PERFORMANCE ANALYSIS OF THE IMPACT OF RAIN ATTENUATED SIGNAL ON MOBILE CELLULAR TERRESTRIAL LINKS IN JOS, NIGERIA

ABSTRACT

The 12 to 18GHz frequency bands are commonly deployed for mobile network metropolitan microwave radio links using small antennas and low transmit power to deliver high channel capacities. Jos Plateau region with the blend of tropical and temperate climate is characterized with high severe rain impairment on terrestrial links operating at frequencies above 10GHz, for mobile network backhaul system remaining a big challenge in the design of a microwave radio link. Therefore, this study presents the performance analysis of the impact of rain attenuated signal on mobile cellular terrestrial links in Jos under clear sky and rain condition. The cell site locations were divided in two clusters of Jos lowland and Jos highland. Drive test tools, radio local monitor terminal (LMT) and Davis weather station were employed over radio links interconnecting live 2G/3G nodal network, for the measurement of the mean value of one minute rainfall rates and the corresponding rain-induced signal.

The results obtained revealed that more budget provision was obtained by the study calculation in over 60% of the study centres. More so, when the study fade margin estimation was put to test, up to 4.27Mbps download speed was achieved, the speed almost as high as the highest speed, 4.29Mbps recorded under the clear sky for ITU-R. More so, as low as 0.7% packet loss was recorded against the study link margin budget under same rain condition causing over 62.3% for PLA010 in Jos lowland cluster. Also, instances of slight under-budgeting were observed in highland clusters PLA064 and PLA025 as 35.01dB and 34.99dB respectively when tested with the Study calculated values.

KEYWORDS: Rain attenuated signal, mobile network, 3G data service, 2G voice service and terrestrial radio link

1.0 INTRODUCTION

A wireless communication system employs electromagnetic waves of a particular range of frequency to transmit data and voice over long distances without the use of wires or cable such as copper, optical fiber for transmission. The type of radio communication system used depends on technology, standards, regulations, radio spectrum allocation and user requirements (Wayne, 2007). A communication network with the whole coverage area divided into cells and sectors is referred to as a cellular network, thus GSM network is referred to as cellular network. GSM network is comprised of a mobile station (MS) which is connected to the base station transceiver (BTS) via air interface as shown in figure 1. When a number is dialed on a G.S.M phone the call is routed to the nearest base station where the Base Transceiver Station (BTS) receives, amplifies, and reroutes the call to the Base Station Controller (BSC). The BSC controls and manages single or multiple BTSs and communicates directly with the Mobile Service Switching Center (MSC) with an interface called the "A" Interface. The MSC finally routes the calls to its destination after the credit status of the call has been confirmed by the pre-billing software (Mughele et al 2011).The base stations radiate electromagnetic waves or radiations and the mobile phones within the area of these radiations are connected to the network. Figure 1 shows the overview of microwave backhaul to the GSM network.

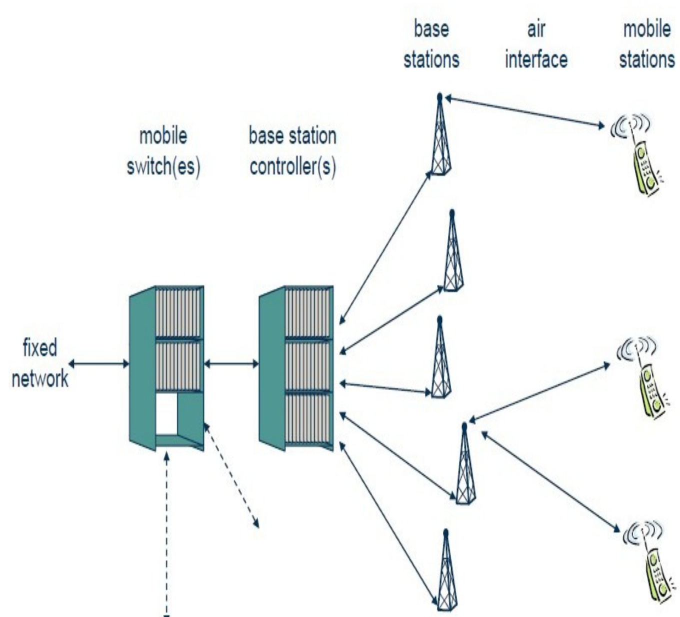

Figure 1: Overview of microwave backhaul link to the GSM network.

The impact of technological change on mobile telecommunications is often described in terms of "generations". Thus, "first generation" mobile technology has referred to the analogue cellular systems that characterized the 1980s and early 1990s, while "second generation" refers to today's digital cellular systems, such as the widely-used Global System for Mobile Communications (GSM). (Xavier, 2001). So-called "Third Generation" (3G) systems or IMT-2000[7] include high-speed data, mobile Internet access and entertainment such as games, music and video programs using image, video and sound to mobile users. (Xavier, 2001). Now the most recent technology is 4G (Mobile WiMax, LTE) with even more improved data rates and efficiency (Sule and Joshi, 2014).GSM is a wireless communication system, which offers increased mobility, flexibility and speed (Frieden, 2009).

The GSM architecture is made up of majorly three sub systems as shown in figure 2. The subsystems are the Mobile Station (MS), Network and Switching Subsystem (NSS), and the Base Station Subsystem (BSS) (Gu and Peng, 2010). The GSM architecture also contains an intelligent network subsystem (IN) which adds more functionality to a network in terms of prepaid services whereby a subscriber can fund his or her account for making calls and sending short message services (SMS) (Sauter, 2011).

The mobile station consists of all the equipment or software required by a subscriber to communicate with the network. It consists of the mobile equipment (ME) and the subscriber identity module (SIM). The ME which is also referred to as the mobile phone consists of a unique international mobile equipment identity (IMEI) which is used to validate and identify it on the network. (Ochang and Irving, 2016). It also consist of Authentication key (Ki) used for authentication (Qureshi and Usman, 2011).

The BSS which is also known as the radio network or the radio subsystem manages all the radio transmission paths between the mobile stations (MS) and other subsystems in the GSM architecture (Sauter, 2011). All radio-related functions between mobile stations and network are performed in the base station subsystem (BSS) (Kabir, 2009). The BSS consist of base station controllers (BSC) and the base transceiver stations (BTS). (Ochang and Irving, 2016). A Base Station Controller (BSC) is a high-capacity switch with radio communication and mobility control capabilities. The functions of the BSC include radio channel allocation, location update, handover, timing advance, power control and paging. It connects, to many BTSs over the Abis-interface (Saikarthik, 2009). The Base Station Transceiver (BTS) is a radio transceivers station that communicates with the mobile stations and its backend is connected to the BSC (Kabir, 2009). The BTS communicates with the mobiles and the interface between the two is known as the Air interface (Um) with its associated protocols (Khadoor and Zarka, 2016).

The NSS is the core component of the GSM architecture which is responsible for call switching, end to end calls, mobility management of subscribers and communication with other networks such as PSTN and ISDN. The components of the NSS include the Mobile Switching Centre (MSC), Home Location Register (HLR), Visitor Location Register (VLR), Equipment Identity Register (EIR), and Authentication Centre (AUC) (Ochang and Irving, 2016). The main element within the core network area of the overall GSM network architecture is the Mobile switching Services Centre (MSC) (Khadoor and Zarka, 2016). The mobile switching center (MSC) performs the telephony switching function. A mobile station must be attached to a single MSC at a time (either homed or visitor), when it is currently active that is not switched off (Kabir, 2009). In this architecture, the HLR serves the entire network and is considered the centralized database of the network. It permanently stores the location profile and subscriber parameters of its assigned mobile terminal (Tripath et al., 2010). The VLR is a database of all subscribers who roam into an area served by an MSC but do not reside there (Chitrapu and Aghili, 2007). Each TSP has their own Equipment Identity Register (EIR) to register International Mobile Equipment Identity (IMEI) number of mobile handset which is used for tracking of devices (Thenuan, 2016). The Authentication Centre (AUC) is an element that is used to authenticate the SIM card of a subscriber on the network (Ochang and Irving, 2016). Figure 2 shows the GSM Overview

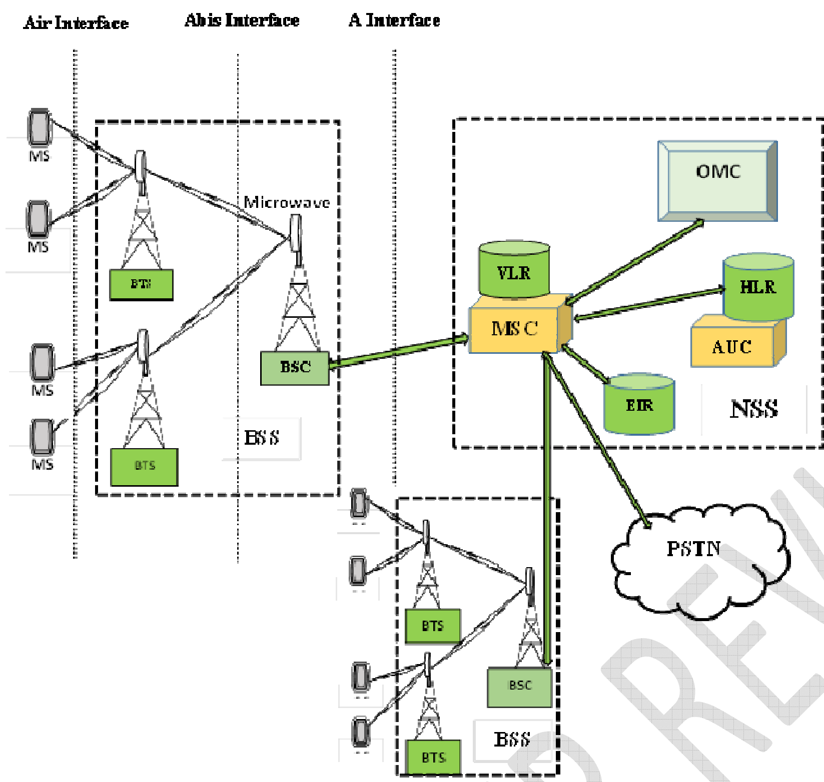

Figure 2: GSM Overview.

UMTS is regarded as a third generation (3G) wireless communication system that acts as a successor to the second generation (2G) communication technologies and is an evolved version of GSM GPRS and EDGE (Poole, 2006). The GSM network was used to provide voice capabilities to subscribers but they was need to support the increasing number of subscribers while providing high speed data services (Ochang and Irving, 2016).

The Core Network (CN) is the part of the UMTS network that provides services to final users; it can be connected to different types of networks supporting different communication protocols (Camarda, 2010). The main function of the CN is to perform packet routing, connection of users, security, billing and the connection of UMTS to external packet switched and circuit switched networks (Neruda and Bestak, 2008).

A Radio Access Network (RAN) is a hierarchical arrangement of cell towers and base stations. The base stations are called base transceiver stations (BTSs) or NobeBs in 3G and in some versions, there are also Radio Network Controllers (RNCs) that link to the BTSs to form a Radio Network Subsystem (RNS). UTRAN is divided into subsystems, each consisting of one radio network controller (RNC) connected to several base transceiver stations (BTSs) (Yang et al, 2006) as shown in figure 3. The RNC controls the radio connections with the mobile stations (MSs) and the wired interface to the core network. (Yang et al, 2006).

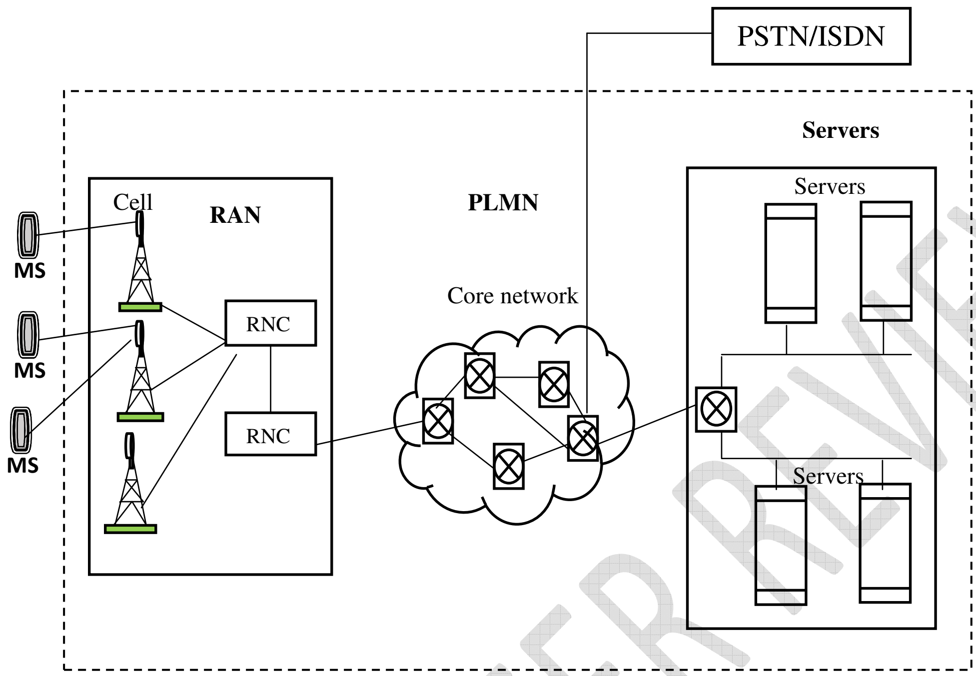

Figure 3: 3G Mobile Network Architecture.

Rain is an important factor in determining the mobile link availability and reliability. A good microwave network design relies heavily on the rain statistics of a particular deployment area. There are three ways rain can affect electromagnetic signal transmission. Rain can attenuate the signal, increase the system noise temperature, and change the signal polarization. All of these three degrades the received signal and are dependent on the carrier frequency. As the carrier frequency increases, their effects become increasingly significant (Nelson, 2000).The principal effect of rain is attenuation. Attenuation is the decrease in the intensity of a signal as a result of absorption of energy and/or scattering out of the path of the detector. Despite the advantages suggested by the use of these frequency bands, the systems can be easily degraded by some natural atmospheric phenomena of which rain is the principal factor and needs to be appropriately quantified so as to enhance reliable communication. Rain can have a significant detrimental effect on the propagation of an electromagnetic signal. Any slight disruption is worrisome to users and could cause some amount of insecurity to the economy.

Different studies have been done on rain attenuated signals and its impact but popularly on the earth to space system, as in the case with satellite system, with very few work on the terrestrial point to point radio links. The few work on terrestrial links have either been in the areas of performance monitoring or error measurement, which has not been to address a specific solution on the services offered by such transmission media. Also, such error measurements are being taken from non-homogenous geographical and climatic conditions, comparable and applicable to such like this study location.

This study have considered the mobility of mobile network with wide range of services including telephony, messaging, internet and broadband data with different quality of service (QoS) parameters for satisfactory performance for minimum transfer delay, delay variation and bit error rate. This study has also identified the need to access high offered data rate services like multimedia streaming, video telephony, network gaming, database access and downloading, the key performance indices of the QoS parameters must be achieved and made possible by domesticating the radio link profiling using the home made data suitable for a specific location of interest. The variable parameters required for mobile services quality such as the bit rate, link bandwidth, propagation delay and packet loss could be largely affected by the radio link quality. Thus, the need to study rain attenuation and its impact in Jos-Nigeria arises as a result of unique climate of the city and to address the impact on terrestrial links.

2. MATERIALS AND METHODS

From the analysis of the signal performance on a live mobile network during clear sky and rainfall in Jos, measurement of the mean value of one minute rainfall rates and the corresponding rain-induced attenuation were taken across eleven live network stations of collocated 2G/3G cell sites in Jos. The weather station rain rate measurements were used to calibrate the bit error rate (BER) measurements of the Abis and Gb links at the cell sites. For the purpose of this study, the cell site locations were divided in two clusters of Jos Highland and Jos Lowland, and thus distributed to represent different rain intensity so as to characterize a wide range of different rain zones for appropriate predictable rain rate model.

During a period of four months (July to October 2018) over 13GHz, 15GHz and 18GHz,the values of radio performance parameters were measured, using the drive test tools, radio local monitor terminal (LMT) and Davis weather station over the links interconnecting live 2G/3G nodal network. Each radio link RSL was measured with the mobile network KPIs, one minute rainfall rate and rain induced attenuation (RSL value before rain minus RSL value under rain).The behavior of the services on 2G and 3G was recorded under different observation during the rainfall events. The data obtained is to determine most suitable rain rate models among the existing models, estimate fade margin for the region to develop fitting link budget for mobile network microwave backhaul. The result will be used as a tool to prepare the link budget for a specific radio link of required service and application.

For the purpose of this study, the methods applied for the research are as follows:

1. The eleven study locations were divided into two clusters, Jos Highland and Jos Lowland. The percentage of link availability desired for the mobile network was considered to be 99.99%. Thus, the need to investigate the level of rain rate exceeded for the two study clusters at 0.01% percentage time of an average year was considered. This was to give anticipated link outage duration of 52.6minutes of the study year for a radio link propagating above 10GHz under the rain induced impairment.
2. Two types of measurements were carried out, the drive test using Huawei optimization TEMs kits and experimental set-up using Davis weather station equipment.
3. Each of the drive test measurements was carried out concurrently with the weather station measurements, Radio Network Optimizer (RNO) measurements, mobile backhaul radios measurements, with synchronized clocking reference, for concurrent timing analysis.
4. Using the Davis weather station, the average annual rainfall from April to October 2018 was computed from the measured data across Jos. The rain rate was computed based on the measured data and the corresponding rain attenuation over the microwave backhaul link signal was estimated and analyzed.

5. The processed data using the best fitted statistical means was used to find the probability of exceeded of the significant months within the study years and ITU-R P.839 recommendation was used to determine the propagation losses due to rain.

To calculate Received Signal Level of PLA064

Consider transmit power, Tx Power =+21dBm, coaxial cable loss =1dB and antenna gain = 36.8dBi as in the case for PLA064 in the study.

Then, Effective Isotropic Radiated Power,

EIRP = Transmitter Antenna Gain (dBi) + TX Power into it (dBm) without Coax Cable Loss)

= 21dBm + 36.8dBi

= 57dBm.

Taking the EIRP = TX Power - Coax Cable Loss + TX Antenna Gain. (1)

Thus the received signal Level, RSL is obtained using the formula,

RX Signal = EIRP - FSL + RX Antenna Gain – Coax Cable Loss

= TX Power - Coax Cable Loss + TX Antenna Gain - FSL + RX Antenna Gain – Cable Loss.

Recall, using a generic frequency f, the equation for the Free Space Loss is:

$$L_{fs} = 32{,}45 + 20^{*}log(D) + 20^{*}log(f) \quad (2)$$

Where L_{fs} is expressed in dB, D is in kilometers and f is in MHz.

Then, Free Space Loss $L_{fs} = 32{,}45 + 20^{*}log(3.382) + 20^{*}log(14.9)$

Consider the Free Space Loss, FSL = 128dB,

Then subtract the FSL (128 dB), add the receiver antenna gain (36.8dBi), subtract the coax cable loss (1dB) and you get the signal reaching the receiver:

RX Signal = EIRP - FSL + RX Antenna Gain – Coax Cable Loss (3)

Receiver antenna Gain, Ga = 36.8dBi,

Coaxial Cabe Loss, Lc =0.5dB x 2= 1dB

Therefore, RRSL = 21dBm-0.5dB+36.8-128dB+36.8dBi-0.5dB = -33.99dBm

Thus, RSL = -33.99dB

To calculate Analytical Study Fade Margin for PLA064

$$\begin{pmatrix} \text{Tx} = 21\text{dBm} \\ \text{RxS} = -69\text{dBm} \end{pmatrix}\begin{pmatrix} \text{ITU} - \text{R fm} = 35.01\text{dBm} \\ \text{LB RSL} = -33.99\text{dBm} \end{pmatrix}$$

ITU RSL Estimation= RSL = R_xS – FM

= 69 – 35.01= -33.99dBm

The Fade Margin = Received Signal (dBm) – Receivers Sensitivity (dBm)

FM = RSL – RxS (4)

Given Measured Early Warning Received Level, RSL_{EW}= -33.8dBm

Analytical Standing FM = R_xS – RSL_{EW}

= 69-33.8= +35.2dB.

Thus,

Link budget ITU Fade margin, FM = -33.99dBm -(-69dBm) =35dB

Similar procedure is repeated to obtain the values for other study locations.

Evaluation Of Rain Attenuated Signal Losses On Mobile Cellular Network Over Terrestrial Radio Link

The International Telecommunication Union recommendation P.530-9 was used to obtained the rain attenuated signal losses on terrestrial radio links at a Frequency of 13/18 GHz. For this study, Actual path length (d) is 20km and Horizontal polarization was considered.

The procedures followed are:

Step 1: The rain rate $R_{0.01}$ exceeded for 0.01% of the time (with an integration time of 1 min) was obtained and presented in Table 17 to 23 for each of the month under study

Step 2: The specific attenuation, γ_R (dB/km) for the frequency, polarization and rain rate of interest was computed using Recommendation ITU-R P.838 as given in equation (83)

Where R is rainfall rate in mm/hr, the coefficients k and α were determined as a function of frequency where k =0.03041 and α = 1.1586 as given by ITU-R for horizontal polarization at frequency of 13 GHz. Equation (83) was used to obtained the specific attenuation for all the rain rate from 1mm/hr to 200mm/hr.

For example, at rain rate of 1mm/hr, $\gamma_R = 0.03041(1)^{1.1586} = 0.03041\ dB/km$ and at rain rate of 200mm/hr, $\gamma_R = 0.03041(200)^{1.1586} = 14.0925\ dB/km$

Step 3: The effective path length d_{eff} of the link was computed by multiplying the actual path length d by a distance factor r.

$$d_{eff} = dr \tag{97}$$

An estimate of this factor is given by:

$$r = \frac{1}{1 + d/d_0} \tag{98}$$

Where, for $R_{0.01} \leq 100$ mm/h:

$$d_0 = 35\ e^{-0.015 R_{0.01}}$$

(98)

For $R_{0.01}$>100 mm/h, the value 100 mm/h was used in place of $R_{0.01}$.

At rain rate of 1mm/hr

$d_0 = 35 \times e^{-0.015(1)} = 34.47,\ r = \frac{1}{1+{}^{20}/_{34.47}} = 0.629$

Therefore, $d_{eff} = 20 \times 0.629 = 12.65km$

Step 4: An estimate of the path attenuation exceeded for 0.01% of the time is given by:

$$A_{0.01} = \gamma_R \, d_{eff} = \gamma_R \, dr \quad \text{dB} \tag{99}$$

At rain rate of 1mm/hr

$$A_{0.01} = 0.3041 \times 12.65 = 0.385dB$$

Step 5: For radio links located at latitudes below 30° (North or South), the attenuation exceeded for other percentages of time *p* in the range 0.001% to 1% may be deduced from the following power law:

$$\frac{A_p}{A_{0.01}} = 0.07 \; p^{-(0.855 \; + \; 0.139 \log_{10} p)} \tag{100}$$

For rain rate of 1mm/hr,

$$A_p = 0.07 \times 0.385 \times 11.550^{-(0.855+0.139Log11.550)} = 0.002dB$$

3.0 RESULTS

Table 1: Computation of Exceeded Frequency of Percentage Time and Rain attenuated signal losses for July 2018

RAIN RATE (mm/h)	**JOS LOWLAND CLUSTER**		**JOS HIGHLAND CLUSTER**	
	Exceeded Freq. of % time	**Rain Attenuated Signal Losses (dB)**	**Exceeded Freq. of % time**	**Rain Attenuated Signal Losses (dB)**
1	14.258	0.002	13.790	0.001
2	11.483	0.005	10.880	0.005
4	7.549	0.017	6.971	0.018
6	3.646	0.053	3.474	0.056
8	2.163	0.120	2.141	0.121
10	1.538	0.211	1.536	0.211
15	1.169	0.423	1.220	0.406
20	0.806	0.808	0.889	0.737
25	0.562	1.413	0.658	1.220
30	0.394	2.342	0.515	1.828
35	0.224	4.547	0.450	2.071
40	0.085	12.443	0.288	3.606

45	0.076	15.196	0.172	7.187
50	0.042	30.193	0.129	10.834
60	0.031	42.323	0.062	22.534
70	0.026	44.176	0.058	26.139
80	0.020	54.615	0.042	37.213
90	0.020	56.151	0.022	49.309
100	0.017	60.442	0.020	50.747
120	0.011	68.126	0.014	64.894
140	0.011	70.244	0.014	65.712
160	0.006	88.512	0.013	70.114
180	0.006	96.264	0.011	76.129
200	0.004	121.761	0.002	81.471

Table 2: Computation of Exceeded Frequency of Percentage Time and Rain attenuated signal losses for August 2018

RAIN RATE (mm/h)	JOS LOWLAND CLUSTER		JOS HIGHLAND CLUSTER	
	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)
1	16.379	0.002	16.234	0.001
2	13.669	0.004	11.057	0.005
4	9.464	0.014	7.211	0.018
6	5.309	0.038	3.337	0.058
8	3.142	0.085	1.906	0.135
10	2.439	0.137	1.350	0.238
15	2.022	0.254	1.090	0.451
20	1.379	0.490	0.667	0.963
25	1.068	0.778	0.448	1.751
30	0.810	1.201	0.271	3.309
35	0.365	2.898	0.219	4.643
40	0.172	6.519	0.203	5.598
45	0.069	16.598	0.174	7.111
50	0.035	35.630	0.154	9.208
60	0.029	44.960	0.107	13.683
70	0.022	53.009	0.082	19.054
80	0.017	64.374	0.042	37.213
90	0.015	67.890	0.033	48.016
100	0.011	71.456	0.013	61.157
120	0.011	73.493	0.012	69.293
140	0.008	98.546	0.010	73.325
160	0.002	110.375	0.002	94.066

Table 3: Computation of Exceeded Frequency of Percentage Time and Rain attenuated signal losses for September 2018

RAIN RATE (mm/h)	JOS LOWLAND CLUSTER		JOS HIGHLAND CLUSTER	
	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)
1	13.412	0.002	11.363	0.002
2	10.648	0.005	8.918	0.007
4	6.847	0.018	5.638	0.025
6	3.312	0.058	3.141	0.073
8	1.912	0.134	2.208	0.141
10	1.317	0.243	1.689	0.232
15	0.984	0.496	1.435	0.417
20	0.655	0.979	1.150	0.685
25	0.435	1.790	0.909	1.050
30	0.282	3.189	0.754	1.464
35	0.141	6.959	0.592	2.051
40	0.087	12.181	0.462	2.796
45	0.043	25.537	0.356	3.744
50	0.043	29.553	0.277	5.184
60	0.025	48.330	0.194	7.024
70	0.018	75.517	0.069	14.178
80	0.016	89.108	0.050	17.747
90	0.016	92.414	0.048	18.768
100	0.011	96.111	0.041	20.572
120	0.010	99.079	0.037	23.798
140	0.002	121.004	0.027	29.421

Table 4: Computation of Exceeded Frequency of Percentage Time and Rain attenuated signal losses for October 2018

RAIN	JOS LOWLAND CLUSTER		JOS HIGHLAND CLUSTER	

RATE (mm/h)	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)	Exceeded Freq. of % time	Rain Attenuated Signal Losses (dB)
1	15.519	0.002	7.432	0.004
2	12.437	0.004	6.113	0.009
4	8.277	0.015	4.298	0.029
6	4.480	0.044	2.540	0.075
8	3.044	0.087	1.913	0.135
10	2.365	0.141	1.599	0.204
15	1.980	0.259	1.321	0.377
20	1.563	0.436	0.999	0.662
25	1.211	0.692	0.790	1.030
30	0.988	0.999	0.609	1.565
35	0.795	1.409	0.470	2.294
40	0.656	1.894	0.358	3.317
45	0.492	2.726	0.264	4.844
50	0.396	8.856	0.199	7.274
60	0.086	17.928	0.112	13.122
70	0.017	59.509	0.047	31.657
80	0.015	61.588	0.042	37.213
90	0.013	66.293	0.022	49.308
100	0.012	68.091	0.014	50.013
120	0.010	74.594	0.013	54.894
140	0.009	89.110	0.012	55.007
160	0.008	97.006	0.012	61.471

Table 5: Measured and calculated results for 3G data service

JOS LOWLAND CLUSTERS

Site code	Transmit Power (dBm)	Calculated min required RSL (dBm)	Receiver Threshold Level, RxS (dBm)	Calculated Fade Margin (dB)	DL Speed from study RSL at Clear Sky (dBm)	Mobile DL Speed from study RSL during Rain Attenuation (dBm)	Packet Loss obtained using study Link Budget
PLA024	20.0	-30.0	-82.0	52.0	4.12	4.10	0.5%
PLA011	20.0	-30.0	-82.0	52.0	4.29	4.27	0.4%
PLA012	20.0	-29.6	-68.5	38.9	4.26	4.24	0.5%
PLA010	20.0	-37.2	-74.5	37.3	4.18	4.15	0.7%
PLA048	20.0	-37.9	-68.5	30.6	4.12	4.11	0.2%
JOS HIGHLAND CLUSTERS							
PLA025	21.0	-33.1	-69.0	35.90	4.31	4.30	0.2%
PLA016	24.0	-43.9	-78.5	34.60	4.33	4.32	0.2%
PLA064	21.0	-33.8	-69.0	35.20	4.28	4.26	0.4%
PLA077	23.0	-37.9	-75.0	37.10	4.32	4.30	0.5%
PLA0901	15.0	-30.19	-68.5	38.31	4.29	4.28	0.2%
PLA001	20.0	-29.0	-68.5	39.50	4.30	4.28	0.4%

Table 6: Measured and calculated results for 2G voice service

JOS LOWLAND CLUSTERS							
Site	**Transm**	**Study**	**Receiver**	**Mobil**	**Mobile**	**Mobil**	**Mobile**

code	it Power (dBm)	Calculated min required RSL (dBm)	Threshold Level, RxS (dBm)	e SQI with ITU budget at Clear Sky	SQI with ITU budget during Rain Attenuation	e SQI with study budget at Clear Sky	SQI with study budget during Rain Attenuation
PLA024	20.0	-48.2	-82.0	+23	+19	+21	+21
PLA011	20.0	-49.7	-82.0	+23	+19	+21	+20
PLA012	20.0	-44.2	-68.5	+25	+20	+23	+22
PLA010	20.0	-52.1	-74.5	+22	+20	+21	+20
PLA048	20.0	-52.9	-68.5	+25	+20	+23	+22
JOS HIGHLAND CLUSTERS							
PLA025	21.0	-57.4	-69.0	+24	+21	+21	+20
PLA016	24.0	-55.1	-78.5	+23	+20	+20	+20
PLA064	21.0	-57.3	-69.0	+24	+21	+21	+20
PLA077	23.0	-55.4	-75.0	+23	+20	+20	+20
PLA0901	15.0	-58.0	-68.5	+26	+22	+24	+22
PLA001	20.0	-56.0	-68.5	+26	+22	+24	+23

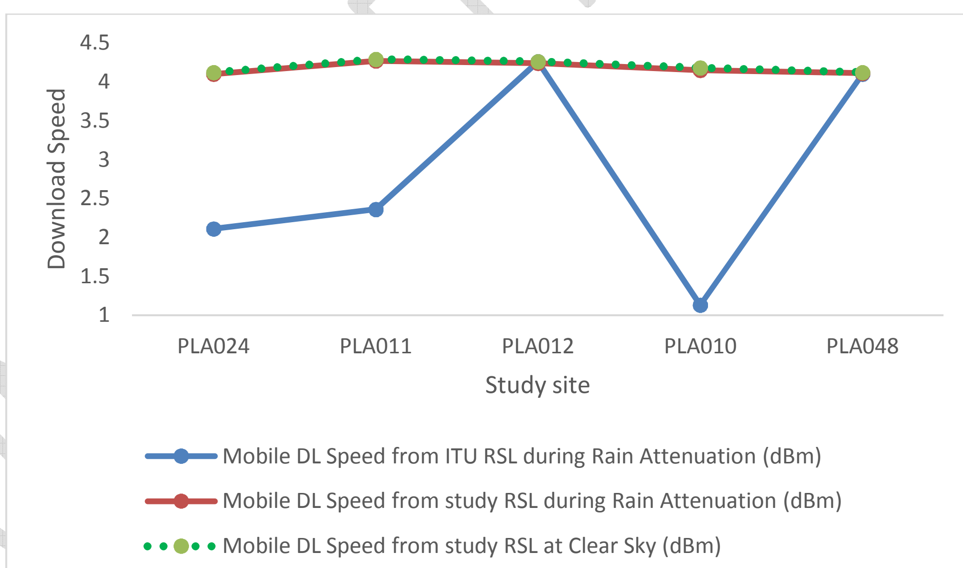

Figure 4: 3G download Speed based on ITU-R RSL compare to 3G download Speed based on study RSL for Jos Lowland Cluster

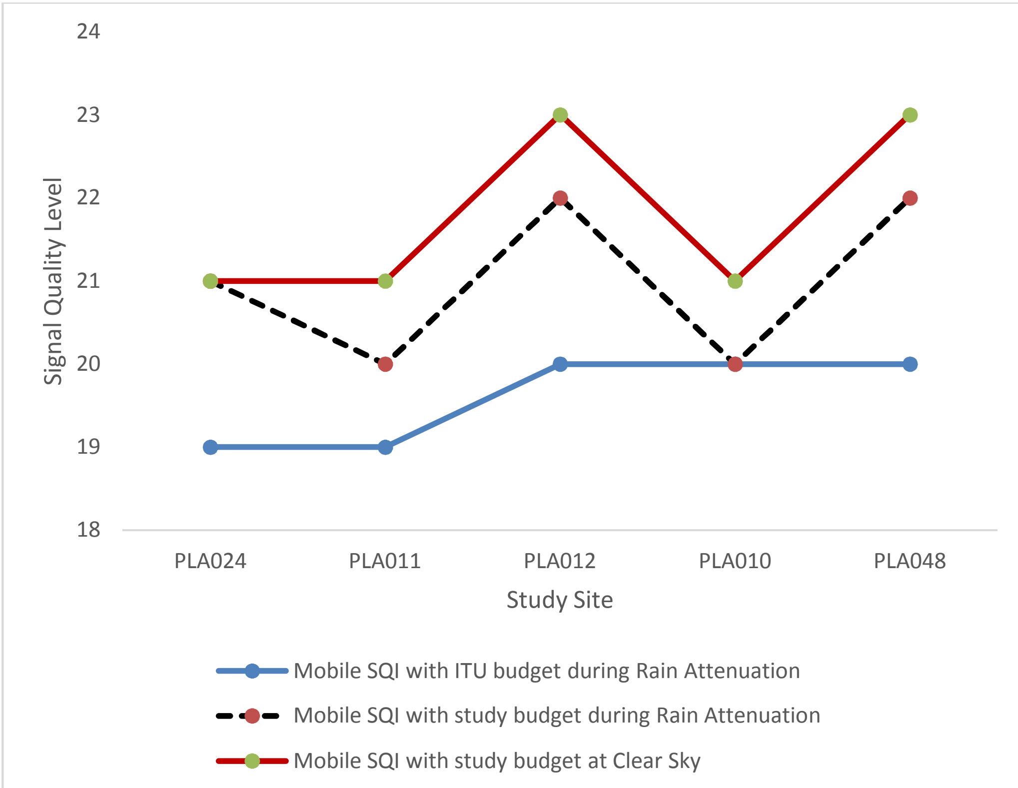

Figure 5: 2G mobile SQL based on ITU-R Budget compare to 2G mobile SQL based on study budget for Jos Lowland cluster

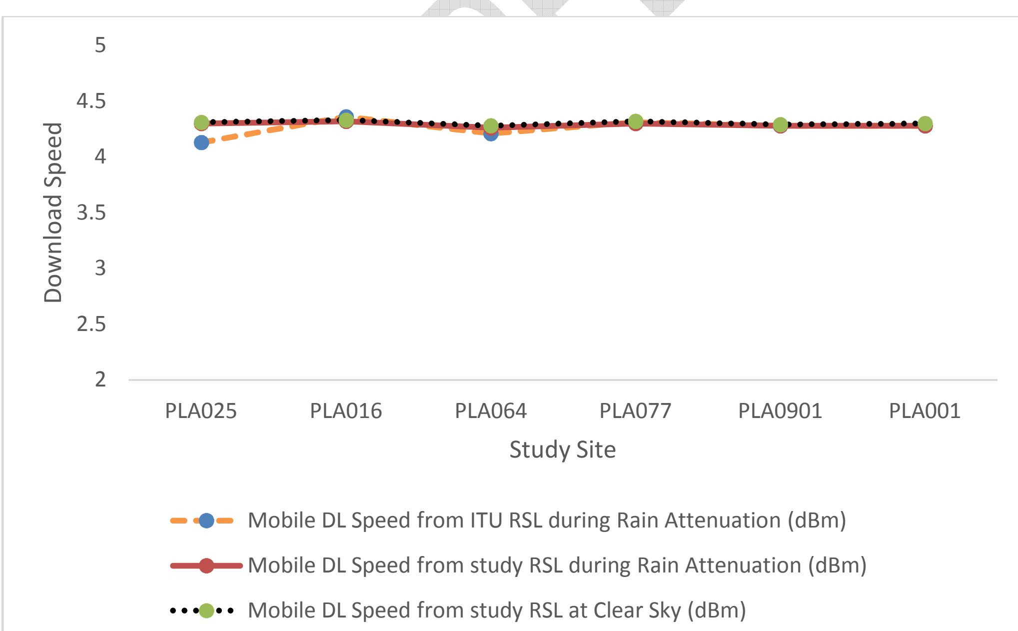

Figure 6: 3G download Speed based on ITU-R RSL compare to 3G download Speed based on study RSL for Jos Highland Cluster

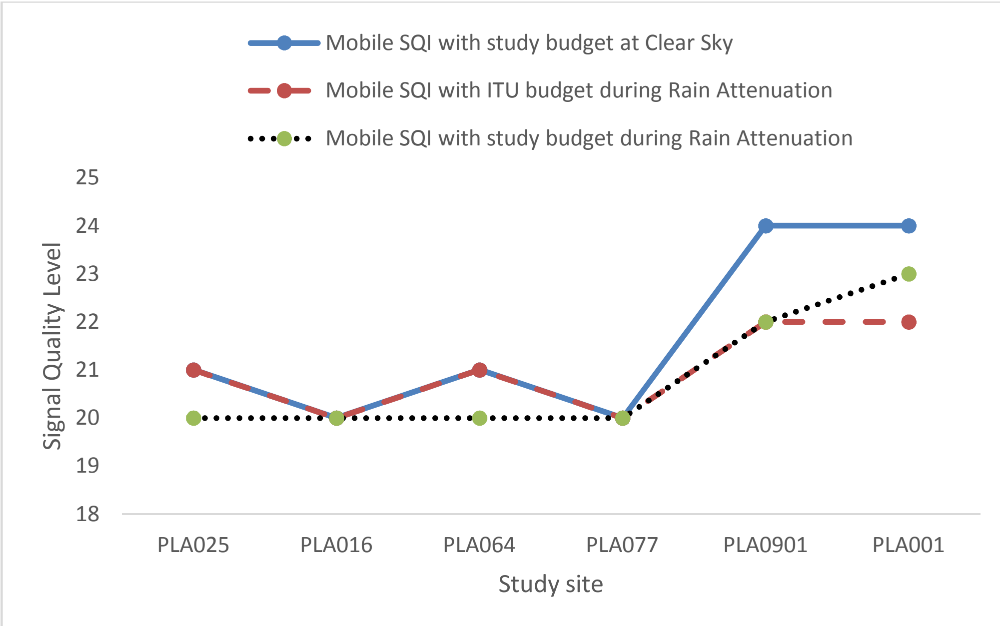

Figure 7: 2G mobile SQL based on ITU-R Budget compare to 2G mobile SQL based on study budget for Jos Highland cluster

4.0 DISCUSSIONS

Table 1, 2, 3 and 4 presents the computation of exceeded frequency of percentage time and rain attenuated signal losses for months of July, August, September and October 2018 respectively. The result shows that Jos lowland clusters recorded higher signal losses compared to the signal losses at Jos highland clusters.

Table 5 presents the measured and calculated results for 3G data service in both lowland and highland clusters while Table 6 presents the measured and calculated results for 2G voice service. The results were computed from the measurement taken to test the reliability ITU-R estimated fade margin for the lowland and highland clusters of Jos both for the clear sky and rain attenuation condition. The same value of the degraded signals was used to calculate the minimum required received signal level for each study location.

Figures 4 and 5 gave the comparative analysis of the ITU-R and Calculated fade margin for data download speed and extent of packet loss for 3G as well as voice clarity in terms of quality index. The plotted graphs showed that more budget provision was obtained by the study calculation in over 60% of the study centres. More so, when the study fade margin estimation was put to test, up to 4.27Mbps download speed was achieved, the speed almost as high as the highest speed, 4.29Mbps recorded under the clear sky for ITU-R. More so, as low as 0.7% packet loss was recorded against the study link margin budget under same rain condition causing over 62.3% for PLA010 in Jos lowland cluster.

Figure 6 and 7, there was a general agreement with ITU-R for sufficient values to the radio link design parameters for the highland cluster as compared to the lowland.

The instances of slight under-budgeting observed by the Study in PLA064 and PLA025 as 35.01dB and 34.99dB respectively when tested with the Study calculated values 35.20dB and 35.90dB respectively, resulted in significant improvement for the QoS performance indices. 4.26Mbps and 4.30Mbps were obtained during rain scenarios culminating into near zero packet loss as compared with ITU budget bar chart in Figure 46 for both PLA064 and PLA025.

5.0 CONCLUSSION

The performance analysis of the impact of rain attenuated signal on mobile cellular terrestrial links in Jos was carried out under clear sky and rain condition. The cell site locations were divided in two clusters of Jos lowland and Jos highland. The results obtained revealed that more budget provision was obtained by the study calculation in over 60% of the study centres. More so, when the study fade margin estimation was put to test, up to 4.27Mbps download speed was achieved, the speed almost as high as the highest speed, 4.29Mbps recorded under the clear sky for ITU-R. More so, as low as 0.7% packet loss was recorded against the study link margin budget under same rain condition causing over 62.3% for PLA010 in Jos lowland cluster. Also, instances of slight under-budgeting were observed in highland clusters PLA064 and PLA025 as 35.01dB and 34.99dB respectively when tested with the Study calculated values.

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