13.4110	0.9165
2150	2.4697	0.4058	1.2852	0.6275
MEAN	4.896083	2.26025	6.095167	1.934958

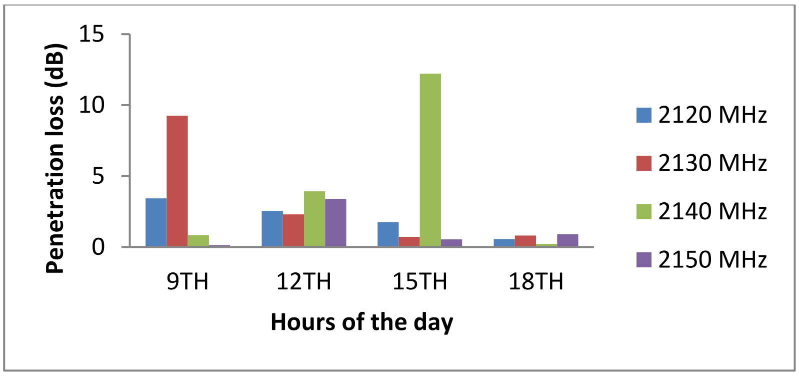

Figure 3: Penetration loss (dB) for different Mobile frequencies at various daily hours via glass

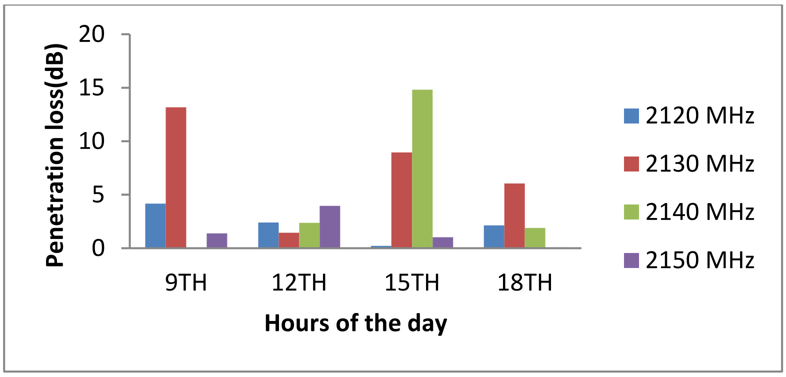

Figure 4: Penetration loss (dB) for different Mobile frequencies at various daily hours via POP

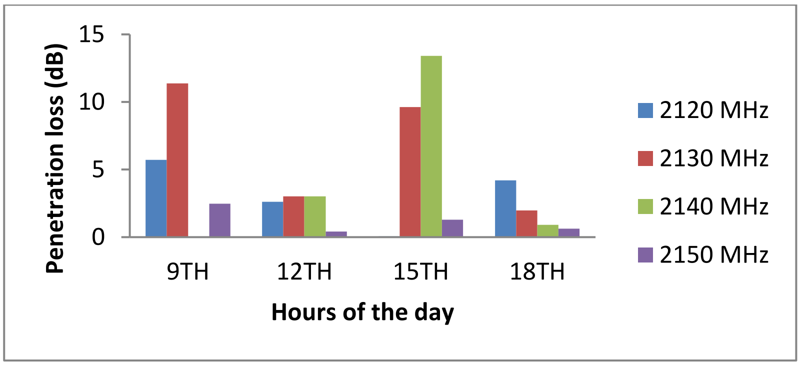

Figure 5: Penetration loss (dB) for different Mobile frequencies at various daily hours via hardboard

5. Conclusion

It was observed that at 12HR and 18HR of the day, the penetration loss was low which means that the rate of call drop and data packet loss will minimal in buildings using the considered ceiling materials Glass POP and hardboard. However the penetration loss was high at 09HR and 15HR of the day which could increase the rate of call drops and data packet loss. It was also observed that the path loss exponent n for all ceiling materials was within the value stipulated for Path loss in Shadowed urban environment with n value ranges between 3.0 and 3.9.on a GSM good line of sight path. Thus, in order to be able to enjoy better GSM communication it would be advised that the 12th and 18th hour of the day be utilized for optimum signal transmission/reception.

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