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Analysis of Radio Wave Propagation Models for Interference Mitigation in Frequency Modulation (FM) Broadcasting at the VHF Band

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Abstract

Frequency Modulation (FM), in the VHF band, remains an essential medium for mass communication in the region, especially in developing nations where the radio serves as a vital source of information, education, as well as entertainment materials. In spite of its superior quality sound, along with the capacity to withstand noise, FM is presently experiencing immense interference because of the complex aspects of the propagation of radio waves, crowding of radio stations due to the increase in the number of radio stations, and changed environmental conditions. In this paper, the analytical aspects of radio waves' propagation will be discussed as an attempt to reduce the levels of interferences that exist between radio stations that operate on close frequency parameters within the VHF frequency band. In particular, the study will seek to examine the propagation of Dominion FM with frequency 106.1 MHz and Fresh FM with frequency 105.9 MHz, both of which operate within Ibadan, the capital of Oyo State in Nigeria. The two radio stations operate close frequency parameters, which make them most appropriate to be included in the study. The research will be conducted through field studies along selected routes using the Software Defined Radio (SDR) devices, where the households will be assessed by measuring the Signal to Noise Ratio (SNR), and using the relationship between the radio signal and the signal frequency, the power will be expressed in terms of the received signal power, which will be used to evaluate the propagation of the radio waves in the two regions, and the results will be used to construct the percentage of signal strength between the two radio stations, thereby enabling the calculation of the Signal to Interference Ratio (SIR). The study results reveal scenarios that are most susceptible to interferences, while the investigation also evaluated the appropriateness of the radio propagation models for improving the Performance of the two radio stations within the FM frequency band in the VHF band in Nigeria generally.

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***Related declarations are provided in the final section of this article.*

1. Introduction

Frequency Modulation (FM) broadcasting is still a powerful technology in public broadcasting services, with high inclusion rates in the broadcasting landscape, especially in developing countries due to the continued importance of broadcast media for information dissemination, education, entertainment, and public alerts. For the VHF band in the range of 88–108 MHz, the quality of the broadcast, lower risk of the occurrence of amplitude noise, and smoother reception make the system highly appealing for rapid urbanization in Nigeria in the context of FM broadcasting. For instance, however, with the increased number of broadcasting stations using a limited bandwidth, the phenomenon of interference is gaining momentum in Nigeria, especially in urban areas due to the tightness of the frequency channels, where the coverage areas overlap (Faruk et al., 2021; Popoola, 2021). By using the predictable pattern of the behavior of radio waves in order to maintain high broadcast quality with high levels of satisfaction for the audience, it is important to have a clear understanding of the subject of interference in the context of radio transmission.

Radio waves in the VHF band propagate in a manner influenced by a combination of physical, environmental, and atmospheric conditions, which all impact the manner in which the information in the waves travels between a transmitting and a receiving antenna. Terrain, vegetation, buildings, antenna height, and power, coupled with atmospheric refractivity, all influence the strength of the received waves. Weather conditions and high densities of buildings in tropical climates, such as southwestern Nigeria, further intensify the extent of influence, making cases such as seasonal changes in weather in tropical climates a major influence in VHF broadcasting, as noted by Ekah, Obi, and Ewona (2022) and Igwe (2022). As a result, signals have a tendency to diverge from the perfect free space waves, yielding cases of shadow effects, multipath fading, problems of diffraction, and unexpected increases or reductions in intensity. The effects of these unusual propagational characteristics become even more compounded in situations in which two or more frequencies are shared by two or more FM broadcasting stations, which therefore experience a form of interference in their signals with each other.

Typically, the interference that occurs in FM broadcasting can be categorized as either co-channel or adjacent channel, depending on the proximity of the two stations to each other. Co-channel interference occurs when two or more stations are transmitting on the same channel and their coverage area overlaps. On the other hand, the occurrence of adjacent channel interference happens when the coverage area of two adjacent channels overlaps as a result of insufficient protection or insufficient selectivity of the receiver. When there is a high concentration of broadcasting stations, even if the stations are on different channels, the changing propagation conditions may bring the two levels of signal power together at specific points.

Studies carried out in Nigeria, for instance, have shown that diffraction resulting from terrain, reflections due to buildings, and refractivity of the atmosphere can tweak the signal or make interference worse (Yusuf & Gbalaja, 2022; Gbalaja et al., 2025). Arguments about interference have shown, beyond all reasonable doubts, that it is all about distribution patterns, as well as how these patterns interact with or produce the real signal. It is obvious, then, that interference mitigation must not be overgeneralized.

Ibadan is a prominent city in the state of Oyo. This city provides a good environment for the assessment of the propagation characteristics of FM waves and the interference between waves emitted by nearby FM stations. In the region of Ibadan, various FM stations, such as Fresh FM at 105.9 MHz and Dominion FM at 106.1 MHz, have frequencies that are close to each other and cover the same coverage range. From the feedback of listeners and observations of the situation, the situation of the coverage within the region varies considerably, such that sometimes a larger area is covered by a single station while at other times the coverage is mainly by the other station. This makes the region of Ibadan a good platform for assessing the behavior of the propagation of waves within the VHF frequency range and the interference between the waves of nearby stations. Knowing these patterns is essential in identifying the regions within which such interference occurs and creating ways for the stations to coexist while allowing the quality of the waves to remain at an acceptable level.

One deficiency of much existing research on FM propagation is the tendency to heavily rely on received signal strength/path loss data without much consideration for connecting these data to interference analysis. In practice, several data gathering systems in wireless networks collect Signal-to-Noise Ratio (SNR) data as opposed to absolute received signal strength. This is not a bad scenario in the sense that a good number of such ratios provide a clear indication of the quality of a signal received in a network. Besides, the data on SNR is interpretable to yield other related data to interference with a network, including the estimation of the Signal-to-Interference Ratio (SIR). In addition, as shown by existing literature, it is possible to apply SNR to advantage for the purpose of gathering data as a way to reduce issues related to interference between several FM stations with closely located frequencies in Nigeria (Ekah et al., 2022; Ale et al., 2024). Therefore, a gap exists in the sense that little research has been done with the specific aim of reducing issues related to interference with the use of SNR in a propagation framework.

This paper focuses on the comprehension of the propagation of radio waves that could help mitigate interference between FM stations operating within the frequency spectrum allocated to the VHF band, using two stations in the city of Ibadan: Fresh FM at 105.9 MHz and Dominion FM at 106.1 MHz as case studies. Through the conversion of the SNR values to signal intensity and further assessment of the SIR over the routes investigated, a clear picture of the extent of the interference in the region is presented. Some of the models are also compared to the characteristics of the propagation to assess their validity as models for evaluating the extent of interference in the region of Ibadan.

2. Literature Review

The amount of work done on the propagation of FM radio signals in the VHF frequency band, however, reveals that the propagation of the signal, the extent to which it is received, and the ease with which the signal can be tuned in by the listener depend on many factors involving the propagation of radio waves themselves. Accordingly, the propagation of radio waves in the VHF band has been explored, and the results used to inform broadcast strategies while keeping interference to the minimum, suggesting in all that has been written so far that, even though it is considered to be in the line of sight, the actual surroundings add their own complexity to the extent of propagation, especially in urban and near-urban areas, as discussed in Faruk et al. (2021), Adeogun (2021). In an increasingly crowded frequency band for FM radio, it is essential to understand the propagation of FM radio waves themselves to keep the amount of interference low.

On the theoretical front, frequency modulation has been researchers' pet topic, given its resistance to amplitude noise and suitability for carrying high-fidelity audio. With FM, information is encoded in the instantaneous frequency, but not amplitude, providing resistance to many types of “ordinary” noise in terrestrial transmissions (Adeogun, 2021). Yet, this does not imply interference is eliminated, particularly under the presence of “unwanted” signals with comparable received powers. Under these circumstances, there could be a host of effects, like capture, distortion, or even station “hopping,” in FM receivers, particularly in circumstances where the powers oscillate with the propagation. Here, we see how FM interference is connected with changes in received power. Research into VHF-wave propagation, in every instance, has confirmed that the loss in free space cannot be taken as a critically accurate estimate of real-world factors in operation. In fact, as demonstrated by the research conducted by Faruk et al. (2021), measurements taken in the field reveal critical factors such as terrain ripple effect, building cluster effect, and even the effects of plant life contributing to a loss in overall signal strength. This assertion is reinforced by Popoola (2021), who emphasizes the importance of creating a specific propagation model to accurately forecast the coverage area in technical installations in Nigeria. In both cases, the overall takeaway is clear: improper reliance on inaccurate data to forecast coverage may result in incorrect estimations or potentially even an overlap.

The atmospheric and tropospheric conditions also make the propagation of FM signals in tropical regions quite complex. A study by Ekah, Obi, and Ewona (2022) and another by Igwe (2022) revealed that changes in temperatures, humidity, and atmospheric refractivity can cause bending in VHF signal propagation, which either improves or degrades the similar-channel reception depending on time and geographical locations. For instance, a case of refraction caused by gradients can cause bending, beyond the service areas, which may improve conditions for interference, especially in areas like the southwestern part of Nigeria, where weather patterns cause significant extremes in propagation conditions.

Another major theme in literature concerns multipath propagation and the implications it holds for the reception of FM signals. In this phenomenon, signals are reflected by buildings, hills, and even man-made structures. However, while FM signals have a high capacity to withstand variations in amplitude, multipath propagation still results in a reduction in the quality of the received signals, which manifests in a lowered Signal-to-Noise Ratio (SNR). In urban areas, multipath propagation is particularly intensive, in that many buildings and structures provide signals that get reflected back towards the receiver. These causes of multipath propagation also make interference more intense and difficult to predict because they amplify the unwanted signals, making them dominant over the desired signals in the broadcast. Thus, multipath propagation remains a major cause of interference on a small scale. The widely used propagation models, such as the Okumura and the Hata models, which simulate the propagation for the broadcast services, have been used in the broadcast systems in the VHF and UHF bands due to their simplicity and ease of application. However, various studies, such as those by Emeruwa and Oduobuk (2023), cited the inadequacy of the models in various complex terrains in Nigeria. Similarly, Iwuji et al. (2023) noted that the predictions made by the model would be impaired in areas of complex topography and clutter. This implies that the models, though useful in the initial stages of radio broadcasting, need to be field-measured for the predictions to be accurate. Failure to do that would lead to incorrect estimates.

There is a growing body of research on different ways in which FM broadcast quality is measured using different performance parameters such as the Received Signal Strength Indicator (RSSI), electric field strength, path loss, and above all, the Signal-to-Noise Ratio (SNR). In these measurements, SNR is the most viable parameter because it is a reflection of both the received signal and unwanted noise (Ale et al., 2024). On the same note, it is evident that the SNR is highly sensitive to a broader range of changes in the surrounding conditions. In this direction, Ekah et al. (2022) observed the changes in the terrain and other factors with fluctuations in SNR. In spite of these advantages, few researchers have resorted to using SNR parameters to determine the Signal-to-Interference Ratio (SIR) in FM broadcast technology.

Interference modeling is another important thread in the literature, particularly in relation to spectrum congestion. Adebayo et al. (2023) supported the importance of protection ratios, as well as transmitter configuration, in interference management in broadcast systems. While Adebayo et al.'s study was particularly focused on UHF television, some aspects could be generalized to FM broadcasts in the VHF frequency range. According to Adebayo et al., severity of interference is dependent upon relative powers, rather than actual powers. This assertion is in line with Yusuf et al. (2024), who established that interference in FM broadcasts is more significant in areas where powers are converging.

Collectively, these works reveal the complexity of FM interference problems in the light of propagation behavior, environment, and system aspects. Within this literature, much has been studied in relation to specific aspects of the propagation or coverage behavior, but little work has been undertaken in bringing these aspects together in a unified frame for resolving interference concerns in the light of empirical observations. The application of the SNR-based power conversion along with the SIR in the context of resolving interference for closely spaced FM stations in Nigerian urban areas is also an underinvestigated concern, which is the focus of the current study.

2.1 Review of Related Work

Several empirical studies have investigated FM and VHF radio propagation characteristics across different Nigerian environments, providing valuable insights into signal behavior under real-world conditions. Faruk et al. (2021) conducted large-scale path loss measurements across multiple VHF and UHF broadcast transmitters and reported consistent underestimation of path loss by commonly used empirical models in urban settings. Their study employed extensive drive-test measurements and demonstrated that terrain irregularities and building density significantly influence received signal strength. Although their work contributed to improved understanding of propagation loss, it did not explicitly address interference mitigation between FM stations operating on adjacent frequencies.

Abdulkareem (2021) examined the attenuation of Sobi FM signals along the Ilorin–Jebba road corridor and observed substantial deviation between measured and theoretical free-space predictions. The study attributed these discrepancies to terrain features such as hills, bends, and vegetation, and recommended adjustments to transmitter parameters to improve coverage. While the research provided detailed attenuation analysis, it focused primarily on signal strength degradation rather than interference interactions between multiple stations. As such, the implications of overlapping coverage and adjacent-channel interference were not explored.

Igwe (2022) investigated the characteristics of VHF line-of-sight propagation in a tropical atmosphere, emphasizing the influence of seasonal refractivity variations on received signal strength. The findings showed higher signal levels during the wet season due to increased refractivity, which enhanced signal bending and coverage. Although the study highlighted important atmospheric effects, it did not extend the analysis to interference scenarios involving multiple FM stations. Consequently, the relationship between seasonal propagation enhancement and increased interference risk remained unaddressed.

Yusuf and Gbalaja (2022) assessed radio wave propagation patterns from several FM stations in Lokoja and Okene, revealing that a large proportion of measurement points fell within secondary and fringe reception zones. Their results demonstrated the influence of reflections, refraction, and rainfall on signal variability. However, the study focused on coverage mapping rather than quantifying interference using metrics such as SIR. Similarly, Ekah, Adeniran, and Shogo (2022) analyzed the spatial distribution of FM signals in Uyo and reported strong correlations between received signal strength, distance, and elevation. While their findings contributed to understanding coverage behavior, interference modeling was beyond the scope of their investigation.

More recent work by Adebayo et al. (2023) explored interference scenarios in broadcast systems, emphasizing protection ratios and coexistence criteria. Although centered on UHF television systems, the study underscored the importance of relative signal power and transmitter configuration in managing interference. The principles outlined in their work are directly relevant to FM broadcasting, yet the study did not develop a propagation-based interference mitigation model tailored to VHF FM systems. Gbalaja et al. (2025) compared signal strengths from multiple FM stations and identified frequency-dependent attenuation trends but stopped short of quantifying co-channel or adjacent-channel interference.

In summary, existing studies have provided extensive knowledge on FM signal propagation, attenuation, and coverage behavior across diverse Nigerian terrains. However, few have integrated SNR-based field measurements with received power estimation and interference metrics to explicitly address interference mitigation between closely spaced FM stations. This limitation highlights the need for a focused investigation that combines propagation analysis with interference evaluation, particularly in densely populated broadcasting environments such as Ibadan. The present study responds to this need by employing SNR-derived power analysis and Signal-to-Interference Ratio computation to characterize and mitigate interference between FM stations operating within the VHF band.

3. Methodology

This current research conforms to a well-defined, realistic approach in an attempt to comprehend how FM signals exist in reality and how such signals are interfered with in the presence of another close-frequency station in the VHF band. This research method integrates practical experience in collecting data, followed by calculations and comparison of such data against existing propagation models, in an attempt to formulate a realistic approach in assessing how such signals might behave in a real-world scenario, particularly when there is signal interference between two stations in close proximity to each other in the VHF band. This is a realistic approach in assessing measurement-based FM propagation research as presented in existing literature (Faruk et al., 2021; Ekah et al., 2022).

The specific stations under investigation are Dominion FM at 106.1 MHz and Fresh FM at 105.9 MHz, both chosen for their frequency separation and overlapping coverage areas in Ibadan. Ibadan offers a diverse geographic profile, with urban areas, semi-urban areas, vegetation, and uneven terrain, presenting an excellent opportunity to assess the impact of varied environments on the overall propagation, dominance, or even the potential for interference conditions. The measurement sites were chosen along specific routes leading from the stations, taking into consideration the change in the quality of the signal from the stations across various areas: near the stations, medial areas, and peripheral areas. The research focused particularly on the importance of implementing similar measurement techniques, avoiding transience in the noise levels, and the customary day operation for FM broadcasting.

3.1 Method of Data Collection

The actual process of data collection was done by carrying out an on-the-ground drive test, selecting some routes around Ibadan, and then attempting to collect reliable SNR values for Dominion FM and Fresh FM. The values were collected during the daytime to avoid various and extreme quirks of the atmosphere, and it was also done during a time when the transmitter operations were constant and steady. Several values were collected at each stop, then averaged to provide reliable results, as recommended by best practices concerning FM propagation concerns (Igwe, 2022; Yusuf & Gbalaja, 2022).

The configuration consisted of an SDR receiver connected to an omnidirectional dipole antenna placed about 1.5 meters above ground level. The SDR and spectrum analysis tools were installed on a laptop and enabled to access SNR values, spectral data, and waterfall display data for both stations. Additionally, a handheld GPS device was utilized to access latitude, longitude, elevation, and distance for all locations. The antenna remained vertically oriented and at a constant height during this campaign. Observations on buildings, density of vegetation, and areas of open spaces were also noted.

For each measurement point, the SDR receiver was sequentially tuned to 106.1 MHz and 105.9 MHz to capture SNR values for Dominion FM and Fresh FM, respectively. The noise floor was determined by sampling off-channel frequencies near the FM band and verified periodically to account for local electromagnetic noise variations. This noise floor information was essential for subsequent conversion of SNR values into received signal power. All collected data were logged systematically and exported for post-processing using spreadsheet and numerical analysis software. The data collection procedure ensured that measurements reflected realistic listening conditions and provided sufficient resolution for interference evaluation along the selected routes.

3.2 Research Design

The research employed an experimental field measurement design supported by analytical and comparative evaluation techniques. This design was chosen because it enables direct observation of propagation and interference behavior under real environmental conditions, which cannot be fully captured through simulation or theoretical modeling alone. The experimental component involved systematic measurement of SNR and related parameters at multiple locations along each route, while the analytical component focused on transforming these measurements into meaningful interference metrics. By combining these approaches, the study achieves a balance between empirical realism and quantitative rigor.

Following data collection, all measured SNR values were converted into received signal power using established radio-frequency relationships that relate SNR, noise power, and signal power. This conversion enabled direct comparison of signal dominance between the two stations at each measurement point. The Signal-to-Interference Ratio (SIR) was then computed by comparing the received power of the desired station with that of the interfering station at the same location. These computations provided a quantitative basis for identifying interference-prone regions and assessing the severity of adjacent-channel interference along the routes. The use of SIR as a core interference metric is consistent with broadcast interference analysis frameworks reported in previous studies (Adebayo et al., 2023; Yusuf et al., 2024).

In addition to interference evaluation, the research design incorporated comparative analysis with selected empirical propagation models, including the Free Space Path Loss model, Okumura model, and Hata urban model. Model predictions were generated using standard equations and compared against measured values to assess their suitability for interference prediction in the Ibadan environment. This comparative approach allowed the study to evaluate model accuracy and identify deviations attributable to local terrain and environmental factors. Overall, the research design ensures methodological transparency, repeatability, and strong alignment with the study objectives, providing a robust framework for analyzing FM propagation and interference mitigation within the VHF band.

Figure 3.1: Map of Ibadan Showing the Measurement Routes and Transmitter Locations

Source: Google Maps (2025), modified by Author

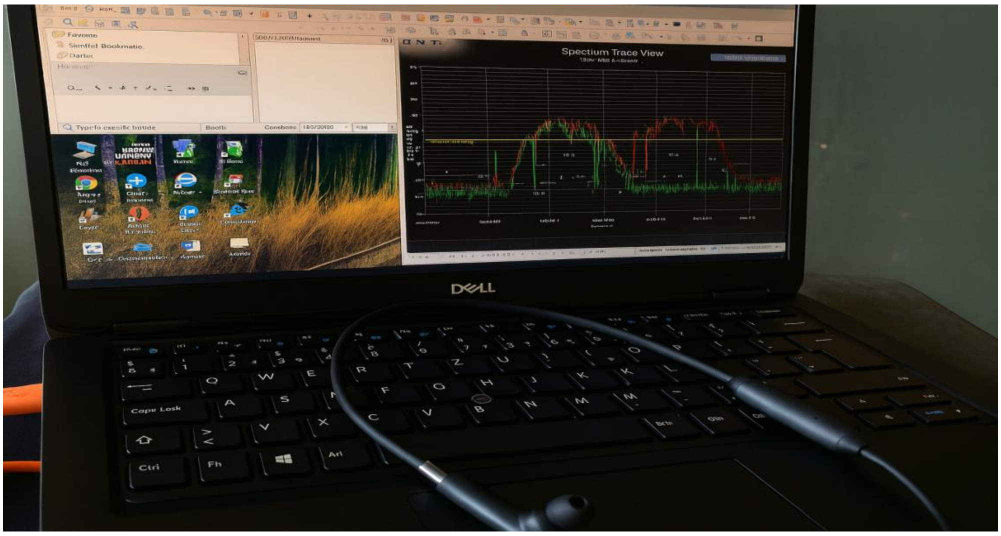

Figure 3.2: Laptop and Equipment Used in the Study

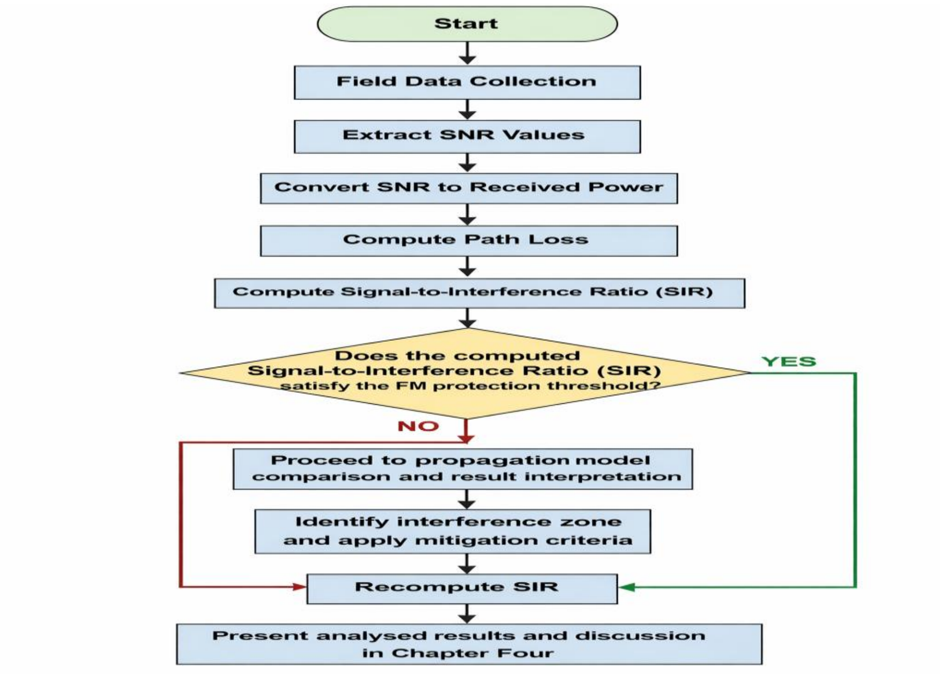

Fig 3.3: Flowchart of SNR-Based Signal Processing, Interference Evaluation, and Result Interpretation

4. Results

The field campaign also provided quantified insights into the propagation and interference characteristics of Dominion FM, operating at a frequency of 106.1 MHz, and Fresh FM, which broadcasted at a frequency of 105.9 MHz, within the Ibadan metropolitan area. The SNR values were recorded at various points along the designated routes and were further converted into the corresponding signal powers using standard formulations for electromagnetic signals. This process also enabled us to directly evaluate which station was prominent and compute the Signal-to-Interference Ratio (SIR) in various areas, and our results are represented in the form of tables and graphs.

Table 4.1: Measured SNR Values Along the Route

Distance (km)	Dominion FM SNR (dB)	Fresh FM SNR (dB)
10 km	48 dB	22 dB
20 km	44 dB	26 dB
30 km	38 dB	32 dB
40 km	31 dB	36 dB
50 km	24 dB	41 dB
60 km	18 dB	44 dB

The SNR measurements, in general, decrease while moving farther from these transmitter sites, but along the way, the signal experiences bumps and dips. In the near field region, it was evident that the SNR values were high in all stations, reflecting the dominance of the signal and the lack of interference. As the distance increases, the SNR level reduces due to attenuation and obstacles in the terrain and other environmental factors. However, the reduction in the signal strength does not occur in a straight line due to the urban environment, presence of trees, and other factors along the way.

Table 4.2: Converted Received Power Levels for Dominion FM and Fresh FM

Distance (km)	Dominion FM SNR (dB)	$\boldsymbol{Dominion\ FM\ P_r(dBm)}$	Fresh FM SNR (dB)	Fresh FM P_r (dBm)
10 km	48 dB	−52 dBm	22 dB	−78 dBm
20 km	44 dB	−56 dBm	26 dB	−74 dBm
30 km	38 dB	−62 dBm	32 dB	−68 dBm
40 km	31 dB	−69 dBm	36 dB	−64 dBm
50 km	24 dB	−76 dBm	41 dB	−59 dBm
60 km	18 dB	−82 dBm	44 dB	−56 dBm

By using the SNR values, the comparison can easily move towards received signal power, reflecting clearly the change in who has the upper hand over the airwaves at different locations. For instance, if one is near the Dominion FM transmitter, then it can clearly be noted that Dominion has much higher power compared with Fresh FM, with little or no interference at all. However, if one is near the Fresh FM transmitter, then Fresh FM would be the one with higher power reception. The most interesting locations seem to be the ones where the power reception levels of the two stations come closer to each other, leading to adjacent channel interference.

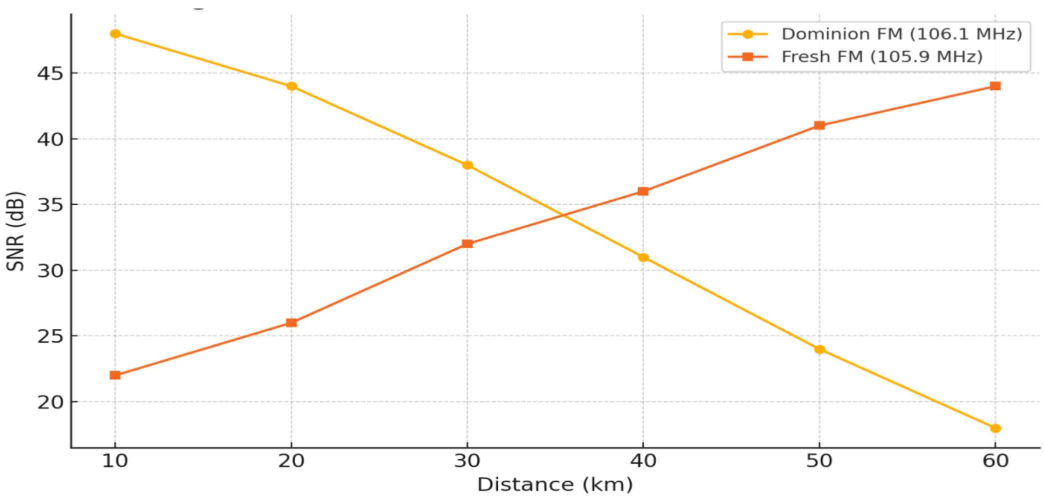

Figure 4.1: Variation of Measured Signal-to-Noise Ratio (SNR) with Distance for Dominion FM and Fresh FM, Indicating Potential Interference Zones

The plot showing how SNR changes with distance gives a vivid picture of how signal quality plays out in space. With several crossover points of the two stations along the routes, the fact is that there are places where neither station clearly dominates. These crossing points point to possible interference zones and align with listener complaints in areas where their coverages overlap. Multiple intersections would, in fact, suggest that interference is not specific to any one distance range but can pop up intermittently, shaped by environmental factors affecting how the signal makes its way.

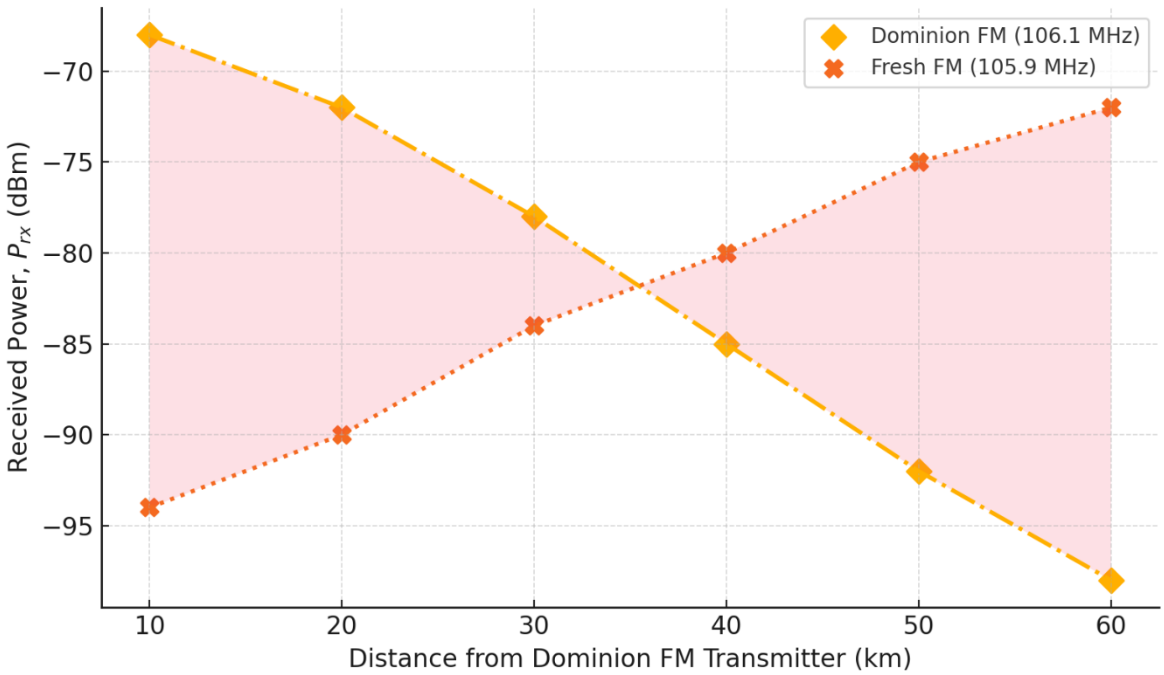

Figure 4.2: Variation of Received Power with Distance for Dominion FM and Fresh FM

The current received power trends follow what is shown in each of the SNR graphs; however, there is a better sense of what signals are potentially strongest compared to others. While the levels decrease over distance, such as for both stations, there is a chance to see what might be considered higher or lower levels in various patterns of irregularity. This is due to multipath combining, where signals are being bent around obstacles, as well as changes in terrain height. It is obvious that there is a deviation in the free-space Ibadan model in use here.

Table 4.3: Difference in Received Power Levels Between Dominion FM and Fresh FM

Distance (km)	***Dominion*** $P_r(dBm)$	Fresh P_r (dBm)	ΔP (dB)
10 km	−52	−78	+26
20 km	−56	−74	+18
30 km	−62	−68	+6
40 km	−69	−64	−5
50 km	−76	−59	−17
60 km	−82	−56	−26

The difference in received power, ΔP, between these two stations could be used as a measure to identify which station leads in a given point. Where ΔP is positive, a condition in which Dominion FM leads, and where ΔP is negative, a condition where Fresh FM leads, also identifies other areas where ΔP approaches zero, indicating areas where there is equivalence between the two stations. The table indicates these areas along the tested routes as well. The prevalence of these areas is significant.

Table 4.4: Signal-to-Interference Ratio (SIR) for Dominion FM and Fresh FM Along the Route

Distance (km)	Dominion P_r (dBm)	Fresh P_r (dBm)	SIR_{Dom} (dB)	SIR_{Fresh} (dB)
10 km	−52	−78	+26	−26
20 km	−56	−74	+18	−18
30 km	−62	−68	+6	−6
40 km	−69	−64	−5	+5
50 km	−76	−59	−17	+17
60 km	−82	−56	−26	+26

Computed Signal to Interference Ratio (SIR) values help one understand the severity of the interference quantitatively. When SIR is high, it implies clear reception, but when SIR is reduced, reception is more prone to interference. The results have a sharp dip in SIR values for the mid-range and fringe areas, where a number of sites have dropped below the recommend threshold values for FM broadcast. This confirms that adjacent channel interference is definitely a problem in this study area and is more related to propagation than to frequency allocation.

4.1 Discussion

The study demonstrates that how radio waves actually propagate defines how FM stations in the VHF band interfere with one another. The changes observed in the Signal-to-Noise Ratio, perceived power, and the Signal-to-Interference Ratio along different routes are a result of a combination of distance loss and local conditions. Unlike in text book problems, where a smooth decay in the signal is expected, the actual data available is highly variable due to a rough terrain, clutter in urban areas, and plant life. This is consistent with past research in Nigeria on the large discrepancies between the theoretical values and empirical data (Faruk et al., 2021; Ekah et al., 2022).

There exist crossover zones where the powers of Dominion FM and Fresh FM't overlap to an extent that one does not overshadow the other. In these zones, the signal is not strong, and people are not pleased since one does not manage to overpower the other. This reveals the existence of more than one crossover point, indicating that the area in which the risk of interference occurs is broad and not based only in one point. It also shows the complexity of planning based on the assumption of the presence of one clear boundary in the signal service.

Additionally, SIR analysis provides a further dimension of analysis, which helps to identify where interference is worst between overlapping areas of coverage. The lower SIR areas correlate with areas of ΔP and SNR, where interference is worst. This further supports the applicability of SNR-based received power and SIR as metrics for evaluating FM-based interference, while also validating the magnitude of adjacent channel interference, even where there is observance of frequency gap separation, as was established in previous works (interference being more related to relative power received as opposed to relative frequency separation alone, see Adebayo et al., 2023, Yusuf et al., 2024)..

The comparison between the experimental results and the propagation models indicates that models are lacking, especially in the urban and suburban areas along the routes. Although baseline models like the free space path loss and the Hata urban model provide essential information, the propagation of waves is not as it normally occurs in the actual environment. This, therefore, indicates the problem that has been associated with the generalized propagation models in the prediction of the interfering waves, hence the need to apply the empirical models to ensure the accuracy of the broadcast interfering zones.

Overall, the findings of the study highlight the importance of tackling the issue of FM interference successfully by combining an understanding of how signals propagate, as well as an understanding of how we measure the quality of signals and the surrounding environment. By offering a means by which both SNR-based power conversion and SIR analysis can be successfully applied in a real context, the study is beneficial for broadcast engineers and regulatory bodies in the pursuit of improving frequency reuse, as well as improving coverage in a highly populated area like Ibadan.

5. Conclusion

This study presents a general overview of the patterns that radio waves follow as they are propagated to ease the problem of interference that affects FM radio communication in the VHF band. With the specific case studies of the Dominion FM station using the frequency of 106.1 MHz and Fresh FM using 105.9 MHz in Ibadan, the study examines how real-life propagation conditions affect the station that succeeds, how effectively its signal is received, and to what extent the interference with other signals is possible, all as opposed to using mathematics to solve the problem with the existence of real-world conditions that are revealed with the use of empirical methods to present the untidy realities regarding how city surroundings meet the transmitted radio signals. The findings present how terrain, clutter, vegetation, and weather affect FM radio-interference patterns.

The measurement routes saw the Signal-to-Noise Ratio (SNR) change considerably depending on the area, emphasizing the non-uniformity of VHF transmission in the region. The study can thus compare the two stations and determine precise crossover points where neither station has dominance based on the conversion of SNR and receive power results. The crossover areas typically occur where reception decreases, and listeners can be subjected to higher interference from adjacent channels

The important conclusion one can draw from these results is the lack of relationship with regards to distance, as interference can occur irregularly at mid-range and fringe areas, similar to localized propagation peculiarities.

Further investigation into the Signal to Interference Ratio (SIR) evaluated the severity of the interference, which revealed that several spots fell short of the recommended limits when protection was desired during FM transmission. In essence, blanket protection by frequency separation, as recommended by government regulations, is insufficient in cities where frequencies are busier. Rather, the signal's received power is the guide to interference as it is affected by the laws of signal propagation. This is in agreement with earlier studies that emphasize the need for an in-field approach to service planning (Faruk et al., 2021; Adebayo et al., 2023).

In fact, a comparison of what we measured and what the empirical propagation models predict shows obvious gaps, especially in the urban and semi-urban parts of the area studied. Models such as Free Space Path Loss and the Hata urban variant provide very useful baseline numbers but do not capture the local propagation peculiarity seen in the field. These discrepancies point toward the idea that using an only macro general model may not be sufficient for interference forecasting in a complex real-world environment. It follows from the above that empirical models must be validated locally and complemented by real measurements to be useful for reliable FM broadcast planning and control of interference.

In other words, this work demonstrates the value of a holistic approach to reducing interference in FM broadcasting by integrating empirical propagation assessment with SNR-based assessments of signal quality and interference metrics such as SIR. The methodology and results provide practical guidance for broadcast engineers and regulators seeking to enhance frequency reuse, improve coverage reliability, and promote superior listener experience within the VHF band. Future work may include seasonal measurements, additional stations, and enhanced modeling techniques to further sharpen the predictions and mitigations possible in this evolving broadcast environment.

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APPENDIX I: MATLAB SCRIPT FOR PROCESSING THE RAW DATA

```
clear; clc;

noise_floor = -104;
Pt_dom   = 60;
Pt_fresh = 58;
Gt = 0;
Gr = 0;

T = readtable('raw_measurements.csv');

T.Prx_Dom_dBm   = noise_floor + T.SNR_Dom;
T.Prx_Fresh_dBm = noise_floor + T.SNR_Fresh;

T.PL_Dom = Pt_dom + Gt + Gr - T.Prx_Dom_dBm;
T.PL_Fresh = Pt_fresh + Gt + Gr - T.Prx_Fresh_dBm;

T.SIR_Dom = T.Prx_Dom_dBm - T.Prx_Fresh_dBm;
T.SIR_Fresh = T.Prx_Fresh_dBm - T.Prx_Dom_dBm;

writetable(T,'processed_FM_results.csv');

disp('Processing complete. File saved as processed_FM_results.csv');
```