Path Profile and Coverage Statistics of Selected Radio Stations for Microwave Propagation Design over a Tropical Location

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Abstract. Pathloss prediction is important for planning terrestrial radio communication at microwave frequencies. This necessitates the continuous evaluation of signal field strength dependence on path and channel characteristics. In this study, drive test analysis of received signal strength (RSS) from selected frequency modulated (FM) radio signals across different routes within Ondo State, Nigeria, was carried out. Signal strength distribution and coverage area statistics were evaluated for each channel on each route. The signals were measured from both high and low power transmitters using DBC BC 1173 digital signal level meter. Also, terrain elevations and location coordinates were measured using Garmin GPS 72 Personal Navigator. Location-specific pathloss model was developed for each transmitting station and their performance was evaluated against existing models. Dependence of signal strength on distance from the transmitter and path elevation was established following a least R² value of 0.67 being returned from the comparative analysis between developed and existing models. This also indicates that the developed model is suitable for pathloss prediction within the location.

1. Introduction
Microwave signals are propagated between frequency 30 MHz and 300 MHz of the electromagnetic spectrum. Frequency range 87.5 MHz to 108.0 MHz are dedicated to frequency modulated (FM) radio transmission which are done using space waves propagation technique consisting of direct and ground reflected waves. As such, ground electrical parameters – conductivity, permittivity and reflectivity; refraction and bulging on the radio path, as well as prevailing meteorological conditions have significant influence on the propagating radio waves [1]. Consequently, signals propagated as space waves are influenced by the hills, mountains, terrains and soil electrical parameters within the propagation path [2]. These and other factors are responsible for the additional losses incurred by propagating field strength when compared with theoretical values predicted by the inverse square law.

Measurement of electric field strength of microwave signals over a given location is important for determining quality of service of communication networks over such location. It equally plays important roles in the analysis of signal coverage area, estimation of signal interference, frequency re-use, as well as allocation of channel frequency and transmitter power [3]. The coverage area classification of radio signal propagating stations is in three categories namely: Primary (1st), Secondary (2nd) and Fringe (3rd) coverage areas. The Primary coverage area can be conceived as a perimeter surrounding the transmitting point/station with signal strength of sufficient intensity to ward-off interfering signals within the region. Quantitatively, the signal strength within such locality
must not be less than 60 dBµV. Such area is exposed to top quality radio service often termed as “grade A1”. On its part, the secondary coverage area is that perimeter about the signal source where the RSS is sufficient for general purpose applications but is unable to completely overcome interference from neighbouring signals. In numerical terms, secondary coverage area is such region where the received signal strength is between 30 and 60 dBµV. The grade of signal quality in such area can best be categorized as B1. Within the perimeter of the fringe coverage area, the received signal strength fluctuates in intensity as does the usefulness of the signal. It is also difficult to shield the signal from interference. The numerical value of the signal strength cannot exceed about 30dBµV. The grade of such signal are often regarded as B2 [4].

Several works involving signal strength path profile have been carried out. A few of the more recent works in this region include [5, 6, 7, 8, 9, 10, 11, 12] to mention but a few. The studies reported among other findings, the investigation and justification of the inverse square law within their selected regions, improvement in spatial utilization of electromagnetic spectrum, coverage area segmentation, dependence of signal strength on rain and other atmospheric parameters, improvement in pathloss prediction from location-dependent models etc. In the studies reviewed, channel comparison and the dependence of signal strength on other path characteristics such as elevation were not reported. Consequently, this study attempts to evaluate path and elevation dependence of FM radio signal strengths from four channels across three routes within Ondo State (Latitude 4° 20’ E – 6° 12’E and Longitude 5° 45’N – 7° 45’N), Nigeria.

2. Methodology
This study was carried out in Ondo State, Nigeria. The map with major routes connecting different parts of the State is shown in Figure 1. The instrument employed for the measurement of field strength is the DBC BC 1173 digital signal level meter while the various terrain elevations and location coordinates were measured using Garmin GPS 72 Personal Navigator. Snapshots of both devices are shown in figures 2 (a) and (b). Measurement was carried out along three routes for several days in the afternoon between 12 noon and 3 PM each day. The routes are designated as route-1, route-2 and route-3

![Figure 1: Map of Ondo state showing routes connecting cities and towns [13].](image)

The radio channels used are (i) FUTA FM radio station broadcasting on channel 93.1 and situated within the campus of Federal University of Technology, Akure; with transmitting power of 0.587kW and
antenna height of 100 m. (ii) Orange FM station, broadcasting on channel 94.5, situated along Irese road, Akure; with transmitting power of 18 kW and antenna height of about 180 m. (iii) Breeze FM station broadcasting on channel 91.9, situated at Ijoka, Akure. (iv) Adaba FM station broadcasting on channel 88.9, situated at Ilara-Mokin in Ondo State, with transmitting power of 25 kW and antenna height of 274.32 m.

3. Result and Discussion

3.1 Field strength Distribution and Coverage statistics

The distribution of received signal strength of FM signals from four radio channels are represented on a spatial map of Akure and environs. Breakdown of the signal strength distribution is summarised in Table 1 below while typical graphs of such distribution are shown in Figures 3 (a-c).

| SN | FM Station | Route-1 Field Strength (dBμV) | Route-2 Field Strength (dBμV) | Route-3 Field Strength (dBμV) |
|----|------------|-------------------------------|-------------------------------|-------------------------------|
| 1  | FUTA       | 30.0-97.5                     | 35.2-97.5                     | 30.3-97.5                     |
| 2  | Orange     | 43.5-83.5                     | 42.9-76.4                     | 37.6-64.2                     |
| 3  | Adaba      | 49.5-83.5                     | 32.5-80.5                     | 34.4-88.9                     |
| 4  | Breeze     | 40.5-64.5                     | 30.4-47.5                     | 37.5-41.5                     |

A number of deductions can be made from these observed distributions. First, a reflection on the antennae deployed by the radio stations and the coverage area of each station is seen in the non-uniformity of maximum and minimum values of radio signal strength recorded in the three routes considered, this is despite the uniformity in distance from the transmitting stations. It strongly suggests that none of the radio stations deployed an isotropic antenna. Similarly, the nature of each station’s transmitting power is also reflected. As established from theory and existing literature, the coverage area is dependent on the power of the transmitter. This becomes evident when the range of the received signal strength is examined. With ranges of received signal strength of each transmitting station on route-1 having values of 67.5 dBμV, 40.0 dBμV, 34.0 dBμV and 24.0 dBμV for channels 93.1, 94.5, 88.9 and
91.9 FM stations respectively; the channels with lower range values are those with high transmitting powers, as such can accommodate wider space and longer distances.

The channel characteristics of the transmitting stations on each of the three routes for the free space propagation are compared. Shown in Figure 4 is a typical path profile of received signal strength of the radio channels on route-2. The progressive decrease in signal strength with increasing distance is observed. Most pronounced trend is observed on channel 93.1 FUTA FM in which the path profile steadily decreased with increasing distance. The profile of channels 94.5, 88.9 and 91.9 stations also reflected this trend. Other factors that could be attributed to the non-uniformity of the RSS ratio to transmission path for the channels include vegetation on the channel path, topography of the path as well as variability in the gains of antenna across the different routes. The performance of every channel’s signal on each of the route was also compared. A critical look at the profile of station 93.1 for instance indicated that the signals attenuated faster on route-3 than it did on routes 1 and 2; this could be the attributed to the terrain, volume of activities, and population densities of the different routes. On route-3 in particular, less human activity and population density occur on the path which may account for why a low-gain directional antenna was deployed for that direction.
3.2 Variation of Signal Strength with Path Elevation

Based on the fact that frequencies within 87.5 MHz and 108.0 MHz are allocated for FM transmission and propagation is usually by Space waves which consist of direct wave, and ground reflected wave. This implies that in addition to electrical parameters of the ground, curvature of the earth surface, and weather conditions; elevation of the point of reception will likely influence wave propagation [1]. For this reason, signals in space wave are to be investigated for susceptibility to effects from hills, mountains, terrains and soil electrical parameters [2]. Consequently, the variation of received signal strength with path elevation across the three routes and four channels are investigated. Figure 5 shows typical path profile of received signal strength variation with path elevation of the radio channels on route-1 for comparison of profiles of elevation with signal strength. Shapes of the curves indicate the existence of some degree of similarity between path elevation and signal strength. Also, correlation statistics for the variation of path elevation with signal strength for the four channels on the routes indicate that R (correlation coefficient) values for channel 93.1 are 0.80, 0.84 and 0.83 for routes 1, 2 and 3 respectively. For channel 94.5, R is 0.63, 0.91 and 0.33 for respective routes, while R is 0.82, 0.82 and 0.46 respectively on channel 88.9. Lastly on channel 91.9, R’s value is 0.86 and 0.93 on route 1 and 2 respectively. The superiority in occurrence of high R values over lower ones strongly suggests the dependence of received signal strength on path elevation, although not in absolute terms.
This implies that terrain with higher elevation values will experience rapid signal attenuation more than terrain with lower elevation values. This is because the radio signal will travel more vertical distance thereby dissipating more energy, while propagating within areas of high terrain elevation.

3.3 Path Loss Modelling and Validation

Existing path loss models have a syntax of multiple dependent factors on the strength of received signal that include distance from the transmitting antennae as well as parameters of the transmitting and receiving stations. Least square fit method was used for developing a location-specific pathloss model for each of the radio channels. The variables include the path distance from the transmitting antenna, height of the transmitting and receiving antennas as well as the propagating frequency. In conformity with the existing models, the log scale values of the parameters were used to develop the location-specific model. Expressing the received signal strength of each FM radio channel as the dependent variable, a multivariate regression analysis was deployed to arrive at a function of the form:

$$P_L = a[\log_{10}(f) + \log_{10}(d) + \log_{10}(h_T) + \log_{10}(h_R)] + k$$

where, $d$, $h_T$ and $h_R$ represent the channel frequency, line-of-sight distance from the transmitting antenna, height of the transmitting antenna and height of the receiving antenna respectively.

Measurement on route-1 was used to develop the function for each channel while the other routes measurement was used for validation. Typical chart of modelling and validation of signal strength dependence on propagation path for radio channel 91.9 FM is shown in Figure 6. Values of model parameters $a$ and $k$ as well as the R$^2$ value of the model validation for all the radio stations are equally shown in Table 2. All the channels returned sufficiently high values of R$^2$, an indication of the suitability.

![Figure 6: Typical linear fit of signal strength path profile for model development](image)

| Coefficients | 93.1 FM | 94.5 FM | 88.9 FM | 91.9 FM |
|--------------|---------|---------|---------|---------|
| $a$          | -52.76  | -30.63  | -28.39  | -23.49  |
| $k$          | 97.61   | 98.5    | 92.62   | 71.8    |

| Goodness of fit | 91.9 FM | 88.9 FM | 94.5 FM | 93.1 FM |
|-----------------|---------|---------|---------|---------|
| SSE             | 205.2   | 215     | 119.6   | 58.7    |
| R-square        | 0.9236  | 0.8698  | 0.9223  | 0.9431  |
| Adjusted R-square | 0.9167  | 0.8462  | 0.9168  | 0.939   |
of the model for pathloss prediction within the study location. Although the R² value for the FM channel 94.5 is significantly lower than the others, it is nevertheless statistically significant enough for establishing validity of the model. The comparatively lower strength of the model’s performance may be due in part to the uniqueness of the paths from the transmission point. It simply implies that other prevailing propagation impairment factors exist on the signal path beyond the losses caused by the free space path and terrain.

To investigate how the location-based modelled herein developed performed relative to existing models, three of the earlier models on pathloss was chosen for performance evaluation. The models include the plane earth propagation model (PEPM), the Okumura model (OKPM) and the Hata’s model (HATA) [15]. The plot of the comparison is shown in Figure 7. It is conspicuous from the chart that the three models under predicts path loss propagation phenomenon for this location.

Figure 7: Comparison of developed model with selected existing models for a typical FM station

4. Conclusion
This work was aimed at determining the path loss of signal strength from four frequency modulated (FM) radio stations in Akure, Southwestern Nigeria. Three routes were employed for drive test measurement. DBC Field Strength Meter BC 1173 – and Global Positioning System (GPS 72) receiver unit were used for signal strength and position measurement. Models were developed that performed very well in predicting pathloss variability across the three routes and for the four radio channels. Comparison of the models with selected existing models revealed that the existing models under predicts path loss phenomenon for this location. This has been attributed to severity of the atmospheric activities in this locality. The model proposed in this project is a valuable tool which can be broadly and successfully deployed. However, this tool cannot be used in isolation as more information is required to improve the results.

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