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Investigation of the Effect Different Antenna parameters (Height, Tilt, and Power) on Network Coverage and System Capacity

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Abstract

The prospective of radio mobile network topology planning would be to provide a configuration that offers the necessary coverage several services, as well as, simultaneously enhances the system coverage and capacity. This work addresses the effect of antenna height, antenna tilt and power on network and network capacity. Furthermore, the effects of the above mentioned elements had been investigated using MATLAB program. Appropriately the goal of the actual investigation is always to have because high signal strength as is possible in the area in which the cell ought to be serving traffic. Beyond the particular serving part of the cell, typically the signal power should be low so as to fight the problem associated with fluctuation within received sign strength through the mobile customers in a cellular. Results of often the investigation display that greatest coverage is actually obtained in 38m elevation, 46dB strength and 2° tilt.

Keywords: Antenna Height; Antenna Tilt; Transmitter Power; 3GPP; SUI.

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1. Introduction

The world is fast becoming a global village and a necessary tool for this process is communication of which telecommunication is a key player. The quantum development in the telecommunications industry all over the world is very rapid as one innovation replaces another in a matter of weeks A major breakthrough is the wireless telephone system which comes in either fixed wireless telephone lines or the Global System of Mobile Communications (GSM). Communication without doubt is a major driver of any economy. Emerging trends in socio-economic growth shows a high premium being placed on information and communication technology (ICT) by homes, organizations and nations [1, 2]. The concept of cellular communications was introduced by Bell Laboratories in 1947 to increase the communication capacity and coverage of mobile systems. Coverage in a cell is dependent upon the area covered by the signal. There has been an increase in the demand for higher quality networks due to the rapid growth and competition for wireless subscribers. Wireless networks are designed for both coverage and capacity requirements. Some common requirements for coverage and quality of service improvement are monitoring the impact imposed on the network by the base station antenna height, tilt and power. This will form basis of this study[3].

2. Impact of Antenna Height on Coverage

The relationship between path loss and antenna height can be establish through the models proposed by 3rd Generation Partnership Project (3GPP) TR 38.900 (Release 14) model, Stanford University Interim (SUI) model, and close-in(CI) reference distance path loss models [4]. The core of the signal coverage calculation for any environment is a path loss model which relates the loss of signal strength to distance between the base stations to the mobile station [5].

2.1 Free Space

Free-space attenuation is defined as the transmission loss caused by the dispersion of the energy of the wave that would occurs were the antennas to be replaced by isotropic radiators placed inside a perfectly dielectric, homogeneous, isotropic and unlimited environment where there are no obstacles between the transmitter and the receiver [6]. The equation for free-space attenuation (A_o) is:

$$Ao = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (1)$$

This equation can be rewritten in logarithmic form, and become:

$$Ao = 32.4 + 20\log_{10}(f) + 20\log_{10}(d) \qquad (2)$$

Where d is the distance in kilometers between the transmitter and the receiver, λ is the wavelength in kilometers and f is the frequency in MHz

2.2 CI-Path Loss Model

The CI model is given by [7]:

$$PL^{CI}(f,d) = FSPL(f,1)[dB] + 10n\log(\frac{d}{1m}) \qquad (3)$$

where $PL^{CI}(f, d)$ is the mean path loss, n is the path loss exponent (PLE), d is the separation distance between transmitter and receiver, FSPL(f, 1 m) is the free space path loss in dB at a T/R separation distance of 1 m at the carrier frequency f, given by [7]:

$$FSPL(F,1m) = 20\log(\frac{4\pi\pi}{c}) \qquad (4)$$

where c is the speed of light. The CI model is based on fundamental principles of wireless propagation, dating back to Friis and Bullington, PLE where the value is 2 in the free space as shown by Friis and the value 4 for the model of the terrestrial X-ray diffraction propagation model. Using d_0 = 1 m in mm-Wave path loss models belongs to reason that base stations will be shorter or mounted indoors, and closer to obstacles [7].

2.3 3GPP Path Loss Model

3GPP Path Loss Model Uma-LOS consists of two sections separated by a breakpoint distance where the attenuation increases beyond the cutoff distance, as given below [8]:

$$PL_{UMa\text{-}LOS} = \begin{cases} PL_1 = 32.4+20\log(d_{3D})+20\log(f_c), & 10m \le d_{2D} \le d_{BP} \\ PL2 = 32.4+20\log(d_{3D})+20\log(f_c)-10\log((d_{BP})^2+(h_{BS}-h_{UT})^2), & d_{BP} \le d_{2D} \le 5km \end{cases} \qquad (5)$$

where f_c is the center frequency in Hz, d is the distance in m. Breakpoint distance dBP = $4h_{BS*}h_{UT*}f_c/c$, and h_{BS} and h_{UT} are the compelling antenna heights at the BS and the UT, respectively.

3GPP Path Loss Model Uma-NLOS is given by[8]:

$$PL_{UMa\text{-}NLOS} = \max(PL_{UMa\text{-}LOS}, PL'_{Uma\text{-}NLOS}) \quad , \quad for \quad 10m \le d_{2D} \le 5km \qquad (6)$$

$$PL'_{UMa\text{-}NLOS} = 13.54+39.08\log_{10}(d_{3D})+20\log_{10}(f_c)-0.6(h_{UT}-1.5)$$

The 3GPP Umi-LOS path loss model in [17] is:

$$PL_{UMi\text{-}LOS} = \begin{cases} PL_1 = 32.4+21\log_{10}(d_{3D})+20\log_{10}(f_c), & 10m \le d_{2D} \le d_{BP} \\ PL_2 = 32.4+40\log_{10}(d_{3D})+20\log_{10}(f_c)-10\log_{10}((d_{BP})^2+(h_{BS}-h_{UT})^2), & d_{BP} \le d_{2D} \le 5km \end{cases} \qquad (7)$$

$$d_{3D} = \sqrt{d_{2D}^{\,2} + h_{UT}^{\,2}}$$

For Umi-NLOS, 3GPP path loss model in [8] is:

$$PL_{UMi\text{-}NLOS}=max\ (PL_{UMa\text{-}LOS}\ ,\ PL'_{Uma\text{-}NLOS})\quad for\quad 10m \le d_{2D} \le 5km \qquad (8)$$

2.4 SUI Path Loss for UHF/MICROWAVE Bands

large-scale path loss in urban environments may be estimated from the Hata model and the COST231 extension of the Hata model for carrier frequency (*fc*) below 2 GHz [9]. Path loss from the SUI model for *fc* above 2GHz is given by [10]:

$$PL_{SUI}(d)=PL(d_o)+10nlog\ (\frac{d}{do})+X_{fc}+X_{RX}+X_{\sigma} \qquad (10)$$

$$PL(d_o)=20log\ (\frac{4\pi d_o}{\lambda}) \qquad (10a)$$

$$n=a-b.h_{TX}+\frac{c}{h_{TX}} \qquad (10b)$$

$$X_{fc}=6log\ (\frac{f_{MHz}}{2000})\ ,\quad f_c > 2GHz \qquad (10c)$$

$$X_{RX}=-10.8log10(\frac{h_{RX}}{2}) \qquad (10d)$$

where λ is the wavelength in meters, PL (d_0) in Eq. (10a) shows the loss of free space in dB at a close reference distance d0; X_{fc} and X_{RX} in Eqs. (1c), (1d) indicate the correction factors for the frequency and receiver heights, respectively, and X_{σ} in the equation. (10) is the typical random shading variable with an average of 0 dB and the standard deviation [dB] such as $8.2< \sigma<10.6$ dB. f_{MHz} in the equation. (10c) is the frequency of the carrier (fc) in MHz; h_{TX} and h_{RX} indicate the height of the transmitting antenna (TX) and the receiver (RX) in meters, respectively. Parameters a, b, and c in Eq. (10b) are constants used to model the types of terrain encountered in the service area. The model is considered to be suited for hilly and dense vegetation with parameters given as $a = 4.6$, $b = 0.0075$, and $c = 12.6$ [10].

2.5 Modified SUI Path Loss Model

The Modified SUI model for mmWave in NLOS environments is given by [10]:

$$PL_{SUI,Mod}[dB]\ (d) = \alpha_{NLOS} \times (PL_{SUI}(d) - PLSUI(d_0)) + PL(d_0) + X_{\sigma} \qquad (11)$$

where α_{NLOS} is the mean slope correction factor (unit less). For the LOS environment, the Friis FS path loss formula was used;

$$PL_{FS,Mod}[dB](d) = \alpha_{LOS} \times (PLFS(d) - PLFS(d_0)) + PL(d_0) + X_{\sigma}\ . \qquad (12)$$

Table 1: adopted parameters

parameter	Nominal value
BS antenna height (meters)	35
BS antenna gain (dBi)	14
BS transmitted power (w)	20
BS TX antenna	Omni &3 sectors
Channel BW(MHz) & channel spacing(KHz)	20 & 15
Carrier center frequency (GHz)	0.7
Tx cable losses (dB)	1
Rx Cable Losses (dB)	1
BS Noise Figure(dB)	4
Required SNR at cell edge(dB)	8
Parameter	**UEs**
UE antenna height(metres)	1.5
UE Noise Figure(dB)	7
UE antenna gain (dBi)	5
UE scheduler scheme	FIFO

The simulation parameters found in Table 2 are gotten through some measurements; with the measured values used as our simulation parameters. One can effectively use equation (3), equation (5) and equation (11) to develop a MATLAB script that will calculate the path loss for CI, 3GPP and SUI at antenna height(20m-38m) respectively. The various calculated path losses for CI, 3GPP and SUI are presented in Table 2;

Table 2: Effect of varying BS antenna height on path loss

BSAntenna height(m)	CI Lp (dB)	3GPP Lp (dB)	SUI Lp (dB)
20	165.4	164.5	238.3
22	164.5	163.7	238.2
24	163.7	162.9	238.1
26	163	162.2	238
28	162.4	161.5	237.9
30	161.8	160.9	237.9
32	161.2	160.4	237.8
34	160.7	159.8	237.7
36	160.2	159.3	237.7
38	159.7	158.8	237.6

Also path loss has a relationship with received power using equation (13) [4, 5].

$$Rxd\ (dBm) = EiRPT_x - L_{MASK} - L_P \qquad (13)$$

Where *R*xd (dBm) is received power in dBm. EiRPTx is maximum Effective Isotropic Radiated Power of the cell in dBm (that is, at the peak gain point of the antenna). LMASK is antenna mask loss value for azimuth and elevation angles respectively in the direction of the path being calculated in dB. When the received signal is directly on the main beam of the antenna, this value will be zero. LP is the path loss in dB.

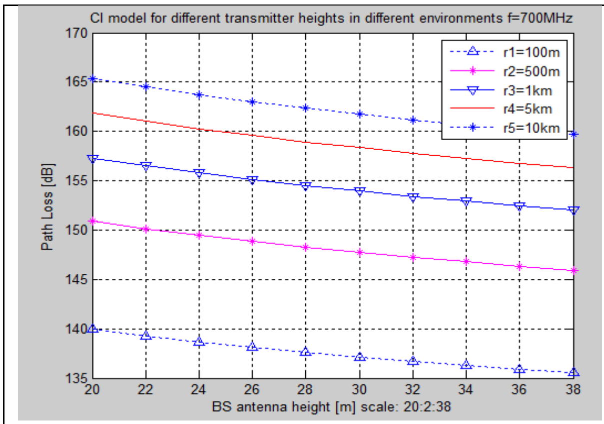
$$EiRP = P_A\ Power + antenna\ G \qquad (14)$$

Where: Antenna G = antenna Gain + 2.14 (if the gain is in dB). In effect, if path loss increases then received power will decrease. If path loss decreases then received power will increase so the signal from the BTS will cover more distance. Having known the values for the path losses for CI, 3GPP and SUI at BS antenna height, one can also determine their various values for the received power (*R*xd) by developing a MATLAB script using equation (13).This will give rise to Table 3.

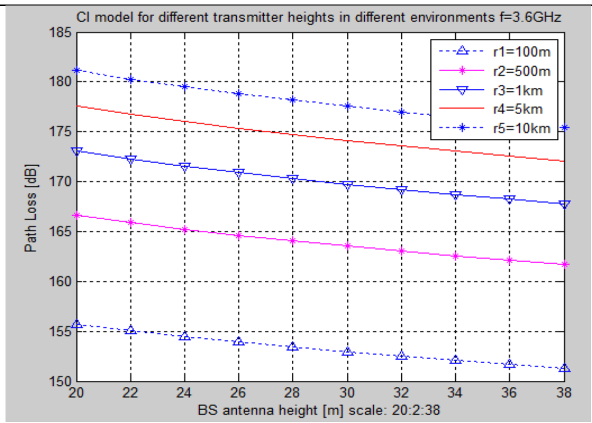
Table 3: Effect on received signal strength by varying BS antenna height.

BS Antenna height(m)	CI (dBm)	3GPP Rxd (dBm)	SUI Rxd (dBm)
20	-105.4	-104.5	-178.3
22	-104.5	-103.7	-178.2
24	-103.7	-102.9	-178.1
26	-103	-102.2	-178
28	-102.4	-101.5	-177.9
30	-101.8	-100.9	-177.9
32	-101.2	-100.4	-177.8
34	-100.7	-99.82	-177.7
36	-100.2	-99.31	-177.7
38	-99.67	-98.84	-177.6

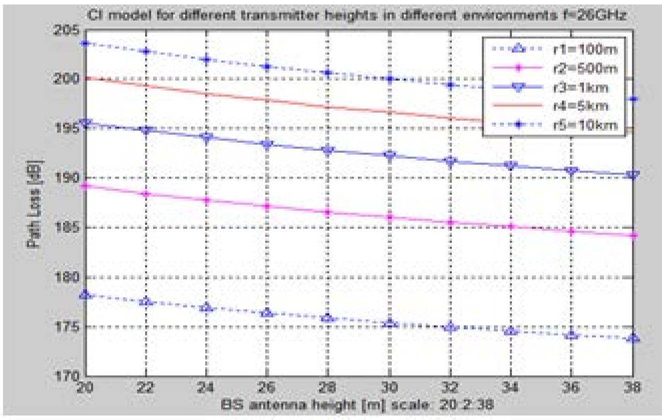
The results of the effect of varying BS antenna height on path loss is depicted by fig. 1, while the result of the effect of varying BS antenna height in received signal strength is depicted by fig. 2.



a)

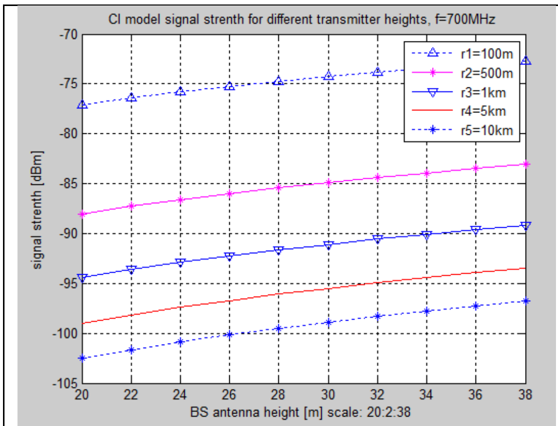


b)

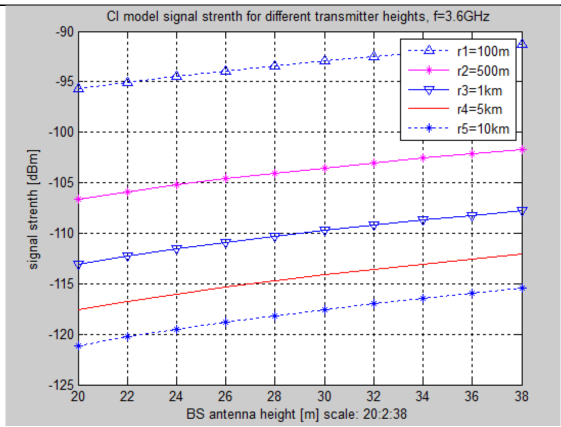


c)

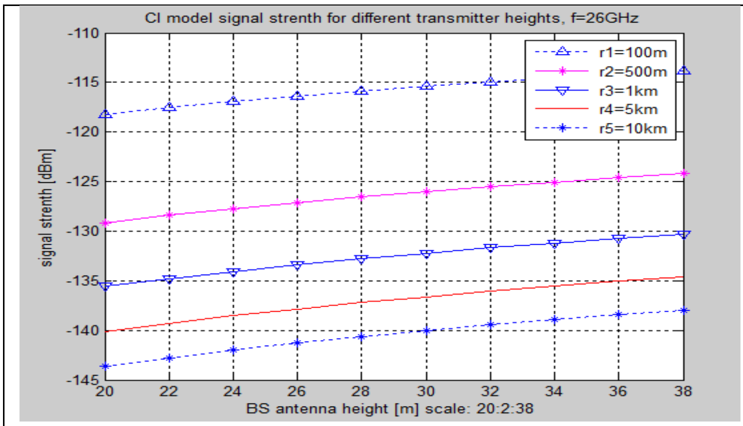
Figure 1: path loss against BS Antenna height for the various distances



a)f=700MHz



b) f==3.6GHz



c) f=26GHz

Figure 2: Plot showing received signal strength against BS antenna height for the various distances

3. Impact of Antenna Tilt on Coverage

Total tilt effect is the sum of both electrical tilt and mechanical tilt. Electrical tilt is constant at 2° as it is manufacturer specific whereas mechanical tilt is varied from 0° to 5°. So the total tilt is usually varied from 0° to 7° roughly, but that can be used in practice. The tilt angles can be estimated through simple calculation of the vertical angle between the antenna and the area of interest. In other words, we chose a tilt angle in such a way that the desired coverage areas are in the direction of vertical diagram.

Using the basic formula of Pythagoras; we have tan ϴ = Opposite / Adjacent;

Angle=Arctan(Height/Distance)

Where; opposite = Height

Adjacent=Distance

Note: the height and distance must be in the same measurement units.

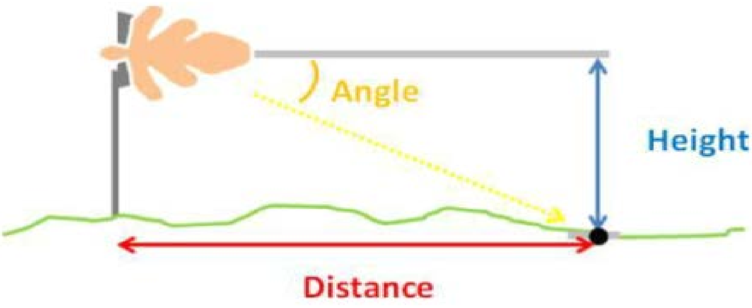


Figure 3: Relationship between antenna height, tilt and T-R distance

Using measurement, one can always obtain the value of the antenna tilt angle, T-R distance or antenna height. So at ϴ = 0° - 5°, values were obtained for the antenna height respectively; which were used together with equations (5.10) to develop another MATLAB script for computing the received signal strength for hata, cost 231 and ECC-33 respectively. The values obtained were presented in Table 4. Table 4 summarizes the impact on received signal level (coverage area) by varying the Antenna Tilt.

Table 4: Effect on received signal strength by varying the BS antenna tilt

Tilt angle (degree)	0	1	2	3	4	5
CI- Rxd (dBm)	-248.1	-249	-225.1	-301.13	-205	-228
3GPP- Rxd (dBm)	-249	-249.2	-225.2	-302.03	-250.5	-229
SUI- Rxd (dBm)	-350.7	-340.3	-302	-441.15	-350	-290

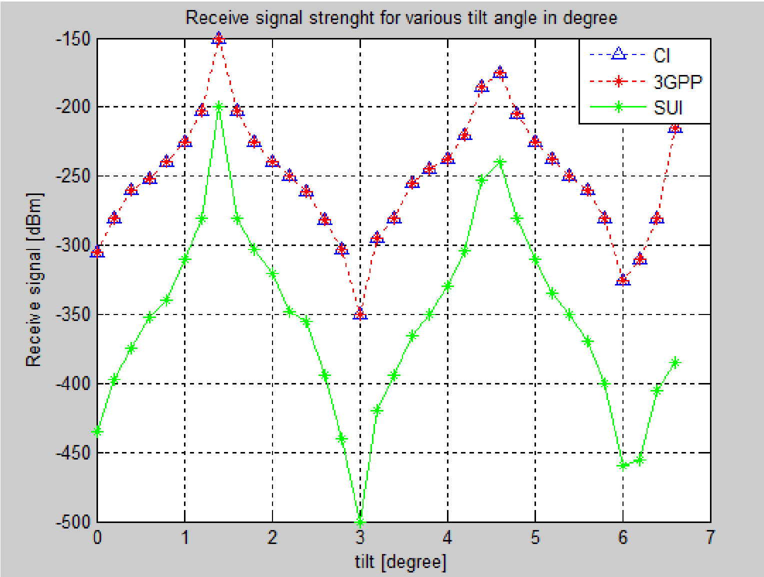


Figure 4: Plot showing the effect of tilt on Received signal level

4. Impact of Transmitter Power on Coverage

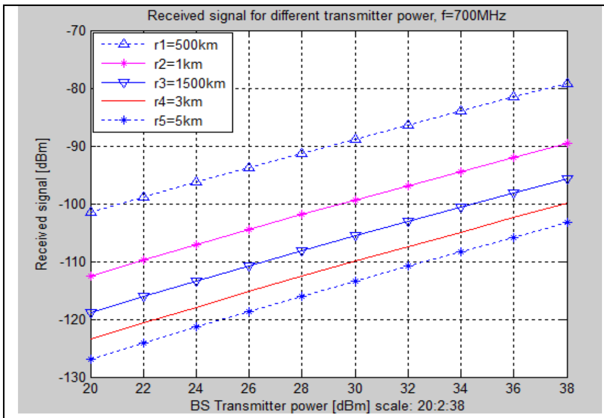
The impact on received signal level (coverage area) by varying the transmitted power from 30 dBm to 46 dBm is shown in table 5. It should be noted that the received signal strength for various path loss models like Hata okumura model, cost 231model and ECC-33 model are calculated using equation (15).

$$Pr = Pt + Gt + Gr - PL - A \qquad (15)$$

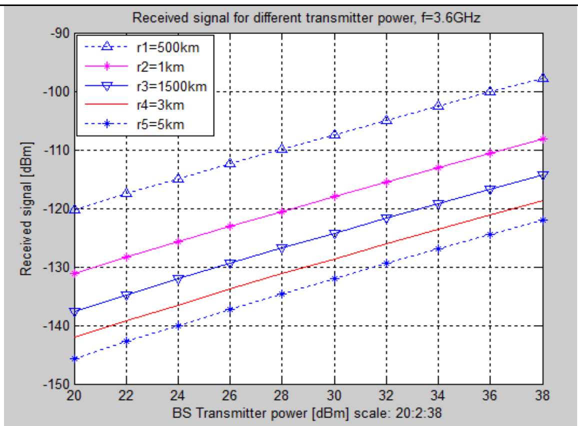
Where Pr is Received Power, Pt is Transmitted Power, Gt is Transmitted antenna gain, Gr is Received antenna gain, PL is Path loss, A is Connector and cable loss. The power received (Rxd) for CI, 3GPP and SUI models when transmitted power vary at a step size of 2dBm, from 30dBm to 46dBm can easily be calculated by developing a MATLAB script using equation 15, having known the values for other parameters in that equation(see Table 5). Coverage and capacity of mobile network is investigated and evaluated on the basis of received signal level and its impact on network coverage and capacity is studied by varying the BS antenna height, antenna tilt, antenna azimuth and transmit power.

Table 5: Effects on received signal strength by varying transmitted power

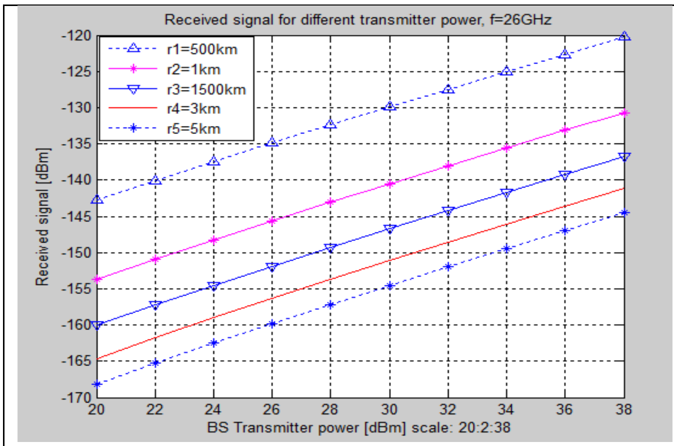
Txd power(dBm)	CI Rxd (dBm)	3GPP Rxd (dBm)	SUI Rxd (dBm)
20	-119.9	-119	-192.8
22	-117	-116.2	-190.7
24	-114.2	-113.4	-188.6
26	-111.5	-110.7	-186.5
28	-108.9	-108	-184.4
30	-106.3	-105.4	-182.4
32	-103.7	-120.9	-180.3
34	-101.2	-100.3	-178.2
36	-98.65	-97.81	-176.2
38	-96.17	-95.34	-174.1



a) F=700MHz



b) F=3.6GHz



c) f=26GHz

Figure 5: Coverage Prediction Plot showing the impact of transmitted power on coverage area (received signal strength).

5. Conclusion

Efficient planning and optimization of mobile networks is a key to guaranteeing superior quality of service and user experience. This paper has developed expressions that can be used for detailed analysis of the criterion of optimization. 5G network operators have various solutions, both short term and long term, to enhance their system capacity. Abnormalities such as forward/reverse link imbalance, excessive soft handoff areas, and improper RF parameter settings could lead to underutilization of system capacity. The empirical path loss propagation models are used to carry out the investigation the received signal strength increases as the antenna height and power increases but higher when CI and 3GPP propagation models are used for the path loss prediction unlike when SUI model is used. Also the received signal strength is higher when the antenna tilt is optimum. The investigation has been completed and as shown in the result analysis, it can be concluded that coverage is highly influenced by the antenna height, antenna power and antenna tilt. For better performance of the network it is required that antenna height and power should be high. While antennas tilt should be optimum. Best coverage is obtained at 38m height, 46dB power and 2° tilt.

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