

Calibration of Empirical Models for Path Loss Prediction in Urban Environment

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Abstract. The reliability and accuracy of radio propagation models depends on the unique localized features in the area under study. In this paper, we calibrate empirical radio propagation models for 1800 MHz cellular network planning in Lagos Metropolis, Nigeria. Drive test are conducted to obtain measured data within suburban and dense urban propagation environment. Received Signal Strength (RSS) and path loss values of radio signals in 1800 MHz cellular networks are recorded for model calibration and evaluation. COST 231–Hata model achieved the closest prediction results relative to the field measurement. Mean Error (ME), Standard Deviation (SD) and Root Mean Square (RMS) results are 11.004 dB, 12.194 dB and 16.43 dB respectively in dense suburban, while the corresponding results are 9.151 dB, 8.151 dB and 12.254 dB in dense urban. ME of all the calibrated propagation prediction models reduced to nearly zero (≈ 0 dB). Also, the SD and the RMS fall within the calibration quality target with ME as less than 1 dB and SD is less than 8.5 dB for each of the calibrated models. In conclusion, the proposed calibrated path loss models achieved minimum mean error and standard deviation. Prediction results improved when terrain type and clutter data were taken into account during path loss calculations.

Keywords: Path loss · Empirical model · Radio propagation · Radio network planning · Mobile communication

1 Introduction

Wireless channel is faced with some technical challenges. The wireless channel suffers multipath propagation problem which resulted in fading [1,2]. The channel is also prone to noise, distortion and signal attenuation [3]. The need to access network without wire connection makes the channel less secure. Thus,

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12254, pp. 301–310, 2020.
https://doi.org/10.1007/978-3-030-58817-5_23

it requires a stronger security mechanism to protect data and/or bandwidth. Consequently, the susceptibility of the radio channel to fading necessitate good network planning the study location [3]. There is a need for efficient network and good quality of service (QoS) for better radio network design by network operators. This has brought mobile network planning and signal optimization into a sharp focus.

Path loss (PL) analysis is paramount to network design in wireless communication systems. The success of mobile radio depends largely on how adequately the network is planned to provide good coverage the selected area. The empirical propagation models were developed using extensive measurement of path loss (PL) data obtained from different observations in an environment [4]. The empirical models are widely used for PL estimation due to their simplicity, but they are not usually accurate especially when deployed in other environment. The authors in [4–9] confirmed that empirical models are not consistent without proper tuning.

PL models are used to predict Received Signal Strength (RSS) at a particular environment in the channel. These models depend heavily on key features of the wireless channel for their development. Hence, adequate knowledge of height of the transmitting and receiving antenna, operational frequency and other physical or human-interactive elements in the propagation environment is a necessary prerequisite in developing these models [10,11]. The predictive abilities of path loss models, which guides mobile network operators in base station location, ensure that signal coverage is maximized, and the costs expended on network resources are minimized. This is of paramount importance as proportional increase in the number of base stations within a geographical area and mobile subscriber is equivalent to better QoS and greater signal coverage [12,13]. Path loss models will help in determining where to position base stations out of possible set of different location options. They serve as functional tools in radio network planning and radio optimization procedures [6,14,15].

As the number of mobile subscribers reaches an unprecedented level an increase in capacity of mobile radio network would be of absolute necessity to accommodate these demands [10]. Increase in mobile radio network capacity, will demand more installations of base stations which in the long-run becomes a more difficult task, in deciding the best location that maximizes coverage and minimizes the expenditures on network infrastructure. In this paper, we investigate the existing propagation prediction models with the view of working on calibration of empirical radio propagation models for GSM 1800 MHz cellular network planning in Lagos Metropolis, Nigeria. The main contributions of this paper are as follows:

(a) We conduct drive test measurements within the dense sub-urban and urban areas of Lagos, Nigeria and record RSS and PL values of radio signals in 1800 MHz GSM cellular networks;
(b) Accuracy of Okumura-Hata, COST 231, and SPM models is evaluated for PL predictions in cellular networks within dense suburban and dense urban propagation environments in Lagos Metropolis, Nigeria;

(c) Okumura-Hata, COST-231, and SPM PL models are calibrated with the field measurement data in ATOLL radio network planning tool so as to adapt the unique localized features of the selected propagation environments;
(d) Standard correction factors and model coefficients are generated for the formulation of modified Okumura-Hata, modified COST-231, and modified SPM PL models.

2 Materials and Method

Radio signal data was collected on a live network of different Base Transceiver Stations (BTS) within a cluster network in Lagos using TEMS Investigation software produced by Ericsson Company. TEMS has the capability of data collection, data analysis and post-processing. TEMS software package is a tool that was used to interfaces phones and other devices to collect data and records same in log files. The log files are thereafter imported in appropriate format (.txt) for further data processing. Eight (8) BTSs were considered in each clutter class for the purpose of propagation model calibration. The number of BTS selected depends on the terrain of the study area. Ten (10) BTS in each clutter class was adopted. During the selection exercise, the stations were ensured to have a good RF clearance to avoid signal obstruction in all direction. The height of the antennas varies between 20 m to 50 m. This study takes into considered the dense sub-urban and dense-urban clutter terrain of Lagos metropolis.

Long-distance routes were selected during drive test to reach the noise level of the receiver. Typically, the distance of 2 km was selected for sub-urban environment whereas 1 km was planned and used for the urban centers. The routes were planned to have equal number of samples for near and far station in all directions. These routes were planned to avoid crossing of forest and rivers for smooth data collection. Global Positioning System (GPS) of the drive test equipment was configured to match that of the mapping data. When planning the drive test measurement survey, the area to be covered was scanned to confirm is no interference.

A single frequency channel known as Broadcast Control Channel (BCCH) was measured during each survey. There are two contiguous unused channels of a clearance of 200 kHz on both sides of the measured signal so as to ensure that the measured frequency is clean. The Lee criterion in terms of sampling rate was satisfied to overcome fading effects. Over a distance of $40\,\lambda$ at least 36 samples were collected. The measured signals were averaged and the mean signal being the one stored. The maximum distance between the measured data is approximately equal to one and a half of the resolution of the clutter. In ATOLL, the drive test data files were imported as ASCII files with TXT extensions. The data files must contain the position of measured data and measured received signal levels for ATOLL to use the imported data files. The files imported also contain BCCH, Serving Cell BCCH, Radio Frequency Channel Number (RFCN), Base Station Identity Code, and Cell Identity (CI).

During the actual received signal strength prediction, one of the existing radio propagation models is selected and used as the prototype. The drive test

data obtained from a live network on the local radio propagation environment is imported into the radio planning tool software (ATOLL). The coefficients of the existing propagation model formula are tuned such that the resulting calibrated propagation prediction model can accurately produce the actual prediction that at least approximately fits the field measured data.

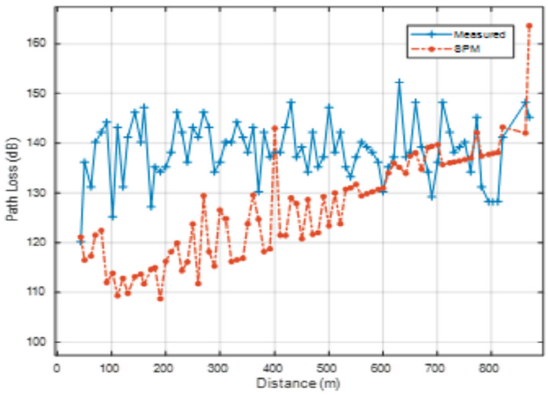
3 Results and Discussion

The propagation coverage predictions were obtained from the existing radio propagation prediction models in-built in the ATOLL network planning tool. Figure 1 shows the predictions of SPM, Okumura-Hata and COST-231 models compared with the field measured data in dense suburban clutter of Lagos Metropolis. Field measured data obtained in the Dense Suburban clutter class has Mean Received Signal Strength (MRSS) of −71.3 dBm. The Okumura-Hata, COST-231 and SPM Models gave Mean Received Signal strength of −49.38 dBm, −64.28 dBm and −58 84 dBm respectively. The mean measured PL in Dense Suburban was 138.51 dB. The mean PL predicted by Okumura- Hata, COST-231 and SPM Models were 117.04 dB, 131.48 dB and 126.03 dB respectively.

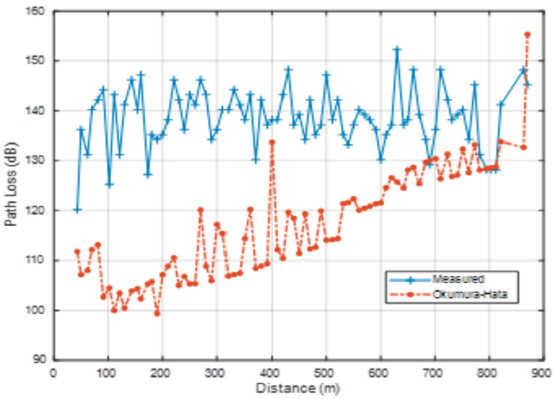
Figure 2 compares the propagation coverage predictions of SPM, Okumura-Hata and COST-231 Models with the PL measured data at different points in the dense urban clutter of Lagos, Nigeria. Mean Received Signal Strength (MRSS) of the mobile station in Dense Urban terrain was −73.51 dBm. Okumura-Hata, COST-231 and SPM predicted MRSS of −62.76 dBm, −64.67 dBm and −58.63 dBm. The mean measured path loss in Dense Urban was 140.71 dB. The mean path losses predicted by Okumura – Hata, COST 231 and SPM were 129.96 dB, 131.87 dB and 125.83 dB, respectively.

Figure 3 shows the prediction results of the calibrated radio propagation models in Dense Suburban terrain. The field measured data obtained in the Dense Suburban clutter class has Mean Received Signal strength of −71.3 dBm. The Calibrated Okumura – Hata, Calibrated COST-231-Hata and Calibrated SPM have MRSS of −73.75 dBm, −73.75 dBm and −73.48 dBm respectively. The mean measured path loss in Dense Suburban was 138.51 dB. The mean path losses predicted by Calibrated Okumura – Hata, Calibrated COST 231-Hata and Calibrated SPM were 140.95 dB, 140.95 dB and 140.68 dB respectively.

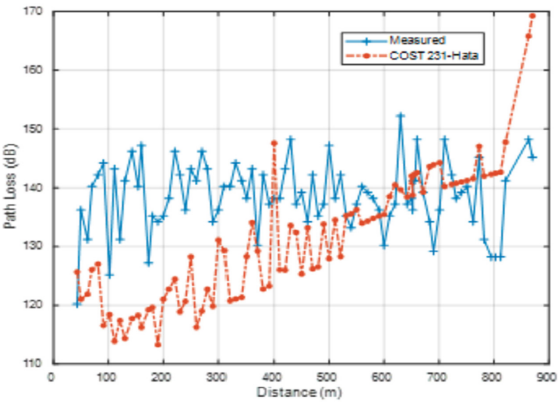
Figure 4 shows the results of the calibrated radio propagation models in Dense Urban clutter class. The MRSS of the Mobile Station in Dense Urban terrain was −73.51 dBm. Calibrated Okumura-Hata, Calibrated COST-231 and Calibrated SPM predicted gave MRSS of −74.65 dBm, −74.61 dBm and −74.96 dBm. The mean measured path loss in Dense Urban was 140.71 dB. The mean path losses predicted by Okumura-Hata, COST-231 and SPM were 141.85 dB, 141.81 dB and 142.16 dB respectively. Mostly, the RSSL diminishes as the distance between the BTS and the MS increases, as anticipated. The RSSL varies randomly between −43 dBm and −100 dBm.



(a)

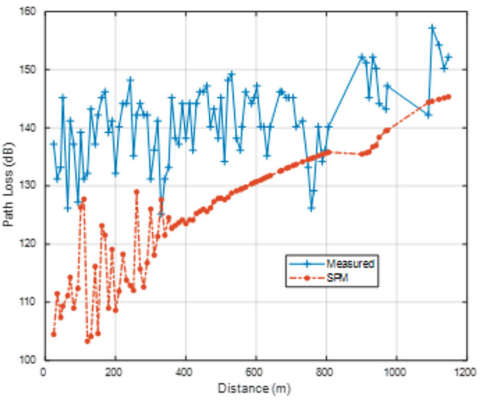


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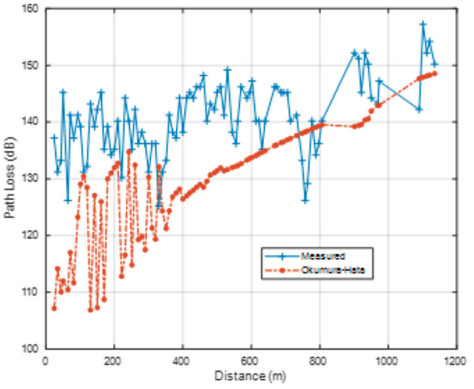


(c)

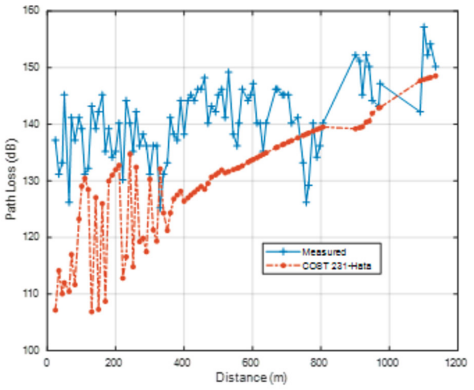
Fig. 1. PL predictions of (a) SPM (b) Okumura-Hata (c) COST 231-Hata models in dense suburban environment



(a)



(b)



(c)

Fig. 2. PL predictions of (a) SPM (b) Okumura-Hata (c) COST 231-Hata models in dense urban environment

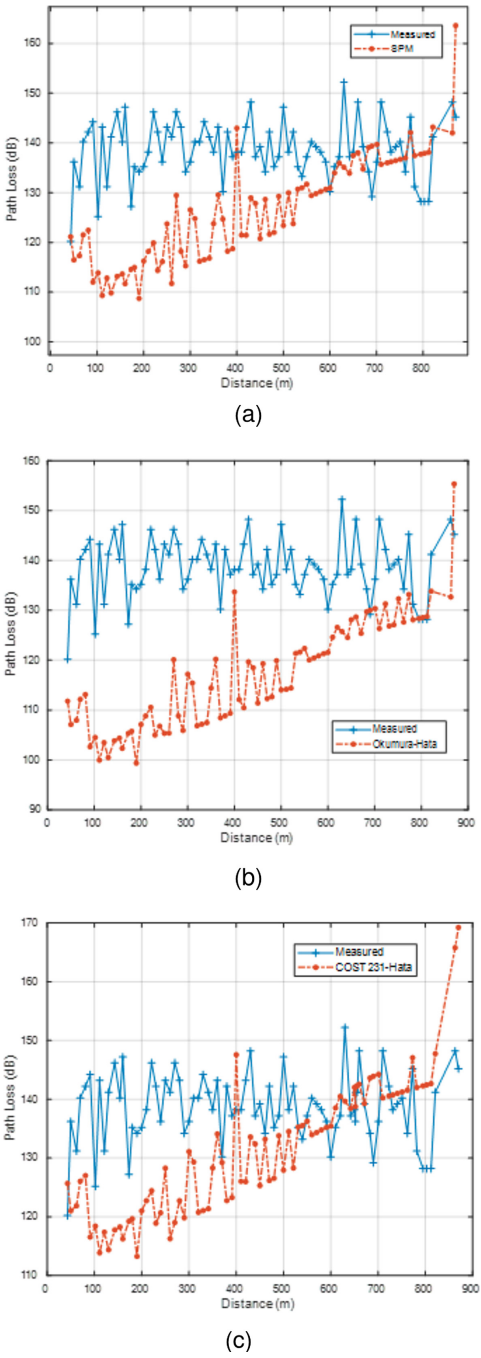
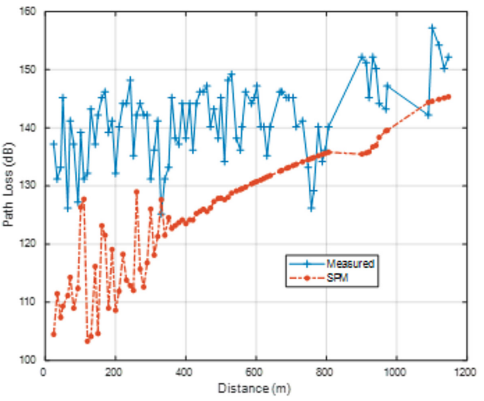
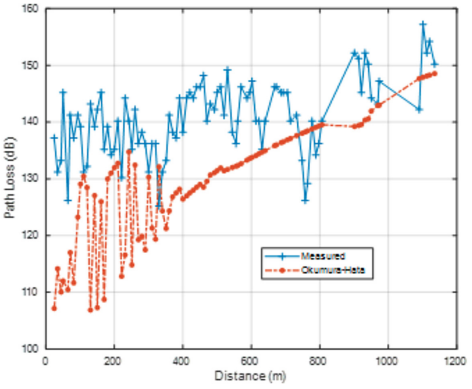


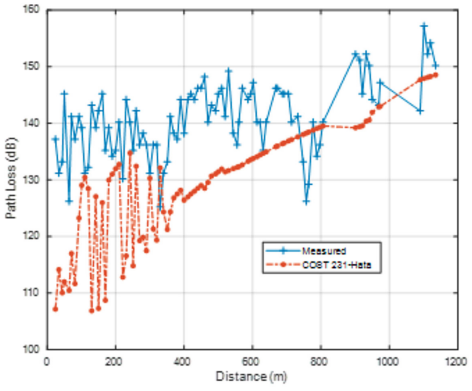
Fig. 3. PL predictions of calibrated (a) SPM (b) Okumura-Hata (c) COST 231-Hata models in dense suburban environment



(a)



(b)



(c)

Fig. 4. PL predictions of calibrated (a) SPM (b) Okumura-Hata (c) COST 231-Hata models in dense urban environment

4 Conclusion

In this paper, we investigated the existing propagation prediction models with the view of working on calibration of empirical radio propagation models for GSM 1800 MHz cellular network planning in Lagos Metropolis, Nigeria. The performance evaluation of the existing empirical model namely: Okumura–Hata, COST-231-Hata and SPM under-estimate the PL at different locations away from the BTS. Consequently, the path losses in both the dense sub-urban clutter and the dense urban clutter of Lagos Metropolis were underestimated by the existing PL models.

In all, COST-231-Hata had the closest prediction results relative to the field measured data in both the Dense Sub-urban and Dense Urban clutter of Lagos. Whereas, the Okumura-Hata gave the widest deviation from the field measured data in the Dense Suburban clutter, while the Standard Propagation Model (SPM) gave the widest deviated results relative to the data obtained in the Dense Urban terrain of Lagos Metropolis. At the end of the calibration process, the mean errors of all the calibrated propagation prediction models have reduced to zero (0 dB). Also, the standard deviations and the root mean squares are now within the calibration quality target of each of the calibrated models. In the Dense Suburban clutter, the Calibrated Okumura – Hata Model gave SD and RME error of 9.083 dB. Calibrated COST 231-Hata model gave SD and RMS error of 9.083 dB. Calibrated Standard Propagation Model gave SD and RMS error of 9.428 dB. In the Dense Urban clutter, the Calibrated Okumura – Hata Model gave SD and RMS error of 7.459 dB. Calibrated COST 231-Hata model gave a standard deviation and root mean square of 7.459 dB. Calibrated Standard Propagation Model gave SD and RMS error of 6.745 dB.

Acknowledgement. This work was carried out under the IoT-Enabled Smart and Connected Communities (*SmartCU*) research cluster of the Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria. The research was fully sponsored by Covenant University Centre for Research, Innovation and Development (CUCRID), Covenant University, Ota, Nigeria.

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