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Project Report
Simulation of Signal Strength on Urban Street

Abstract:

In mobile communication systems, the strength of the signal received by a mobile phone plays a very vital role in the communication between the two connected users over the channel. Proper signal is required to receive and place calls. There are many factors which decide the signal strength that is received by a mobile phone in urban area. There is loss in received signal strength when the path of propagation between the mobile and the transmitting tower is blocked by obstructions. In urban areas the obstructions might be buildings, trees etc. which will block the direct path of signal giving rise to small scale fading due to multipath propagation and shadowing. In this project report we have simulated the received signal strength by a mobile phone at various locations on a street between two buildings. We observed that the signal strength and the total path loss varies depending on the location of the mobile phone.

Introduction:

In an urban area, there are many obstructions in the line of sight of the mobile tower and a mobile phone due to which loss in signal strength occurs. Physical phenomena's like refraction, reflection, diffraction, absorption and multipath interference will affect the path loss. Initially when a signal travels through the space to the mobile phone, the loss encountered by it is called as free space path loss. The free space path loss is given by,

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

Where *r* is the range normalized to 1km and *f* 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. There are three main type of interference:

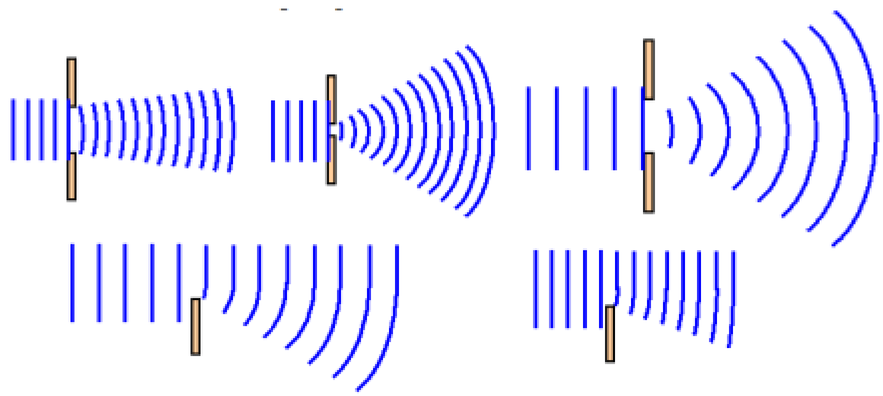
Multipath interference: When the mobile receives a primary signal and one or more reflections of that same signal. This is called multipath interference.

Constructive interference: When the received reflected signal and received the primary signal have the same phase difference, then it adds up to the amplitude of the primary signal. This is called constructive interference.

Destructive interference: When the received reflected signal and received the primary signal have different phase difference, then the phase difference of primary signal decreases and this type of interference is called destructive interference.

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: Any beam bending that cannot be explained by either reflection or refraction is explained by diffraction. In other words, 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.*"



It plays a very important role in communication in urban areas as urban areas are mostly comprised of buildings and the wave bending from the edges of the buildings can only be described by the concept of diffraction.

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 mainly 4 cases of diffraction which are given below:

1.Empirical Expression for Path loss:

This path loss empirical formula is designed for estimating path loss in densely built-up urban areas. This loss mainly depends on the height of a mobile antenna. For different mobile antenna size we calculate this loss differently

for h_m < 10 m,

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

for h_m> 10 m,

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

3. 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. nB is the number of buildings (edges) that are close enough to the direct path to cause significant diffraction dB is the spacing between adjacent edges.

rB is the distance from the base station to the first diffracting edge

$h0$ is the height of the buildings (edges)

hB 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

$Ln$is the excess path loss due to diffraction by the nB building edges

The flat-edge model assumes that rB»nBd

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

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

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. Excess Path loss model:

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 considered when summing the two field contributions at the receiving end. In this case the phase of different rays arriving plays a vital role in deciding the power of received signal.

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

4. Diffraction due to single knife-edge

The edge of an absorbing block act as knife edge blocking the part of wave front. 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,

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

$d1$ is the distance from the transmitter to the screen

$d2$ is the distance from the screen to the receiver

he is the excess height of the top of the screen

When the direct ray just grazes the top of the absorbing screen, making both $\boldsymbol{he}$ and $\boldsymbol{v}$ 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

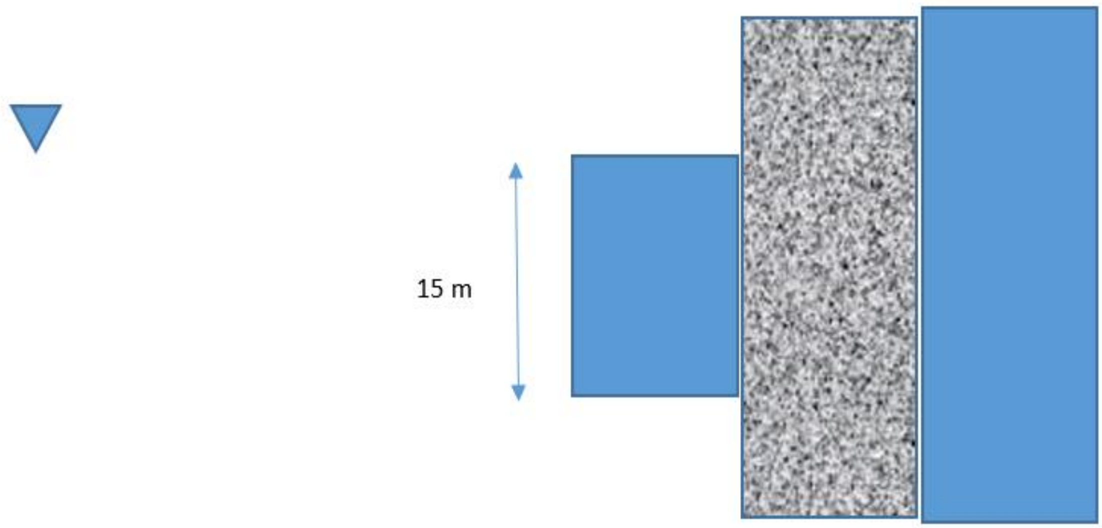
he = −0.6r1

$r1$ is the radius of the first Fresnel zone

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

Simulation:

The mobile receiver is following the three paths as mentioned in the diagram. All the three paths A, B and C have diffraction, reflection and direct rays interference to them.



→At Path A:

While the user is on path A there is no direct obstacle in the line of sight of the transmitter and the mobile user. So, there would be two rays reaching to the user- direct and reflected. By putting these losses in the Huygen Fresnel principle and integrate it along the street we get the graphs of signal strength with respect to the distance.

→At Path B:

At this path user will receive two different signals. One from the reflection and one from the refraction. The path loss is given by excess path loss and flat edge model. Flat edge model will take in account the refraction of the signal from the edge of building 1. Also there is a knife edge diffraction from the side of the building. . By putting these losses in the Huygen Fresnel principle and integrate it along the street we get the graphs of signal strength with respect to the distance.

→At Path C:

Ath this path we consider all the losses from path A and additionally we use knife edge diffracted ray from the top of the building. Here the receiver also receives a line of sight loss when it is near building 2. By putting these losses in the Huygen Fresnel principle and integrate it along the street we get the graphs of signal strength with respect to the distance.

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Code for path A:

```
clc
close all
f=800
hm=1.0)
hb=100                      %height of transmitter
lambda=(3*10^8)/f
for d=1:30
r=(1820+d)*0.001;
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=1:1:30;
end
plot(x,y)
title('Signal Strength at Point A')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

Code for path B:

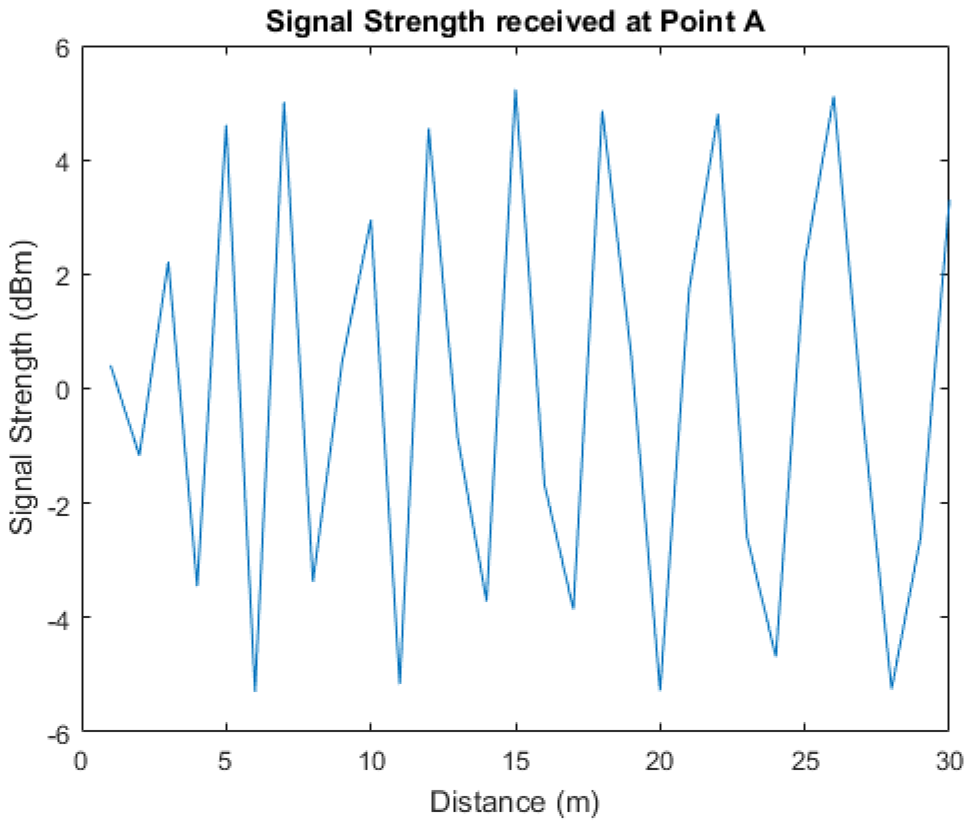
```
clc
close all
f=900
hm=1.0
hb=100
h0=30
ds=20                          %distance between two buildings
nb=1
db=1820                        %the spacing between adjacent edges
lambda=(3*10^8)/f
for d=1:30                     %integrating along the width of the road
r=(1820+d)*0.001;              %distance between transmitter and receiver
s=atand((hb-h0)/r);

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;
E(d)=10*(1/(1i*lambda))*(exp(-1i*L*d));          %huygens-fresnel diffraction
principle
double(E)
y=E;
x=1:1:30;
end
plot(x,y)
title('Signal Strength at Point B')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

Code for path C:

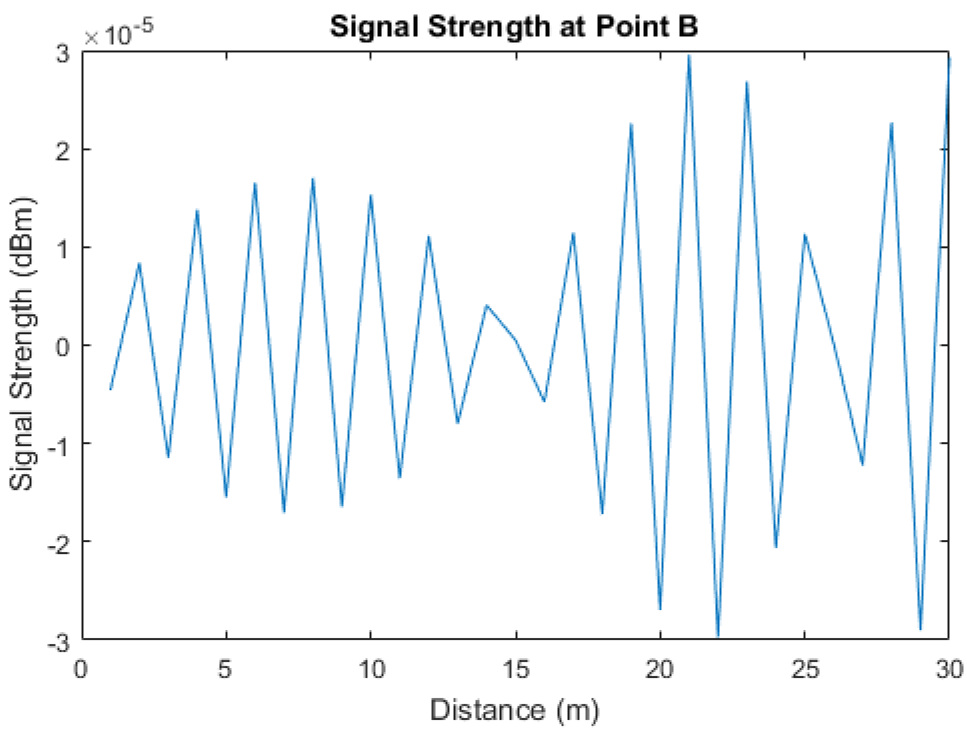
```
clc
close all
f=900
hm=1.0
hb=100
h0=30
ds=20
nb=1

db=1820
lambda=(3*10^8)/f
he=2.28
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=1:30 %integrating along the width of the road
r=(1820+d)*0.001;
s=atand((hb-h0)/r);

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));
double(E)
y=E;
x=1:1:30;
end
plot(x,y)
title('Signal Strength at Point C')
xlabel('Distance (m)')
ylabel('Signal Strength (dBm)')
```

OUTPUTS:

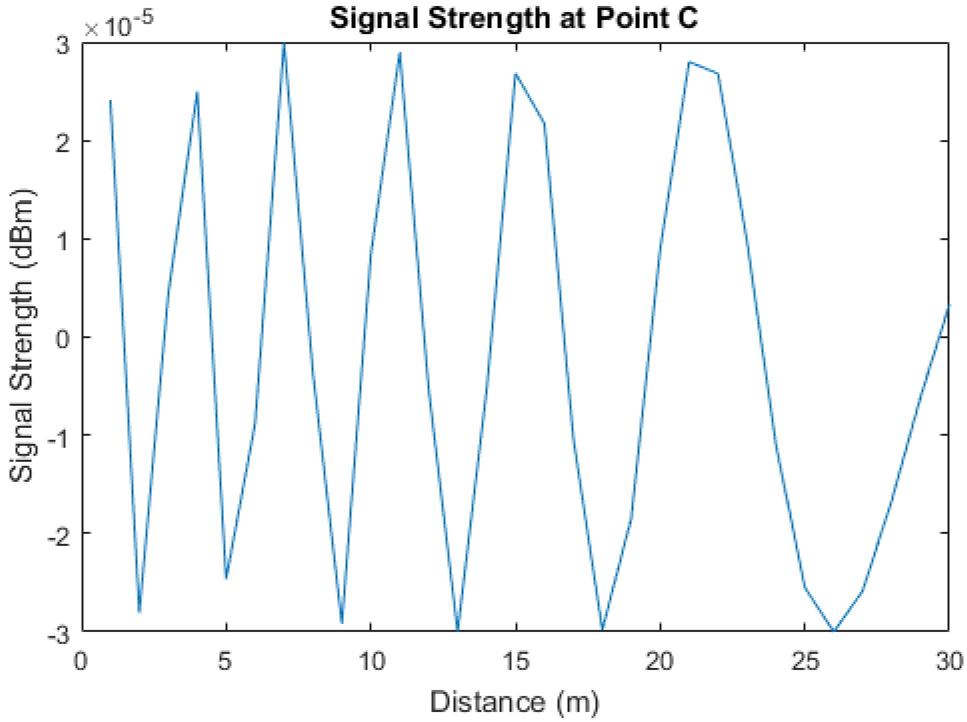
→For A:



→For B:



→For C:



Conclusion:

The graphs show that as the mobile receiver moves from one place to another in an urban area, the signal strength can vary from weak to strong depending on the location of the person. This implies that a single measurement of the signal strength is not enough to give an analysis over a huge area because so many losses are occurring at a moment of time. To increase the efficiency or to decrease the loss in the urban areas, signal strength should be checked from each and every possible path in the urban areas.

References:

[1]. Victor L. Granatstein: Physical principles of wireless Communications: 2nd edition.