REPORT -2

WIRELESS COMMUNICATIONS

Prof. Dr. Said E. El-Khamy
Communication & Electronics

Asmaa Gamal Abdel-Halem Mabrouk Nagy
أسماء جمال عبد الحليم مبروك ناجي
15010473

Outdoor Fading Propagation Models in 3G and 4G

"Supplemented By: The Detailed Proofs of The Rayleigh & Rician distributions"

1. Outdoor Propagation Fading Models

1.1. The Longley–Rice Model :

The Longley–Rice model (LR) is a radio propagation model: a method for predicting the attenuation of radio signals for a telecommunication link in the frequency range of 40 MHz to 100 GHz.

The Longley-Rice propagation model, also known as the Irregular Terrain Model (ITM), is a widely used empirical model for predicting radio wave propagation in the VHF and UHF frequency bands.

The model takes into account various factors affecting radio wave propagation over irregular terrain, including terrain profiles, frequency, antenna heights, and atmospheric conditions. It is particularly useful for predicting signal coverage and interference in broadcasting, cellular communication, and other wireless communication systems.

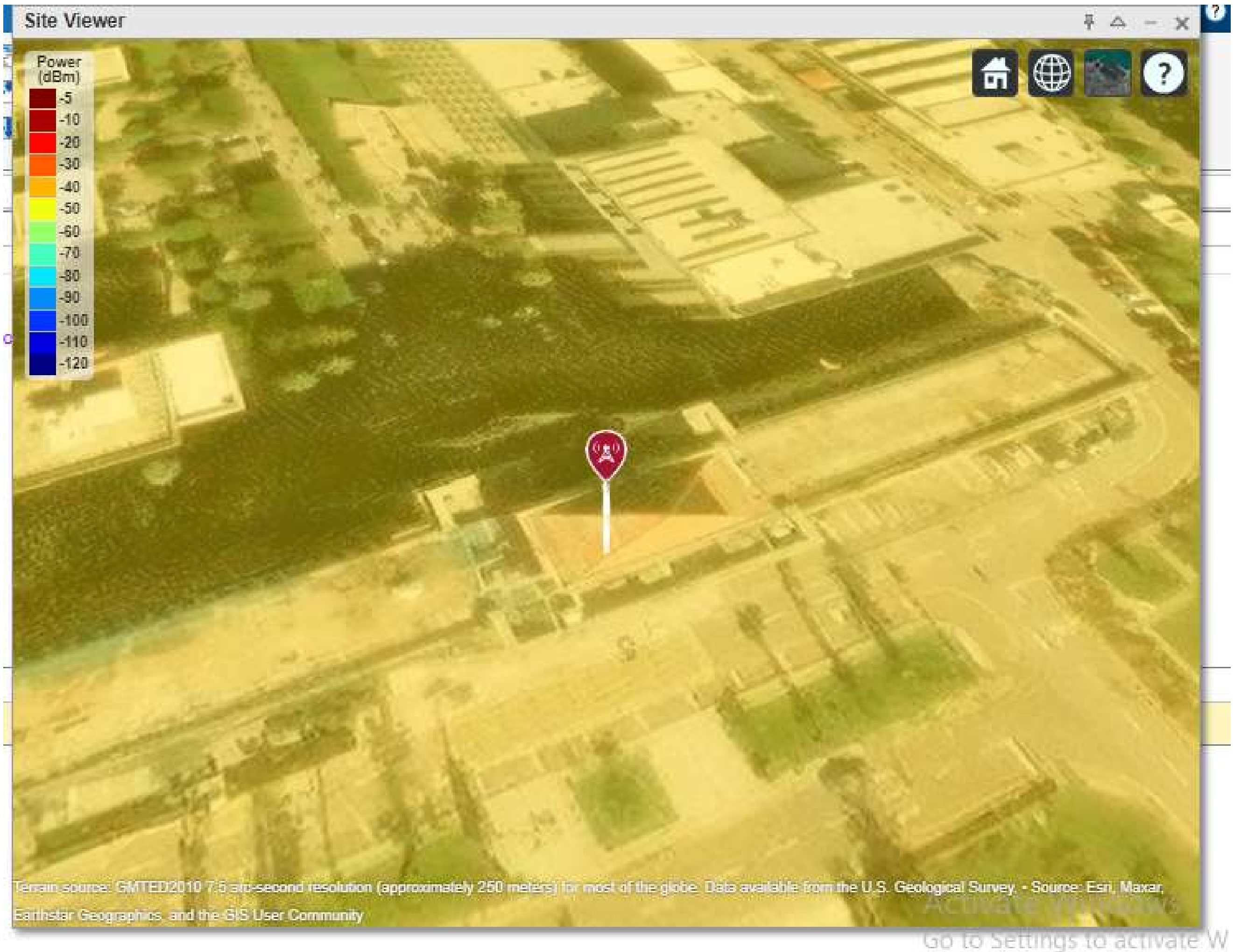
Some key features and components of the Longley-Rice model include:

1. Terrain Data: The accuracy of the model's predictions depends on the resolution and quality of the terrain data used. Higher resolution digital elevation models (DEMs) provide more accurate results, especially in areas with rugged terrain or significant variations in elevation.
2. Profile Calculation: It calculates a hypothetical smooth earth profile (SEP) based on the terrain data, which is used to estimate the path loss.
3. Atmospheric Attenuation: It incorporates atmospheric effects such as absorption, refraction, and scattering, which can affect signal propagation.
4. Frequency Dependence: The model accounts for the frequency dependence of various propagation effects, including diffraction, reflection, and ground wave propagation.
5. Antenna Heights: It considers the heights of the transmitting and receiving antennas above ground level, as these significantly influence signal propagation.
6. Propagation Loss Prediction: The Longley-Rice model predicts the total path loss between the transmitter and receiver, which includes contributions from free-space loss, terrain-induced loss, diffraction loss, and atmospheric attenuation. The predicted path loss is often expressed in terms of received signal power relative to the transmitted power (e.g., in dB).
7. Coverage Prediction: Based on the predicted path loss, the model can estimate the coverage area of a transmitter and assess the received signal strength at different locations.
8. Validation and Calibration: The Longley-Rice model has been extensively validated and calibrated using field measurements and data from various propagation studies.

Overall, the Longley-Rice propagation model is a valuable tool for engineers and planners in the design and optimization of radio communication systems, especially in areas with complex terrain where line-of-sight propagation is not feasible. It is commonly used in the planning and deployment of broadcasting networks, cellular networks, and other wireless communication systems to ensure reliable signal coverage and quality.

Display the coverage area for a transmitter using the Longley-Rice model:

```
pm = propagationModel("longley-rice");
tx = txsite("Name","handasa","Latitude",31.206221764740672,"Longitude",29.92474467666568);
coverage(tx,pm,"SignalStrengths",-100:-5)
```



Model the behavior of electromagnetic radiation from a point of transmission over irregular terrain, including buildings, by using the Longley-Rice model, also known at the Irregular Terrain Model (ITM) . Represent the model by using a LongleyRice object.

1.1. Okumura Model:

The Okumura model is a radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model is ideal for using in cities with many urban structures but not many tall blocking structures. The model served as a base for the Hata model.

Okumura model was built into three modes. The ones for urban, suburban and open areas. The model for urban areas was built first and used as the base for others.

This model is widely used for estimating path loss in urban and suburban environments at frequencies between 150 MHz and 1 GHz, primarily for mobile communication systems such as cellular networks.

- **Propagation Parameters:** The Okumura model defines specific propagation parameters for each environment type (urban, suburban, rural) and frequency range. These parameters are based on statistical analysis of field measurements and represent the average propagation characteristics observed in each environment.
- **Urban Environment:** In urban areas, the Okumura model accounts for high building density, street canyons, and other man-made structures that can cause multipath propagation, shadowing, and diffraction effects. It typically incorporates higher path loss values compared to suburban and rural areas due to increased signal attenuation caused by obstacles and reflections.
- **Suburban Environment**: Suburban areas in the Okumura model are characterized by a mix of residential and commercial buildings, with lower building density compared to urban areas. The model accounts for fewer obstacles and less severe multipath effects, resulting in lower path loss values compared to urban areas.
- **Rural Environment**: Rural areas are characterized by open terrain with fewer buildings and obstacles. The Okumura model typically assumes less signal attenuation in rural environments compared to urban and suburban areas, resulting in lower path loss values, especially at longer distances from the transmitter.
- **Propagation Models:** The Okumura model consists of two primary propagation models: the median path loss model and the standard deviation model. The median path loss model provides the average path loss value for a given distance and environment type, while the standard deviation model accounts for the variability or uncertainty in path loss due to factors such as terrain irregularities and building variations.
- **Frequency Dependence:** The Okumura model considers the frequency dependence of path loss, with separate propagation parameters defined for different frequency bands within the 150 MHz to 1 GHz range. Higher frequency bands typically experience higher path loss due to increased atmospheric absorption and scattering effects.
- **Corrections and Extensions**: Over the years, several corrections and extensions to the original Okumura model have been proposed to improve its accuracy and applicability to modern communication systems. These include adjustments for antenna heights, terrain characteristics, building types, and urban morphology.
- Comparison with Other Models: The Okumura model is often compared with other empirical propagation models such as the COST-231 Hata model, Walfisch-Ikegami

model, and Lee model. These models have been developed based on similar principles but may incorporate different assumptions and parameters based on the specific characteristics of the environments and regions they were designed for.

Overall, the Okumura model remains a valuable tool for estimating path loss in mobile communication systems, especially in urban and suburban environments where accurate propagation modeling is essential for network planning and optimization. Despite its age, the Okumura model continues to be widely used and referenced in the field of radio wave propagation.

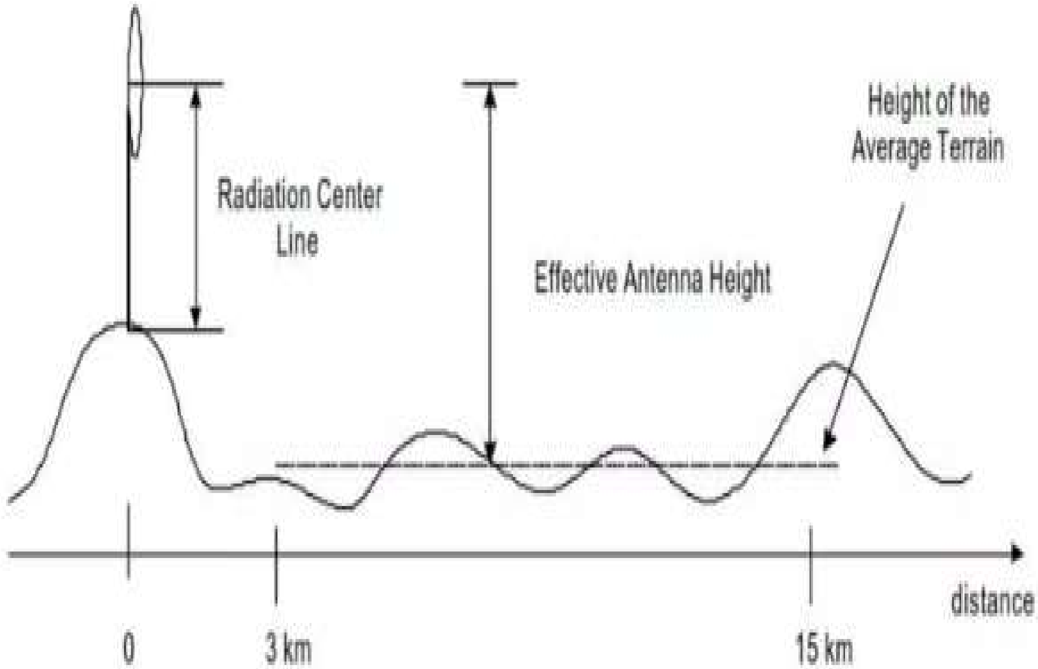
various elements influencing radio wave propagation in suburban and urban settings, such as:

1. **Distance:** One of the main factors affecting path loss according to the model is the distance between the transmitter and the receiver. It takes into consideration scenarios of both non-line-of-sight (NLOS) and line-of-sight (LOS) propagation.

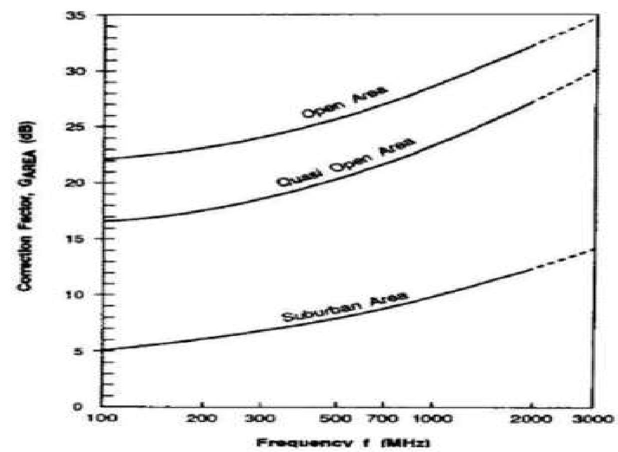
2. **The transmitted signal's frequency** is taken into account by the model since higher frequencies often result in larger route losses because of increased air absorption and dispersion.
3. **Antenna Heights:** It considers the elevations above ground of the transmitting and receiving antennas. When assessing the degree of direct path loss and the existence of barriers, antenna heights are important factors
4. **Correction Factors:** Based on extra variables including frequency bandwidth, building heights, and irregular topography, the model incorporates correction factors to modify path loss estimations.

It takes into consideration a number of propagation mechanisms, such as scattering, diffraction, reflection, and free-space loss. In urban and suburban areas, these mechanisms are integrated into the model to estimate the total path loss.

Validation and Calibration: Using comprehensive field measurements carried out in various geographical locations and environmental circumstances, the Okumura model has been validated and calibrated. This guarantees that the model predicts path loss accurately for a variety of scenarios.



4. **Environment Type**: The Okumura model categorizes environments into urban, suburban, and rural based on factors such as building density, street layout, and terrain characteristics. Different propagation parameters are used for each environment type to account for their unique characteristics.



The Okumura model is formally expressed as:

$$L = L_{\mathrm{FSL}} + A_{\mathrm{MU}} - H_{\mathrm{MG}} - H_{\mathrm{BG}} - \sum K_{\mathrm{correction}}$$

where,

- L = The median path loss. Unit: Decibel (dB)
- LFSL = The free space loss. Unit: decibel (dB)
- AMU = Median attenuation. Unit: decibel (dB)
- HMG = Mobile station antenna height gain factor.
- HBG = Base station antenna height gain factor.
- Kcorrection = Correction factor gain (such as type of environment, water surfaces, isolated obstacle etc.)

Okumura's model is wholly based on measured data and doesn't provide any analytical explanation

The whole disadvantage is its slow response to rapid change in terrain

The model is fairly good in urban and suburban and not as good in rural areas

Common standard deviation between prediction and measured path loss are 10dB to 14dB

Figure 1: Map of Ado – Ekiti (source Google Earth)

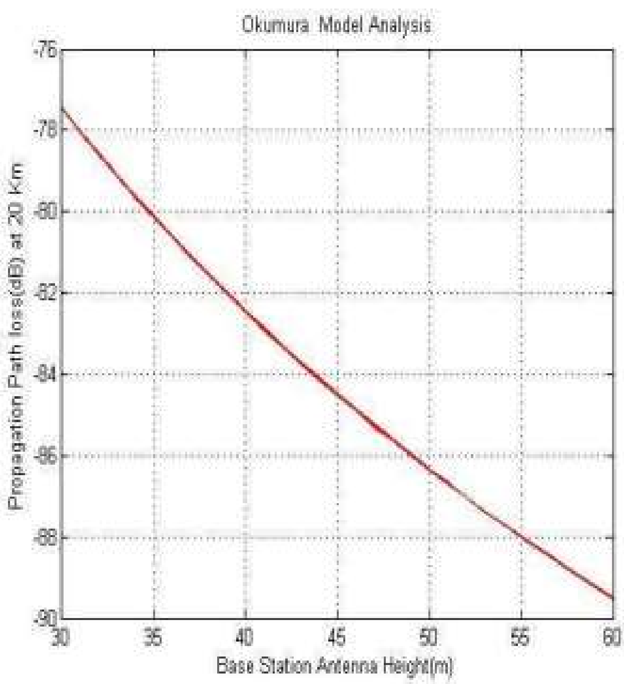


Figure 4: Path-loss for Okumura Model for Base Station Variation

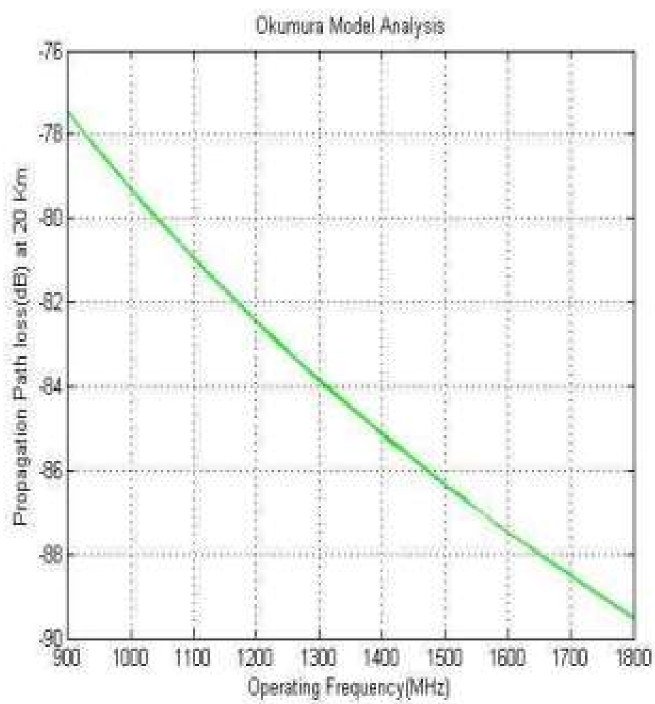


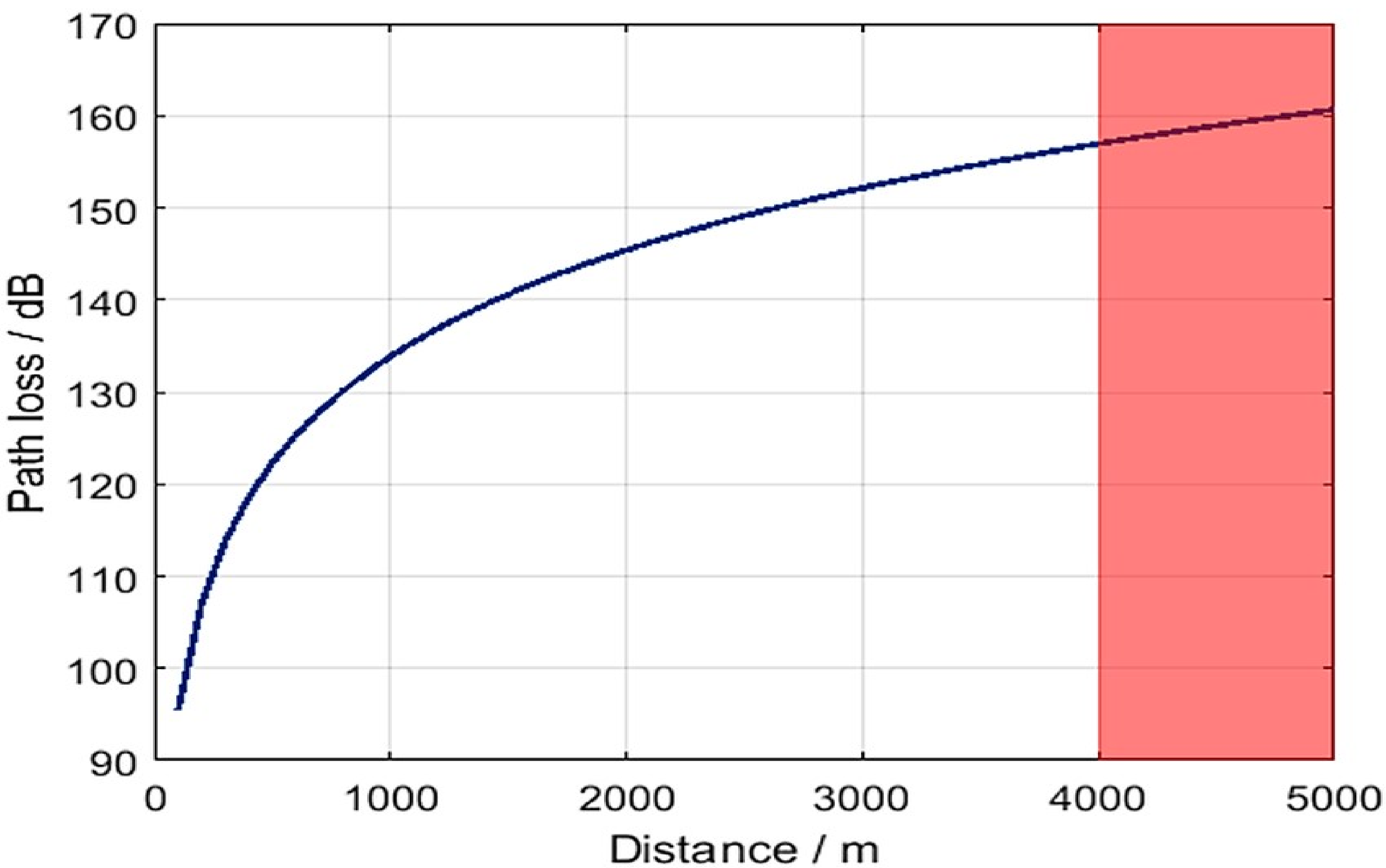
Figure 5: Path-loss for Okumura Model for Operational Frequency Variation

1.3. The Okumura-Hata Model:

The Okumura-Hata model is an empirical radio propagation model primarily used for estimating path loss in urban and suburban environments for frequencies between 150 MHz and 1500 MHz. It builds upon the principles of the original Okumura model but introduces additional parameters and modifications to improve its accuracy and applicability to modern mobile communication systems, especially cellular networks.

Here are some key features of the Okumura-Hata model:

1. Frequency Range: The Hata model is applicable to a wider frequency range compared to the original Okumura model, covering frequencies from 150 MHz to 1500 MHz. This makes it suitable for various mobile communication systems operating in the VHF and UHF bands.
2. Propagation Parameters: Similar to the Okumura model, the Hata model defines specific propagation parameters for different environment types (urban, suburban, rural) and frequency bands. These parameters are based on statistical analysis of field measurements and represent the average propagation characteristics observed in each environment.
3. Path Loss Prediction: The Hata model predicts the path loss between a transmitter and receiver based on distance, frequency, antenna heights, and environment type. It incorporates both free-space loss and additional path loss components due to terrain, building density, and other environmental factors.



PATH LOSS FOR SMALL AND MEDIUM SIZED CITIES. THE RED SHADED AREA DEPICTS THE DISTANCES WHICH ARE EXCEEDING THE TOTAL LINK BUDGET OF THE USED LORA TRANSCEIVER

4. Environment Types: The model distinguishes between urban, suburban, and rural environments, with different propagation parameters for each environment type. Urban areas typically experience higher path loss due to higher building density and more severe multipath effects, while rural areas have lower path loss values due to fewer obstacles and less attenuation.
5. Antenna Heights: The Hata model takes into account the heights of both the transmitting and receiving antennas above ground level, as antenna heights significantly influence signal propagation and path loss.
6. Empirical Calibration: Like the Okumura model, the Hata model has been calibrated using extensive field measurements conducted in various geographic regions and environmental conditions. This calibration ensures that the model provides accurate path loss predictions for a wide range of scenarios.
7. Simplifications and Limitations: Despite its accuracy in many scenarios, the Hata model makes simplifications and assumptions about propagation conditions and environment characteristics. It may not accurately represent complex urban environments with irregular terrain or densely packed buildings.

Overall, the Okumura-Hata model remains a widely used and accepted tool for estimating path loss in urban and suburban environments for mobile communication systems, especially cellular networks. It provides valuable insights into signal coverage and attenuation, aiding network planning and optimization efforts. However, it is important to consider its limitations and potential inaccuracies, especially in scenarios that deviate from its underlying assumptions.

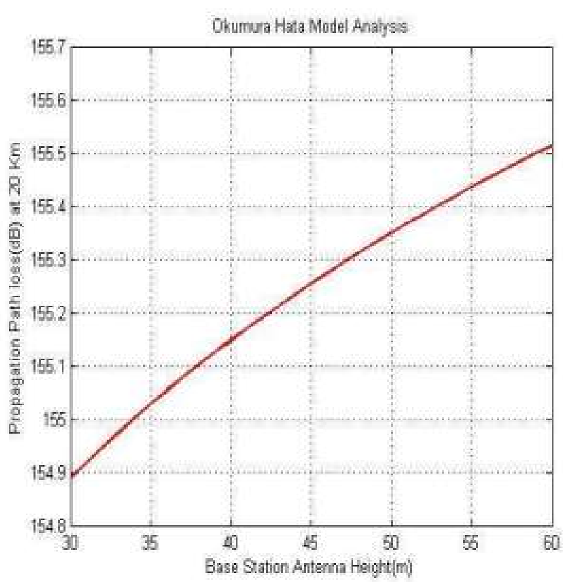


Figure 6: Path-loss for Okumura Hata Model for Base Station Variation

3.1 Comparison of Okumura Hata and Okumura Models on the Basis of Base Station Antenna Height

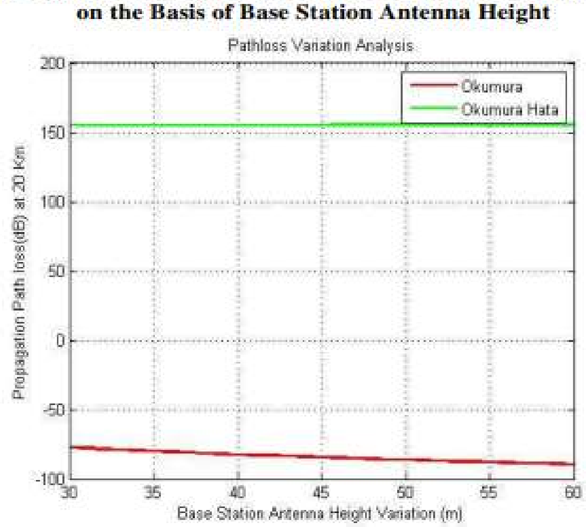


Figure 8: Comparison of both models on Base Station Variation

- there is less path-loss of the signal for Okumura Hata model due to change in base station antenna height as compared to Okumura model which make the signal of Okumura Hata model to reach better distance and more effective coverage.

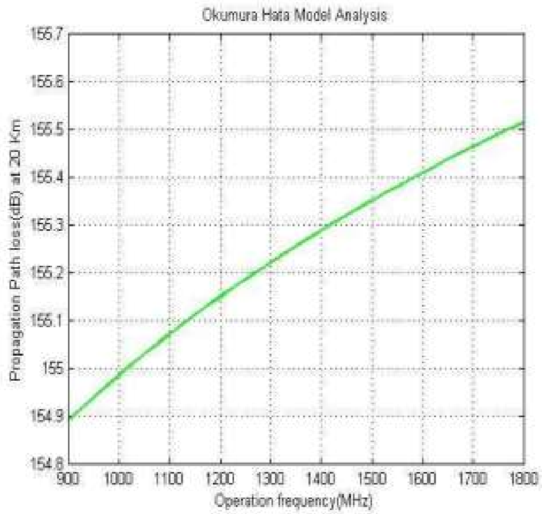


Figure 7: Path-loss for Okumura Hata Model for Operational Frequency Variation

3.2 Comparison of Okumura Hata and Okumura Models on the Basis of Operational Frequency

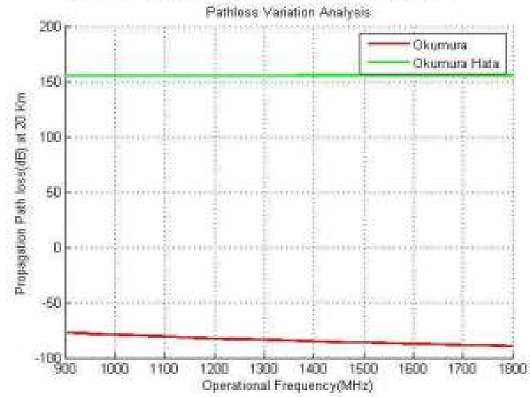


Figure 9: Comparison of both models on Operational Frequency Variation

As shown in figure 9, there is again less loss of signal as it travels across the channel for Okumura Hata model compared to Okumura Model.

- There is path-loss improvement for Okumura model compare to Okumura Hata model with respect to base station

The Hata model for urban environments is the basic formulation since it was based on Okumura's measurements made in the built-up areas of Tokyo. It is formulated as following:

$$L_U = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_B - C_H + [44.9 - 6.55 \log_{10} h_B] \log_{10} d$$

For small or medium-sized city,

$$C_H = 0.8 + (1.1 \log_{10} f - 0.7) h_M - 1.56 \log_{10} f$$

and for large cities,

$$C_H = \begin{cases} 8.29 \left(\log_{10}(1.54 h_M) \right)^2 - 1.1 & \text{, if } 150 \le f \le 200 \\ 3.2 \left(\log_{10}(11.75 h_M) \right)^2 - 4.97 & \text{, if } 200 < f \le 1500 \end{cases}$$

where

- L_U = Path loss in urban areas. Unit: decibel (dB)
- h_B = Height of base station antenna. Unit: meter (m)
- h_M = Height of mobile station antenna. Unit: meter (m)
- f = Frequency of transmission. Unit: Megahertz (MHz)
- C_H = Antenna height correction factor
- d = Distance between the base and mobile stations. Unit: kilometer (km).

Software Architecture for Hata Model

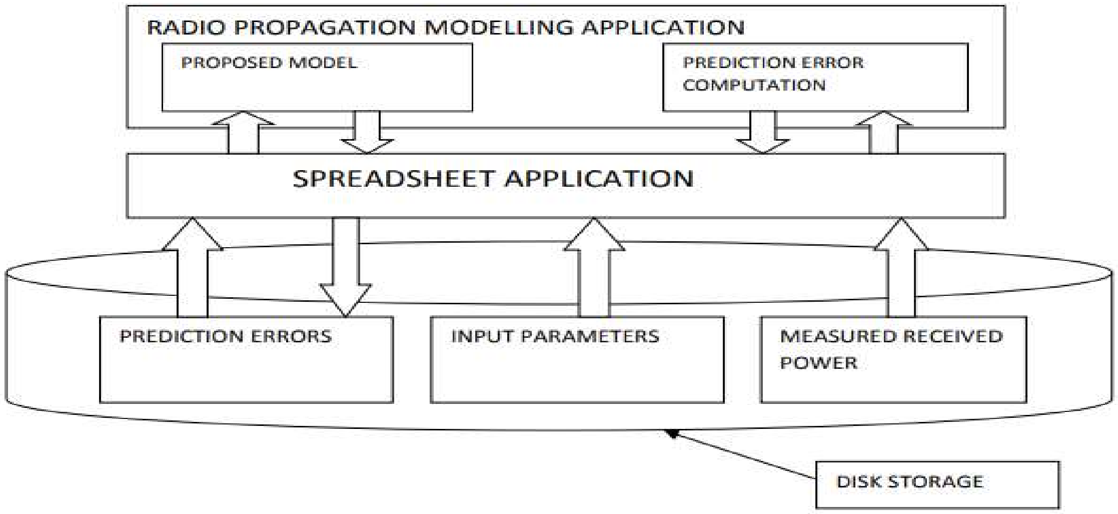


Figure 2: Software Architecture

2. Propagation Model in 3G And 4G

The Longley-Rice propagation model, the Okumura model, and the Hata model can all be used in the planning and analysis of 3G and 4G networks, but they serve different purposes and have different areas of applicability within the context of mobile communication systems.

- **Longley-Rice Propagation Model:**

Applicability to 3G and 4G: The Longley-Rice model is a versatile model that can be applied to various frequency bands, including those used in 3G (UMTS/HSPA) and 4G (LTE) networks.

Features: It takes into account terrain profiles, frequency, antenna heights, and atmospheric conditions, making it suitable for analyzing signal propagation in different environments.

Use Cases: The Longley-Rice model is often used in network planning, coverage prediction, and interference analysis for both 3G and 4G networks, especially in areas with complex terrain or non-line-of-sight conditions.

- **Okumura Model:**

Applicability to 3G and 4G: The Okumura model, including the Hata extension, is commonly used for estimating path loss in urban and suburban environments for frequencies between 150 MHz and 1500 MHz, which encompass the frequency bands used in 3G and 4G networks.

Features: It considers environment types (urban, suburban, rural), antenna heights, and frequency, providing specific propagation parameters for each scenario.

Use Cases: The Okumura model is frequently employed in the planning and optimization of cellular networks, including 3G and 4G deployments, to estimate signal coverage and path loss in urban and suburban areas.

- **Hata Model:**

Applicability to 3G and 4G: The Hata model is an extension of the Okumura model and is also commonly used for estimating path loss in urban and suburban environments for frequencies between 150 MHz and 1500 MHz, making it applicable to 3G and 4G networks.

Features: It includes additional parameters and modifications to improve accuracy and applicability to modern mobile communication systems compared to the original Okumura model.

Use Cases: Like the Okumura model, the Hata model is used in the planning and optimization of cellular networks, including 3G and 4G deployments, for estimating signal coverage and path loss in urban and suburban areas.

In summary, all three models (Longley-Rice, Okumura, and Hata) can be used in the planning and analysis of 3G and 4G networks. The choice of model depends on factors such as the specific requirements of the network deployment, the availability of terrain data, and the desired level of accuracy in predicting path loss and coverage.

3. The Detailed Proofs of The Rayleigh & Rician distributions

3.1. Rayleigh Fading Distribution Proof

To prove the Rayleigh fading distribution, let's consider a scenario in wireless communication where the received signal experiences fading due to multiple independent signal paths with equal power arriving at the receiver. This scenario is often modeled using the Rayleigh fading distribution, which is a special case of the Rician distribution with a zero LOS component.

Let's denote the received signal amplitude as R, which is the magnitude of the complex-valued received signal S. If S is a complex Gaussian random variable with zero mean and variance σ2, then R follows a Rayleigh distribution.

The probability density function (PDF) of R for the Rayleigh fading distribution can be derived as follows:

Received Signal Amplitude: The received signal amplitude R is given by the magnitude of the complex-valued received signal S:

$R=|S|=\sqrt{\boldsymbol{x^2+y^2}}$

To find the probability density function (PDF) of R, we will first find the cumulative distribution function (CDF) of R, and then differentiate it to obtain the PDF.

The CDF of R is given by:

$FR(r)=P(R\leq r)=P(\boldsymbol{x^2+y^2}\leq r)$

Since X and Y are Gaussian random variables with mean 0 and variance σ2, the joint PDF of X and Y is given by the bivariate Gaussian distribution:

$$f_{X,Y}(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Now, let's express the event $\sqrt{\boldsymbol{x^2+y^2}}\leq r$ in terms of X and Y:

$\sqrt{\boldsymbol{x^2+y^2}}\leq r$

$\boldsymbol{x^2+y^2\leq r^2}$

This represents the area of a circle with radius r centered at the origin in the XY-plane.

Integrating the joint PDF over this region gives us the probability:

$$P(R \leq r) = \int_{-r}^{r} \int_{-\sqrt{r^2-y^2}}^{\sqrt{r^2-y^2}} f_{X,Y}(x, y)\, dx\, dy$$

After performing the integration, simplifying the expression, and differentiating with respect to r, we obtain the PDF of R, which is the Rayleigh distribution.

$$f_R(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}$$

This is the probability density function of a Rayleigh-distributed random variable with parameter σ, where σ represents the scale parameter of the distribution.

This proof demonstrates how the Rayleigh distribution arises from the sum of squared Gaussian random variables, which is a common scenario in wireless communication systems where signals experience random amplitude variations due to multipath propagation.

3.2. Rician Fading Distribution Proof:

The Ricean fading distribution is a probability distribution commonly used to model wireless communication channels where there is a dominant line-of-sight (LOS) signal component along with scattered multipath signals. It is often used in scenarios where there is a strong LOS component in addition to fading caused by reflections, diffractions, and scattering.

The Ricean fading distribution is characterized by two parameters: the amplitude of the LOS component (usually denoted as K) and the scale parameter of the scattered component (usually denoted as σ).

To derive the Ricean fading distribution, let's consider a wireless communication channel where the received signal is a combination of a dominant LOS component and a scattered multipath component. We denote the received signal amplitude as R.

The probability density function (PDF) of R for the Ricean fading distribution can be derived as follows:

Received Signal Amplitude: The received signal amplitude R can be expressed as the sum of the LOS component K and the scattered multipath component R=$\sqrt{\boldsymbol{k^2+y^2}}$ where Y follows a Rayleigh distribution with scale parameter σ.

Probability Density Function of R: To find the PDF of R, we need to determine the joint probability density function (PDF) of K and Y, and then use a transformation to find the PDF of R.

Since K is a constant (the amplitude of the LOS component), the joint PDF of K and Y is simply the PDF of Y (Rayleigh distribution) shifted by K.

The PDF of R is obtained by integrating the joint PDF of K and Y over all possible values of Y:

$$f_R(r) = \int_0^\infty f_Y(r-k) f_K(k)\, dk$$

After performing the integration, we obtain the Ricean fading distribution:

$$f_R(r) = \frac{r}{\sigma^2} e^{-\frac{r^2+K^2}{2\sigma^2}} I_0\left(\frac{rK}{\sigma^2}\right)$$

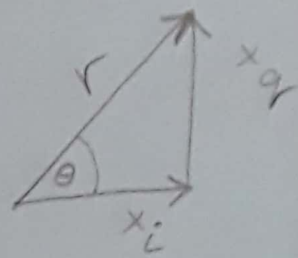
where Io(·) is the modified Bessel function of the first kind of order zero.

This is the probability density function of a Ricean-distributed random variable R with parameters K and σ. The parameter K represents the amplitude of the LOS component, and σ represents the scale parameter of the Rayleigh-distributed scattered component.

This derivation illustrates how the Ricean fading distribution arises from the combination of a dominant LOS component and a scattered multipath component, which is a common scenario in wireless communication systems experiencing fading due to both LOS and multipath propagation.

Proof ①: Rayleigh Fading Model of NLOS Multipaths Propagation

$\therefore x(t) = x_i + j x_q = r e^{j\theta}$



$\therefore r = \sqrt{x_i^2 + x_q^2}$, $\theta = \tan^{-1} \frac{x_q}{x_i}$

$\therefore x_i = r\cos\theta$, $x_q = r\sin\theta$

$\therefore$ to Change Variables in a Joint probability:

$P(r,\theta) = |J|\ P(x_i, x_q)$ $\xrightarrow{\text{where}}$ $|J| = \begin{vmatrix} \frac{\partial x_i}{\partial r} & \frac{\partial x_i}{\partial \theta} \\ \frac{\partial x_q}{\partial r} & \frac{\partial x_q}{\partial \theta} \end{vmatrix} = r$

$\therefore P(r,\theta) = r\ P(x_i, x_q)$

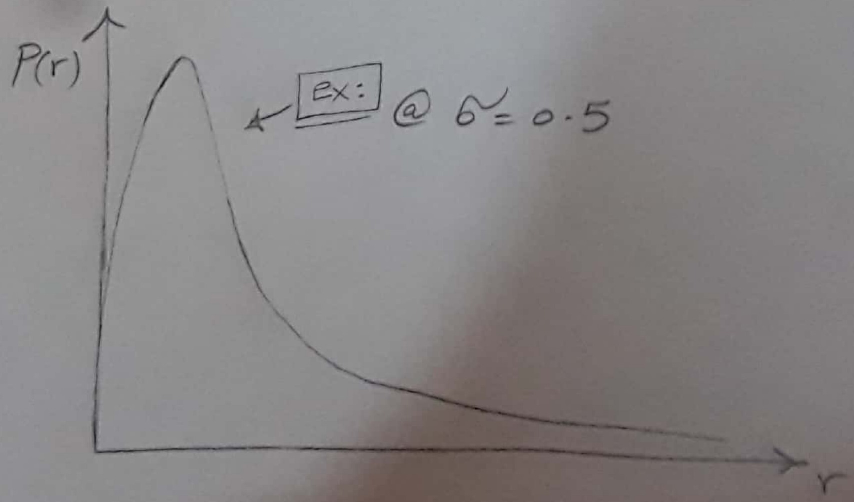
$\because x_i$ & x_q Gaussian (i.i.d) R.V. with Zero Mean

$\therefore P(x_i, x_q) = P(x_i)\,P(x_q) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x_i^2}{2\sigma^2}} \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x_q^2}{2\sigma^2}} = \frac{1}{2\pi\sigma^2} e^{\frac{-r^2}{2\sigma^2}}$

$$\therefore \boxed{P(r,\theta) = \frac{r}{2\pi\sigma^2} \cdot e^{-r^2/2\sigma^3}}$$

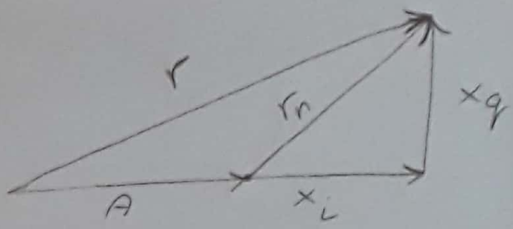
$\therefore P(r)_{\text{Rayleigh}} = \int_0^{2\pi} P(r,\theta)\, d\theta =$

$$\boxed{PDF_{\text{Rayleigh}} = \frac{r}{\sigma^2}\, e^{\frac{-r^2}{2\sigma^2}}}$$ #



Proof ②: Rician Fading Model of LoS & MultiPath Propagation

$\because X(t) = A + x_i + j x_q = r e^{j\theta}$



$\therefore r = \sqrt{(A+x_i)^2 + x_q^2}$

$= \sqrt{x^2 + y^2}$

$\theta = \tan^{-1}\frac{x_q}{x_i + A} = \tan^{-1}\frac{y}{x}$

$\therefore x = r\cos\theta \quad , \quad y = r\sin\theta$

$\therefore P(r,\theta) = |J| \; P(x,y) \xrightarrow{\text{where}} |J| = \begin{vmatrix} \frac{\partial x}{\partial r} & \frac{\partial x}{\partial \theta} \\ \frac{\partial y}{\partial r} & \frac{\partial y}{\partial \theta} \end{vmatrix} = r$

$\because$ x is gaussian R.V. with mean A]

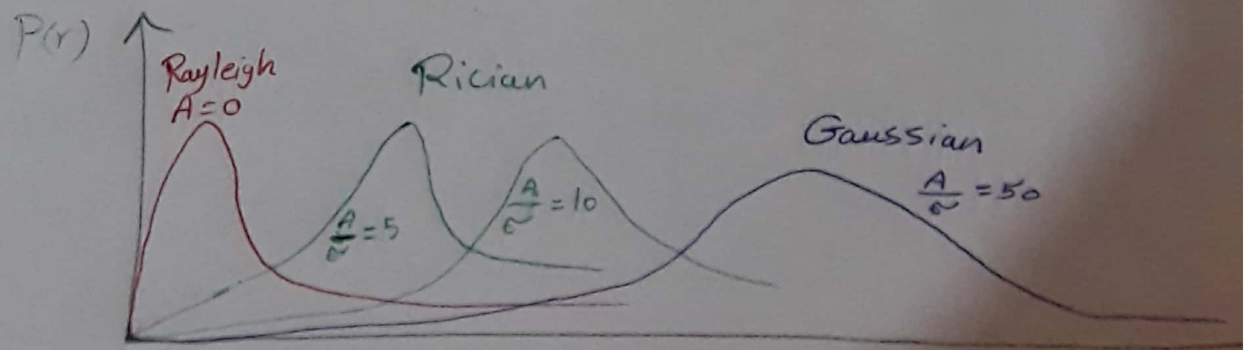
y ″ ″ ″ mean 0] and → x, y is indep

$\therefore P(x,y) = P(x)\,P(y) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(x-A)^2/2\sigma^2} \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{-y^2/2\sigma^2}$

$= \frac{1}{2\pi\sigma^2} e^{-(r^2+A^2-2xA)/2\sigma^2}$

$$\boxed{\therefore P(r,\theta) = \frac{r}{2\pi\sigma^2} e^{-\frac{r^2+A^2}{2\sigma^2}} \cdot e^{\frac{rA\cos\theta}{\sigma^2}}}$$

$$\boxed{\therefore P_{Rician}(r) = \int_0^{2\pi} P(r,\theta)\,d\theta = \frac{r}{\sigma^2} \cdot e^{-\frac{(r^2+A^2)}{2\sigma^2}} \cdot I_0\left(\frac{rA}{\sigma^2}\right)}$$ #




thank you


BYE