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Performance assessment of cross polarization models at millimetre wavelengths along Earth–Space path in Nigeria

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Rain-induced depolarization impairments have been a constraint on the effective use of satellite communication systems at millimetre wave band especially in the tropical regions like Nigeria. This region often experiences high and varying degree of rainfall intensity accompanied with large raindrops due to distortion of raindrops when dual orthogonal polarization is employed to double the channel capacity without increasing the bandwidth. This paper examines the performance of five cross polarization discrimination (XPD) models at millimetre wavelengths over ten (10) different locations in Nigeria using five years climatological data acquired from Tropospheric Observatory Data Acquisition Network (TRODAN) of the Centre for Atmospheric Research (CAR). The performance of five different XPD models namely: recent ITU-R 618-15, old ITU-R-722, SIM, CHU and DHW were tested based on the level of estimated interference due to tropospheric effects. The results revealed that at Ku-band uplink/downlink frequencies (10/14 GHz), the unwanted signals will completely overshadow the co-polarized signal between 0.001 and 0.018% of time for the new ITU-R model at Jos, Yola, Sokoto and Nsukka. However, at fade level between 8.93 and 11.08 dB, the crosstalk is prevalent at the receiving station. Though, the recent ITU-R model received wider acceptance, the performance in this study is ranked the lowest while SIM model displayed the best performance. The study therefore recommends, SIM model as the most preferred model to be adopted in estimating depolarization in this region. However, further experimental data for validation is suggested to substantiate this assertion.

Key words: Millimeter waves, cross polarization discrimination (XPD) models, co-polar attenuation, earth-space paths, tropical region.

INTRODUCTION

The effects of rain at millimetre wave on satellite communication systems have received considerable attention especially at frequencies above 10 GHz. The characteristics of signal transmission through the atmosphere vary significantly as the frequency of propagation increases due to the atmospheric conditions. As the demand for digital information broadcast grows rapidly, so also is the demand for high-transmission data rates. The congestion of the frequency bands lower than 10 GHz makes it necessary to expand the lower

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frequency band for transmission of high data rates (Ojo, 2012). The urge for high broadband communication services led to migration to higher frequencies such as Ka (20/30 GHz) and Q (40/50 GHz) bands in order to increase facility and utilize the large capacity provided by these frequency bands to reduce the congestion at lower frequency bands (Ojo, 2012; Karasuwa et al., 2016). The large bandwidths needed for signal transmission at frequencies higher than 10 GHz are prone to problems due to atmospheric effects that may reduce the performance of terrestrial/ground to space and vice-visa communication systems (Uma et al., 2007, Ojo et al., 2010; Karasuwa et al. 2016). Frequency re-use system was introduced to reduce the problem of congestion of the frequency band by employing dual orthogonal polarization to double the channel capacity without increasing the bandwidth. This system is susceptible to propagation impairments due to distortion of raindrops which become increasingly pronounced as the frequency of the propagation is increased (Uma et al., 2007). Despite the propagation problems encountered with frequency re-use system using millimetre and microwave frequencies, it was found to be highly helpful for telecommunication services especially for long distance link because of the fairly good bandwidth (Karasuwa et al., 2016). One of the problems of implementation of this communication system is the depolarization effect (cross talk) on the signals between the two orthogonally polarized channels. Cross Polarization Discrimination (XPD) is a measure of depolarization. XPD can also be defined as the ratio of energy received in the wanted (transmitted) polarization to the energy received in the unwanted (orthogonal) polarization.

Propagation measurements at frequencies above 10 GHz have been investigated extensively in the temperate climatic region while such studies are sparse in the tropical region. This is so for the tropical regions because the available data is inadequate particularly in view of the complex and varying climatic behaviour of the tropics (Green, 2004; Maitra and Adhikari, 2011; Maitra et al., 2012). In most of the studies, measurements made in the temperate regions are usually used for propagation modeling, which often lead to poor prediction of propagation impairments when applied to the tropical regions (Green, 2004). Therefore, more extensive studies are required to have comprehensive understanding of propagation effects in the tropical locations like Nigeria (Ojo, 2012; Yusuf and Nor, 2012). This study presents the assessment of performance of some cross polarization models employing dual orthogonal polarization along communication links at millimetre wavelengths over Nigeria.

There are several models formulated for computing rain-induced cross polarization discrimination (XPD) at millimetre waves bands but this study considers and compare five models due to its versatility namely recent ITU-R (ITU-R 618-12, 2015), Old ITU-R (ITU-R 722, 1982), DHW model (Dissanayake et al., 1980), Simple Isolation Model-SIM model (Stutzman and Donald, 1984) and Chu model (Chu, 1982). The performance of these models is assessed and compared by the level of interference (XPD) obtained from each model based on same parameters.

RESEARCH METHODOLOGY

Five years (2008 – 2012) of rain rate data used for the study were obtained from Tropospheric Observatory Data Acquisition Network (TRODAN) of the Centre for Atmospheric Research of National Space Research and Development Agency (NASRDA), Kogi State University, Anyigba, Nigeria. The data collected spreads across ten (10) selected locations in Nigeria. The selected locations are: Akure (7.17° N, 5.18° E), Akungba (7.47° N, 5.74° E), Anyigba (7.49° N, 7.17° E), Lagos (6.52° N, 3.37° E), Makurdi (7.73° N, 8.54° E), Nsukka (6.84° N, 7.37° E), Jos (8.89° N, 8.85° E), Yola (9.20° N, 12.48° E), Port Harcourt (4.85° N, 7.05° E), and Sokoto (13.00° N, 5.25° E). The selected locations are further categorized based on vegetative covers as Rainforest zone (Akure, Lagos, Port Harcourt and Akungba) and Savannah zone (Ayingba, Nsukka, Jos, Makurdi, Yola and Sokoto). The data obtained from these locations were used to deduce the level of performance of the cross polarization models. Each experimental site is equipped with the Campbell Automatic Weather Station (AWS) to measure total rain accumulation and rain rates among the measurements. The equipment consists of sensors for the measurement of climatological parameters such as rain, atmospheric pressure among others. Also, included in the equipment are solar power panels to guarantee continuous supply of electrical power, data logger and automatic control system.

XPD are computed for millimetre wave frequencies of each location using the data acquired based on the selected models for various rain types, rain rates, and canting angles.

The step by step procedure for estimating XPD for rain depolarization statistics for 6 ≤ f ≤ 55 GHz at θ ≤ 60° based on the selected models are as follows:

New ITU-R model (ITU-R 618-12, 2015)

The frequency dependent term was calculated using:

$$C_f = \begin{cases} 60\log f - 28.3 & 6 \le f \angle 9\,\text{GHz} \\ 26\log f + 4.1 & 9 \le f \angle 36\,\text{GHz} \\ 35.9\log f - 11.3 & 36 \le f \le 55\,\text{GHz} \end{cases} \quad (1)$$

where f is the frequency in GHz.

The rain attenuation dependent terms, C_A was also calculated using:

$$C_A = V(f)\log A_P \quad (2)$$

where A_p is the estimated rainfall attenuation (in dB) exceeded for the required percentages of time and $V(f)$ is given as:

$$V(f) = \begin{cases} 30.8 f^{-0.21} & 6 \le f \angle 9GHz \\ 12.8 f^{0.19} & 9 \le f \angle 20GHz \\ 22.6 & 20 \le f \angle 40GHz \\ 13.0 f^{0.15} & 40 \le f \le 55GHz \end{cases} \quad (3)$$

The polarization improvement factor, C_τ for the depolarization is obtained using:

$$C_{\tau} = -10\log\left[1 - 0.484\left(1 + \cos 4\tau\right)\right] \quad (4)$$

where $C_{\tau} = 0\, for\ \ \tau = 45^{0}$ for circular polarization and reaches the maximum value of 15 dB for $\tau = 0$ or 90°.

The elevation angle dependent term for $\theta \leq 60^{0}$ was obtained using:

$$C_{\theta} = -40\log\left(\cos\theta\right) \quad (5)$$

while the canting angle dependent term was derived from:

$$C_{\sigma} = 0.0053\sigma^{2} \quad (6)$$

where σ is the effective standard deviation of the raindrop canting angle distribution (in degrees). σ takes the value 0, 5, 10 and 15° for 1, 0.1, 0.01 and 0.001% of the time, respectively. For this study, σ was taken as 10°.

The XPD due to rain $\left(XPD_{rain}\right)$ was therefore obtained using:

$$XPD_{rain} = C_{f} - C_{A} + C_{\tau} + C_{\theta} + C_{\sigma}\left(dB\right) \quad (7)$$

This model permits the evaluation of the cumulative distribution function of cross polar discrimination by means of an equiprobability relationship between the attenuation and the XPD.

Old ITU-R 722 model (ITU-R 722, 1982)

$$XPD = 30\log\left(f\right) - 10\log 0.5\left[1 - \cos\left(4\tau\right)e^{-0.0024\sigma^{2}}\right] - 40\log\left(\cos\theta\right) + 0.0053\sigma_{\theta}^{\ 2} - V\log\left(A_{p}\right) \quad (8)$$

$$V = \begin{Bmatrix} 20 & 8\angle f \leq 15GHz \\ 23 & 15\angle f \leq 35GHz \end{Bmatrix}$$

Simple Isolation Model-SIM model (Stutzman and Donald, 1984)

$$XPD = 9.5 + 17.3\log\left(f\right) - 42\log\left(\cos\theta\right) - 10\log 0.5\left[1 - \cos\left(4\tau\right)e^{-0.0024\sigma^{2}}\right] + 0.0053\sigma_{\theta}^{\ 2} - 20\log\left(F_{0}\right) - 19\log\left(A_{p}\right) \quad (9)$$

Chu model (Chu, 1982)

$$XPD = 11.5 + 20\log\left(f\right) - 40\log\left(\cos\theta\right) - 20\log\left(A_{p}\right) \quad (10)$$

DHW model (Dissanayake et al., 1980)

$$XPD = 8.16 + 21\log\left(f\right) - 20\log\left(\sin\left(2\tau\right)\right) - 40\log\left(\cos\theta\right) + 0.0053\sigma_{\theta}^{\ 2} - 20\log\left(A_{p}\right) \quad (11)$$

Where the constants are $\sigma_{m} = 3^{o}$, $\sigma_{\theta} = 12^{o}$ an $F_{0} = 0.65$.

All parameters retain their usual notations and meaning.

This study compares performance of some existing depolarization models. All the models considered are of the form $XPD = U - V\log A$ and predictions of XPD are made under the same conditions. Elevation angle of 42.5° and polarization tilt angle of 45° were chosen for estimation of XPD. These values were chosen because most satellites operate at polarization tilt angle of 45°, (a condition for circular polarization though its depolarization effect is higher than the effect due to linear polarization) and the orbital position of Nigeria satellite (NigComSat-1R) is at elevation angle of 42.5°.

RESULTS AND DISCUSSION

Here the simulated results are presented.

Cumulative distribution of XPD for frequency at 10 GHz for all models

Figure 1 presents the cumulative distribution of XPD for the selected locations in the rainforest zone for 10 GHz frequency. XPD values are found to increase as probability of exceedance increases for all the models. XPD based on SIM model displays highest values of about 50.0 dB at 0.001% of time while the recent ITU-R model shows lowest values of about 10.0 dB at the same time percentages. Although DHW model, old ITU-R model and Chu model are found to be in good agreement, however, they show little deviation from SIM model. The unwanted signals from orthogonal channels would become deplorable for the new ITU-R model while depolarization in the other models will be very low. Signal links might not require correction technique in these models except for new ITU-R model.

In Figure 2, for locations in the savannah zone, XPD values increase as probability of exceedance is increased. Also, SIM displays the highest value. There is good agreement on the performance between DHW model, old ITU-R model and Chu model while there is disagreement in performance between the recent ITU-R model and other model. However, XPD values goes to negative for new ITU-R model which shows a different trend in XPD compared to other models. The unwanted signals from orthogonal channels would become deplorable for the recent ITU-R model. The equations of XPD as function of percentage of time (*p%*) can be expressed as (Durodola et al., 2018).

For Nsukka

$$XPD = 3.815In(p\%) + 15.22 \quad (12)$$

From (12), when $P\% = 0.018\%$ then $XPD = 0$

For Jos

$$XPD = 3.814In(p\%) + 16.38 \quad (13)$$

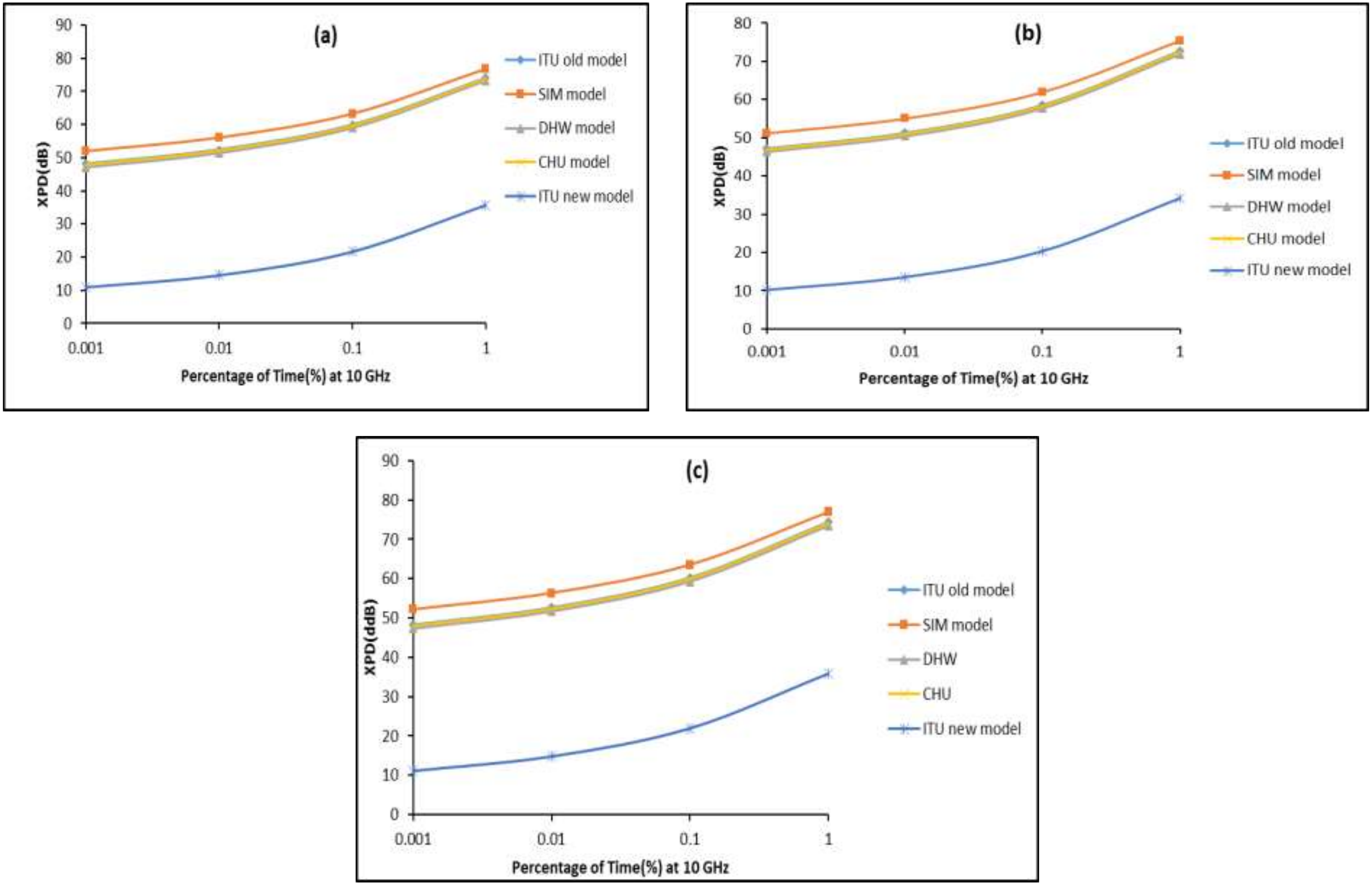

Figure 1. Cumulative distribution of XPD for frequency at 10 GHz for locations in the rain forest zone (a) Lagos (b) Port–Harcourt and (c) Akure.

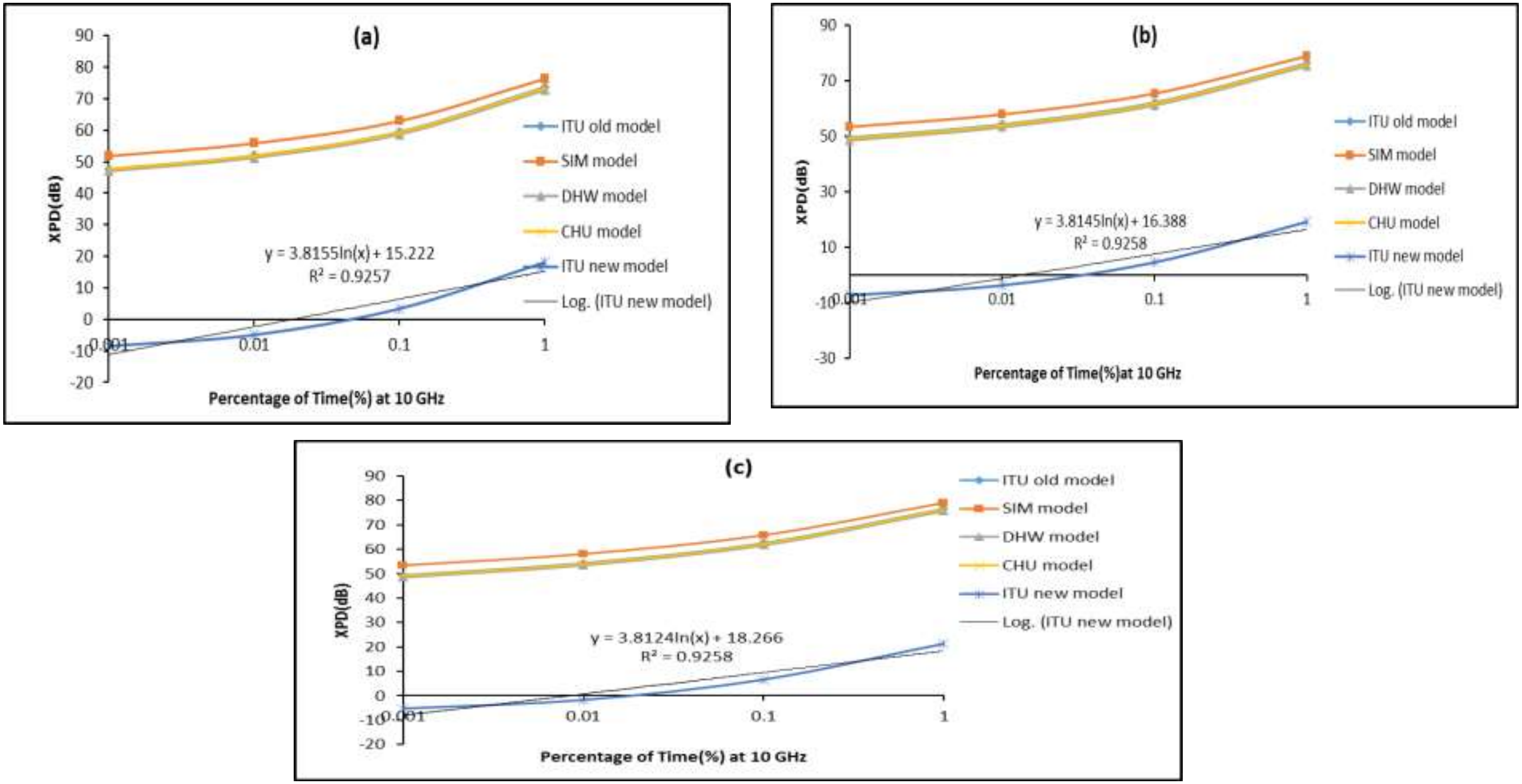

Figure 2. Cumulative distribution of XPD for frequency at 10 GHz for locations in the savannah zone (a) Nsukka (b) Jos and (c) Sokoto.

Therefore, when $P\% = 0.014\%$ then $XPD = 0$

For Sokoto

$$XPD = 3.812 In(p\%) + 18.26 \tag{14}$$

Therefore, when $P\% = 0.008\%$ then $XPD = 0$

Equations (12 – 14) imply that the interference would be extremely high as XPD is degraded to zero and between 0.001 and 0.018% of time in Figure 2, the unwanted signals will completely overshadow the co-polarized signal for the recent ITU-R model and no meaningful communication can take place under this condition.

It is therefore mandatory under this condition to increase the fade margin and apply mitigation technique for good signal transmission to occur.

Cumulative distribution of XPD for frequency at 12 GHz for all models

At frequency of 12 GHz, for locations in the rainforest zone as presented in Figure 3, XPD values also increase as probability of exceedance increases. SIM has the highest value of XPD while the recent ITU-R model shows lowest values. Performance of DHW model, old ITU-R model and Chu model are found to be in good agreement while SIM is deviated from other models marginally but the recent ITU-R model is in total disagreement with other models. Crosstalk will be minima for SIM while it would be maxima for the recent ITU-R models because of its low vales of XPD in these locations.

At frequency of 12 GHz, for locations in the savannah zone as presented in Figures 4 and 5, XPD values also increase as probability of exceedance increases. SIM has the highest value of XPD while the recent ITU-R model shows lowest values. DHW model, old ITU-R model and Chu model are in very good agreement while SIM is deviated slightly from DHW, old ITU-R and Chu models. The recent ITU-R totally deviated from other models. This result also shows that there would be higher interference using the recent ITU-R than in other models. The new ITU-R model behaves differently in the trend as XPD goes to negative values.

The modeling expression has agreement factor of about 93% in the recent ITU-R model.

For Nsukka, the expression is:

$$XPD = 3.815In(p\%) + 15.22 \quad (15)$$

Therefore, when $P\% = 0.018\%$ then $XPD = 0$

For Jos,

$$XPD = 3.814In(p\%) + 16.38 \quad (16)$$

Therefore, when $P\% = 0.014\%$ then $XPD = 0$

For Sokoto,

$$XPD = 3.812In(p\%) + 18.26 \quad (17)$$

Therefore, when $P\% = 0.008\%$ then $XPD = 0$

For Yola,

$$XPD = 3.814In(p\%) + 16.36 \quad (18)$$

Therefore, when $P\% = 0.014\%$ then $XPD = 0$

Equations (15 - 18) show that the cross talk would be exceedingly high as XPD is degraded to zero and unwanted signals will entirely overshadow the co-polarized signal between 0.001 and 0.018% of time; however, other models do not experience this type of scenario as they predict low interference between orthogonal channels at the receiver stations. Signal transmission will often suffer high interruption due to very high interference in frequency reuse systems.

The same trend could be observed at uplink frequency of 14 GHz, although with different values of XPD for each of the models at both rain forest (Figure 6) and savannah zone (Figure 7).

Cumulative distribution of XPD for Ka frequency band for all models

Figure 8 presents the cumulative distribution of XPD for the selected locations in the rainforest zone for Ka frequency band. XPD shows comparable trends as in Figure 6. There is decrease in XPD as the frequency increases when compared to Ku bands in all the models indicating higher cross talk in all the models. This is in agreement with Adetan and Afullo (2013). SIM maintains its highest values of XPD. The performances of the models show good agreement at 1% of time but the recent ITU-R model does not agree with other models and also displayed the lowest values of XPD among the models. All the models disagree with each other between 0.001 and 0.1% of time. Generally speaking, signal interruptions due to interference will be more because of low values at higher frequency while value of XPD at 0.001% of time for the recent ITU-R model in Port Harcourt is almost becoming zero, implying an unfavorable situation for signals communication if employed for signal transmission in frequency reuse systems.

Figure 9 also presents the cumulative distribution of XPD at Ka frequency band, for locations in savannah zone. XPD continues to increase as probability of exceedance increases. As usual with the previous observation based on this study, SIM has the highest values of XPD and disagrees with other models; however, its performance exhibits agreement with other models at 1% of time. The performance of the recent ITU-R model is always in total disagreement with other models.

The recent ITU-R model is the most largely deviated among other models. At 0.001% of time, the recent ITU-R model would exhibit the highest interference with the orthogonal channels at receiver stations among other models if used for signal transmission in a frequency reuse systems. However, SIM model would experience the least cross talk among other models.

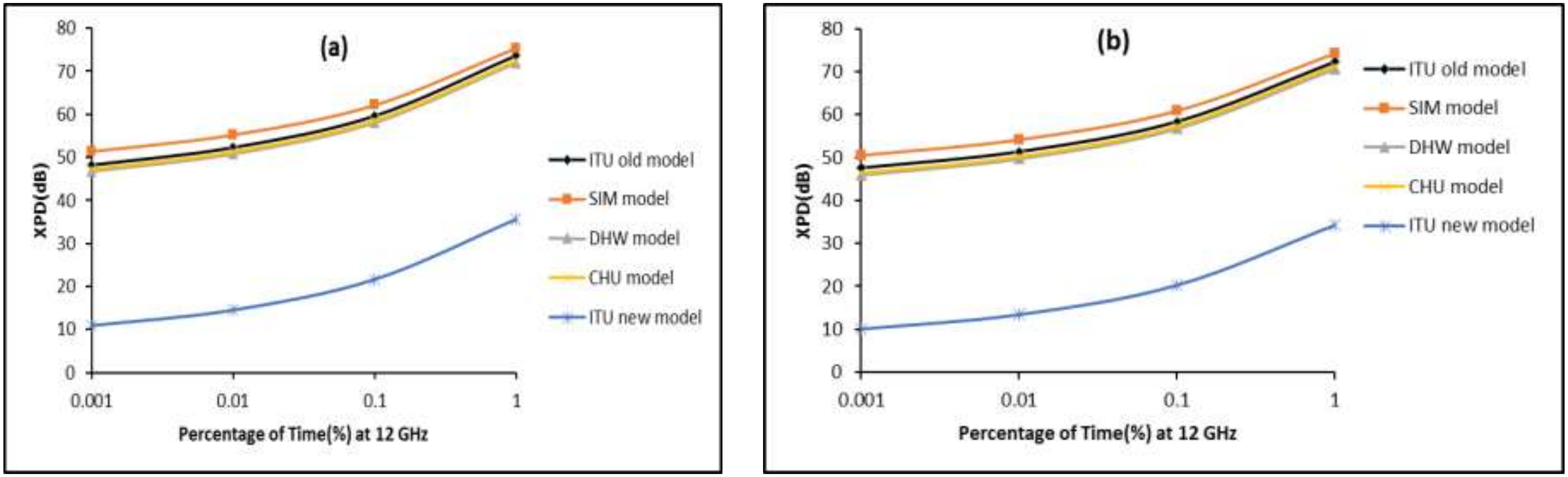

Figure 3. Cumulative distribution of XPD for frequency at 12 GHz for locations in the rain forest zone (a) Lagos and (b) Port Harcourt.

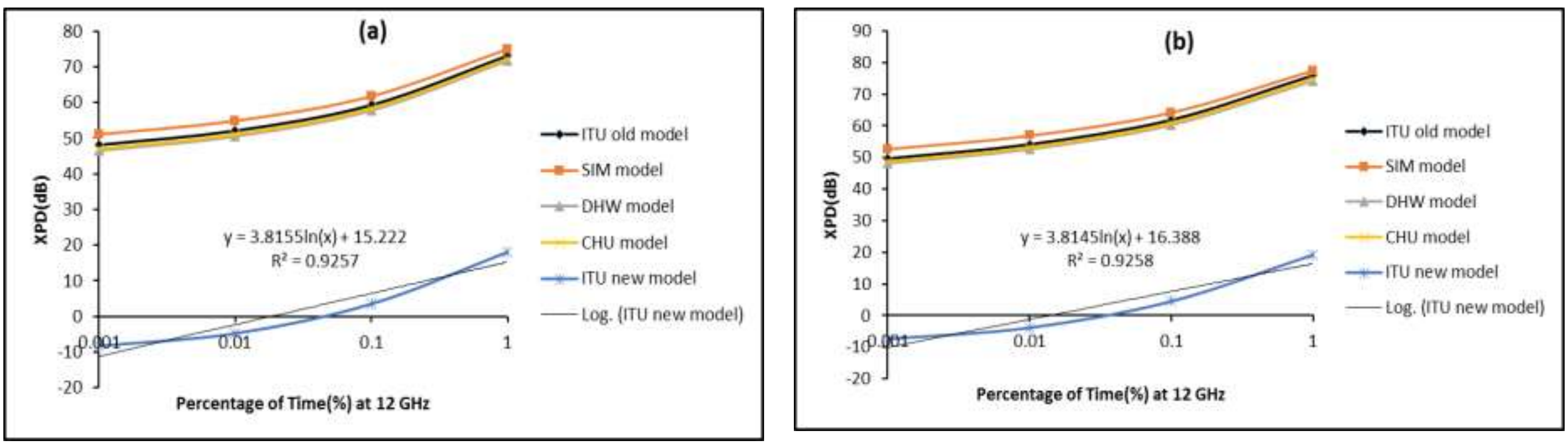

Figure 4. Cumulative distribution of XPD for frequency at 12 GHz for locations in the savannah zone (a) Nsukka and (b) Jos.

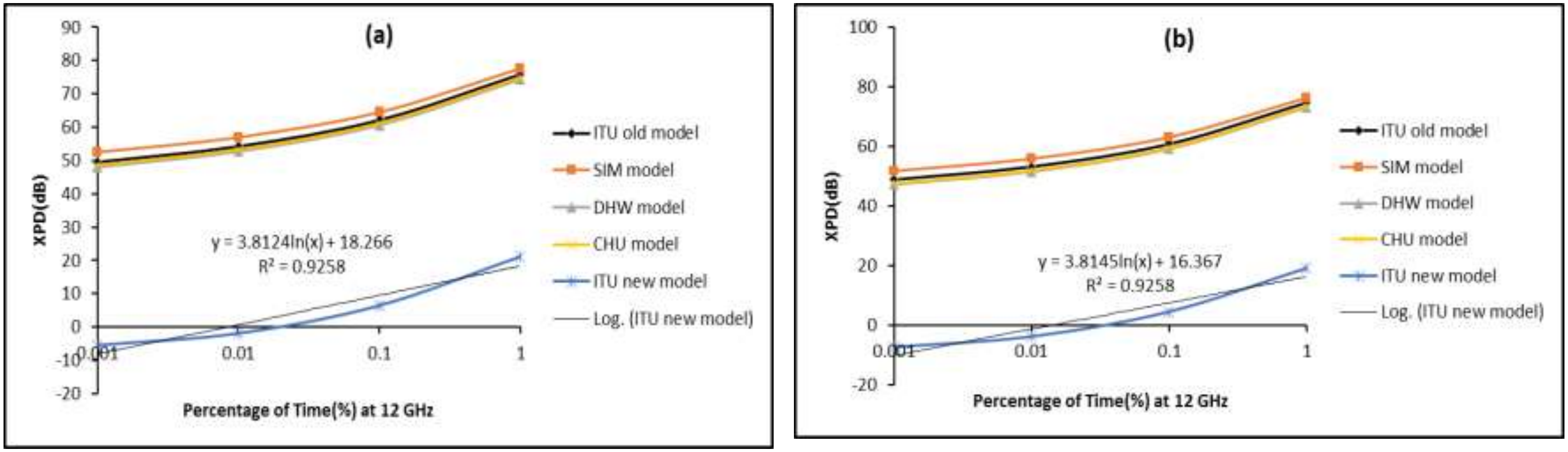

Figure 5. Cumulative distribution of XPD for frequency at 12 GHz for locations in the savannah zone (a) Sokoto and (b) Yola.

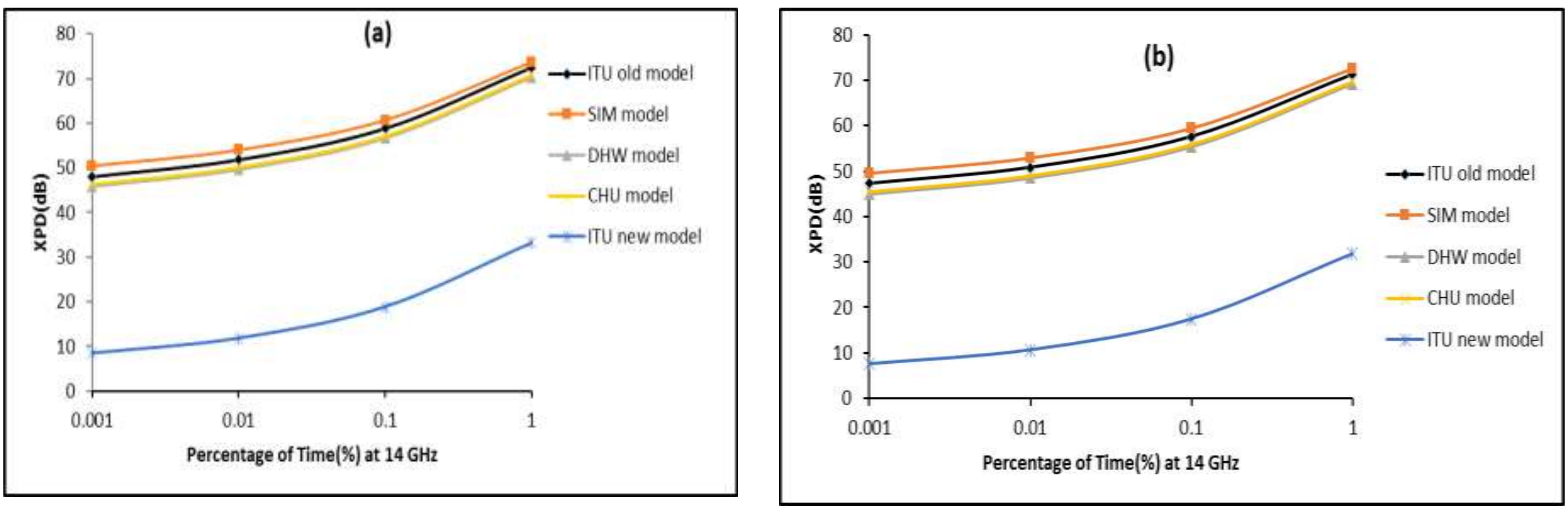

Figure 6. Cumulative distribution of XPD for frequency at 14 GHz for locations in the rain forest zone (a) Lagos and (b) Port–Harcourt.

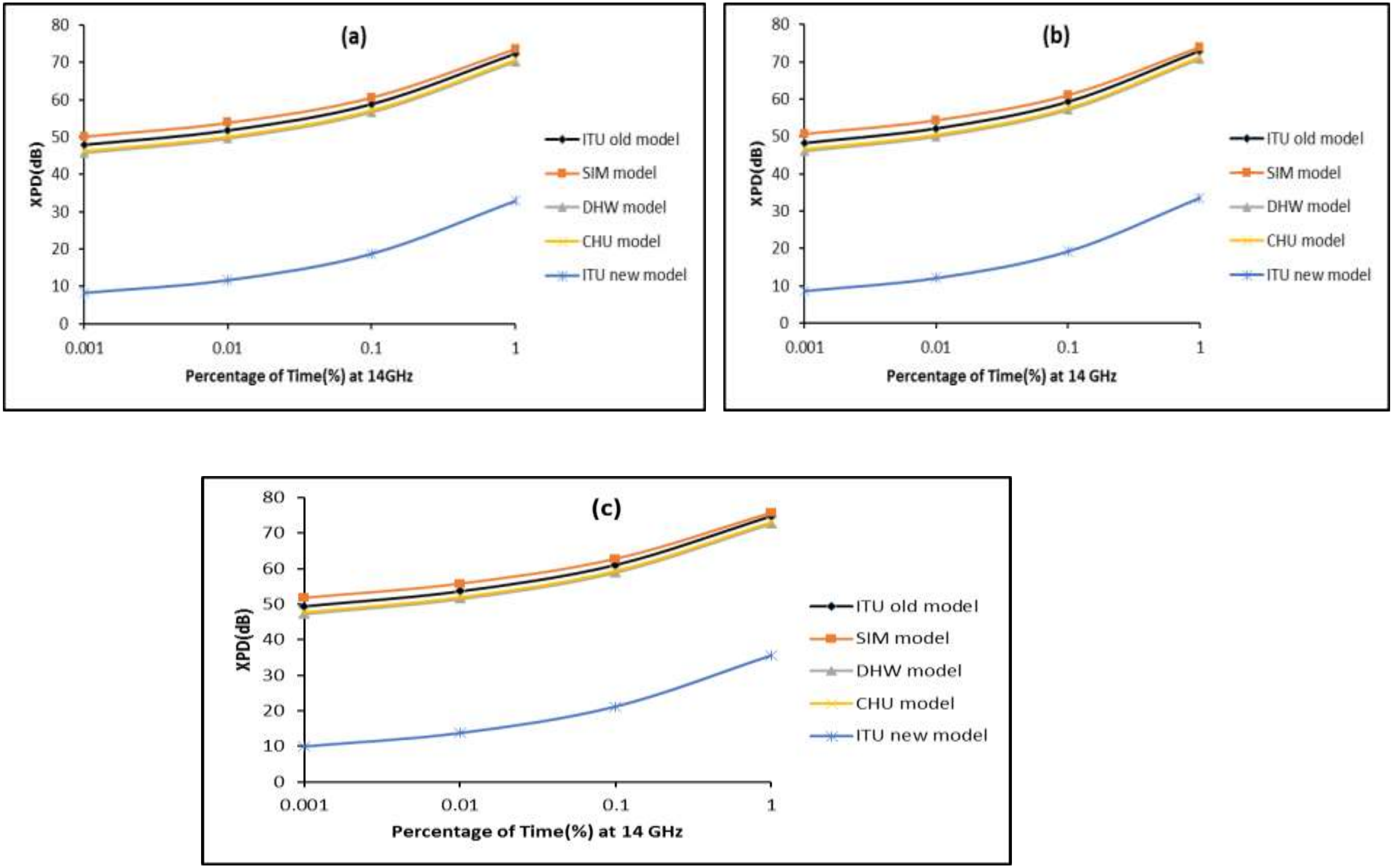

Figure 7. Cumulative distribution of XPD for frequency at 14 GHz for locations in the savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

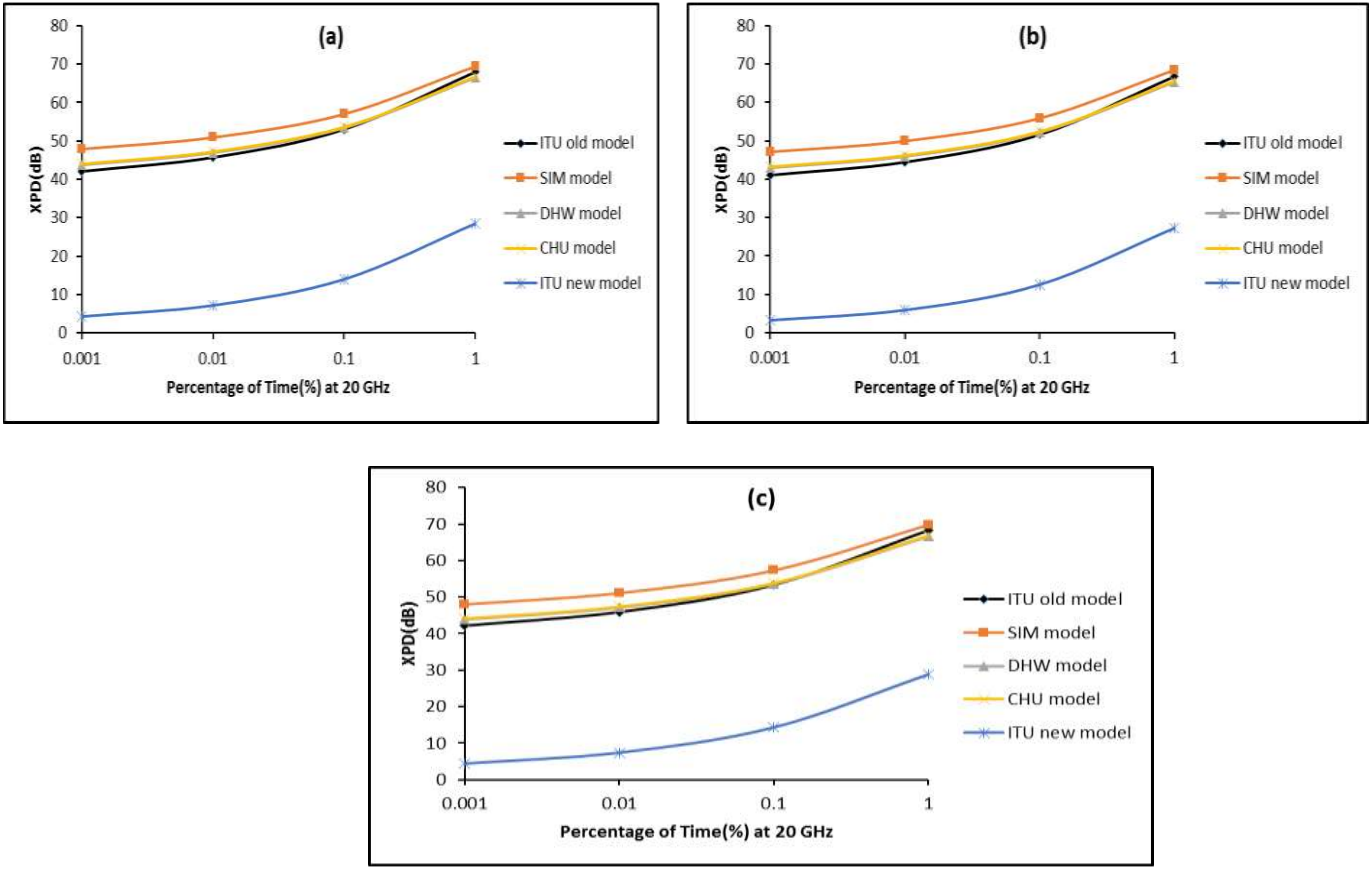

Figure 8. Cumulative distribution of XPD for Ka band for locations in the rainforest zone (a) Lagos (b) Port–Harcourt and (c) Akure.

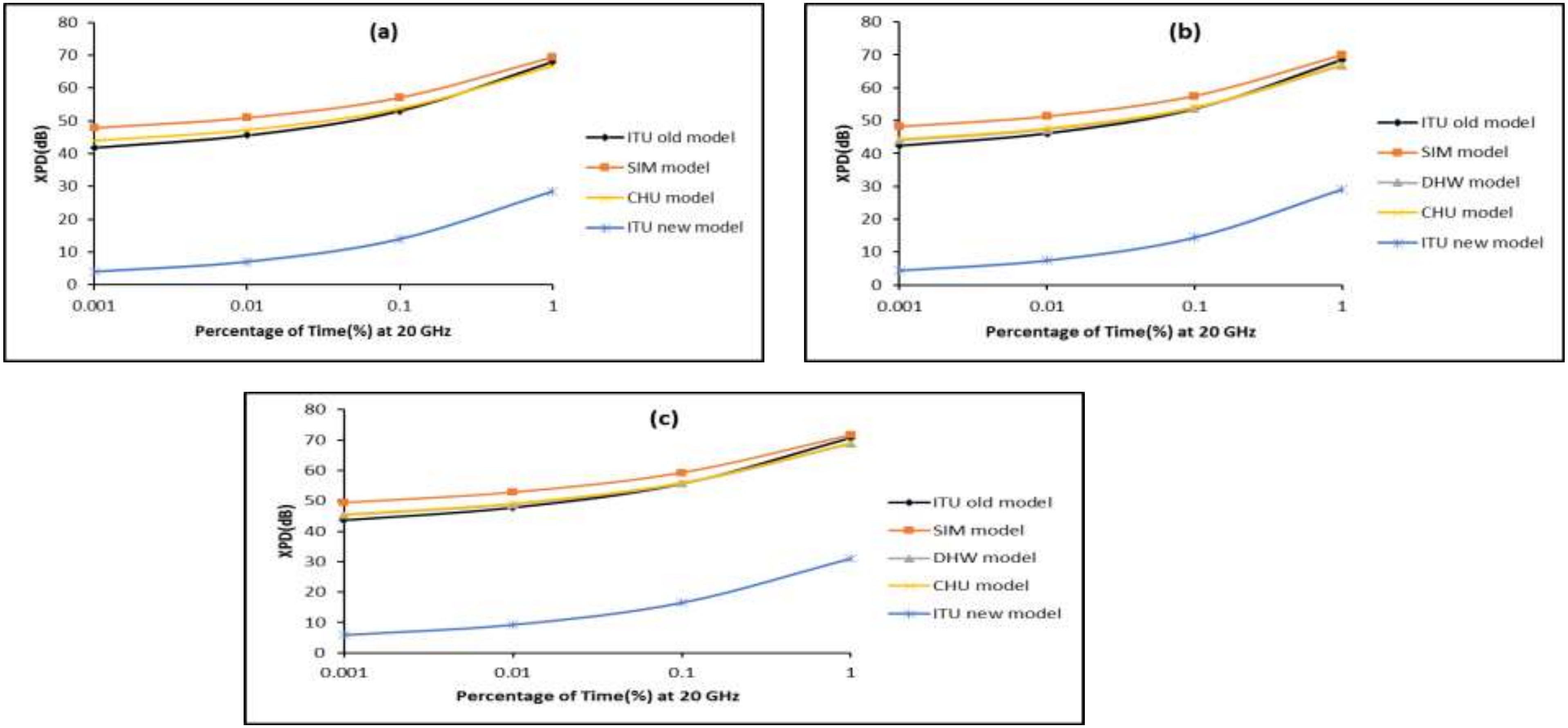

Figure 9. Cumulative distribution of XPD at Ka band for locations in the savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

Cumulative distribution of XPD at Q frequency band for all models

Also at Q band frequency, for locations in rainforest zone (Figure 10), XPD values increases as percentage of time increases. As revealed in the work of Adetan and Afullo (2013) and Uma et al. (2007), XPD decreases further as the frequency is increased for all the models in all the locations signifying high interference between orthogonal channels at the receiver stations. The performance of the model shows that there is agreement among DHW, old ITU-R, and Chu models between 0.001 and 0.1% of time while SIM shows marginal disagreement with other models but the recent ITU-R model displays total disagreement with other models. The performance of the models at 1% of time shows that SIM and Old ITU-R models are found to agree but they deviated slightly from DHW and Chu models. In all the locations, only the recent ITU-R model exhibits highest cross talk among other models.

For locations in savannah zone as presented in

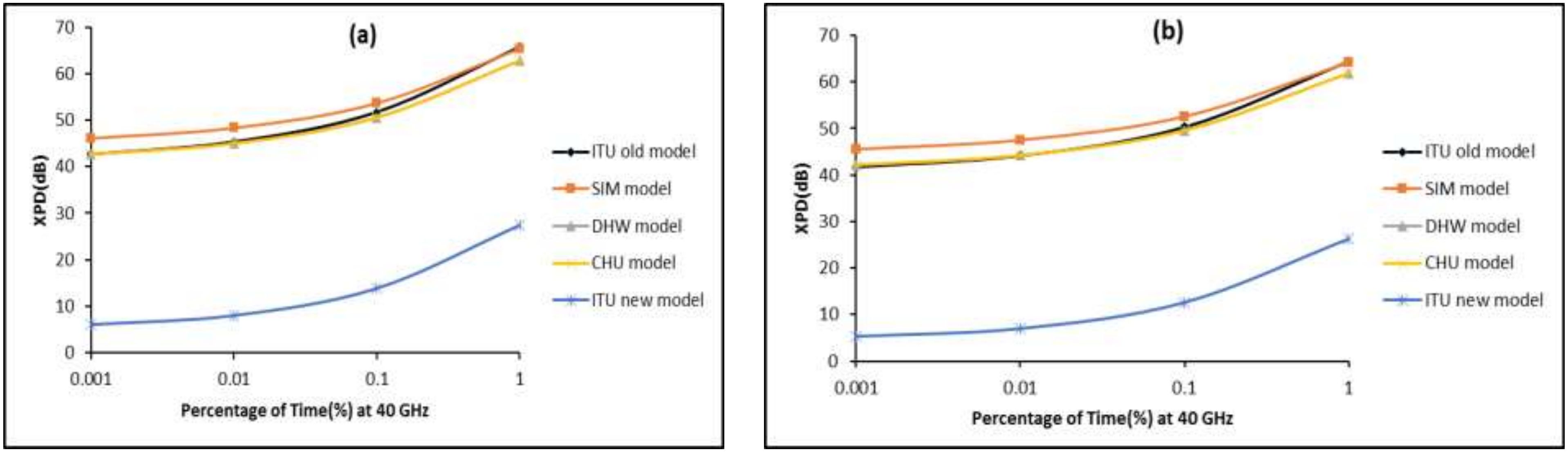

Figure 10. Cumulative distribution of XPD at Q band for locations in the rain forest zone (a) Lagos and (b) Port–Harcourt.

Figure 11, XPD values increases as percentages of time increases. There is agreement in performance of DHW, Old ITU-R, and Chu models between 0.001 and 0.1% of time while SIM and old ITU-R models show agreement between 0.1 and 1% of time. However, SIM and old ITU-R models disagree with DHW and Chu models at 1% of time.

The recent ITU-R model displays total disagreement with other models and also has the lowest values of XPD. SIM model has the highest values of XPD indicating the lowest unwanted signals in the co polarized signals during radio waves transmission. Old ITU-R model tends to attain the same values with SIM at 1% of time. Among the models, it is only SIM that will produce good quality of signals as the output signals at the receiver stations during propagation for a frequency reuse systems.

Variation of XPD with co-polar attenuation for frequency at 12 GHz for all models

Influence of XPD on co-polar attenuation is also considered. For example, at the frequency of 12 GHz, for locations in the rainforest zone (Figure 12), XPD values decrease as co-polar attenuation (CPA) increases. The decrease in XPD appears to be linear for CPA lower than 5.0 dB and thereafter tend to be parallel for all the models. These results show a good agreement with Uma et al. (2007), Ojo et al. (2010) and Adetan and Afullo (2013). DHW model, Old ITU-R model and Chu model are found to agree while SIM showed higher values of XPD at all times. However, the recent ITU-R is in total disagreement with other models and also displays the lowest value. This implies that the recent ITU-R model predicts higher cross talk than other models even though the CPA is generally low while SIM predicts lowest amount of unwanted signal among other models at the receiver stations. Communication between radio signals at the downlink of Ku band will often be interrupted because of high depolarization in the new ITU-R; however, the quality of signals received at receiver stations would be high in other models.

For locations in the savannah zone as presented in Figures 13 and 14, XPD values decrease as co-polar attenuation (CPA) increases with the recent ITU-R model based on the lowest value. DHW model, old ITU-R model and Chu model show good agreement while SIM is marginally deviated from DHW, old ITU-R and Chu models. SIM predicts the lowest amount of unwanted signal among other models at the receiver stations. However, XPD values for the recent ITU-R model exhibits different trend from Figures 12. The

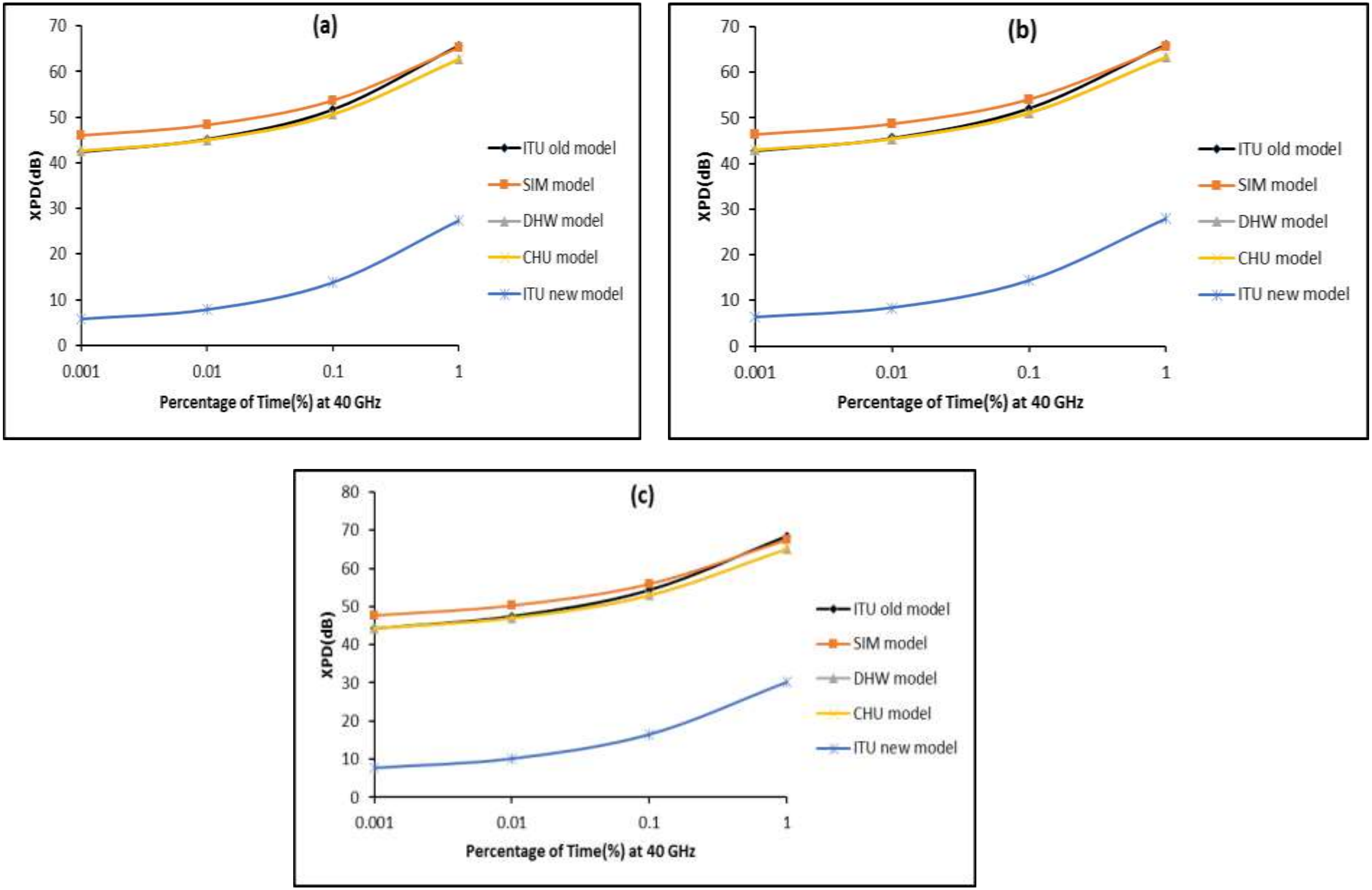

Figure 11. Cumulative distribution of XPD at Q band for locations in the savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

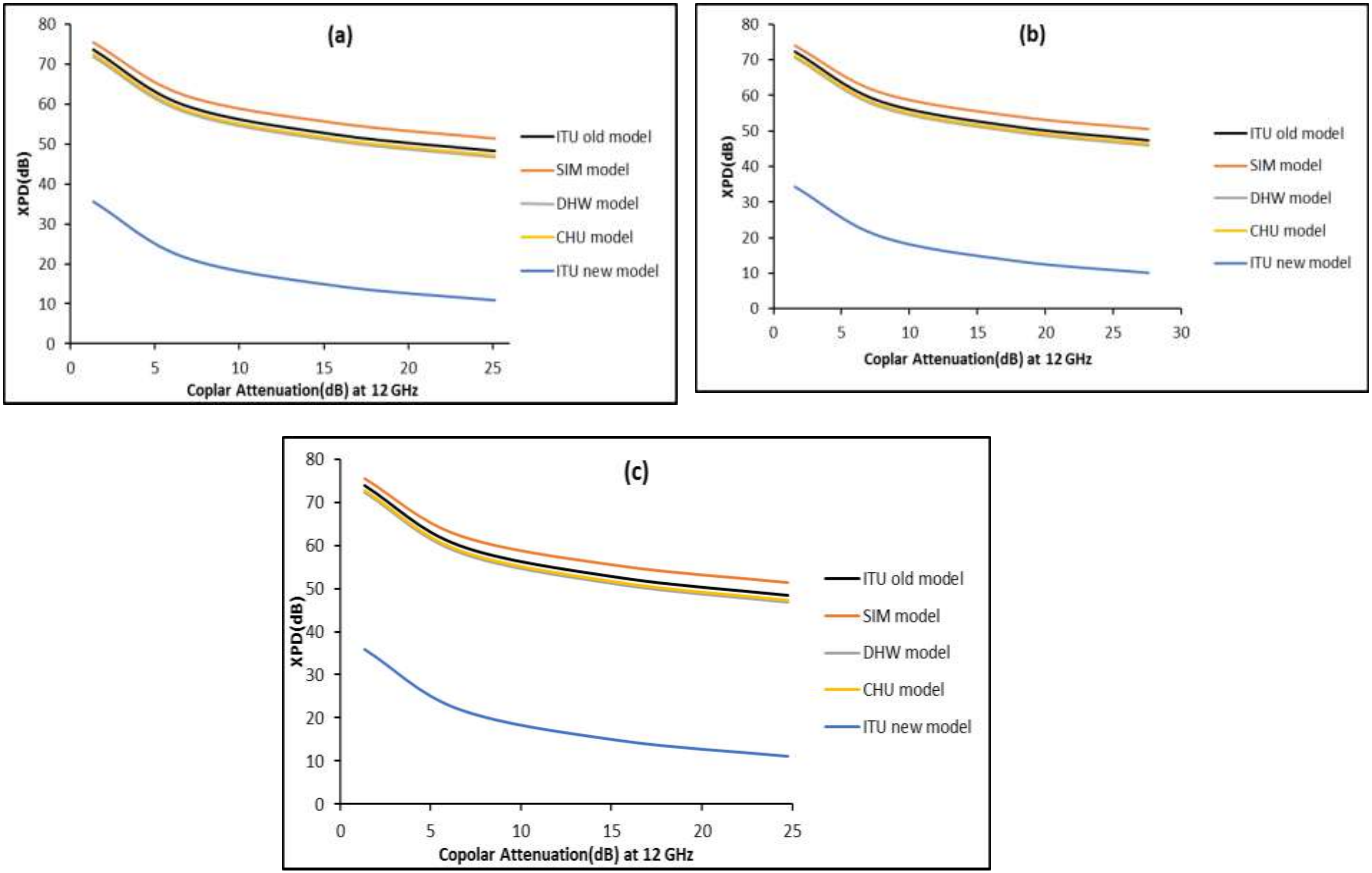

Figure 12. XPD versus CPA for frequency at 12 GHz for locations in the rain forest zone (a) Lagos (b) Port–Harcourt and (c) Akure.

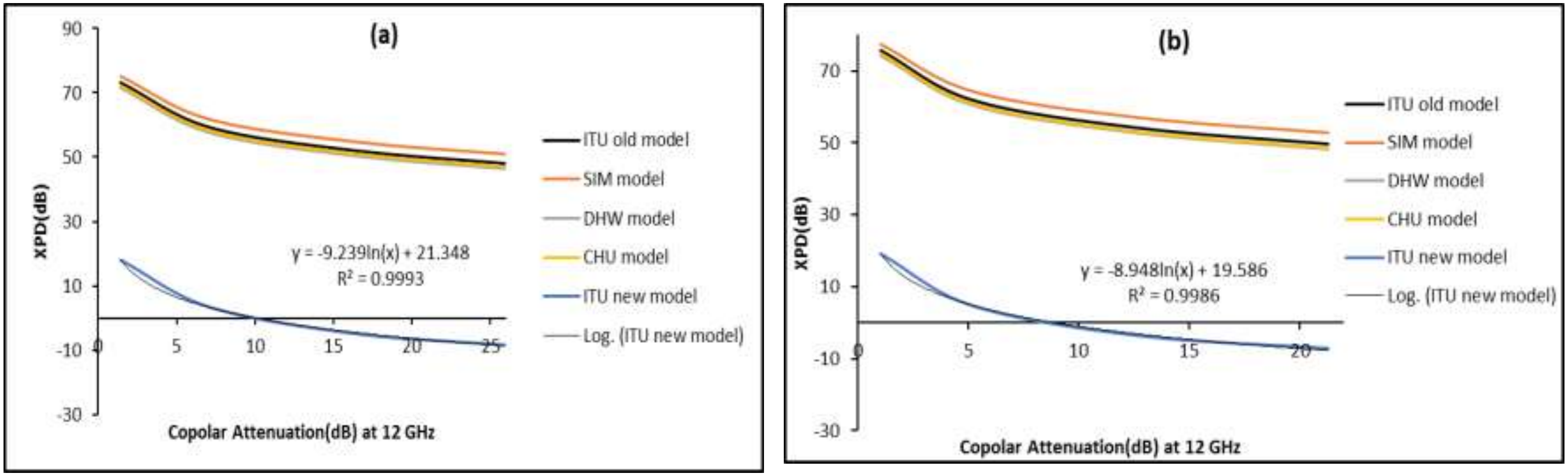

Figure 13. XPD versus CPA for frequency at 12 GHz for locations in the savannah zone (a) Nsukka and (b) Jos.

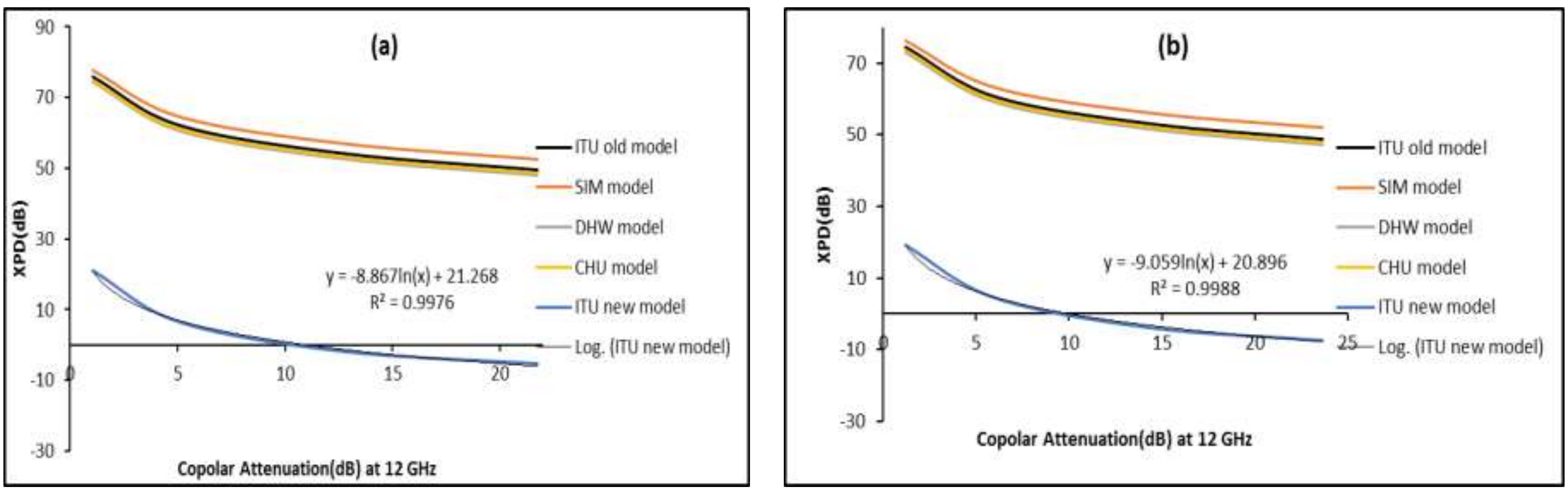

Figure 14. XPD versus CPA for frequency at 12 GHz for locations in the savannah zone (a) Sokoto and (b) Yola.

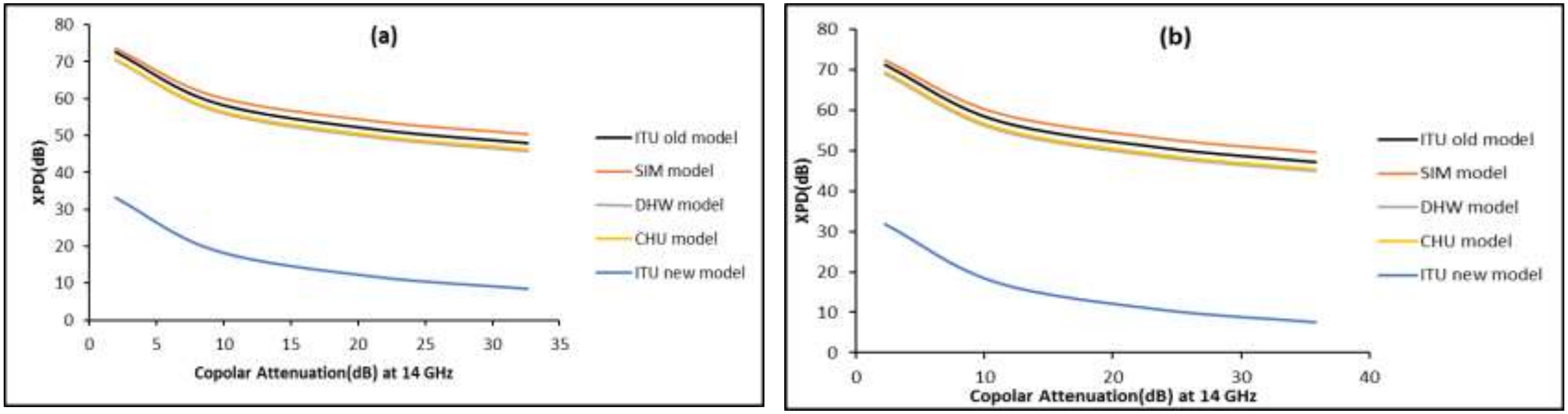

Figure 15. XPD versus CPA for frequency at 14 GHz for locations in the rain forest zone (a) Lagos and (b) Port–Harcourt.

modeling expression for the XPD logarithmically as a function of A_P can be expressed as:

$$XPD_{Nsukka} = -9.24 In(A_p) + 21.35 \quad (19)$$

Therefore, when $A_P = 10.08dB$ then $XPD = 0$

$$XPD_{Jos} = -8.95 In(A_p) + 19.59 \quad (20)$$

Therefore, when $A_P = 8.93dB$ then $XPD = 0$

For the savannah region at 12 GHz, the expression is:

$$XPD_{Sokoto} = -8.87 In(A_p) + 21.27 \quad (21)$$

Therefore, when $A_P = 11.00dB$ then $XPD = 0$

$$XPD_{Yola} = -9.06 In(A_p) + 20.90 \quad (22)$$

Therefore, when $A_P = 10.04dB$ then $XPD = 0$

Equations (19 - 22) imply very high interference at the receiver stations in frequency re-use system as XPD degraded to zero when attenuation reaches the values between 8.93 and 11.00 dB as presented in Figures 13 and 14. However, if attenuation is further increased beyond these values, crosstalk will overshadow as cross polarized signals become higher than co-polarized signal. Mitigation technique is required in these conditions to reduce depolarization and improve quality of output signals at receiver stations of dual orthogonal polarization systems.

The same trend could be observed at uplink frequency of 14 GHz, although with different values of XPD and co-polar attenuation for each of the models at both rainforest (Figure 15) and savannah zone (Figure 16).

Variation of XPD with co- polar attenuation at Ka frequency band for all models

At rain forest zone as presented in Figures 17 and 18 for downlink and uplink Ka frequency bands respectively, XPD values decrease as co-polar attenuation (CPA) increases. There is a decrease in XPD value as the frequency increases. The attenuation is higher at downlink of Ka band than at the Ku band frequency. SIM has the highest values of XPD and deviated from DHW, Old ITU-R, and Chu models; however, DHW, Old ITU-R and Chu models are found to agree between attenuation of 4.00 and 19.00 dB, thereafter Chu model deviated from DHW and old ITU-R models. The recent ITU-R model does not show good agreement with other models and also has the lowest values of XPD indicating the highest cross talk when compared with other models. These locations are in the zone with high rainfall intensity implying high cross talk in the locations and consequently weaker radio signals output is expected especially with the recent ITU-R model during signals transmission.

The attenuation is higher at the uplink than at downlink of Ka band, indicating more absorption of signals at the uplink. The decrease in XPD

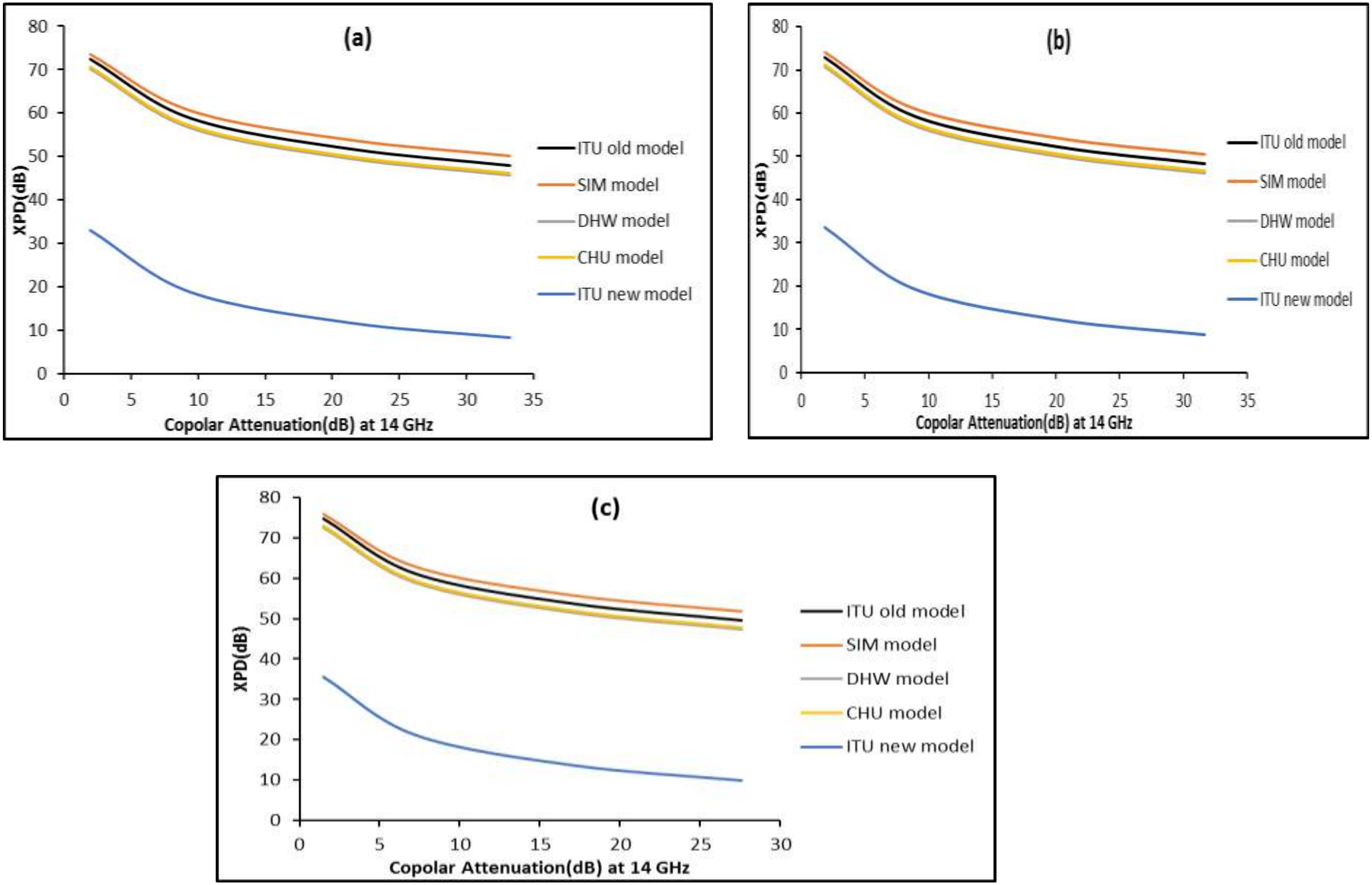

Figure 16. XPD versus CPA for frequency at 14 GHz for locations in the tropical savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

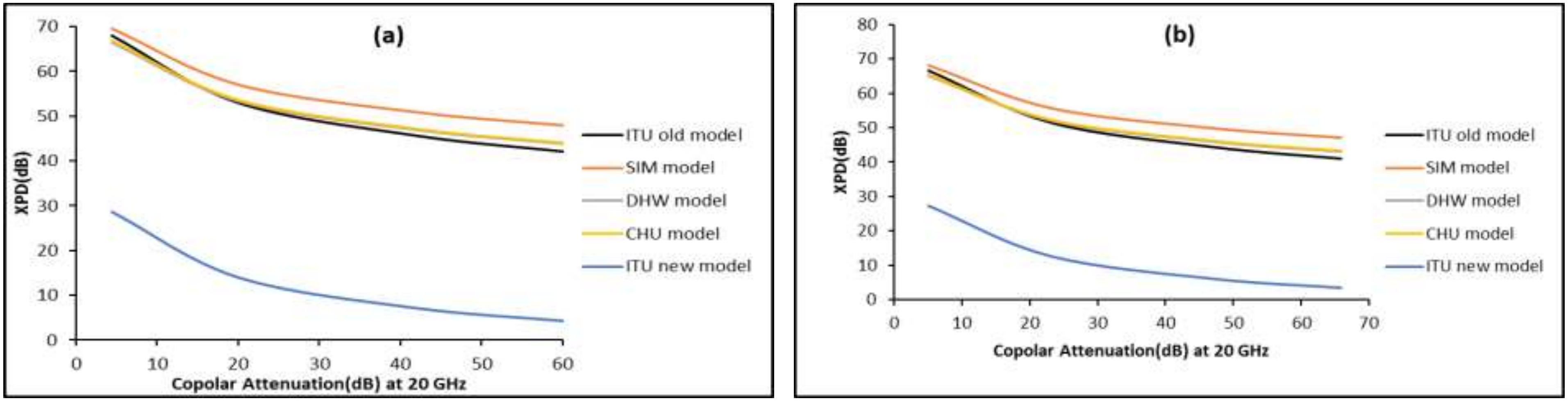

Figure 17. XPD versus CPA for frequency at Ka-downlink for locations in the rainforest zone (a) Lagos and (b) Port–Harcourt.

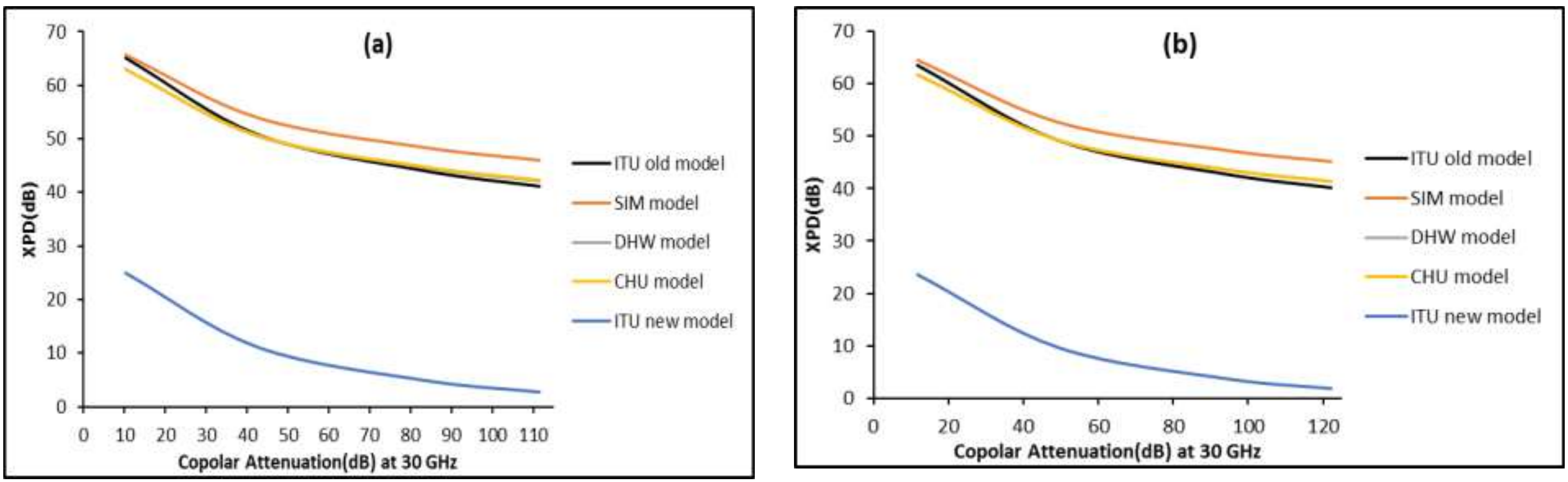

Figure 18. XPD versus CPA at uplink of Ka band for locations in the rainforest zone (a) Lagos and (b) Port–Harcourt.

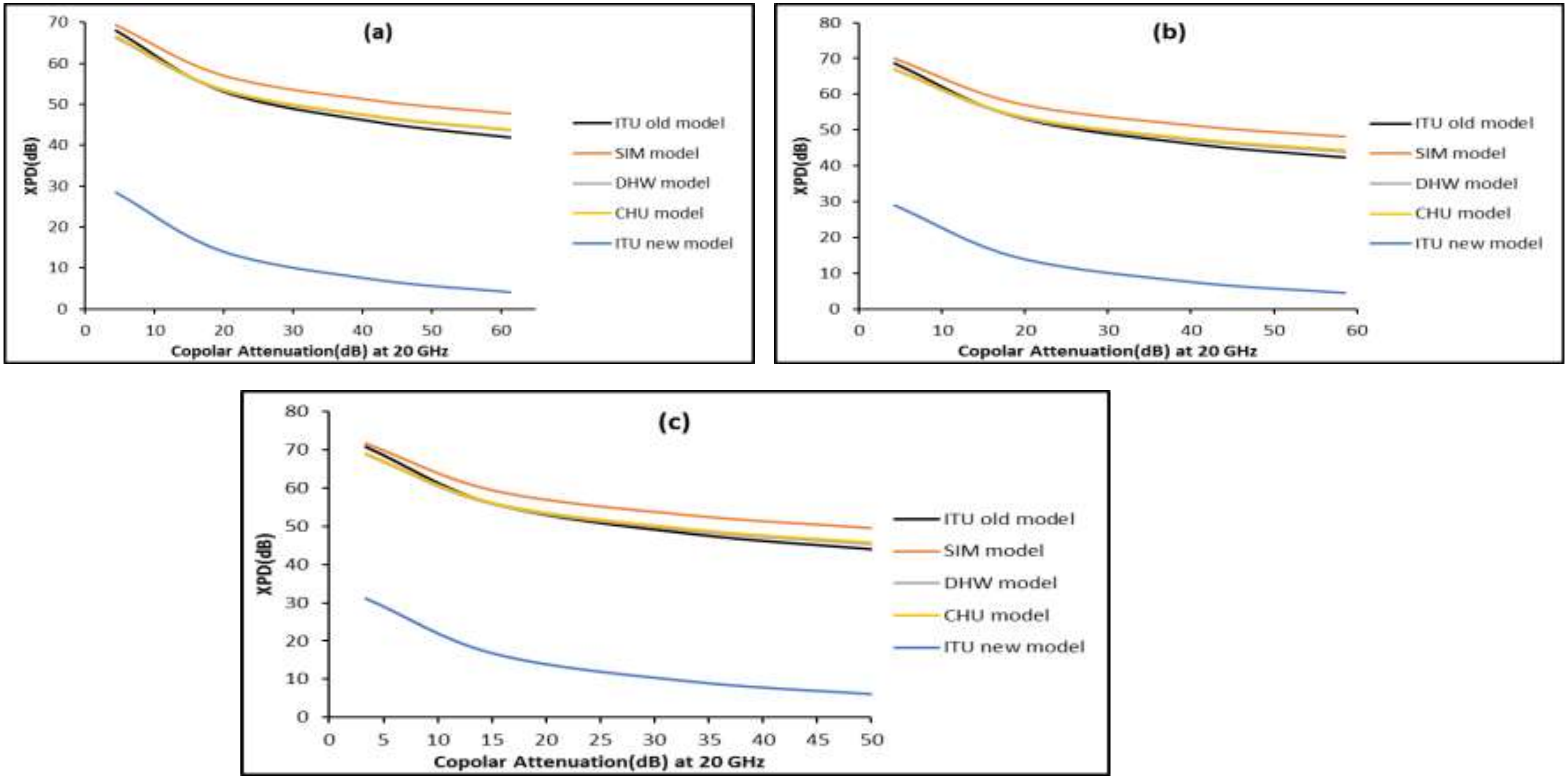

Figure 19. XPD versus CPA at downlink of Ka band for locations in the savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

values as co-polar attenuation (CPA) increases justify the inverse relation between XPD and CPA. SIM, DHW and Old ITU-R model are found to agree at attenuation of about 10.00 dB while Chu models deviates from others. SIM has the highest values of XPD and deviated from DHW, Old ITU-R, and Chu models; however, DHW, Old ITU-R and Chu models are found to agree between attenuation of 20.00 and 50.00 dB. Chu model shows negligible deviation from DHW and Old ITU-R models beyond 50.00 dB

The recent ITU-R model does not show good agreement with other models and widely deviated from other models. The recent ITU-R model also predicts the highest interference between orthogonal channels when compare with other models as it displays the lowest values of XPD. Generally speaking, XPD becomes poorer at uplink of Ka frequency band than at its downlink band. Mitigation technique is required if good quality of radio signals is desired in propagation of signals using dual orthogonal polarized systems.

The savannah zone for the downlink and uplink Ka frequency band is presented in Figures 19 and 20 respectively. At the downlink of Ka frequency band, SIM does not agree with DHW, Old ITU-R, and Chu models while very little agreement is

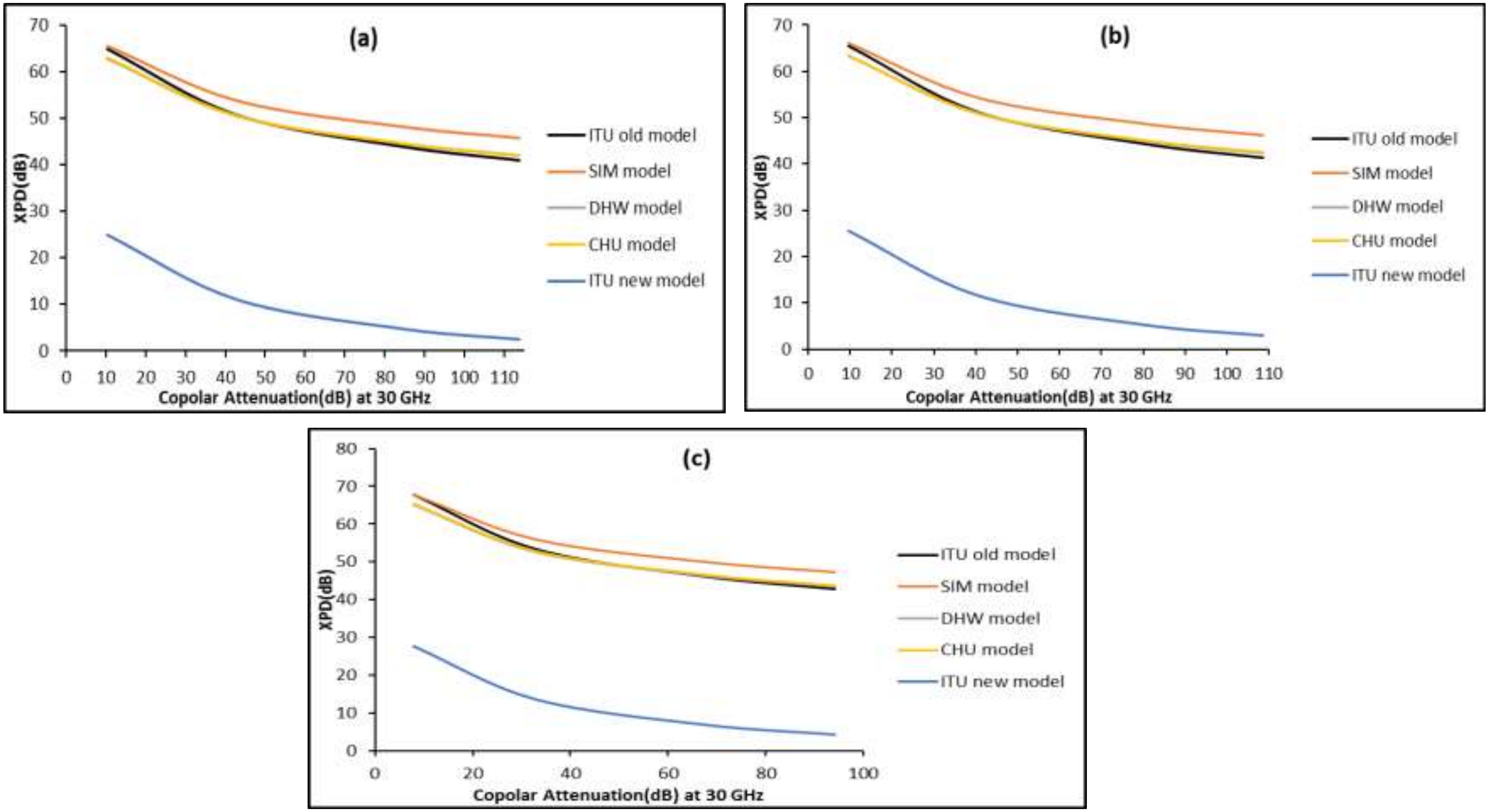

Figure 20. XPD versus CPA at uplink of Ka band for locations in the savannah zone (a) Anyigba (b) Makurdi and (c) Jos.

shown among DHW, Old ITU-R, and Chu models beyond co-polar attenuation of 20 dB. The recent ITU-R model totally disagrees with other models and also predicts the highest unwanted signals at receiver's station when compared with other models as it displays lowest values of XPD.

At the uplink (Figure 20) when the co-polar attenuation is about 90.00 dB, XPD values tend to zero value for the recent ITU-R model implying a very high cross talk at the receive station of the communication system. Initially SIM model shows an agreement with DHW, old ITU-R models before its deviation. Also, Chu model shows disagreement with SIM, DHW and old ITU-R models but later agree with them after attenuation of about 30 dB. Radio waves propagation will be the most favorable in terms of quality of output signals with SIM model.

Conclusion

The performance estimation of XPD models at millimetre wave bands employing dual polarization in Nigeria for signal transmission along Earth-Space propagation links has been presented. The performance of XPD models was examined at Ku, Ka, Q and V bands. Based on the five models considered, the results show that other models apart from the recent ITU-R model display similar performance. All the models predicted low XPD as frequency and CPA increases. At most of the frequencies considered, nearly all the models performed well with slightly deviation from each other while reverse is the case with the recent ITU-R model. Since the recent ITU-R model does not agree with the other models, it suggests that it will be prone to high depolarization than other models as it exhibits very low XPD. At downlink and uplink Ku band, the recent ITU-R model shows that unwanted signals will completely overshadow co-polarized signal between 0.001 and 0.018% of time for Jos and Yola, Sokoto and Nsukka. Similarly, when the fade level reaches value ranging from 8.93 to 11.08 dB, the crosstalk will be prevailing at the receiver stations in these locations. Though, the recent ITU-R received wider acceptance, its performance in this study is ranked the lowest while SIM model displayed the best performance. The study therefore recommends, SIM model as most preferred model to be adopted in estimating depolarization in the tropical location like Nigeria. The assertion in this study will be useful tools in assessing the level of depolarization effect along satellite communication links in Nigeria especially at centimetre and millimetre wave bands. However, further experimental data for validation is suggested to substantiate this assertion.

CONFLICT OF INTERESTS

Authors declare that there is no conflict of interests on this work

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