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COMPARATIVE ANALYSIS OF WIRELESS SIGNAL PROPAGATION: RS AND GIS APPROACH

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Abstract

Mobile network systems have become an integral part of daily life, facilitating communication and access to information. However, they are not without their challenges, particularly in the urban areas where signal strength can be affected by factors such as distance, vegetation, and building density. In this study, four different cellular networks signal strength was determined near their respective base stations in an ancient town of Osogbo, Nigeria exploring the free space method. The investigation of the signal strength was carried out mainly around built-up areas and vegetation/forest areas using a Blackberry 7290 wireless handheld receiver. The GPS and EM data obtained were fed into GIS to locate the cellular towers and to create the NDVI and digital elevation pattern map of the study area using the satellite images obtained for the study. Signal strength predicted by integration of Normalized Difference Vegetation (NDVI) methodology was compared with the four different cellular networks obtained. The comparative analysis reveals that values remains almost similar. The study found that RS and GIS approach can provide an effective means of analyzing cellular signal strength, useful for network planning and development in urban areas.

Keywords: Cellular networks, NDVI, GPS and EM, Digital Elevation Pattern, RSS

1.0 Introduction

In today's digital age, cellular networks have become an essential part of modern society, facilitating seamless communication, data exchange, and information access across the globe. The ubiquity of mobile devices and the increasing demand for high-quality voice and data services have elevated the importance of consistent and robust cellular signal strength (Adebayo, 2006). However, the propagation of radio signals in urban environments is a complex phenomenon influenced by various factors, including buildings, terrain, vegetation, and atmospheric conditions. Although theoretical models such as free space propagation have traditionally predicted signal strength, these models often oversimplify real-world scenarios (Nadir *et al*.., 2016). Urban environments present unique challenges due to signal blockage and multipath effects induced by structures, foliage, and other obstacles. Geographic nuances, such as terrain variations and vegetation presence, exacerbate signal attenuation, reflection, and diffraction, introducing complexity into signal strength assessment (Sharma *et al*.., 2012). Propagation models in a forested environment, in particular, are especially valuable and complex due to the randomly distributed leaves, twigs, trunks, and trees. Various methods have been employed to model propagation loss. There are experimental measurements, empirical models, analytical, and computational electromagnetic methods (Golam *et al.*., 2015). Each method has its applicability and limitations. Remote Sensing (RS) and Geographic Information Systems (GIS) offer an innovative avenue to address the limitations of conventional propagation models. RS techniques, encompassing satellite imagery and LiDAR data, furnish intricate insights into land cover, land use, and topography, which are pivotal for precise signal propagation prediction. Coupled with GIS capabilities, these technologies facilitate spatial analysis and signal coverage visualization, affording a holistic perspective on cellular network performance (Chen *et al.*, 2012). Among the array of RS and GIS techniques, the Normalized Difference Vegetation Index (NDVI) emerges as a potent tool. NDVI, a widely utilized gauge of vegetation health and density, reflects the absorption and reflection of visible and near-infrared light by plants. In urban landscapes, NDVI offers insights into the effect of vegetation on signal propagation. By correlating NDVI values with signal strength metrics, the study unlocks the potential to discern the impact of vegetation on signal attenuation or enhancement, enhancing the precision of cellular signal strength predictions (Naveenchandra *et al.,* 2011, Sujuan, 2015).

2.0 MATERIALS AND METHODS

2.1 Description of the Study Area

Nestled in the heart of Southwestern Nigeria, Osogbo stands as the vibrant capital of Osun State, a city rich in history, culture, and commercial significance. The city's strategic location, spanning Latitude 9.7°N and Longitude 4.5°E, places it approximately 88 kilometers northeast of Ibadan, 100 kilometers south of Ilorin, and 115 kilometers northwest of Akure, establishing it as a pivotal crossroads in the region. Osogbo's coordinates, Latitude 9.7°N and Longitude 4.5°E, position it on an elevated plateau, soaring over 500 meters (800 feet) above sea level. The city serves as a hub for economic activities, trade, and cultural exchange. Its central role is further underscored by its projected population growth. In 1991, the population was recorded at 187,219, while by 2006, it had grown to 288,455. Projections for 2016 anticipated a population of 395,500, indicating the city's continued expansion.

2.2 Data Acquisition Method and Analysis

A drive test within the study area was conducted to obtain the actual signal strength of four GSM base station transmitters located in the dense urban of Osogbo (Olorunda Egbedore and part of Ede North LGA). The actual field belonging to different mobile network operators have been monitored with BlackBerry 7290 Wireless Handheld (TM) receiver (T-Mobile USA, Inc.) which has the capacity to measure the power of the transmitting signals in dBm.

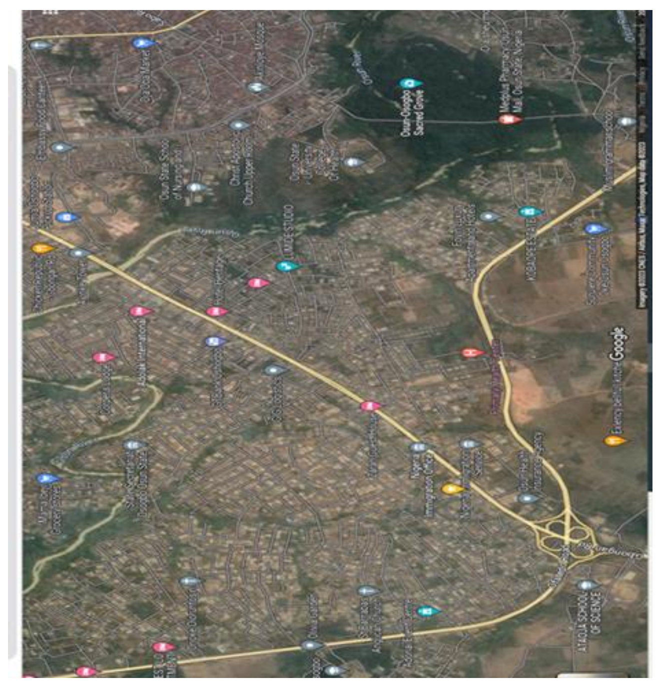

Figure 1: Ariel View of Osogbo (Source Google Earth)

The actual signal strength and elevation of the terrain (in meters) at each sample point was recorded by the BlackBerry receiver along with the coordinate information of that spot simultaneously by a GPS. The sensitivity of receiver is less than -115dBm. Thus, it was possible to import all of the field signal strength data into the geographic information system easily. The field measurement data was later used in appraising the accuracy of the Normalized Difference Vegetation Index (NDVI) prediction of signal strength. The Digital Elevation pattern of the study area was created from high-resolution satellite data (SPOT-5 HRVIR acquired with a spatial resolution of 10 meters). This step was taken in order to determine the locations and understand the spread of mobile towers of different GSM operators in the study area. For the Normalized Difference Vegetation Index analysis, the LANDSAT-5 TM data acquired were used to generate NDVI image of the study area for the extraction of DN values of the Base Transmission points. Among the various Vegetation Indices available, the Normalized Difference Vegetation Index (NDVI) stands out as one of the most widely used. NDVI is calculated on a per-pixel basis as the normalized difference between the red (band 3) and near infrared (band 4) from the landsat data. The generation of NDVI data sets was done on the Arc View 3.2a software using the following formula:

$$Landsat\ NDVI = \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3}$$

This formula yields a value that ranges from -1 (usually water) to +1 (strongest vegetative growth). The DN values of the NDVI image of the study area were extracted for further process in the prediction of signal strength of four GSM network providers namely, MTN, Globacom, Airtel, and Etisalat.

2.3 Estimation Metrics

In assessing the accuracy and effectiveness of the NDVI predictive method, (Willmott *et al*., 1985) recommended employing key statistical indicators to measure the disparity between measured and predicted (model) values. These critical indicators include the Mean Bias Error (MBE) and Root Mean Square Error (RMSE). Other statistical indicators used in the analysis include Standard Deviation (SD) and Average Ratio (AR). The mathematical representations of these metrics are as follows:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}|RSS_m - RSS_p|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|RSS_m - RSS_p\right|^2}$$

$$SD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(|RSS_m - RSS_P| - MBE)^2}$$

where RSS_m and RSS_p are the field measured values and NDVI predicted values and other symbols retain their usual meaning.

3. Results and Discussion

3.1 Optimizing Wireless Network Quality with Elevation Pattern-Aware Transmitter Placement

The effectiveness of a wireless communication network hinges significantly on the strategic placement of transmitters. Transmitters positioned in advantageous locations guarantee a high-quality signal and an excellent quality of service (Naveenchandra *et al*., 2011). Conversely, inadequately situated transmitters lead to insufficient signal coverage, resulting in an overall degradation of network performance. An examination of the elevation pattern map derived from contour lines in our study area (Figure 2), reveals that mobile towers have historically been positioned with limited consideration for elevation factors, particularly in regions such as Osun shrine, Aregbesola (Ogooluwa area), Akindeko market (Olaiya area), Government Reserved Area (GRA, Okefia), Dada Estate (Capital Hotel area), and Lameco. These areas are characterized by low-lying terrain and are traversed by the main route of Osun River and its tributaries. To achieve robust coverage and ensure effective network service in these areas, telecom companies have taken into account the distribution of network traffic among various antennas. Consequently, they have opted to install additional mobile towers on the terrain (Daramola, 2021).

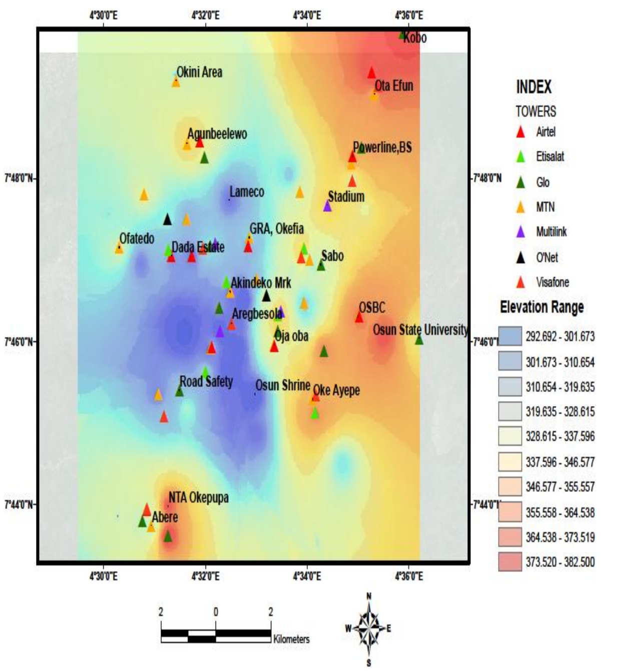

Figure 2: Elevation Pattern overlaid with Location of Towers

3.2 Comparing NDVI Results to Field Measurements of Signal Strength

This study employs NDVI to elucidate how the local environment influences signal strength across diverse areas. NDVI serves as a valuable indicator of vegetation status, ranging from 0.1 to 0.6. Higher NDVI values signify denser and lusher vegetation, whereas non-vegetated regions, including built-up areas, rocky terrain, and bare soil, typically yield NDVI values close to zero. Conversely, water bodies tend to display a negative NDVI trend. Signal strength measurements were conducted at various locations within the study area, and these sample points were superimposed onto the NDVI image generated for the study (Figure 3).

The signal strength measurements were primarily taken in open spaces, built-up urban areas, and densely vegetated or forested zones in Osogbo and its vicinity. The field measurements obtained were subsequently compared to the predicted signal strength values derived from NDVI. The results of this comparative analysis are presented in Table 1 for reference. The comparative chart of both methods has been drawn for the four GSM companies namely, MTN, Globacom, Airtel and Etisalat (Figure 4–7).

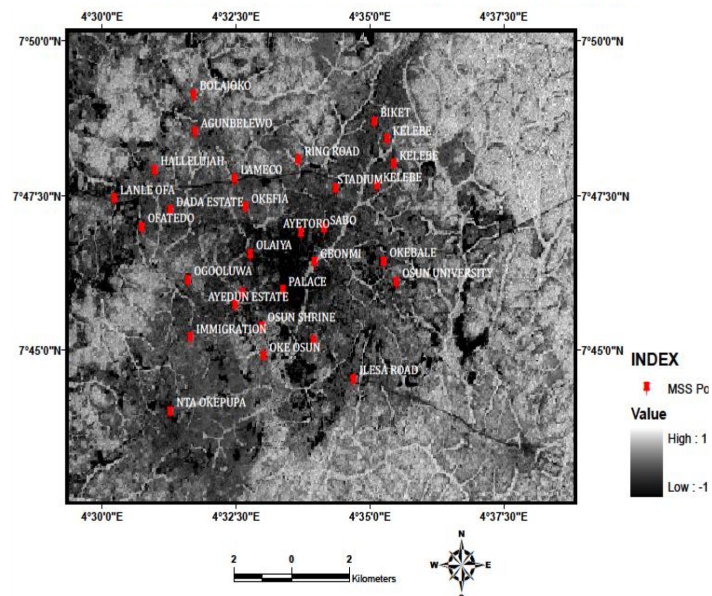

Figure 3: Overlaid Map of NDVI with Measured Signal Points

It found that values remains almost similar though lower values were observed from the predicted values. The largest impediment to increasing the predictive accuracy appears to be the lack of building data, terrain height and distance from the tower in the NDVI algorithm, hence, the accuracy of predicting a particular point's visibility is not very high. These results agree with the work done by Naveenchandra *et al*. (2011) at the Udupi district of Karnataka state, along the west coast of peninsular India. The same reasons was also pointed out by [Dodd 2001] in his thesis done in Blacksburg, VA. The prediction can be greatly improved by incorporating viewshed analysis (taking into account factors like terrain height, building height and distance from tower) along with NDVI method which will be explored in future research.

Table 1: Comparison of Signal Strength Measurement by Field

SI. No	Latitude in decimal degree	Longitude in decimal degree	Elevation in meter	Measured Signal Strength (Field Survey) in dBm				Predicted signal Strength (NDVI Method) in dBm
				MTN	Glo	Airtel	Etisalat	
1	7.78718	4.52108	326	-66	-70	-70	-71	-76.05
2	7.78264	4.51224	315	-65	-84	-87	-79	-71.74
3	7.79019	4.50365	334	-53	-75	-84	-83	-71.62
4	7.79794	4.51625	340	-48	-77	-75	-79	-77.16
5	7.79557	4.54114	312	-63	-65	-65	-63	-69.42
6	7.80829	4.5288	352	-54	-52	-60	-72	-83.09
7	7.81818	4.52844	342	-74	-81	-73	-94	-100.15
8	7.78797	4.54453	325	-57	-73	-48	-68	-79.56
9	7.80076	4.56102	327	-58	-97	-76	-81	-74.47
10	7.79307	4.57263	351	-69	-71	-72	-58	-75.57
11	7.81097	4.58462	361	-63	-54	-53	-71	-79.72
12	7.80625	4.58857	362	-69	-71	-86	-92	-83.14
13	7.79961	4.59063	356	-78	-85	-76	-88	-74.29
14	7.79372	4.58549	346	-62	-80	-61	-84	-68.20
15	7.78217	4.56894	334	-57	-54	-71	-70	-74.92
16	7.78108	4.5618	338	-51	-76	-71	-84	-68.20
17	7.77322	4.56602	328	-68	-68	-66	-80	-74.91
18	7.77332	4.58753	363	-52	-58	-55	-73	-68.20
19	7.76776	4.5915	372	-82	-60	-80	-81	-93.12
20	7.76834	4.52664	293	-57	-67	-69	-50	-76.83
21	7.73308	4.52115	373	-55	-74	-56	-56	-69.52
22	7.75287	4.52734	335	-70	-87	-74	-70	-75.08
23	7.76164	4.54131	303	-66	-75	-59	-74	-74.65
24	7.77534	4.54598	302	-67	-73	-65	-76	-68.20
25	7.76483	4.54363	304	-78	-88	-61	-61	-68.20
26	7.74793	4.55019	312	-60	-70	-73	-77	-74.06
27	7.75593	4.5496	303	-80	-87	-84	-86	-114.85
28	7.76565	4.5561	333	-65	-70	-51	-65	-68.20
29	7.75204	4.56574	358	-51	-87	-81	-59	-77.60
30	7.74168	4.57813	330	-100	-108	-100	-77	-82.27

3.3 Performances of the Analyzed NDVI Method

The statistic performances of the analyzed NDVI method in estimating wireless signal propagation in relation to the four GSM operators in the study area are shown in Tables 2. The overall findings of this work showed that the NDVI method of prediction when compared with four GSM operator (MTN, GLO, AIRTEL, and ETISALAT) field signal exhibit systematic overestimation in the predictions of Received Signal Strength (RSS).

Table 2: Statistical Performance of RSS and NDVI Method

	MBE	RMSE	SD	AR
MTN	0.34	1.83	1.77	0.84
GLO	0.20	1.10	1.07	0.97
AIRTEL	0.20	1.10	1.07	0.91
ETISALAT	0.17	0.92	0.89	0.96

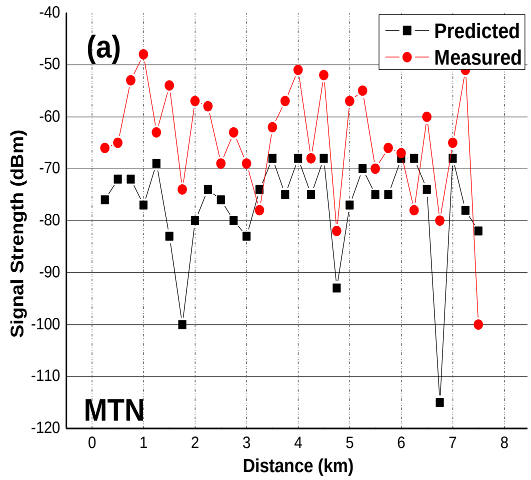

Figure 4: NDVI prediction Results with Field Measurement

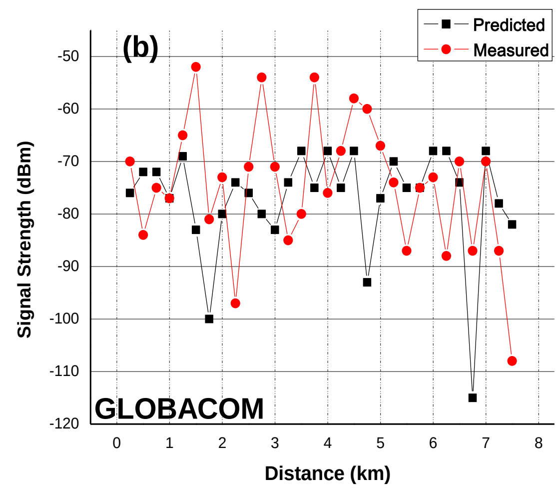

Figure 5: NDVI prediction Results with Field Measurement

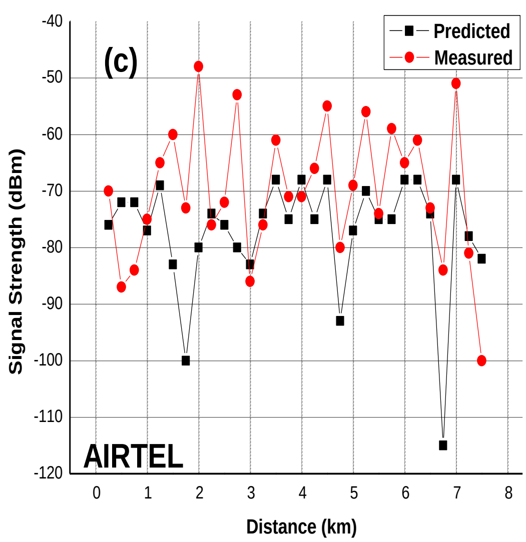

Figure 6: NDVI prediction Results with Field Measurement

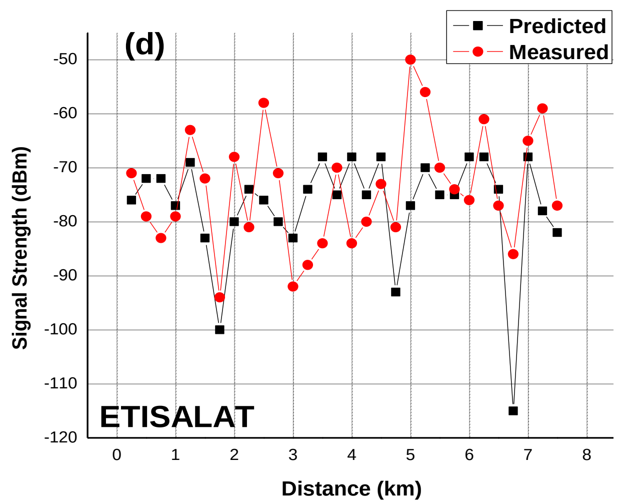

Figure 7: NDVI prediction Results with Field Measurement

5.0 Conclusion

The study has demonstrated that signal strength prediction driven by RS and GIS techniques can markedly enhance predictive accuracy when contrasted with the theoretical free space model, which neglects local terrain features. The work highlights the importance of strategic transmitter placement and the utilization of NDVI in optimizing wireless network quality within the challenging context of urban environments. The study underscores the critical importance of strategic transmitter placement in determining the effectiveness of a wireless communication network. Optimal transmitter locations ensure high-quality signal transmission and an excellent quality of service, as emphasized in previous studies. The research underscores the importance of the Normalized Difference Vegetation Index (NDVI) for assessing the health and density of vegetation and, to a certain extent, has improved the accuracy of predicting wireless signal propagation. Additionally, the study recommends that future research should prioritize view shed analysis, which encompasses factors such as terrain height, building height, and proximity to the tower, for more comprehensive insights.

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