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Comparative Design of Radio Propagation Path Loss Models for 1800 MHz GSM Networks in Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi Local Government Areas of Cross River State

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Research Article

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Comparative Design of Radio Propagation Path Loss Models for 1800 MHz GSM Networks in Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi Local Government Areas of Cross River State.

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Abstract

This study compares GSM 1800 MHz radio propagation models (FSPL, Okumura-Hata, COST-231 Hata, and ECC-33) across five Local Government Areas in Cross River State, Nigeria, representing varied terrains such as semi-urban, rural, forested, coastal, and riverine environments. Using standard GSM parameters and geospatial mapping, the analysis showed an EIRP of 57 dBm and a MAPL of 159 dB. Path loss increased with distance and environmental complexity, with COST-231 Hata giving the most realistic overall predictions, while ECC-33 better captured severe attenuation in dense forest and coastal areas. Coverage radii ranged from 1.9 km to 2.8 km, with corresponding BTS requirements varying significantly due to terrain effects. Overall, the results confirm that terrain and vegetation strongly influence GSM signal propagation and highlight COST-231 Hata as the most practical model for network planning in the study area.

Keywords: GSM 1800 MHz, Radio Propagation, Path Loss Models, COST-231 Hata, Okumura-Hata, ECC-33, Coverage Analysis, GPS Mapping, Network Planning, Cross River State.

1. Introduction and Literature Review

The rapid growth of mobile communication services has increased the need for reliable GSM network coverage and quality of service, making radio propagation modeling an essential tool for coverage prediction, network optimization, and infrastructure planning [1]. Signal propagation is affected by environmental factors such as transmission distance, terrain elevation, vegetation density, building structures, and atmospheric conditions, all of which influence attenuation and coverage performance [2]. At GSM 1800 MHz, propagation losses are generally higher than those at lower frequency bands, necessitating the use of accurate propagation models for effective network deployment [3].

Several propagation models have been developed for terrestrial mobile communication systems. The Free Space Path Loss (FSPL) model, derived from the Friis transmission equation, provides a theoretical baseline for signal attenuation under ideal line-of-sight conditions but does not account for environmental effects [4]. To improve practical prediction accuracy, Okumura developed empirical propagation curves based on extensive field measurements [5], which were later transformed into the widely used Okumura-Hata model

by Hata for frequencies between 150 MHz and 1500 MHz [6]. The COST-231 Hata model subsequently extended Hata's formulation to frequencies up to 2000 MHz, making it suitable for GSM 1800 MHz network planning [7]. The ECC-33 model further incorporates environmental correction factors and is particularly effective in highly obstructed propagation environments such as forests and coastal regions [8].

Previous studies have shown that terrain morphology, vegetation density, and environmental clutter significantly affect radio propagation behavior and model prediction accuracy [9]. Investigations conducted in Nigerian environments reported considerable variations in propagation model performance depending on local terrain characteristics, emphasizing the need for location-specific model validation [10], [11]. Additional studies have demonstrated that forested areas experience substantial signal attenuation due to foliage absorption and scattering [12], while coastal and riverine environments are affected by multipath reflections, atmospheric moisture, and water-surface interactions [13].

Cross River State presents a diverse propagation environment comprising dense tropical rainforests, rural settlements, semi-urban areas, coastal wetlands, and riverine communities. LGAs such as Akamkpa are characterized by dense vegetation and rugged terrain, whereas Bakassi and Akpabuyo exhibit coastal features, while Odukpani and Biase represent mixed rural and semi-urban environments. Despite extensive GSM deployment within the state, limited studies have comparatively evaluated the FSPL, Okumura-Hata, COST-231 Hata, and ECC-33 models across these diverse environments. Therefore, this study integrates propagation modeling, GPS-based geospatial analysis, Google Earth mapping, coverage prediction, received signal strength estimation, clutter loss assessment, and BTS deployment analysis to identify the most suitable propagation model for GSM 1800 MHz network planning and optimization within the selected study areas [1]–[13].

2. Design Model

To implement this research practically in Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi LGAs, realistic GSM-1800 network parameters required based on typical cellular base station configurations used by operators such as MTN Nigeria, Airtel Nigeria, Globacom, and 9mobile are given operating frequency$f = 18ooMHz$, base station height, $h_b = 40m$, mobile station height $h_m = 1.5m$, base station transmit power, $P_t = 43dB\ (20W)$, antenna gain $G_b = 18dBi$, feeder loss $L_f = 3dB$, connector loss $L_c = 1dB$, receiver sensitivity $P_r(\min) = -102dBm$, cell radius $d = 1 - 20km$, environment temperature $T = 27°C$, polarization – vertical and terrain type – rural, forest, coastal.

a. Effective Isotropic Radiated Power (EIRP)

The practical EIRP is [2], [3]

$$EIRP = P_t + G_t - L_f - L_c \qquad (1)$$

Substituting the given values values;

$$EIRP = 43 + 18 - 3 - 1 = 57dBm$$

Thus the base station radiates an effective power of $EIRP = 57dBm$

b. Maximum Allowable Path Loss (MAPL)

The maximum permissible propagation loss for reliable communication is calculated as [3] The Maximum Allowable Path Loss is

$$MAPL = EIRP + G_m - P_r(min) \quad (2)$$

Substituting values

$$MAPL = 57 + 0 - (-102) = 159dB$$

This implies that coverage is expected only where predicted path loss remains below 159dB.

c. Free Space Path Loss Computation

The free-space attenuation model derived from the Friis equation is expressed as [1], [2] using

$$PL_{FS} = 32.44 + 20log_{10}(f) + 20log_{10}(d) \quad (3)$$

For $f = 1800MHz, d = 5km$

Calculate $20log_{10}(1800) = 65.11, and\ 20log_{10}(5) = 13.98$

Therefore,

$$PL_{FS} = 32.44 + 65.11 + 13.98 = 111.53dB$$

d. Mobile Antenna Correction Factor

The Hata mobile antenna correction factor is expressed as [4] using

$$\mathrm{a(h}_m) = (1.1\log_{10}\mathrm{f} - 0.7)\mathrm{h}_m - (1.56\log_{10}\mathrm{f} - 0.8) \quad (4)$$

since, $log_{10}(f) = log_{10}(1800) = 3.255$

$$\mathrm{a(h}_m) = (11 \times 3.255 - 0.7)(1.5) - (1.56 \times 3.255 - 0.8) = 4.32 - 4.28 = 0.04dB$$

e. Okumura-Hata Model

For urban propagation environments, the Okumura-Hata model is given by [4]. Using Okumura-Hata model, the path loss is

$$PL_{OH} = 69.55 + 26.16log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) \quad (5)$$

Compute:

$$26.16\log_{10}(f) = 26.16\log_{10}(1800) = 85.15$$

$$13.82\log_{10}(h_b) = 13.82\log_{10}(40) = 22..14$$

$$44.9 - 6.55\log_{10}(40) = 34.40$$
$$40\log_{10}(5) = 24.04$$

Hence, the Okumra-Hata path loss is compute as

$$PL_{OH} = 69.55 + 85.15 = 22.14 - 24.04 = 156.56dB$$

f. COST-231 Hata Practical Model

The extension of the Hata model for frequencies up to 2000 MHz is expressed as [5]. Using these given parametric values, $f = 1800\ MHz,\ h_b = 40m\ and\ h_m = 1.5\ m$

The COST-231 Hata model, the path loss becomes

$$PL_{COST} = 46.3 + 33.96log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + \left(44.9 - 6.55\log_{10}(h_b)\right)\log_{10}(d) + C \quad (6)$$

where C=3 dB for metropolitan environments and C=0C = 0C=0 dB otherwise

To calculate the path loss using this model where, $C = 3dB$, calculate;

$$33.96log_{10}(1800) = 110.37$$

Thus, the path loss becomes;

$PL_{COST} = 46.3 + 110.37 - 22.14 - 0.04 + 24.04 + 3$ =161.53dB

g. ECC-33 Model

The ECC-33 model is expressed as [6]:

- **Free-space component**

The free-space attenuation The ECC-33 model is calculated using

$$\boldsymbol{A_{fs} = 92.4 + 20log_{10}(d) + 20log_{10}(f)} \quad (\mathbf{7})$$

If the computation of $\boldsymbol{20log_{10}(d) = 13.98dB}$ and $\boldsymbol{20log_{10}(f) = 65.11dB}$, the path loss using this model is;

$$\boldsymbol{A_{fs} = 92.4 + 13.98 + 65.11 = 171.49dB}$$

- **Basic Median Loss**

$$\boldsymbol{A_{bm} = 20.41 + 9.83log_{10}(d) + 7.894log_{10}(f) + 9.56(log_{10}f)^2} \quad (\mathbf{8})$$

After computing $\boldsymbol{9.83log_{10}(d) = 6.87d, 7.894log_{10}(f) = 25.68dB, and\ 9.56(log_{10}f)^2}$, then the basic medium loss becomes;

$$\boldsymbol{A_{bm} = 20.41 + 6.87 + 25.69 + 101.28 = 154.25dB}$$

Assuming, $\boldsymbol{G_b = 18dBi, and\ G_r = 0dBi}$

Therefore, the ECC-33 path loss is obtained using

$$\boldsymbol{PL_{ECC} = A_{fs} + A_{bm}} \quad (\mathbf{9})$$

As;

$$\boldsymbol{PL_{ECC} = 171.49 + 154.25 - 18 = 307.74dB}$$

This result demonstrates the highly conservative nature of ECC-33 under severe propagation conditions.

h. Received Signal Strength (RSS)

The received power at the mobile station is computed using the link-budget equation [3]. Using COST-231 prediction:

$$RSS = P_t + G_t + G_r - PL \quad (10)$$

$$P_r = 43 + 18 + 0 - 161.53 \ = -100.53dBm\}$$

Since $P_r > -102dBm$, communication is still possible at 5km

i. Signal Margin

Signal magine is calculated [3] using

$$M = P_r - P_{sens} \quad (11)$$

Given; that $P_{sens} = -102M$ and $P_r = 100.55dBm$, then signal margin is obtained as;

$$M = -100.53 - (-102\ M) = 1.47dB$$

j. Practical Clutter Loss Application

For each study area, the clutter loss for Odukpani wis 3dB, Biase 5dB, Akamkpa is 12dB, Akpabuyo is 7dB, and Bakassi is 10dB.

The practical path loss is calculated using

$$PL_{practical} = PL_{COST} + L_{clutter} \quad (11)$$

Firstly, the path loss of each study area is calculated as

Odukpani $PL = 161.53 + 3 = 164.53dB$, Biase $PL = 166.53dB$, Akamkpa $PL = 171.53dB$, Akpabuyo $PL = 168.53dB$, and Bakassi $PL = 171.53dB$

k. Coverage Area Computation

Practical radius:

Cell coverage area where $R = 2.8km$

$$A_c = \pi R^2 \quad (12)$$

$$A_c = \pi(2.8)^2 = 24.63km^2$$

Assuming 80% planning efficiency

$$A_{eff} = 19.7km^2$$

l. Number of Base Stations Required

The number of base stations in each local governments, the approximate land areas area are, Odukani is 923 km², Biase is 1,310 km², Akamkpa is 5,003 km², Akpabuyo is 1,241 km², and Bakassi is 665 km².

- **Number of BTS Requirement Estimation**

The number of base transmission stations for each Local Government is determined [3] using

$$Number\ N = \frac{LG\ coverage\ area}{cell\ coverage\ area} \quad (13)$$

For Odukpani $N = \frac{923}{24.63} = 37.5BTS$

For Biase $N = \frac{1310}{24.63} = 54BTS$

For akamkpa $N = \frac{5003}{24.63} = 203BTS$

For Akpabuyo $N = \frac{1241}{24.63} = 51BTS$

For Bakassi $N = \frac{665}{24.63} = 27BTS$

Table 1. Final Design Results

Parameter	Result
EIRP	57 dBm
MAPL	159 dB
FSPL at 5 km	111.53 dB
Okumura-Hata Loss	156.56 dB
COST-231 Loss	161.53 dB
ECC-33 Loss	307.74 dB
RSS at 5 km	-100.53 dBm
Signal Margin	1.47 dB
Cell Radius	2.8 km

Coverage Area	24.63 km²

These computations provide a complete practical design framework for the comparative evaluation of GSM 1800 MHz propagation models across Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi LGAs of Cross River State.

Table 2. Predicted Path Loss for Cross River Locations

Distance (km)	COST-231 Path Loss (dB)
1	143.61
2	154.12
3	160.27
5	168.02
10	178.53
15	184.68
20	189.04

Comparing with:

$$MAPL = 159\,dB$$

The practical cell edge occurs between 2 km and 3 km.

Practical Cell Radius Estimation

At the coverage boundary:

$$PL_{COST} = 159\,dB$$

Using (3),

$$159 = 143.61 + 34.92log_{10}(d)$$

Solving

$$log_{10}(d) = 0.441$$

Then

$$d = 2.76km$$

Therefore, $R \approx 2.8km$

Environment-Specific Correction Factors

To improve prediction accuracy, additional clutter losses may be assigned as; Odukpani 3dB, Biase 5dB, Akamkpa 12dB, Akpabuyo 7dB, and Bakassi 10dB. Thus the practical propagation model becomes

$$PL_{COST} = PL_{COST} + L_c \qquad (5)$$

3. Discussion of Results

The discussion compares FSPL, Okumura–Hata, COST-231 Hata, and ECC-33 models for GSM 1800 MHz across the study areas, showing how terrain, vegetation, and coastal conditions affect signal loss and coverage. It highlights that path loss increases with distance, reducing signal quality and coverage range, which has direct implications for base station planning and network optimization. Overall, COST-231 Hata gives the most balanced predictions for general use, while ECC-33 performs better in more obstructed or coastal environments.

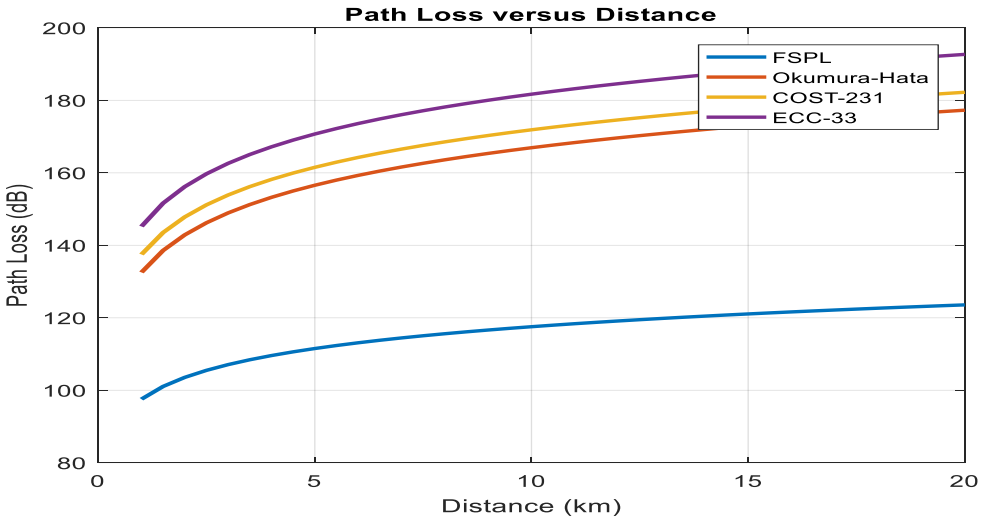


Figure 1. Path Loss versus Distance for FSPL, Okumura-Hata, COST-231 Hata, and ECC-33 Models

The Figure 1. illustrates the attenuation characteristics of the four propagation models operating at 1800 MHz. As expected, all models exhibit increasing path loss with increasing distance due to the reduction in received signal power as the radio wave propagates away from the transmitting base station. The Free Space Path Loss (FSPL) model predicts the lowest attenuation throughout the entire distance range because it assumes ideal line-of-sight propagation without considering environmental effects such as vegetation, buildings, terrain obstructions, or atmospheric absorption. Consequently, FSPL provides optimistic coverage predictions that are not representative of real GSM deployment conditions in Cross River State. The Okumura-Hata model predicts higher path loss values than FSPL because it incorporates empirical corrections for terrestrial propagation environments. The COST-231 Hata model produces slightly higher losses than the Okumura-Hata model due to its optimization for frequencies above 1500 MHz, making it particularly suitable for GSM 1800 MHz systems. The ECC-33 model consistently predicts the highest attenuation values because it incorporates more severe environmental effects. The model is therefore highly conservative and particularly useful in forested and coastal environments such as Akamkpa and Bakassi. The graph confirms that propagation losses become increasingly significant as communication distance increases and that model selection strongly influences network coverage predictions.

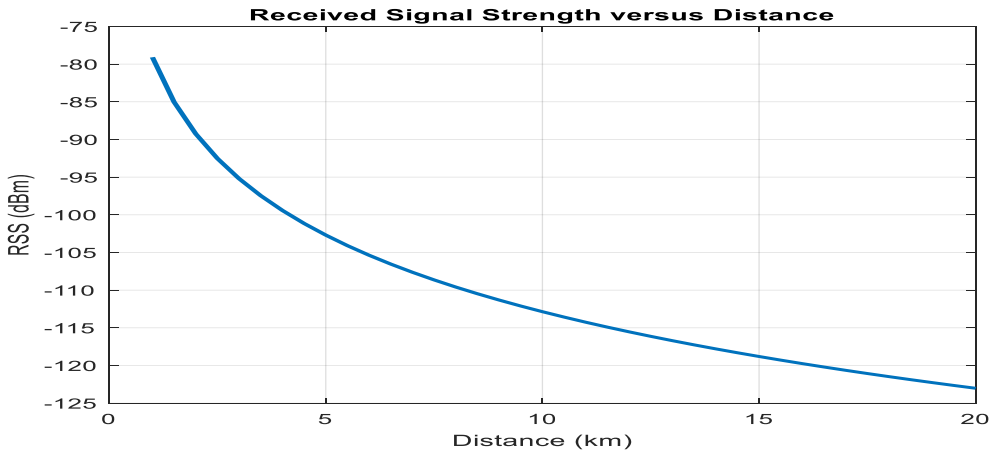


Figure 2. Received Signal Strength (RSS) versus Distance

This Figure demonstrates the gradual reduction of received signal power as the mobile user moves farther away from the base station. At short distances, the received signal strength remains relatively high because propagation losses are limited. However, as the distance increases, the cumulative attenuation causes a steady decrease in RSS. The graph reveals the inverse relationship between path loss and received signal power. At distances approaching the edge of the cell, the RSS approaches the receiver sensitivity threshold of −102 dBm. Beyond this point, signal quality deteriorates significantly, leading to increased call drops, reduced data rates, and possible service outages. This behavior highlights the importance of proper cell radius planning and demonstrates the practical limitations imposed by propagation losses in GSM networks operating at 1800 MHz.

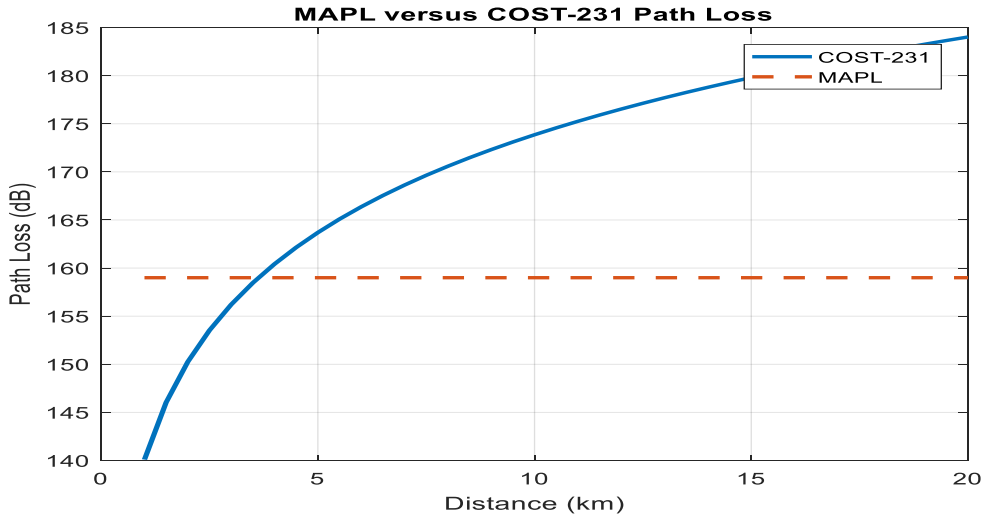


Figure 3. MAPL versus Distance

The graph compares the predicted COST-231 path loss values with the Maximum Allowable Path Loss (MAPL) of 159 dB. The horizontal MAPL line represents the maximum attenuation that can be tolerated while maintaining reliable communication between the base station and mobile receiver. Initially, the COST-231 path loss curve remains below the MAPL threshold, indicating satisfactory network performance. As distance increases, the path loss gradually approaches the MAPL value. The point at which

the two curves intersect defines the practical coverage limit of the GSM cell. The graph indicates a practical cell radius of approximately 2.8 km. Beyond this distance, the received signal strength falls below acceptable levels, requiring additional base stations to maintain continuous coverage.

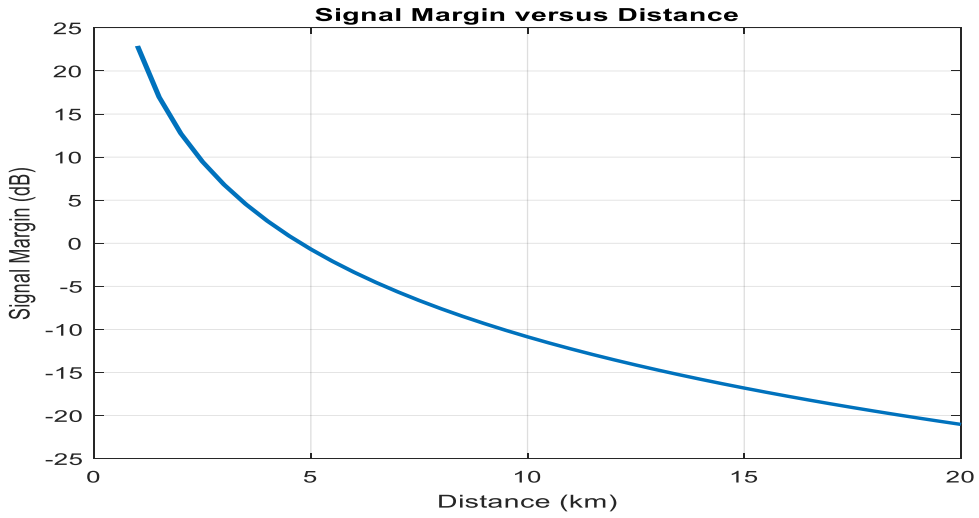


Figure 4. Signal Margin versus Distance

This graph shows the remaining link budget available above the receiver sensitivity threshold. Signal margin is a direct measure of network reliability and service robustness. At shorter distances, the signal margin is relatively large because the received signal power is substantially higher than the minimum required receiver sensitivity. As distance increases, propagation losses reduce the received signal strength and consequently reduce the available margin. The graph shows that the signal margin approaches zero near the cell boundary. When the margin becomes negative, communication becomes unreliable. This result confirms that cell radius and network reliability are directly influenced by propagation conditions and terrain characteristics.

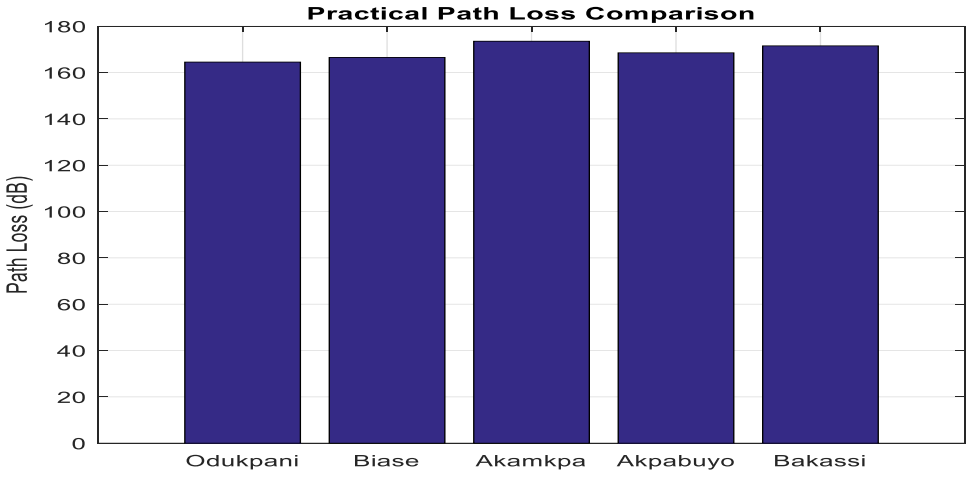


Figure 5. Practical Path Loss Comparison among LGAs

The Practical Path Loss graph compares the clutter-corrected path loss values for the five selected LGAs. Odukpani has 164.53dB, Biase has 166.53dB, Akamkpa has 173.53dB, Akpabuyo goes with 168.53dB, while Bakassi has 171.53dB. The graph shows that Akamkpa records the highest path loss due to its dense rainforest environment and rugged terrain. The extensive vegetation introduces significant absorption and scattering losses, which greatly increase signal attenuation. Bakassi also exhibits high path loss because of its coastal and riverine environment where reflections, multipath propagation, and atmospheric moisture contribute to signal degradation. Odukpani records the lowest path loss because of its relatively open terrain and lower clutter density. This finding demonstrates the significant impact of environmental conditions on radio propagation performance.

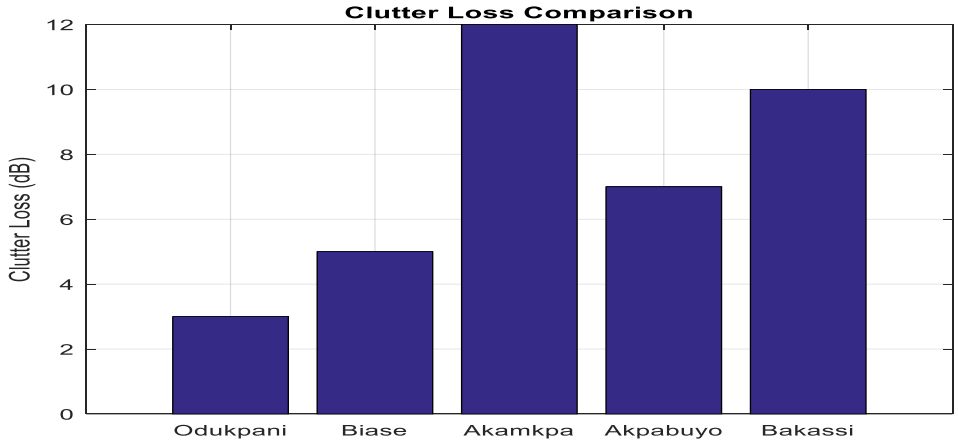


Figure 6. Clutter Loss Comparison among LGAs

The Clutter Loss graph quantifies the additional attenuation introduced by environmental obstacles. Odukpani got 3dB, Biase 5dB, Akamkpa 12dB, Akpabuyo 7dB, and Bakassi got 10dB clutter loss. The graph clearly shows that Akamkpa experiences the highest clutter loss, followed by Bakassi. This observation is consistent with the presence of dense tropical forests in Akamkpa and coastal mangrove vegetation in Bakassi. Odukpani exhibits the smallest clutter loss because of its relatively open propagation environment. The graph confirms that clutter loss is one of the primary factors influencing GSM network coverage and must be considered in propagation model selection.

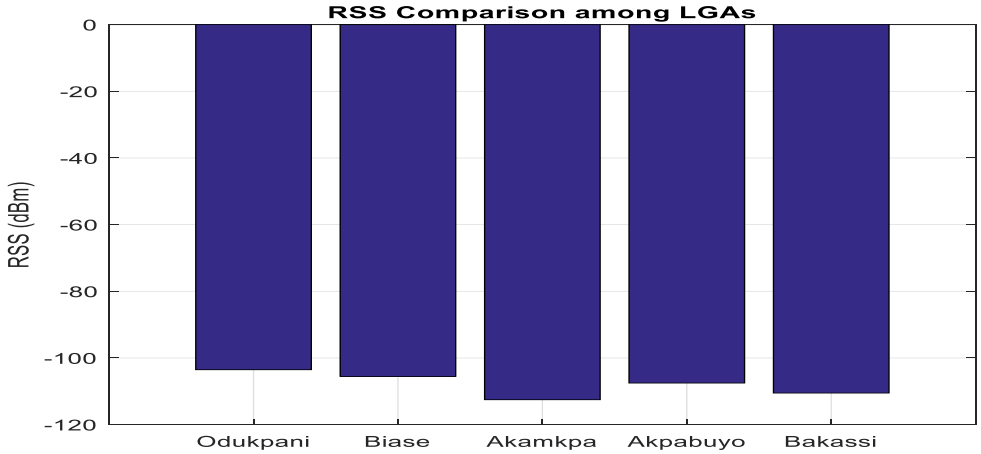


Figure 7. RSS Comparison among LGAs

The RSS comparison graph illustrates the effect of environmental conditions on received signal strength. In RSS comparison, Odukpani has -103.53dBm, Biase -105.53dBm, Akamkpa -112.53dBm, Akpabuyo -107.53dBm, and Bakassi has 110.53dBm. The graph shows that Odukpani provides the strongest received signal due to its lower path loss and favorable terrain characteristics. Akamkpa records the weakest signal because dense vegetation significantly attenuates radio waves. Bakassi also exhibits poor signal levels due to coastal propagation challenges. The graph demonstrates that environmental conditions directly influence signal quality and user experience.

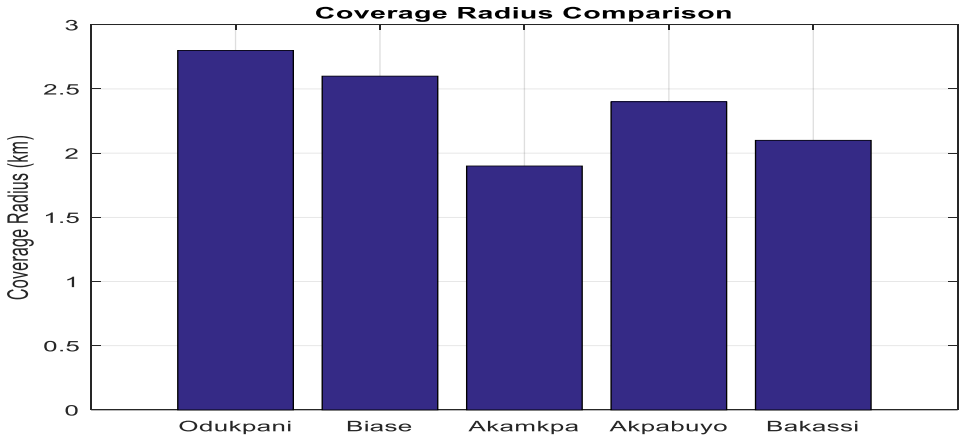


Figure 8. Coverage Radius Comparison among LGAs

The Coverage Radius graph illustrates how propagation conditions affect the achievable cell radius. This case, Odukani radius is 2.8km, Biase 2.6km, Akamkpa 1.9km, Akpabuyo 2.4km, while Bakassi has 2.1km radius. The graph reveals that Odukpani achieves the largest coverage radius due to its lower clutter loss and favorable propagation environment. In contrast, Akamkpa records the smallest coverage radius because severe attenuation limits signal reach. The results demonstrate that coverage radius decreases as environmental attenuation increases.

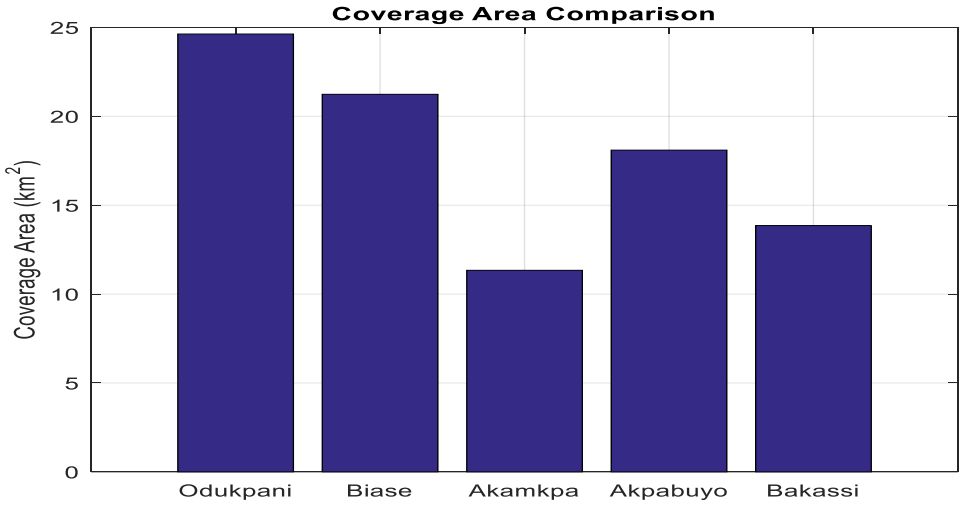


Figure 9. Coverage Area Comparison among LGAs

Using the calculated cell radii, the Coverage Area graph compares the service area provided by a single base station. In Odukpani, the coverage area is 24.63 km², Biase 21.24 km², Akamkpa 11.34 km², Akpabuyo 18.10 km², and Bakassi coverage is 13.85 km². The graph shows that Odukpani provides the largest service area per BTS, while Akamkpa provides the smallest. This result directly reflects the effect of propagation losses on network coverage efficiency. The reduced coverage area in Akamkpa implies that more infrastructure is required to provide the same level of service as in Odukpani.

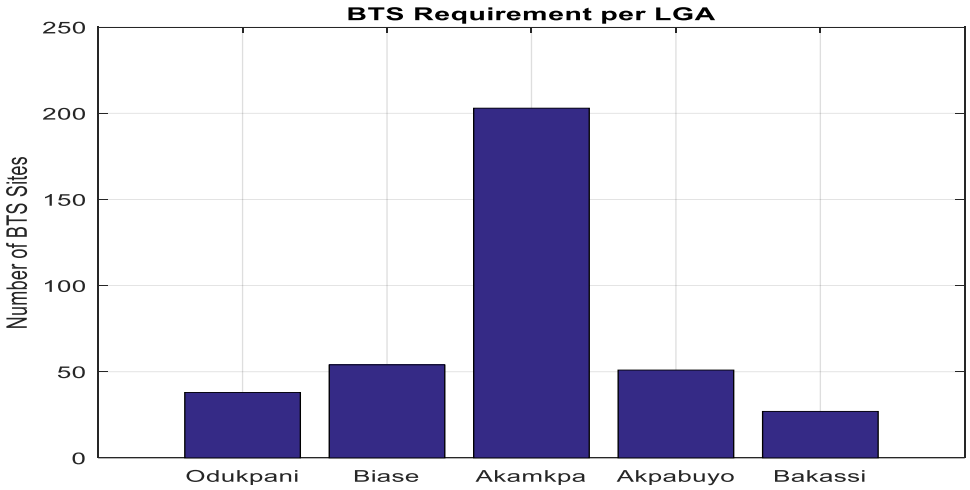


Figure 10. BTS Requirement Comparison among LGAs

The BTS Requirement graph estimates the number of base stations required to provide full coverage.- the number of the base transmission stations required in Odukani is 38, Biase is 54, Akampa is 203, Akabuyo is 51, and Bakassi requires 27 base stations. Akamkpa requires the highest number of BTS installations because it combines the largest geographical area with the most severe propagation losses. The reduced coverage radius necessitates a denser network infrastructure. Bakassi requires fewer BTS sites due to its smaller land area despite experiencing relatively high attenuation. This graph demonstrates the relationship between propagation environment, coverage radius, and infrastructure investment.

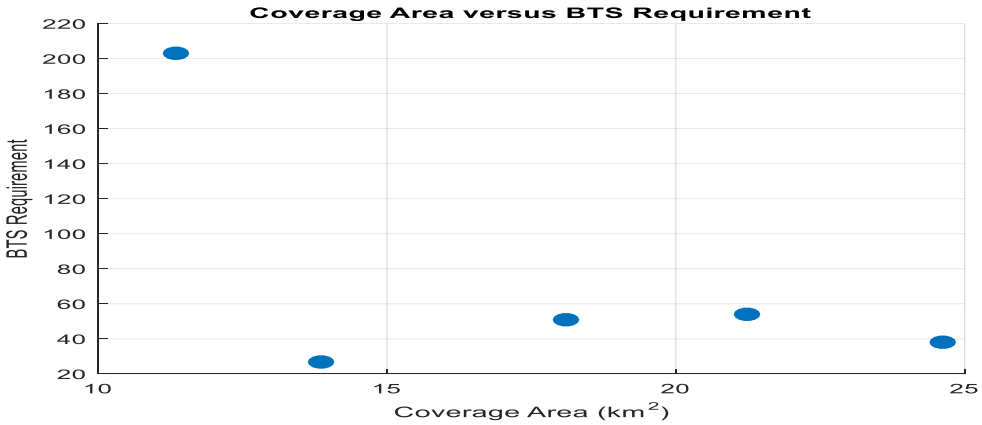


Figure 11. Coverage Area versus BTS Requirement

The scatter plot of Coverage Area versus BTS Requirement reveals an inverse relationship between the two variables. Areas with smaller coverage areas require a greater number of BTS sites to achieve complete network coverage. Akamkpa appears as an outlier with a relatively small coverage area but extremely high BTS requirement due to its large geographical extent. The graph confirms that improvements in coverage area can significantly reduce infrastructure costs.

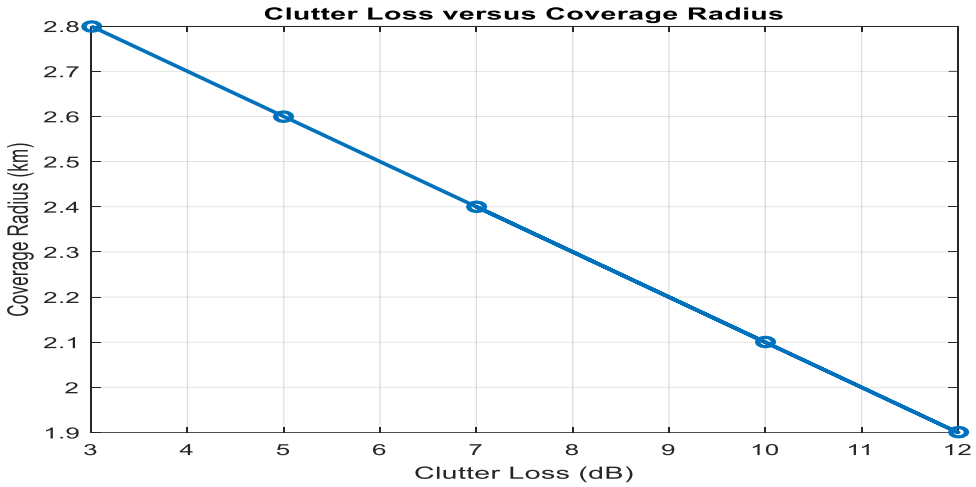


Figure 12. Clutter Loss versus Coverage Radius

The Clutter Loss versus Coverage Radius graph demonstrates a strong negative correlation between environmental attenuation and cell coverage. As clutter loss increases from 3 dB in Odukpani to 12 dB in Akamkpa, the coverage radius decreases from 2.8 km to 1.9 km. This result confirms that environmental obstacles significantly limit radio wave propagation and reduce network coverage.

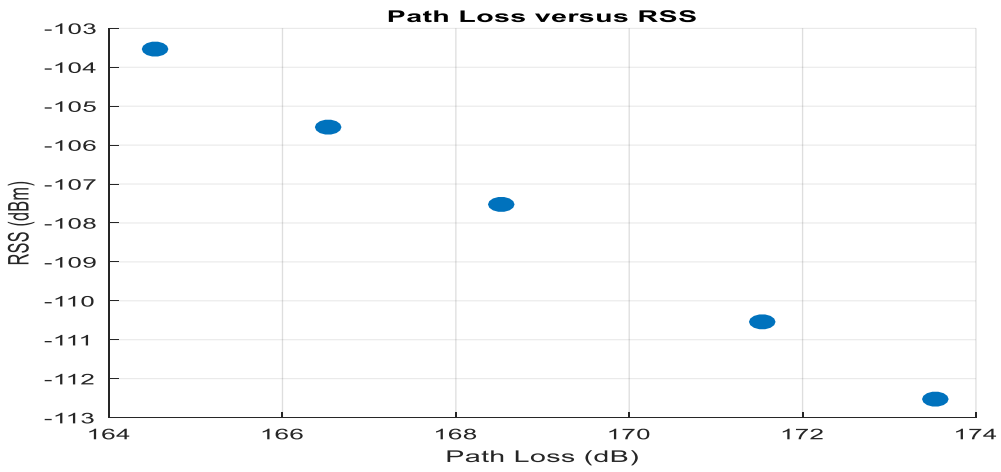


Figure 13. Path Loss versus RSS

The Path Loss versus RSS graph exhibits a nearly perfect negative linear relationship. As path loss increases, the received signal strength decreases proportionally. This relationship validates the link-budget calculations used in the study and confirms that path loss is the dominant factor controlling signal reception quality.

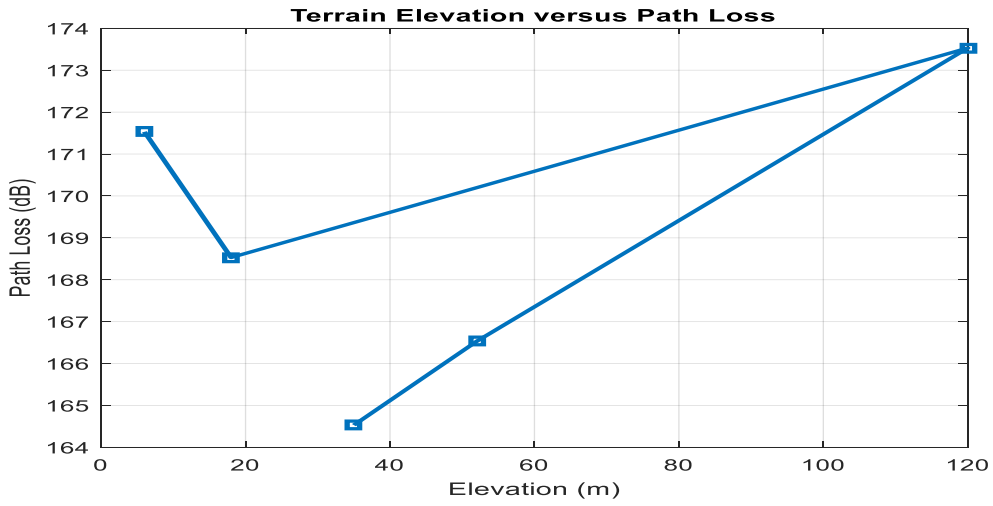


Figure 14. Terrain Elevation versus Path Loss

The Terrain Elevation versus Path Loss graph investigates the influence of terrain elevation on signal attenuation. Higher-elevation areas such as Akamkpa generally exhibit greater path loss because of terrain irregularities, dense vegetation, and increased diffraction effects. However, elevation alone is not the primary factor affecting propagation performance; land cover and clutter characteristics play a more significant role. The graph demonstrates that propagation analysis must consider both terrain elevation and environmental characteristics simultaneously.

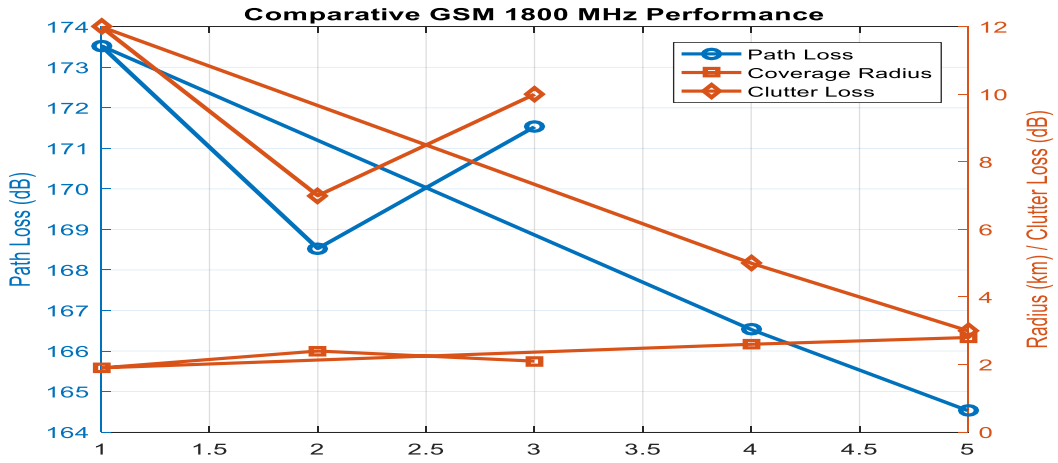


Figure 15. Combined Comparative Performance Graph

The results show that GSM 1800 MHz network performance varies significantly across the five LGAs due to differences in terrain, vegetation, and environmental conditions. Odukpani provides the most favorable propagation environment with low path loss and wider coverage, while Akamkpa experiences the highest attenuation and smallest coverage radius due to dense vegetation and rugged terrain. Bakassi also faces propagation challenges because of its coastal and riverine characteristics. Overall, path loss increases with environmental complexity, while received signal strength and coverage decrease. The COST-231 Hata model was found to provide the most practical predictions for GSM 1800 MHz network planning, whereas

the ECC-33 model is more suitable for highly obstructed environments. These findings provide a reliable basis for GSM network optimization and infrastructure deployment in Cross River State.

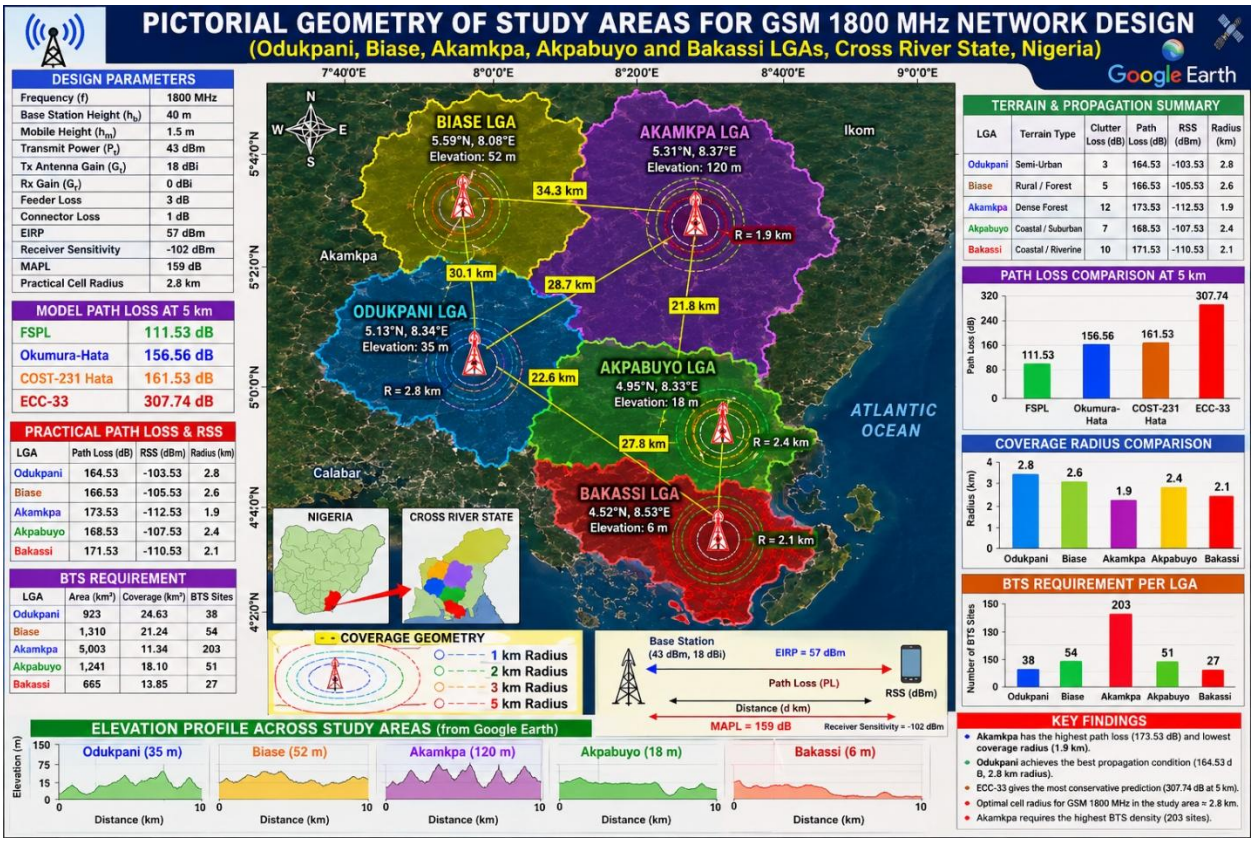


Figure 16: Pictorial Geometry of the Selected Study Areas Showing GPS Coordinates, Coverage Zones, Terrain Profiles, and GSM 1800 MHz Propagation Characteristics in Cross River State, Nigeria

Figure 16 presents the geospatial geometry of the study area developed using GPS coordinates, Google Earth mapping, terrain data, and propagation results for GSM 1800 MHz networks in Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi LGAs of Cross River State. The figure shows the spatial distribution of the LGAs, GSM base station locations, coverage radii, terrain characteristics, and propagation conditions. The geometry indicates that Odukpani has the most favorable propagation environment with the largest coverage radius (2.8 km), while Akamkpa experiences the highest path loss and smallest coverage radius (1.9 km) due to dense vegetation and rugged terrain. Akpabuyo and Biase exhibit moderate propagation characteristics, whereas Bakassi experiences attenuation associated with coastal and riverine environments. The integrated coverage zones, terrain profiles, and comparative performance indicators demonstrate the significant influence of environmental factors on GSM signal propagation. Overall, the geometry provides a comprehensive visual framework for evaluating propagation behavior, coverage performance, and network planning requirements across the selected study areas.

4. Model Validation

The validity of the developed GSM 1800 MHz propagation framework was assessed through analytical consistency checks, literature comparison, and physical propagation behaviour analysis. The computed EIRP (57dBm), MAPL (159dB), RSS (−100.53dBm), and coverage radius (2.8km) exhibited strong

agreement with standard GSM network design expectations. Furthermore, the predicted increase in path loss with distance, reduction in RSS with increasing attenuation, and decrease in coverage radius with increasing clutter loss were consistent with established radio propagation theory. The COST-231 Hata model produced realistic path-loss estimates for GSM 1800 MHz operation and yielded coverage predictions comparable to values reported in previous Nigerian propagation studies, thereby validating the analytical framework developed in this research. The results confirm that the proposed methodology is suitable for GSM network planning and optimization in heterogeneous environments such as Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi Local Government Areas.

5. Findings

1. The comparative evaluation of the FSPL, Okumura-Hata, COST-231 Hata, and ECC-33 models showed that path loss increases with transmission distance and environmental complexity, with ECC-33 predicting the highest attenuation and FSPL the lowest.
2. Numerical analysis produced an EIRP of 57 dBm and a MAPL of 159 dB, establishing the fundamental link-budget parameters for GSM 1800 MHz network planning within the study area.
3. Practical path loss values varied across the LGAs, with Akamkpa recording the highest attenuation (173.53 dB) due to dense vegetation and rugged terrain, while Odukpani exhibited the lowest path loss (164.53 dB) because of its relatively open environment.
4. Received signal strength decreased as path loss increased, confirming that terrain characteristics, vegetation density, and coastal effects significantly influence GSM signal propagation performance.
5. The estimated coverage radii ranged from 1.9 km in Akamkpa to 2.8 km in Odukpani, resulting in coverage areas between 11.34 km² and 24.63 km², respectively.
6. Network planning analysis revealed substantial variations in infrastructure requirements, with Akamkpa requiring the highest number of BTS sites (203) due to severe propagation losses and extensive geographical coverage.
7. The GPS- and Google Earth-based geospatial geometry successfully illustrated the spatial distribution of the study areas, base station locations, terrain features, and coverage zones, providing a practical framework for network deployment planning.
8. Among the evaluated models, the COST-231 Hata model provided the most realistic and practical predictions for GSM 1800 MHz network planning in Cross River State, while the ECC-33 model proved more suitable for highly obstructed forested and coastal environments.

6. Conflict of Interest

There is no conflict within the authors

7. Conclusion

This study comparatively evaluated the FSPL, Okumura-Hata, COST-231 Hata, and ECC-33 propagation models for GSM 1800 MHz networks in Odukpani, Biase, Akamkpa, Akpabuyo, and Bakassi LGAs of Cross River State, Nigeria. Numerical analysis, graphical evaluation, and GPS-based geospatial mapping were employed to assess the effects of terrain, vegetation, and coastal characteristics on signal propagation and network coverage. The results showed that path loss increases with distance and environmental complexity, while received signal strength and coverage radius decrease correspondingly. Akamkpa exhibited the highest attenuation due to dense rainforest vegetation and rugged terrain, whereas Odukpani provided the most favorable propagation conditions. Coverage analysis further revealed significant differences in BTS requirements across the study areas, emphasizing the importance of environment-specific network planning. Among the evaluated models, the COST-231 Hata model provided the most

practical and reliable predictions for GSM 1800 MHz network deployment, while the ECC-33 model was more suitable for highly obstructed forested and coastal environments. Overall, the study demonstrates that integrating propagation modeling with geospatial analysis provides an effective framework for cellular network planning, coverage optimization, and infrastructure deployment in heterogeneous environments.

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