Digital Communication

Report : Lab 1

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Q1) Okumura Model - The okumura model is an empirical wireless propagation model that is widely used for urban environments. The model is applicable in the following conditions :

1. Frequencies in the range 150MHz and 1920MHz.
2. Distances between 1km to 100km.
3. Antenna heights between 3m to 100m.

The empirical path loss of okumura at a distance d, parameterized by the carrier frequency f_c is :

$$P_L(d)\,dB = L(f_c, d) + A_{mu}(f_c, d) - G(h_t) - G(h_r) - G_{AREA}$$

Where $L(f_c,d)$ is the free space path loss at distance d and carrier frequency f_c, $A_{mu}(f_c,d)$ is the median attenuation relative to free space, $G(h_t)$ is the base station antenna gain, $G(h_r)$ is the mobile antenna gain and G_{AREA} is the gain due to the type of environment. The unit of f_c is MHz. The values of A_{mu} and G_{AREA} are obtained from Okumura's empirical plots. Okumura derived formulas for $G(h_t)$ and $G(h_r)$:

$$G(h_t) = 20log_{10}(\frac{h_t}{200})$$
$$G(h_r) = 10log_{10}(\frac{h_r}{3}),\ h_r \le 3m$$
$$= 20log(\frac{h_r}{3}),\ 3m < h_r < 10m$$

The okumura model is wholly based on measured data and does not provide any analytical explanation. A major disadvantage of this model is its slow response to changes in terrain. Thus, it is generally used in urban environments.

Okumura-Hata Model - The Hata model is an empirical formulation of the graphical path loss data provided by Okumura. It presents the urban area propagation loss as a standard formula and supplies correction equations for other applications. It is valid from 150MHz to 1500MHz. The standard formula for urban areas is given by :

$$P_{L,urban}(d)\,dB = 69.55 + 26.16\,log_{10}(f_c) - 13.82\,log_{10}(h_t) + (44.9 - 6.55\,log_{10}(h_t))\,log_{10}(d) - a(h_r) \rightarrow eq1$$

The unit of f_c is again MHz and that of d is km. The parameters in this model are the same as under the Okumura model, and $a(h_r)$ is a correction factor for the mobile antenna height based on the size of the coverage area. For small to medium sized cities, this factor is given by :

$$a(h_r) = (1.1\,log_{10}(f_c) - 0.7)h_r - (1.56\,log_{10}(f_c) - 0.8)\,dB\ ,\ for\,f_c < 300MHz$$

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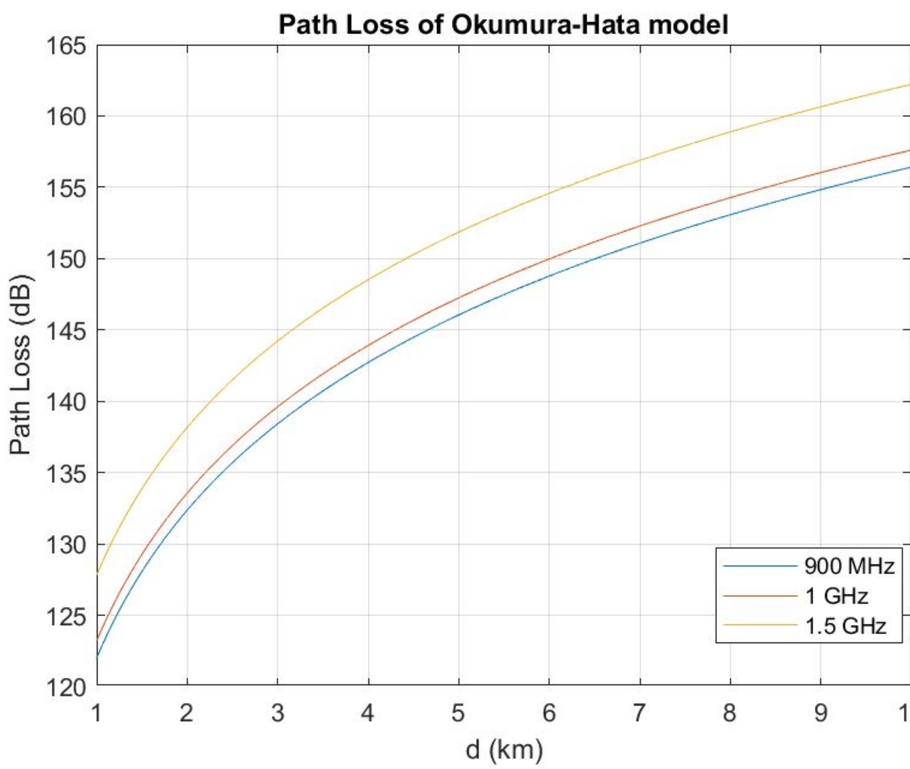
For large cities :

$$a(h_r) = 3.2(log_{10}(11.75h_r))^2 - 4.97\ dB\ \ , for\ f_c\ \geq 300MHz$$

The mobile antenna correction factor (for large cities) increases with increase in the mobile antenna height and does not depend on distance or the carrier frequency. Thus, in this scenario, this model does not apply any path-specific corrections.

Q2) The path loss for three different frequencies in an urban area, computed using the Okumura-Hata model is shown in graph 1. Since the required carrier frequencies are greater than 300MHz, the correction factor for large cities has been used. The height of transmitting antenna is 40m and the receiving antenna 3m.



Graph 1 : Path loss, h_t = 40m and h_r = 3m

Q3)

Observations :

1. The path loss increases with increase in the distance of propagation. This is consistent with the path loss equation of the Okumura Hata model (4th term in equation 1).
2. The path loss increases with increase in carrier frequency. This is also consistent with equation 1 (2nd term).
3. The path loss decreases with increase in receiver antenna height ($a(h_r)$ term).

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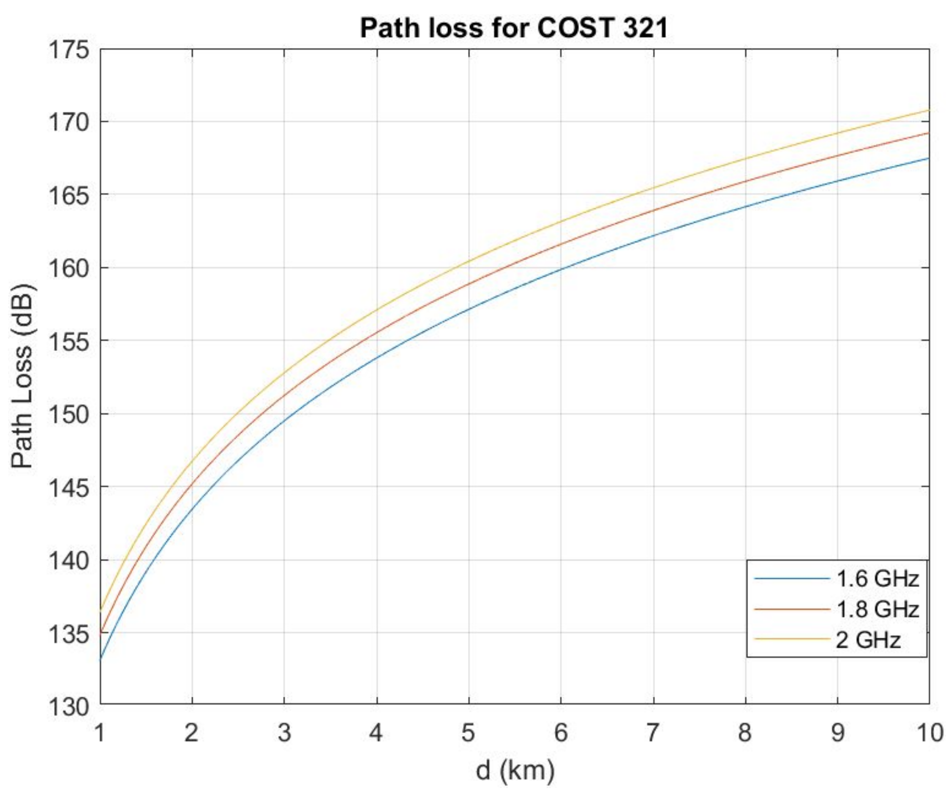
Q4) Cost 231 Extension to Hata model - The Hata model was extended by the European cooperative for scientific and technical research (EURO-COST) to 2 GHz as follows :

$$P_{L,urban}(d)dB = 46.3 + 33.9\ log_{10}(f_c) - 13.82\ log_{10}(h_t) - a(h_r) + (44.9 - 6.55\ log_{10}(h_t))\ log_{10}(d) + C_M$$

Where C_M is 0 dB for medium sized cities and 3 dB for metropolitan area. The units are the same as the Okumura model. This model is restricted to the following conditions :

1. $1.5GHz < fc < 2\ GHz$
2. $30m < ht < 200\ m$
3. $1m < hr < 10\ m$
4. $1Km < d < 20\ Km$

Q5) The path loss for three different frequencies in a metropolitan area, computed using the COST 231 extension model is shown in graph 2. The correction factor for large cities has been used. The height of transmitting antenna is 40m and the receiving antenna 3m. C_M = 3 dB.



Graph 2 : Path loss for metropolitan area, h_t = 40m and h_r = 3m

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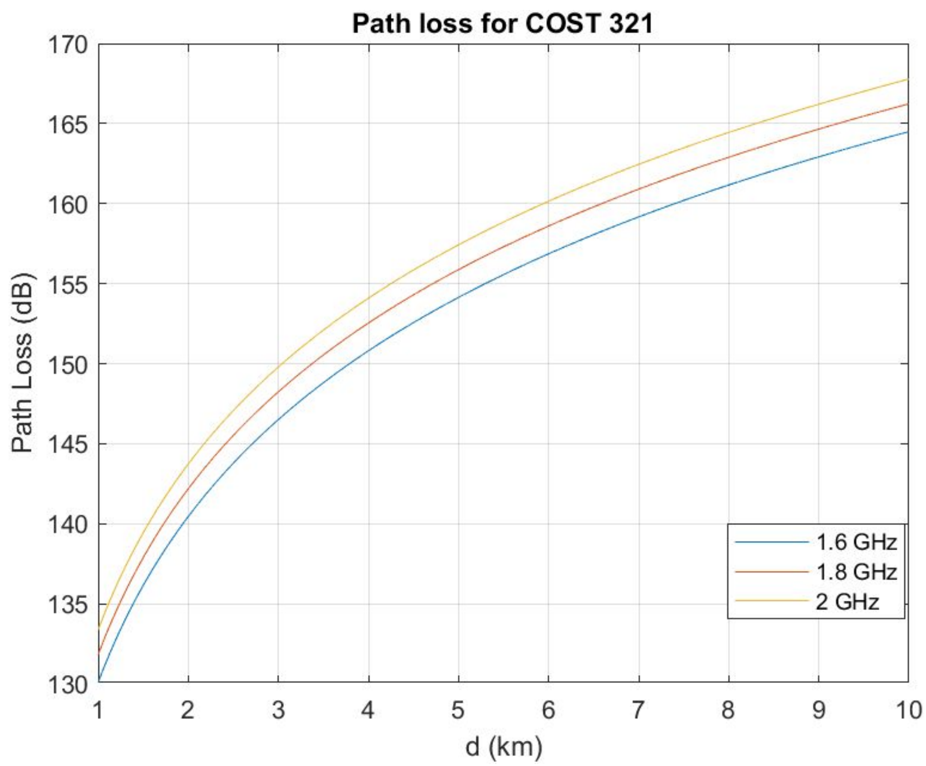
Observations :

1. The path loss increases with increase in the distance of propagation. This is consistent with the path loss equation of the COST 231 extension model (5th term).
2. The path loss increases with increase in carrier frequency. This is also consistent with the equation (2nd term).
3. The path loss decreases with increase in receiver antenna height ($a(h_r)$ term).

Q6) The path loss for three different frequencies in a medium sized city area, computed using the COST 231 extension model is shown in graph 3. The correction factor remains the same (since f_c > 300 MHz). The height of transmitting antenna is 40m and the receiving antenna 3m. C_M = 0 dB.



Graph 3 : Path loss for medium sized city area, h_t = 40m and h_r = 3m

Observations :

1. The path loss increases with increase in the distance of propagation. This is consistent with the path loss equation of the COST 231 extension model (5th term).
2. The path loss increases with increase in carrier frequency. This is also consistent with the equation (2nd term).
3. For a medium sized city area, C_M = 0 dB. Thus, the path loss (dB) graph for this area is offset by -3 dB as opposed to a large city.

Q7) **CONCLUSION**

- **A comparison of the Okumura-Hata and COST231 model :**
    1. The Okumura-Hata model can be used upto a frequency of 1.5 GHz. In order to extend its application, the path loss equation was modified and an extra term added, C_M which accounts for the kind of the area, such as a metropolitan city or a medium sized city. The COST231 Extension to Hata model can be used for frequencies 1.5 GHz to 2 GHz.
    2. Comparing graph 1 and graph 2, the path loss of the COST 231 model changes faster than the path loss of the Okumura-Hata model with respect to frequency. This can also be directly inferred from the frequency dependent terms of the equations of the two models ($26.16\ log_{10}(f_c)\ <\ 33.9\ log_{10}(f_c)$).

REFERENCES

1. Theodore S. Rappaport, Wireless Communication Principles and Practice (2002), Chapter 3, Sections - 3.10.3, 3.10.4 and 3.10.5.
2. Andrea Goldsmith, Wireless Communications (2005), Chapter 2, Sections - 2.5.1, 2.5.2, 2.5.3.

APPENDIX

```
% Okumura-Hata model

d = 1:0.001:10; %distance in metres
ht = 40; %transmitting antenna height
hr = 3; %receiving antenna height
%MHz
fc1 = 900 * (1);
fc2 = 1 * (10^3);
fc3 = 1.5 * (10^3);

%correction factor for large cities
ahr = 3.2*(log10(11.75*hr)).^2 - 4.97;

Lurban1 = 69.55 + 26.16*log10(fc1) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr;
Lurban2 = 69.55 + 26.16*log10(fc2) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr;
Lurban3 = 69.55 + 26.16*log10(fc3) + (44.9 - 6.55*log10(ht))*log10(d) -
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```
13.82*log10(ht) - ahr;

figure(1);
plot(d,Lurban1);
title('Path Loss of Okumura-Hata model');
xlabel('d (km)');
ylabel('Path Loss (dB)');
grid on;
hold on;

plot(d,Lurban2);
plot(d,Lurban3);

%COST 231 extension
cm = 3; %metropolitan city
%MHz
fc1 = 1.6 * (10^3);
fc2 = 1.8 * (10^3);
fc3 = 2 * (10^3);

Lurban1 = 46.3 + 33.9*log10(fc1) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr + cm;
Lurban2 = 46.3 + 33.9*log10(fc2) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr + cm;
Lurban3 = 46.3 + 33.9*log10(fc3) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr + cm;

figure(2);
plot(d,Lurban1);
title('Path loss for COST 321');
xlabel('d (km)');
ylabel('Path Loss (dB)');
grid on;
hold on;

plot(d,Lurban2);
plot(d,Lurban3);

cm = 0; %medium sized city

Lurban1 = 46.3 + 33.9*log10(fc1) + (44.9 - 6.55*log10(ht))*log10(d) -
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```
13.82*log10(ht) - ahr + cm;
Lurban2 = 46.3 + 33.9*log10(fc2) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr + cm;
Lurban3 = 46.3 + 33.9*log10(fc3) + (44.9 - 6.55*log10(ht))*log10(d) -
13.82*log10(ht) - ahr + cm;

figure(3);
plot(d,Lurban1);
title('Path loss for COST 321');
xlabel('d (km)');
ylabel('Path Loss (dB)');
grid on;
hold on;

plot(d,Lurban2);
plot(d,Lurban3);
```