On the Impact of Propagation Models on TV White Spaces Measurements in Africa.

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Abstract—**Currently, use of geo-location databases is the preferred method for detecting TV white spaces by white space devices in the United States of America. The approach protects TV transmitters and receivers from interference sufficiently by keeping a record of the TV transmitters' information, and relying on propagation models to determine the protection area of the TV transmitters. Thus accurate radio propagation by the propagation models is the key to determining the protection area of the TV transmitters. How accurate the propagation models determine the protection area is largely dependent on the terrain characteristics and environmental factors that vary widely from one area to another. These propagation models have been tested in different regions of the world but scarcely in the developing world where white space is assumed to provide broadband connectivity. As such, it is unclear at the moment how accurate the geo-location databases will detect TV white spaces in the developing world. Therefore, this paper argues that unless thorough tests have been conducted with the propagation models in the developing world, the use of geo-location databases in predicting TV white spaces in those regions may not produce optimal results.**

Keywords—**FCC, Interference, Radio Spectrum Utilization and Management, Access Network Technologies, Radio Propagation Studies.**

I. INTRODUCTION

Interference by white space devices (WSDs) to licensed incumbents operations in the television white spaces (TVWSs) could hinder the proliferation of future wireless networks in the TV band, which has greater transmission range and better penetration property as compared to the higher frequency bands [1]. Currently, extensive research is going on in various research centres and institutions to find ways of avoiding the interference as much as possible. White space devices could avoid causing harmful interference by accurately detecting the white spaces and transmitting only at times when the licensed incumbents are not transmitting. One of the possible approaches proposed in the literature for white space detection is the use of geo-location databases. This approach requires a white space device to be able to determine its location, either locally or via the base station it associates with. When the location is known, a geo-location database, which is dynamically updated, can be queried to determine the available spectral opportunities for a given location. The database information is derived from a geographical information system (GIS) that take information such as
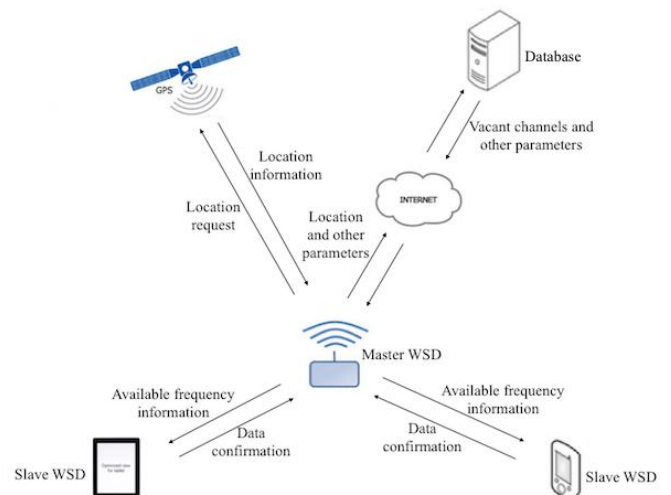

Fig I: Simple White Space Network based on Geo-location Database

primary user location, geographic topography, allowed white space device transmitter power, primary user protection requirements [2] and sophisticated propagation modeling to compute the white spaces at any given location [3]. Figure I show a simple white space network that uses geo-location database to determine TV white spaces.

Currently, this method is the preferred method for detecting TV white spaces by white space devices because it guarantees high protection of the spectrum incumbents [4] from the interference. How accurate geo-location databases are in determining the protection area of the TV transmitters is largely dependent on how accurate the propagation models predict the TV signal attenuation (path loss) over distance. Propagation models are designed for specific types of environment and terrain, and as such, their accuracy in predicting signal attenuation is largely affected by these two factors. Their efficiency in predicting the path loss suffers when they are used in an environment other than the one for

which they have been designed [5] because different types of terrain environment cause different attenuation levels in practice. The developing world has got its own unique terrain type of environment different from the developed world. Most of these propagation models have been tested in different regions of the developed world but scarcely in the regions of the developing world where white space is assumed to provide broadband connectivity. As such, it is unclear at the moment how accurate the geo-location databases will detect TV white spaces in those regions. Therefore, this paper argues that thorough studies have to be conducted with these propagation models in the developing world and the results compared with field measurements before geo-location databases are fully adopted as the main source of detecting TV white spaces in the developing world.

This paper is structured as follows: section II introduces empirical propagation models; terrain impact on the accuracy of the propagation models is discussed in section II (A). To build a practical foundation for our argument, we look at some of the studies that have been carried in the developing world in section II (B); section II (C) draws up some conclusions from the studies; section III looks at performance evaluation done by the authors on a public safety white space network in Cape Town with the results discussed in section IV; section VII concludes.

II. EMPIRICAL PROPAGATION MODELS

In wireless radio communication systems, propagation models can be classified into theoretical (also called deterministic) or empirical (also called statistical). Deterministic models predict transmission losses by mathematical analysis of the path geometry of the terrain between the transmitter and the receiver and the refractivity of the troposphere [6], and calculate received signal power at a particular location [7]. These models require detailed geometric information on terrain profile, location and dimensions of buildings [7]. Accuracy of deterministic models is usually very high but at the expense of high computing complexity, which may be prohibitive for some complex environments [8]. Empirical models are based on extensive measurements and mainly give prediction of path loss [9] as a function of various parameters, e.g. antenna heights, distance, frequency, etc. [7]. They add environmental-dependent loss variables to the free-space loss to compute the net path loss in the corresponding environment [9]. Empirical models are easier to implement, with less computational cost, but they are less accurate [7] especially if they are used in different environments other than the ones they were built for. In this paper, we are focusing on empirical models only because they are more often used in practice [5] than deterministic. Specifically, Longley-Rice (L-R) model, Hata model, CCIR model and Friis Free Space Path Loss (FSPL) will be considered in this paper. The next few paragraphs are dedicated to giving and explaining the formulae for these models. The L-R model is implicitly covered in this paper through Radio Mobile [10], and as such, it is discussed briefly.

A. Longley-Rice Model

It is a very detailed model developed in the 1960s and has been refined over the years. It calculates the median transmission loss by using the path geometry of terrain profile and the refractivity of the troposphere. It also accounts for climate, and subsoil conditions when predicting the path loss. Because of the level of detail in the model, it is generally applied in the form of a computer program that accepts the required parameters and computes the expected path loss [11]. In this experiment, Radio Mobile software was used to simulate the path loss for L-R model since the software uses the model as its underlying model to simulate radio frequency (RF) propagation.

B. Hata model for urban areas

It is the developed version of Okumura model and sometimes called Okumura-Hata model. The model incorporates the graphical information from Okumura model and develops the information further to realize the effects of diffraction, reflection and scattering caused by city structures [12]. It is suited for both point-to-point and broadcast transmissions. Its equation for urban area is given below:

$$PL_{Hata}(dB) = 69.55 + 26.16log_{10}f_{MHz} - 13.82log_{10}h_t - a(h_r) + (44.9 - 6.55log_{10}h_t)log_{10}d_{km}$$

where h_t and h_r are base station and mobile antenna heights in meters respectively, d_{km} is the link distance, f_{MHz} is the frequency of transmission.

The term $a(h_r)$ is an antenna height-gain correction factor that depends upon the environment [13]. It is equal to zero for $h_r = 0$ otherwise it is equal to $3.2(log_{10}11.75h_r)^2 - 4.97$ with $f_{MHZ} > 300$, which was the case in our situation.

C. Egli Model

It is a model that assumes gently rolling terrain between transmitter and receiver, and does not require terrain elevation data between them. It is normally used for point-to-point communication. It is applicable in scenarios where there is line-of-sight (LOS) transmission between one fixed antenna and one mobile antenna, and where transmission has to go over an irregular terrain. The model is not applicable to rugged terrain areas and where there is significant obstruction such as vegetation in the middle of the link [14]. Its equations for the propagation loss are given as follows:

$$PL_{Egli} = \begin{cases} 20\log_{10}f_{MHz} + P_o + 76.3, & h_r < 10 \\ 20\log_{10}f_{MHz} + P_o + 83.9, & h_r > 10 \end{cases}$$

$$P_o = 40\log_{10}d_{km} - 20\log_{10}h_t - 10\log_{10}h_r$$

where f_{MHz} is the frequency of transmission, d_{km} is the link distance, h_t is the base station antenna height in meters and h_r is the mobile station antenna height in meters.

D. Ericsson 9999 Model

The model was developed as modification and extension of Okumura-Hata model. The model allows adjusting parameters

according to a given scenario. The path loss equation as evaluated by this model is given as:

$$PL_{Ericsson} = a_0 + a_1 log_{10}d_{km} + a_2 log h_t + a_3 log\ h_t * log_{10}d_{km} - 2(log_{10}(11.75*h_r))^2 + g(f)$$
$$g(f) = 44.99 log10 f_{MHz} - 4.78(log10 f_{MHz})^2$$

where d_{km} is the distance between transmitter and receiver, f_{MHz} is the transmission frequency, h_t is the base station antenna height, h_r is the receiver terminal antenna height.

a_0, a_1, a_2 and a_3 are model parameters and they are constant but they can be changed according to the scenario (environment) [15]. The defaults values given by the Ericsson model for urban areas are $a_0 = 36.2$, $a_1 = 30.2$, $a_2 = -12.0$ and $a_3 = 0.1$.

E. FSPL

In a line-of-sight radio system, losses are mainly due to free-space path loss (FSPL). FSPL is proportional to the square of the distance between the transmitter and receiver as well as the square of the frequency of the radio signal [16]. In other words, free-space path loss increases significantly over distance and frequency. It is the simplest model and has been used to study white space availability in a number of research papers. Its simplified formula is given as:

$$L_{FSPL}(dB) = 32.4 + 20 log_{10}d_{km} + 20 log_{10}f_{MHz} \qquad (iv)$$

The next section discusses how different terrain influences prediction accuracy of propagation models.

III. TERRAIN IMPACT ON SIGNAL PROPAGATION ACCURACY

Empirical propagation models are designed specifically for a particular terrain profile classified as urban, suburban or rural. Each model can be useful for some specific environment and the accuracy of any particular technique or algorithm depends on the fit between the parameters available for the area concerned and the parameters required by the model [5]. The challenge is that the same categories definitions cannot be applied with the same accuracy [4] in the developed and developing world. Therefore, probability of these models having high prediction errors in one location than the other is high especially if the locations are lying in these two different regions. It is not enough to use a propagation model in a particular region because the region's terrain type fits with the terrain type the model was built for. These models are built based on measurements conducted in regions they were designed for. So for any specific environment, measurements have to be carried out and the values compared with the values obtained from the models otherwise white space devices will cause harmful interference to primary users or significant amount of white space will be wasted as a result of inaccurate prediction of the white spaces. A propagation model performs woefully in predicting signal propagation if it is used in a region different from the one it was built for. Therefore, there is a need to conduct a thorough study of these models in the developing world to gain a better understanding of how geo-location databases will perform in this region.

A. Some studies done in the developing world

With the announcement by the Federal Communications Commission (FCC) in the USA that unlicensed devices can opportunistically use TV white spaces, countries in the developing world are seizing the opportunity to study the behavior of these propagation models in their terrain environment knowing very well that they will play a very important role in the peaceful coexistence of white space devices with licensed primary operations [17]. The next section discusses some of these studies that have been carried out elsewhere.

- INDIA:

[18] compared the measured path loss to various path loss prediction models to find the best-fit model in Kutch Bhuj area, India. They were motivated to carry out the study because the propagation models were giving unsatisfactory results when compared with measured data. They considered Free Space Path Loss model, Okumura-Hata model, Walfisch-Ikegami model and ECC-33 model in their experiment. They found that ECC-33 and Okumura- Hata were the best-fit models for the area as their predicted path loss values were closest to measured data.

- BRAZIL:

[19] conducted similar studies to [18] in Brazil that compared the field strength measurements of a digital TV signal in five cities with the values predicted by some models to find which of them was best suited to the topology of the sites involved. Their main motivation was to help digital TV broadcasters to project the coverage of their TV stations properly and to help regulators to distribute the channels harmoniously. Their study involved the following cities; Rio de Janeiro, São Paulo, Belo Horizonte, Recife and Brasilia, which are all major state capitals, and ITU-R P .526, Deygout-Assis Knife Edge, ITU-R P .1546, and CRC-Predict were involved in the study, all applicable in the UHF band. In general, they found that the model that best fitted to the field measurements was the ITU-R P.1546. They observed that the ITU-R P.1546 model behaved better in cities with reasonably flat terrain, and low variance in altitude. Their study also found that the models that calculate the attenuation by diffraction, i.e., ITU-R P.526 and Deygout-Assis's Knife Edge variations produced very small errors in points that had a free line-of-sight to transmitter and where the obstruction was accurately modeled. Based on this, they concluded that the major limiting factor of field strength prediction's accuracy of point-to-point models is the lacking of information in digital elevation models, that don't take buildings into consideration.

- MALAYSIA

[5] investigated the performance of six common models with measured data in four locations in the suburban area of Kuala Lumpur, the capital of Malaysia. The authors were motivated to conduct the study because studies conducted there and in other tropical countries found that many common path loss models perform less efficiently when compared to measured data. So they wanted to investigate and determine the models that suit the Malaysian environmental conditions. Log-normal Shadowing, Lee, Stanford University Interim

(SUI), COST231, Hata, Egli and the Electronic Communication Committee (ECC)-33 models were involved in the study. They found that the SUI and the Log-normal Shadowing models gave a better prediction in general.

- NIGERIA

[20] conducted a study to assess the fitness of nine empirical widely used path loss models using five novel metrics to gauge their performance in Kwara State, Nigeria. The models involved are Hata, COST 231, Walfisch-Ikegami, Egli, ITU-R P.529-3, ITU-R P.1546-4, CCIR, Davidson and FSPL. They conducted field strength measurements in the VHF and UHF regions along six different routes that spanned through the urban, suburban and rural areas of Kwara State, and converted the measurement results into path losses and compared with the models' predictions. They found that there was no single model that provided good fit consistently. However, they found that CCIR model agrees with the measured path loss within the first 2 km along any route. Thereafter, CCIR over estimates the path loss. Their study also revealed that Walfisch Ikegami, ITU- R P.1546-4 and Egli models underestimate the path loss throughout the range of interest. ITU-R P.529-3, Hata, Davidson and COST 231 model give better results.

- MALAWI

The opportunistic use of TV white spaces has enabled researchers to try and deploy pilot white space networks in some parts of the world including the developing world. One such pilot network was deployed in Malawi after an assessment study on TV White Spaces in Malawi [21] showed that there are a lot of idle channels in the TV band that could be used for other purposes. This and almost zero broadband connectivity in the rural areas motivated the authors in [21] to deploy a white space network with the aim of providing broadband connectivity to rural Malawi. In the pilot study, measurements were made to establish the coverage and performance that could be achieved around the pilot base station in the network. Propagation models were also used in the establishment of the coverage area, and they found that the coverage achieved matched reasonably well with predictions made by propagation models. They used Friis, Okumura-Hata, and Asset propagation models.

B. Conclusion drawn from the studies

Looking at the motivations of all the studies above, they were all driven by either unsatisfactory results from the models or it was unclear how the propagation models could perform. These two factors support our argument that it is unclear at the moment which propagation models perform better in a developing world environment and that thorough studies have to be conducted to understand which of the models perform better in a developing world environment. It is only when propagation models, which are well suited to developing world environment are known that interference or TV white space wastage could be avoided. Those models will predict the TV signal propagation accurately and eventually avoid the two undesirable factors above that can hinder the secondary usage of TV white space efficiently.

IV. PERFORMANCE EVALUATION

To have our own picture of how propagation models perform in the TV frequency band, the authors performed ground truth evaluation of the approaches by conducting actual spectrum measurements and comparing values of the path losses obtained from the measurements against those predicted by the propagation models discussed in the previous section at the University of the Western Cape, Cape Town in South Africa. This section gives a detailed discussion of how the whole process was carried out.

A. Measurement Setup

Indoor spectrum measurements were done at the University of the Western Cape (UWC) in Cape Town, South Africa, which is a typical urban area. The indoor measurement location was in a closed room on the ground floor of the Computer Science Department on latitude *33°56`3.80``S* and longitude *18°37`46.7``E*. The RF Explorer model WSUB1G was used in the measurement process. The model was fitted with a Nagoya NA-773 wideband telescopic antenna, which has wide band measurement capability. The RF Explorer is capable of analyzing spectrum bands from *240 MHz* to *960 MHz*. Its complete technical specifications can be found in [22]. The measurement configuration is shown in Figure II. The Windows PC Client tool was installed on a desktop computer before connecting the RF explorer to the computer to have additional functionality. Using the set-up in Figure IV, continuous spectrum monitoring was done for a period of one week.

B. TV transmitters used

Three TV transmitters located at different distances from the measurement location were identified and used in the experiment. The broadcasting parameters for the transmitters with respective TV services are shown in Table I [23].

Tygerberg transmitter is sitting at latitude 33S5231 and longitude 18E3544; Aurora transmitter at latitude 33S49 39 and longitude 18E3829; Table Mountain transmitter is at latitude 33S5726 and longitude 18E2411 [23]. Figure III shows a visual picture of how these transmitters are located with respect to UWC's location where the measurements were taken. Radio Mobile software [10] was used to generate/render the picture.
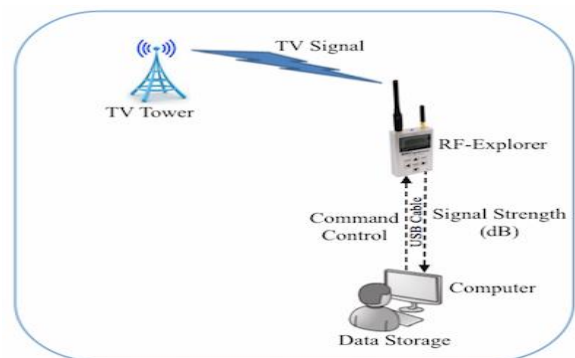

Fig II: Measurement configuration

Table I: TV Transmitter Parameters and Associated TV Stations

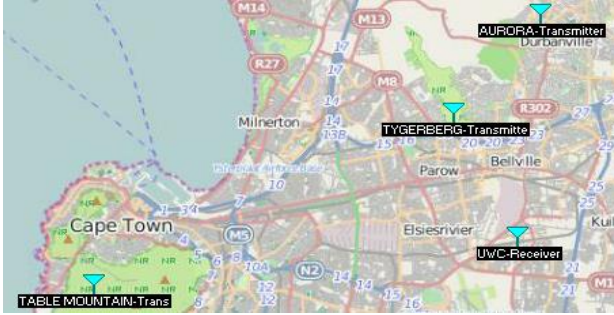| Transmitter Name	Broadcast Frequency (MHz)	Channel Number	ERP (KW)	TV Service	Link Distance (Km)
Tygerberg (T1)	479.25	22	2	SABC1	7.3
Aurora (T2)	551.25	31	0.003	SABC2	11.9
Table Mountain (T3)	647.25	43	0.5	SABC3	21.0

Fig III: Transmitters' location and receiver location

C. Results

Our results have been classified into two, simulation results and experimental results. Simulation results include path loss predictions from Radio Mobile software, which uses the Longley-Rice model with irregular terrain as the underlying propagation model and the prediction results from the other propagation models. Experimental results are the results from our measurements.

1. Simulation Results

Radio Mobile software [10] was used to simulate the radio links. Figure IV shows the simulated links from each of the transmitter to the receiver at UWC.

The Fresnel zone picture from Radio Mobile software [10] of one of the radio links is shown in Figure V. The figure also shows the technical parameters that were used for transmitter and receiver setup.
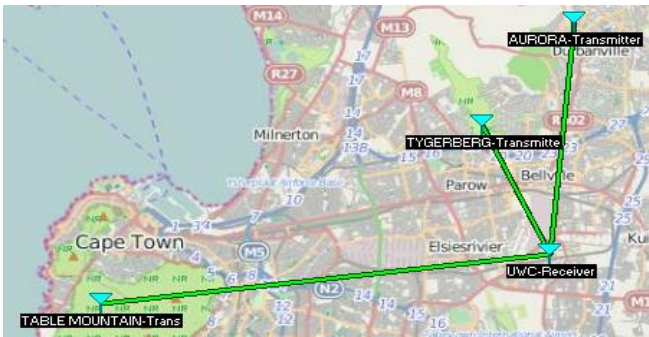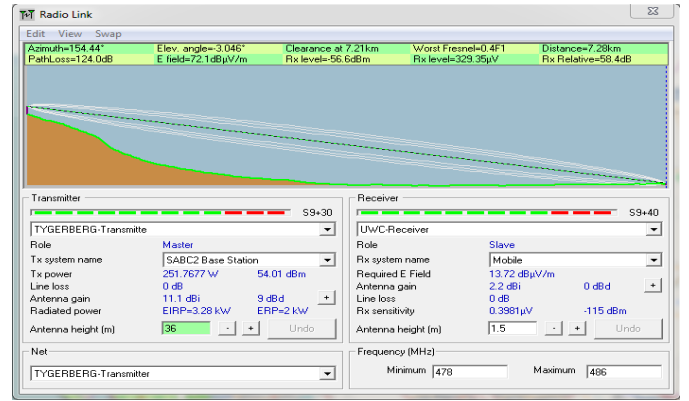

Fig IV: Radio links

Fig V: Tygerberg-UWC Radio Link

Using the propagation models' equations in section II and Radio Mobile software for the L-R model, the path loss of each model from each transmitter to the receiver was calculated. The predicted path losses are shown in Table II.

2. Experimental results

The weeklong measurements from each channel were averaged and the mean values were taken as the received signal power levels at the measurement site from the transmitters. To derive the path loss from these measurements, we first obtained effective isotropic radiated power (EIRP) for each of the transmitters by adding *2.2* to the effective radiated power (ERP) in *dBm* from Table II. The value of *2.2* is a gain of the half wave dipole. The antenna gain of the receiver was assumed as *2.2 dBi* with *0 dB* cable loss since the antenna was directly connected to the RF-Explorer. Using the free space loss equation *EIRP – Path loss + G_r = R_x*, where G_r is the antenna gain of the receiver and R_x is the received signal power, we calculated the path losses. Table III provides a summary of the mean values of the received signal power levels and calculated path losses.

Table II: Path loss predictions

Transmitter	Path Losses (dBm)				
	L-R	Hata	Egli	Ericsson	FSPL
T1: 7.3 Km	127	149	133	126	103
T2: 11.9 Km	137	158	143	134	109
T3: 21.0 Km	142	169	154	143	115

Table III: Path loss estimates from measurements

Transmitter	EIRP (dBm)	Signal Strength (dBm)	Path Loss (dBm)
Tygerberg (T1)	65.2	-96.9	164.3
Aurora (T2)	36.9	-103.2	142.3
Table Mountain (T3)	59.1	-106.0	167.3

The TV transmitter database from the Independent Communications Authority of South Africa (ICASA) [23] where the TV transmitter parameters in Table II were obtained does not include antenna parameters such as pointing direction and pattern. Therefore, the EIRPs in Table V can be best thought of as upper bounds since the measurement location was not likely to see highest gain diretion from the transmitter

antennas under consideration. Practically, the correct EIRPs should be less than those in Table V as those can be achieved only if the measurement location was in the pointing directions of the respective transmitter antennas.

To get a clearer picture of the pattern of the predicted path losses by the models compared to the derived path losses from the measured data, they were both plotted in graphs against distances from the transmitters as shown in Figure X. It was also easy to compare the relative performance of the other models against the L-R model, which is regarded as the default model for predicting TV signal attenuation by the Federal Communications Commission (FCC) in one of its ruling [8].

D. Discussion

From the graph, it is easy to see that there is not much agreement between the path losses derived from the measurement data and the path losses predicted by the models. Since the measurements were done indoors and the models did not account for the building penetration loss encountered by the signals when propagating from outside to the inside of the building, a clear conclusion cannot be drawn as whether the models performed badly or not. More measurements and tests with the models that take into account the building penetration loss need to be done to ascertain which models do better in and around UWC.

Relative performance comparison of the other models against the L-R model shows that there is close agreement between the Ericsson 9999 model and the Longley-Rice model. Hata model and FSPL model vary widely from the L-R model and the Egli model did not perform badly when compared with the L-R model.
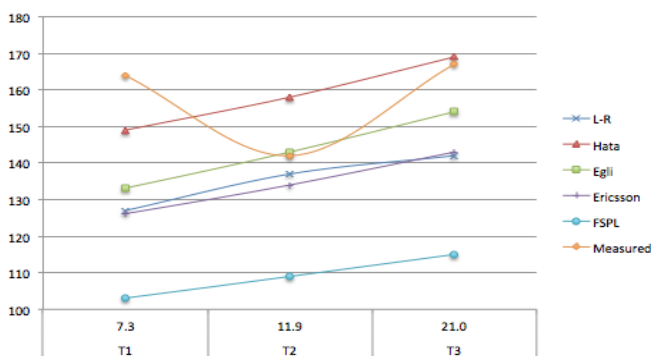

Fig IV: Path losses of the models and measured data

V. CONCLUSION AND FUTURE WORK

This paper argued about conducting thorough studies to have a clear picture of which propagation models fit with developing world environment. The argument originates from the situation on the ground that geo-location databases are now preferred as the main source of TV white space but how they will perform in the developing world environment is not clear as there has not been extensive studies of signal propagation by propagation models in these regions. The paper looked at how propagation models are impacted by different terrain environment. It also looked at some of the studies that have been done on propagation in some of the developing world countries to find better-fit models for them. The studies show that most of the developing world countries are unclear of the propagation models, which accurately predict signal propagation in their environment, supporting our argument that studies have to be done to determine which propagation models work best for this environment. The study of these models will benefit the design of heterogeneous cities public safety networks operating in the white space bands to carry all form of data: sensor readings, voice, and emergency data. The technical management of such networks is a new opportunity for the redesign of the traffic engineering techniques proposed in [24,25,26] for wireless sensor networks and [27,28,29] for connection oriented networks.

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