Digital Communication
Report : Lab 2

26 January 2020

Ajay Ramesh Ranganathan (IMT2017502)

Q1) 3GPP Model : This model is applicable under the following scenarios :

1. Frequency range 0.5 - 100GHz.
2. Urban macrocell, Rural macrocell, indoor office, urban microcell street canyon.
3. Bandwidth upto 10% of centre frequency but not greater than 2GHz
4. Mobility at one end of the link.

The path loss equation for the 3GPP model for an urban macrocell is given below :

$$PL_{Uma-LOS}(dB) = PL_1 \, for \; 10m \le d_{2D} \le d_{BP}{}'$$
$$= PL_2 \, for \; d_{BP}{}' \le d_{2D} \le 5km$$

Where,
$$PL_1(dB) = 28.0 + 22log_{10}(d_{3D}) + 20log_{10}(f_c)$$
$$PL_2(dB) = 28.0 + 40log_{10}(d_{3D}) + 20log_{10}(f_c) - 9log_{10}((d_{BP}{}')^2 + (h_{BS} - h_{UT})^2)$$

With the conditions, $1.5m \le h_{UT} \le 22.5m$ and $h_{BS} = 25m$

Where, h_{UT} is the receiver antenna height and h_{BS} is the transmitter antenna height (m) and f_c is in GHz. d_{3D} is the distance between the antennas and d_{2D} is the distance between the bases of the antennas (in metres). The distances were calculated as shown in Figure 1.

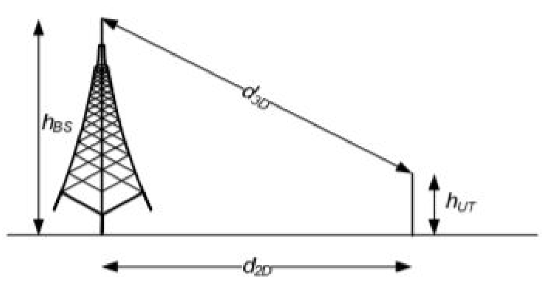


Figure 1: Source - [1]

$d_{BP}{}'$ is called the break point distance and is calculated as

$$d_{BP}{}' = 4h'_{BS}h'_{UT}f_c/c$$

Where c is the velocity of light (m/s), f_c is in Hz and h'_{BS} and h'_{UT} are computed as

$$h'_{BS} = h_{BS} - h_E$$
$$h'_{UT} = h_{UT} - h_E$$

Where h_E is the effective environment height.

This distribution of shadow fading is log-normal and its standard deviation for the urban macrocell is 4 dB. The distribution for the random variable (which represents the random variation due to shadowing) in dB is given by :

$$p(\psi_{dB}) = \frac{1}{\sqrt{2\pi}\sigma_{\psi_{dB}}} exp[-\frac{(\psi_{dB} - \mu_{dB})^2}{2\sigma_{\psi_{dB}}^{\ 2}}]$$

Thus, the effective path loss equation now becomes :

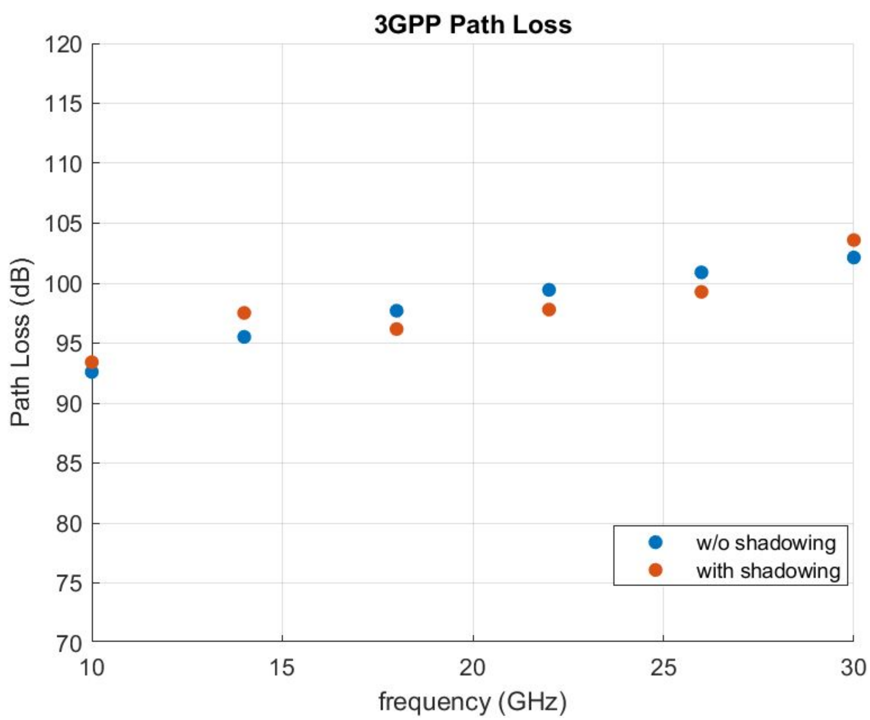
$$PL_1(dB) = 28.0 + 22log_{10}(d_{3D}) + 20log_{10}(f_c) - \psi_{dB}$$
$$PL_2(dB) = 28.0 + 40log_{10}(d_{3D}) + 20log_{10}(f_c) - 9log_{10}((d_{BP}{}')^2 + (h_{BS} - h_{UT})^2) - \psi_{dB}$$

Q2) The path loss in dB for a dense urban macrocell (Line of Sight), where the height of the transmitting antenna located at (0,0,75) is 25m and the height of the receiver antenna located at (0,50,4) is 2m, was computed for 6 frequencies between 10MHz and 30MHz.

The distances d_{3D} and d_{2D} were computed as shown in Figure 1.

$$d_{3D} = 106.4707m$$
$$d_{2D} = 50m$$

In this situation the value of h_E is 1, σ_{dB} = 4 and μ_{dB} = 0. The path loss (dB) with respect to frequency with and without shadowing is shown in Graph 1.



Graph 1: Path Loss

OBSERVATIONS

1. The value of $d_{BP}{}'$ is *3202.2, 4483.1, 5764.0, 7044.9, 8325.8, 9606.6 m* respectively for the 6 frequencies. Since, the 2D distance is 50m, which is less than the breakpoint distance, the first path loss equation was used for all the frequencies.
2. The path loss increases with the increase in frequency from 10GHz to 30 GHz.
3. The random variations due to shadowing has been effectively captured by the log-normal shadowing model. As a result the path loss varies randomly according to the distribution mentioned in page 2. A comparison between applying the log-normal shadowing model along with the path loss model and just the path loss model is clearly visible in Graph 1. Graph 1 shows one particular realization of the random variable values.

Q3) The antenna gain is given to be 1. Thus, the received power can be computed from the path loss equation :

$$PL_1\,(dB) = 28.0 + 22log_{10}(d_{3D}) + 20log_{10}(f_c) - \psi_{dB}$$

Where, $PL_1(dB) = 10log_{10}(\frac{P_t}{P_r})$, taking P_t and P_r in Watt.

The equation thus becomes :

$$10log_{10}(\frac{P_t}{P_r}) = 28.0 + 22log_{10}(d_{3D}) + 20log_{10}(f_c) - \psi_{dB}$$

Given that P_t = 47dBm, this equation can be solved to obtain P_r. Solving this equation in MATLAB with appropriate units, yields :

Frequency	10GHz	14GHz	18GHz	22GHz	260GHz	30GHz
P_r (dBm)	-46.4116	-50.5215	-49.1724	-50.7994	-52.2766	-56.5966

The above table shows the received powers for the different frequencies in dBm. The received powers were computed for the same realization of ψ_{dB} values that are shown in Graph 1.

Q4) The transmitter gain was calculated by solving the following equation for G_t :

$$10log_{10}(\frac{P_t}{P_r}) = 28.0 + 22log_{10}(d_{3D}) + 20log_{10}(f_c) - 10log_{10}(G_t) - \psi_{dB}$$

Frequency	10GHz	14GHz	18GHz	22GHz	260GHz	30GHz
G_t (dB)	66.4116	70.5215	69.1724	70.7994	72.2766	76.5966

Q5) The minimum number of antennas was calculated as :

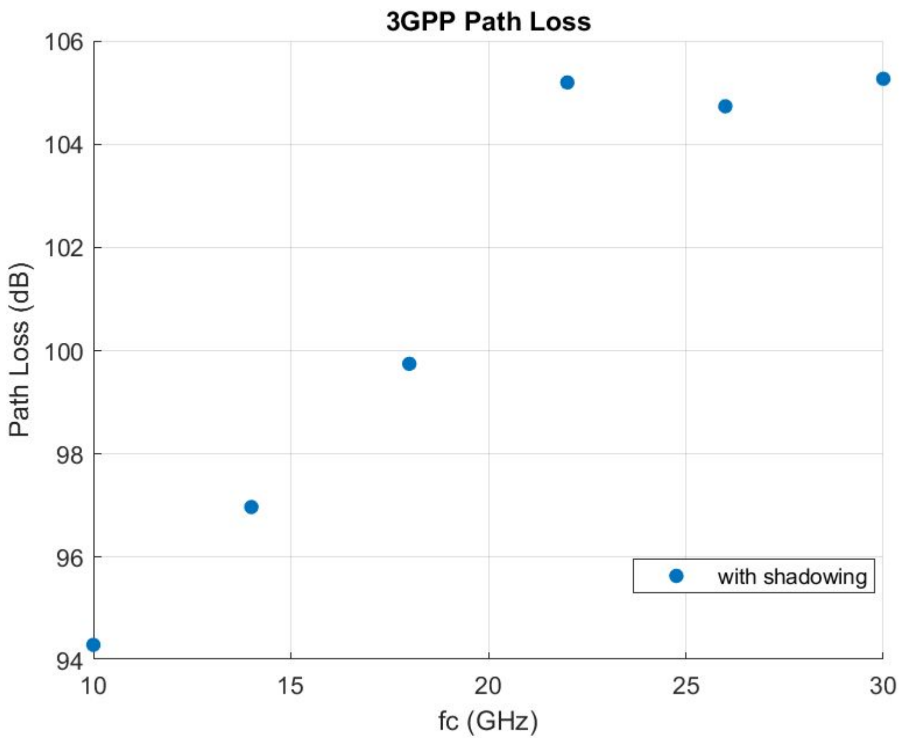
$$Number\ of\ Antennas\ =\ \frac{G_t}{8}$$

Where, the maximum directional gain of an antenna is 8dBi.

Thus, the number of antennas for respective frequencies are :

Frequency	10GHz	14GHz	18GHz	22GHz	260GHz	30GHz
No. of antennas	9	9	9	9	10	10

Q6) The path loss when the receiver position is changed to (0,100,4) is shown in Graph 2.



Graph 2: Path Loss

OBSERVATION

1. The d_{3D} distance increases from 106.47m to 137.2443m. Thus, the path loss for a particular frequency is slightly higher than the scenario in Q1.

2. The breakpoint distance remains the same, since it depends only on antenna heights. The d_{2D} distance now is 100m, which is still less than the break point distances. Thus, the first path loss equation will be used.

REFERENCES

[1]. 3GPP : https://www.etsi.org/deliver/etsi_tr/138900_138999/138901/14.03.00_60/tr_138901v140300p.pdf
[2]. Andrea Goldsmith - Wireless Communications

APPENDIX

```
%3GPP Path Loss model.
clear all;
%Effective environment height
he = 1;
ht = 25;
transmitter_pos = [0,0,75+ht];
h_t = ht - he;
hr = 2;
receiver_pos = [0,50,4+hr];
h_r = hr - he;

%defining the distances (in metres)
d_3d = norm(transmitter_pos - receiver_pos);
d_2d = sqrt(sum((transmitter_pos(1,2) - receiver_pos(1,2)).^2));
disp(d_3d);

%Carrier frequency in GHz
fc = 10:4:30;

c = physconst('LightSpeed');

%breakpoint distance
d_p = (4 * h_t * h_r * (10^9)/c).* fc;
L = [];

%Path Loss without shadowing
for i = 1:length(fc)
    if d_2d < d_p(i)
```

```
        L = [L,28.0 + 22 * log10(d_3d) + 20 * log10(fc(i))];
    else
        L = [L,28.0 + 40 * log10(d_3d) + 20 * log10(fc(i)) - 9 *
log10((d_p(i))^2 + (ht - hr)^2)];
    end

end


%plotting the pathloss
figure(1);
scatter(fc,L,'filled');
title('3GPP Path Loss');
xlabel('frequency (GHz)');
ylabel('Path Loss (dB)');
ylim([70,120]);
grid on;
hold on;

[rec_power,gain,L] = pathLossShadowing(fc,d_2d,d_3d,d_p);
scatter(fc,L,'filled');
disp(rec_power);
disp(gain);

receiver_pos = [0,100,4+hr];

%defining the distances (in metres)
d_3d = norm(transmitter_pos - receiver_pos);
disp(d_3d);
d_2d = sqrt(sum((transmitter_pos(1,2) - receiver_pos(1,2)).^2));
d_p = (4 * h_t * h_r * (10^9)/c).* fc;

[rec_power,gain,L] = pathLossShadowing(fc,d_2d,d_3d,d_p);
figure(2);
scatter(fc,L,'filled');
title('3GPP Path Loss');
xlabel('fc (GHz)');
ylabel('Path Loss (dB)');
grid on;
%Path Loss with shadowing
```

```
function [rec_power,gain,L] = pathLossShadowing(fc,d_2d,d_3d,d_p)

syms pr_toSolve Gt;
gain = [];
L = [];
rec_power = [];
pt = 10^((47 - 30)/10);
pr = 10^((20 - 30)/10);

for i = 1:length(fc)

    if d_2d < d_p(i)

        psi = normrnd(0,4);

        Pr = solve(10*log10(pt/pr_toSolve) == 28.0 + 22 * log10(d_3d) + 20
* log10(fc(i)) - psi,pr_toSolve);
        rec_power = [rec_power,Pr];

        G = solve(10*log10(pt/pr) == 28.0 + 22 * log10(d_3d) + 20 *
log10(fc(i)) - 10*log10(Gt) - psi,Gt);
        gain = [gain,G];

        L = [L,28.0 + 22 * log10(d_3d) + 20 * log10(fc(i)) - psi ];

    else
        psi = normrnd(0,4);

        Pr = solve(10*log10(pt/pr_toSolve) == 28.0 + 22 * log10(d_3d) + 20
* log10(fc(i)) - psi,pr_toSolve);
        rec_power = [rec_power,Pr];

        G = solve(10*log10(pt/pr) == 28.0 + 22 * log10(d_3d) + 20 *
log10(fc(i)) - 10*log10(Gt) - psi,Gt);
        gain = [gain,G];
        L = [L,28.0 + 40 * log10(d_3d) + 20 * log10(fc(i)) - 9 *
log10((d_p(i))^2 + (ht - hr)^2)- psi];

    end
```

```
end

rec_power = double(rec_power);
rec_power = 10*log10(rec_power) + 30;

gain = double(gain);
gain = 10*log10(gain);

end
```