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ELE 691

Simulation of Signal Strength on Urban Street

Abstract:

In mobile communication, the signal strength must be adequate for a cell phone to properly place or receive calls. The signal strength varies according to the distance between the base station and the mobile receiver. There is loss in signal strength when the path of propagation is blocked by obstructions and in urban environment there are various such obstructions like trees and buildings which will block the direct path of signal giving rise to small scale fading due to multipath propagation and shadowing. In this report, we simulated the signal strength of a cell phone at various locations on a street between two buildings. We observed that the total path loss and therefore the signal strength is different at each location.

Introduction:

In an urban environment, due to the obstructions in the propagation path, a number of physical phenomena like reflection, refraction, diffraction, absorption and multipath interference will influence the path loss. Originally, the signal experiences a path loss when it travels through the space called as free space path loss. The path loss due to the physical phenomena mentioned above is additional to the ***free space path loss***. The free space path loss is given as,

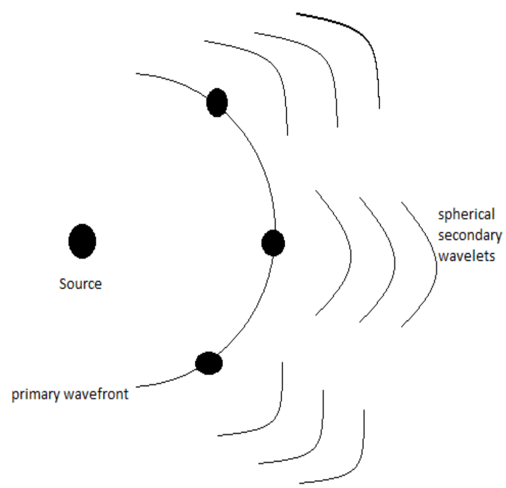
$$L_F(\text{dB}) = 32.4 + 20 \log r_{km} + 20 \log f_{MHz} \qquad (1)$$

Where r_{km} is the range normalized to 1km and f_{MHz} is the frequency normalized to 1MHz.

A radio wave travelling from the base station towards the cell phone is reflected from the glass coated surfaces of the buildings or other reflective surfaces. There can be multiple reflections too. Any given radio may receive both the primary signal and one or more reflections of that same signal. This is called as ***multipath interference***. If the reflected signal and the primary signal have the same phase difference, then it adds up to the amplitude of the primary signal. this type of interference is called ***constructive interference***. If the phase difference is different than the amplitude of the primary signal decreases and this type of interference is called ***destructive interference***. Reflections can also leave gaps in RF coverage by canceling out (nulling) the primary signal.

For a radio wave incident on a building, at the boundary, some of the waves will be reflected, and some will enter the new medium and be ***refracted***. Rather than a sudden boundary to two different media, radio waves will often be refracted by areas where the refractive index gradually changes. This may happen as the radio waves propagate through the atmosphere where small

changes in refractive index occur. Typically, it is found that the refractive index of the air is higher close to the earth's surface, falling slightly with height. In this case the radio waves are refracted towards the area of higher refractive index. This extends the range over which they can travel.
Diffraction plays a large role in cell phone communications in urban areas. It is the bending of radio waves around objects that block the direct path of wave propagation. The phenomenon of diffraction is proposed by Christian Huygens (1629 to 1695) and Augustin Fresnel (1788 to 1827). The Huygens Fresnel diffraction principle states that *"Every point on the primary wavefront serves as a source of secondary spherical wavelets of same temporal frequency and polarization."*



The spherical wavelet is given by,
$\bar{E}\,(\bar{r})\,ds\,\frac{e^{-jk\bar{r}}}{\bar{r}}$

The field on any surface will be the integration of these spherical wavelets given by, $u(X_i, Y_i) = \frac{1}{j\lambda}\iint g(X_{0,}Y_0)\frac{e^{-jk\bar{r}}}{\bar{r}}\,dxdy$

In this report we have considered various cases of diffraction which are given below,

1. **Diffraction due to single knife-edge**
   The edge of an absorbing block act as knife edge blocking the part of wavefront.
   The loss due to knife edge diffraction is given as,
   $L_{ke}(v) = -20log|F(v)|$
   Where,
   $|F(v)| = \frac{1}{2}\left(\frac{1}{2} + C(v)^2 - C(v) + S(v)^2 - S(v)\right)$
   $C(v)$ is Fresnel cosine integral = $\int_0^v cos\frac{\pi v^2}{2}\,dv$
   $S(v)$ is Fresnel sine integral = $\int_0^v sin\frac{\pi v^2}{2}\,dv$
   v is the diffraction principle given by,

$$\nu = h_e \sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}}$$

d_1 is the distance from the transmitter to the screen
d_2 is the distance from the screen to the receiver
h_e is the excess height of the top of the screen
When the direct ray just grazes the top of the absorbing screen, making both h_e and ν equal to zero, the excess path loss is still 6 dB. The excess path loss does not decrease to zero until the edge of the screen is withdrawn, so that it falls below the edge of the direct path by a significant amount given by
$h_e = -0.6r_1$
r_1 is the radius of the first Fresnel zone

$$r_1 = \sqrt{\frac{\lambda d_1 d_2}{(d_1 + d_2)}}$$

2. **The Flat-Edge Model for Path loss from the Base Station to the Final Street**
   The flat-edge model is applied to account for excess diffraction loss due to the buildings along a direct path from the base station antenna to the far edge of the building at the start of the final street. It models each building as an absorbing screen with a knife edge.
   n_B is the number of buildings (edges) that are close enough to the direct path to cause significant diffraction
   d_B is the spacing between adjacent edges
   r_B is the distance from the base station to the first diffracting edge
   h_0 is the height of the buildings (edges)
   h_B is the height of the base station antenna
   ζ, the angle between the direct path and a horizontal line across the tops of the buildings
   $L_n$is the excess path loss due to diffraction by the n_B building edges
   The flat-edge model assumes that $r_B » n_B d_B$

$$k = -\frac{\zeta\left(\pi \frac{d_B}{\lambda}\right)1}{2}$$

$$\zeta = \tan^{-1}\frac{h_B - h_0}{r}$$

   For k= 0, the direct path just grazes the tops of the edges
   L_n (dB) = –(3.29 + 9.9 log n_B) log (–κ) – (0.77 + 0.26 log n_B)

3. **Ikegami Model of Excess Path loss in the Final Street**
   After diffraction by the edge of the final building, the signal may reach the mobile antenna by two paths:
   1. Directly from the final edge to the antenna
   2. From the final edge to the wall of the opposite building, and then to the antenna by specular reflection

The waves on the two paths of different lengths will have different phases when they arrive at the antenna, and this phase difference must be taken into account when summing the two field contributions.

$L_I = 10\log f_{MHz} + 20\log(h_0 - h_m) - 10logd_s - 22.7$

4. **The Delisle/Egli Empirical Expression for Path loss**

   G.Y. Delisle has proposed an empirical formula for estimating path loss in densely built-up urban areas.

   for h_m < 10 m,

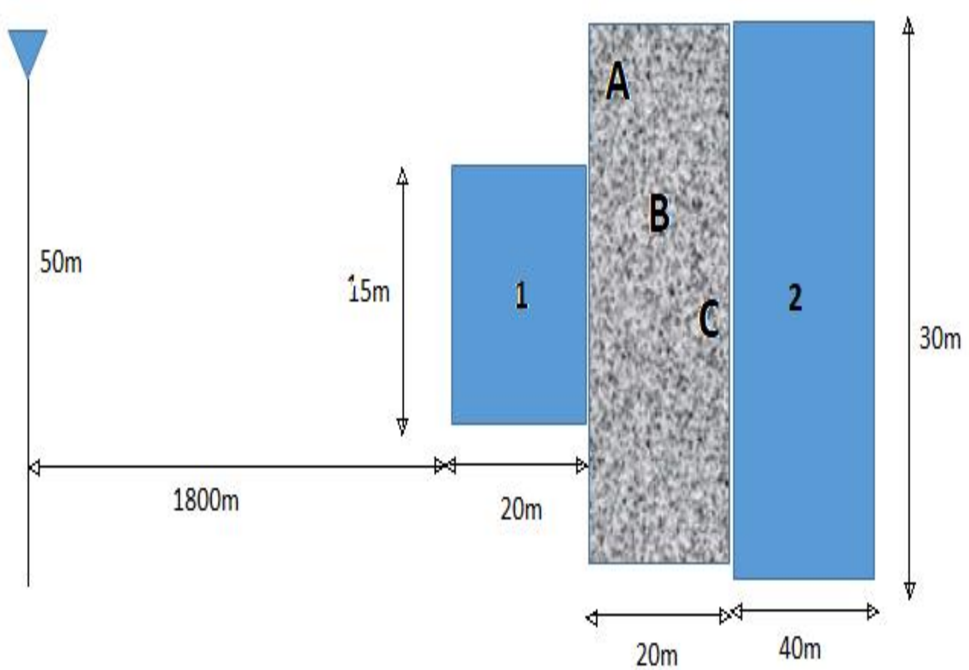
   $L_{empirical}(dB) = 40logr_{km} + 20logf_{Mhz} - 20logh_b + 76.3 - 10logh_m$

   for h_m> 10 m,

   $L_{empirical}(dB) = 40logr_{km} + 20logf_{Mhz} - 20logh_b + 86.3 - 20logh_m$

Simulation:

Consider the mobile receiver on the street at three locations, at A, B and C. The analysis of signal strength at each of these points is given as follows:



- **At Location A**
  Here, there is no obstacle between the base station antenna and the mobile receiver. Therefore, the mobile receiver at this point will receive line of sight signal directly. The total losses at this point is loss due to free space propagation and loss due to line of sight propagation. We put these loses in Huygens-Fresnel principle and integrate along the length of the street.

- **At Location B**
  At this point, the mobile receiver receives more than one signal. The propagation path of the signal is blocked by building #1. Therefore, the receiver will receive the diffracted signal from building #1 and the reflected signal from building #2. The path loss is given by the Flat-edge model and Ikegami model. Flat-edge model has been applied to account for excess diffraction loss due to the buildings along a direct path from the base station antenna to the far edge of the building at the start of the final street. It models each building as an absorbing screen with a knife edge. The waves on the two paths of different lengths will have different phases when they arrive at the antenna, and this phase difference must be taken into account when summing the two field
  contributions. This calculation is done by the Ikegami model. Also, there is a knife edge diffraction from the side of building#1. We put these loses in Huygens-Fresnel principle and integrate along the length of the street.

- **At Location C**
  At this point we consider all the loses from location B in addition to the knife edge from the top edge of building #1. If the height above the direct propagation path is zero i.e. the signal is just grazing the top edge of building #1, we experience an additional loss of 6dB. Here the mobile receiver also experiences a line of sight path loss when the receiver moves near building #2.

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Results:

Codes

For Location A

```
clc
clear all
close all
f=900 %frequency (assumed)
hm=1.5 %height of mobile receiver (assumed)
hb=50 %height of transmitter (base station)
lambda=(3*10^8)/f %wavelength
for d=1:20 %integrating along the width of the road
        r=(1820+d)*0.001; %distance between transmitter and receiver
        Le=40*log(r)+20*log(f)-20*log(hb)+86.3-20*log(hm); %line of sight path
loss
        Lf=32.4+20*log(r)+20*log(f); %free space path loss
        L=Le+Lf; %total path loss at point A
        E(d)=10*(1/(1i*lambda))*(exp(-1i*L*d))*10^5;          %huygens-fresnel
diffraction principle
        double(E)
        y=E;
        x=1:1:20;

      end
plot(x,y)
title('Signal Strength at Point A')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

For Location B

```
clc
clear all
close all
f=900  %frequency (assumed)
hm=1.5 %height of mobile receiver (assumed)
hb=50  %height of transmitter (base station)
h0=30 %height of the building
ds=20  %distance between two buildings
nb=1   %the number of buildings (edges) that are close enough to
        %the direct path to cause significant diffraction
db=1820 %the spacing between adjacent edges
lambda=(3*10^8)/f %wavelength
for d=1:20 %integrating along the width of the road
        r=(1820+d)*0.001; %distance between transmitter and receiver
        s=atand((hb-h0)/r); %the angle between the direct path and a horizontal
line across
                            %the tops of the buildings
        k=-s*(sqrt((pi*db*f)/(3*10^8)));
        Li=10*log(f)+20*log(h0-hm)-10*log(ds)-22.7; %Ikegami model
        Lf=32.4+20*log(r)+20*log(f); %free space
        Ln=-(3.29+9.9*log(nb))*log(-k)-(0.77+0.26*log(nb)); %flat edge model
        L=Ln+Li+Lf; %total path loss at point B
```

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```
        E(d)=10*(1/(1i*lambda))*(exp(-1i*L*d));  %huygens-fresnel  diffraction
principle
        double(E)
        y=E;
        x=1:1:20;

      end
plot(x,y)
title('Signal Strength at Point B')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

For Location C

```
clc
clear all
close all
f=900 %frequency (assumed)
hm=1.5 %%height of mobile receiver (assumed)
hb=50 %height of transmitter (base station)
h0=30 %height of the building
ds=20  %distance between two buildings
nb=1  %the number of buildings (edges) that are close enough to
        %the direct path to cause significant diffraction
db=1820 %the spacing between adjacent edges
lambda=(3*10^8)/f %wavelength
he=2.28 %the excess height of the top of the screen with respect to the direct
path
v=0.90 %diffraction parameter
cv=0.7648 %Fresnel cosine integral
sv=0.3398 %Fresnel sine integral
fv=0.5*(0.5+(cv^2)-cv+(sv^2)-sv)
for d=1:20 %integrating along the width of the road
        r=(1820+d)*0.001; %distance between transmitter and receiver
        s=atand((hb-h0)/r); %the angle between the direct path and a horizontal
line across
                            %the tops of the buildings
        k=-s*(sqrt((pi*db*f)/(3*10^8))); %wave number
        Li=10*log(f)+20*log(h0-hm)-10*log(ds)-22.7; %Ikegami model
        Lf=32.4+20*log(r)+20*log(f); %free space loss
        Le=40*log(r)+20*log(f)-20*log(hb)+86.3-20*log(hm);
        Lg=6; %grazing path loss
        Ln=-(3.29+9.9*log(nb))*log(-k)-(0.77+0.26*log(nb)); %flat edge model
        Lk=-20*log(fv) %knife edge
        L=Ln+Li+Lf+Le+Lg+Lk;
        E(d)=10*(1/(1i*lambda))*(exp(-1i*L*d));%huygens-fresnel    diffraction
principle
        double(E)
        y=E;
        x=1:1:20;
      end
plot(x,y)
title('Signal Strength at Point C')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

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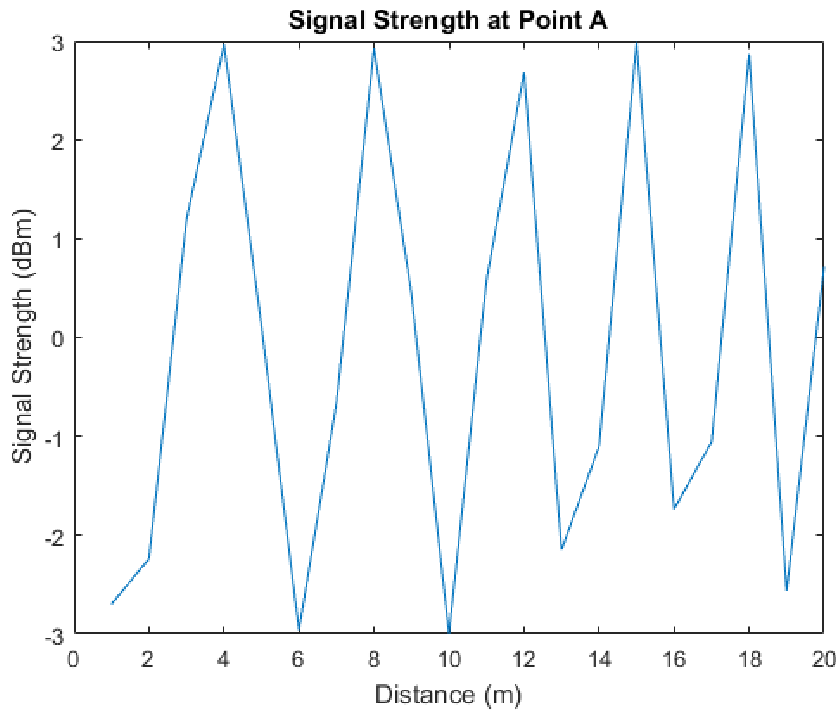
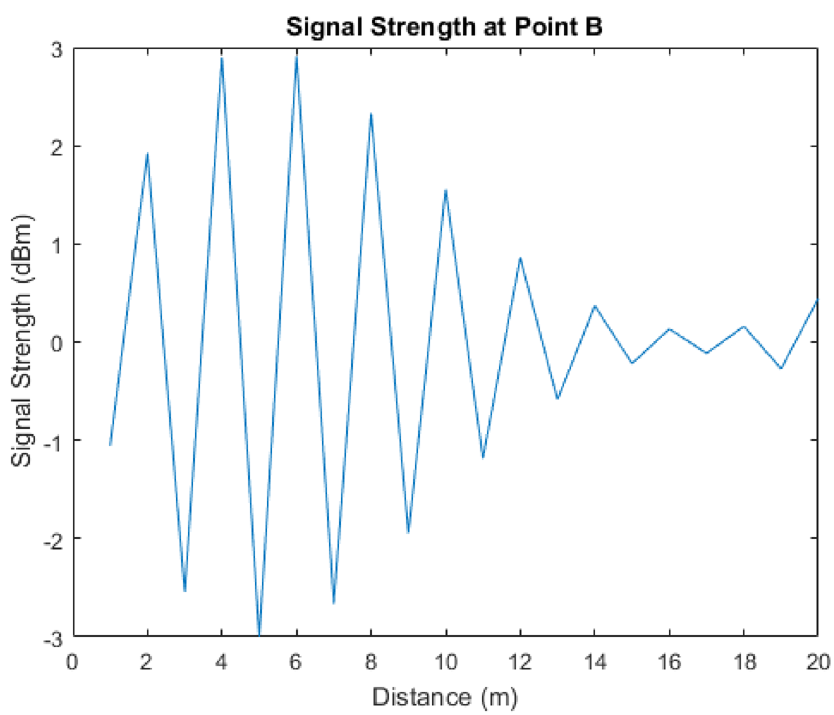
Outputs

Location A



Location B



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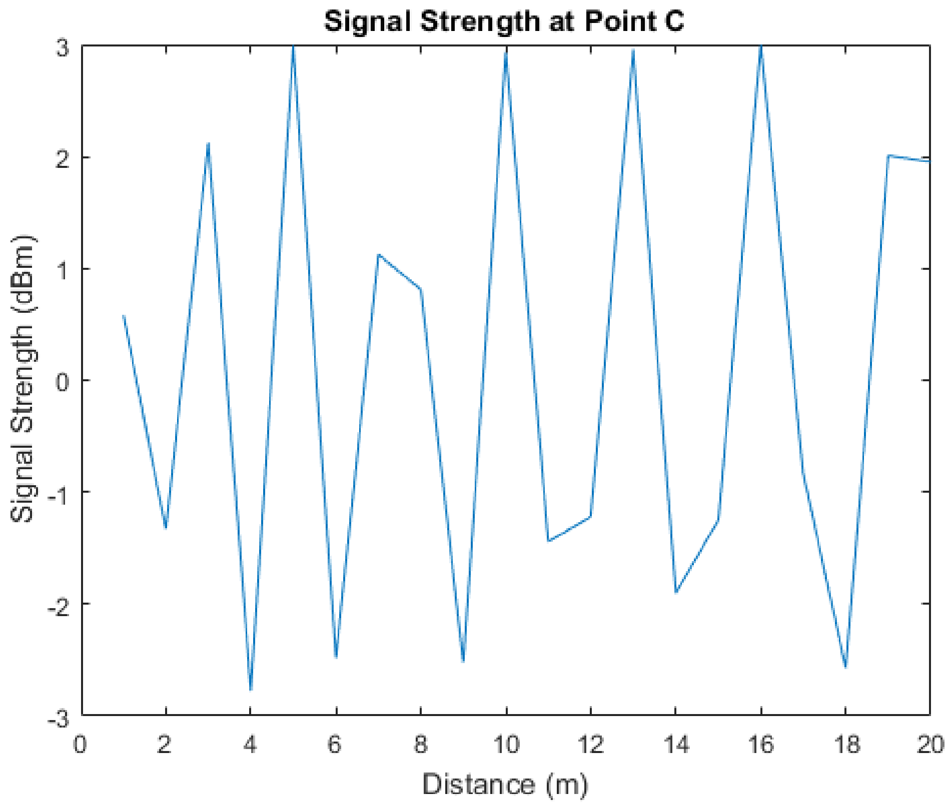
Location C



Conclusion:

The graphs show that small scale fading due to mutipath is more in an environment with diverse forms of obstructions. The result confirmed that the type of fading experienced by a signal propagating through a mobile wireless channel depends on the nature of the transmitting signal with respect to the characteristics of the channel. The increase in small scale fading must be due to the existence of various propagating paths (reflected, diffracted, and direct path). This implies that a single measurement of signal strength might not be sufficient since different measurements can lead to quite different results due to changing conditions. Based on the findings made in this work, the report recommends that network designers should make routine practical measurements of signal strength especially in dense suburban and urban environment where building structures are erected regularly so as to ascertain what improvement they need to make to maintain high quality of service.

References:

[1]. The International Journal of Engineering and Science (IJES) || Volume || 3 || Issue || 9 || Pages || 73-79 || 2014 || ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

[2]. Victor L. Granatstein: Physical Principles of Wireless Communication: 2nd edition.