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Investigating the Impacts of Base Station Antenna Height, Tilt and Transmitter Power on Network Coverage

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ABSTRACT : *The target of radio network topology planning is to provide a configuration that offers the required coverage for different services, and simultaneously maximizes the system coverage and capacity. This paper addresses the impact of antenna height, tilt and power on network coverage and system capacity. Moreover, the impacts of the aforementioned elements were investigated using MATLAB simulation tools. Accordingly the goal of the investigation is to have as high signal strength as possible in the area where the cell should be serving traffic. Beyond the serving area of the cell, the signal strength should be as low as possible so as to combat the problem of fluctuation in received signal strength by the mobile users in a cell. Results of the investigation show that best coverage is obtained at 38m height, 46dB power and 2° tilt.*

KEYWORDS: *Antenna, Base Station, MATLAB, Received Signal Strength*

I. 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.

II. IMPACT OF ANTENNA HEIGHT ON COVERAGE

The antenna height is the basis of base station coverage area. If the antenna height is increased, path loss is lessened and on decreasing the antenna height path loss increases [3]. The relationship between path loss and antenna height can be establish through the models proposed by hata, okumurah, Electronic and communication committee(ECC-33) and European cooperative for scientific and technical research(Cost-231)[8]. The path loss in dB for the various environments under hata-okumura is given in equations below:

- For Urban Area

$$P_{L\,(URBAN)}\,(dB) = A + B \log (d) \tag{1}$$

Where;
$P_{L\,(URBAN)}$ (dB) = path loss for urban area in dB
d = distance between transmitter (Tx) and receiver (Rx) in kilometre,
'A' = represents a fixed loss that depends on frequency of the signal.
These parameters are given by the empirical formula:
$A = 69.55 + 26.16 \log (f) - 13.82 \log (h_b) - a\,(h_m)$.
$B = 44.9 - 6.55 \log (h_b)$.

Where,
f = operation frequency measured in MHz,
h_b = height of the base station antenna in meters,

h_m = mobile antenna height in meters and
a (h_m) = is correction factor in dB
For effective mobile antenna height a (h_m) is given by:

- for small and medium size cities
  a [h_m] = [1.1 log (f) - 0.7] h_m – [1.56log(f) - 0.8],
- for large cities,

a[h_m] = 8.29[log1.54h_m]^2 – 11, f ≤ 200MHz
a[h_m] = 3.2[log11.75h_m]^2 – 4.97, f ≥ 400MHz
For Sub-Urban Area the path loss is given as:
$P_{L\,(SUB-URBAN)}$(dB) = $P_{L\,(URBAN)}$ – 2[log (f/28)^2 – 5.4]dB (2)

For Rural Area the path loss is given as:
$P_{L\,(RURAL)}$ (dB) = $P_{L\,(URBAN)}$ – 4.78log (f)^2 + 18.33logf – 40.94dB (3)

The range of value for validity of Hata model is
150 ≤ f ≤ 1500MHz
30 ≤ h_b ≤ 200m
1 ≤ h_m ≤ 10m
1 ≤ d ≤ 20km.

The path loss using COST 231 model for signal strength prediction is given as:
- For Urban Area

P_L (dB) = 46.33 + 33.9 log (f) - 13.82 log (h_b) – a(h_m) + [44.9 - 6.55 log (h_b)] log(d) (4)
Where;
a[h_m] = [1.1 log(f) - 0.7] h_m – [1.56log(f) - 0.8],

Whereas the path loss using ECC-33 model is given as:
P_L (dB) = A_{fs} + A_{bm} – G_t – G_r (5)

Where;
A_{fs} = free space attenuation,
A_{bm} = basic median path loss,
G_t = BS height gain factor and
G_r = received antenna height gain factor.
They are individually defined as:
A_{fs} = 92.4 + 20 log (d) + log (f)
A_{bm} = 20.41 + 9.83log d + 7.894log f + 9.56[log (f)]^2
G_t =log (h_b/200) [13.958 + 5.8 log d]^2 for medium city environments,
G_r = [42.57 + 13.7 log (f)][log (h_m) - 0.585]

Where,
f = operating frequency in GHz,
The simulation parameters found in Table 1.0 are gotten through some measurements; with the measured values used as our simulation parameters. One can effectively use equation (1), equation (4) and equation (5) to develop a MATLAB script that will calculate the path loss for hata, cost 231 and ECC-33 at antenna height(20m-38m) respectively.

Table 1.0: Simulation parameters and their Specifications

Parameters	Values
Operating Frequency(f)	900MHz
Base Station Transmission power	43dBm
Mobile Transmission power	30dBm
Base Station antenna height	38m
Mobile station antenna height	1.5m
Transmitter antenna gain	17.5dB
Distance between transmitter and Receiver	1-10(km)
Connector Losses	2dB
Cable losses	1.5dB
BS threshold level	-110dBm

The various calculated path losses for hata, cost 231 and ECC-33 are presented in Table 2.0

Table 2.0 Effect of varying BS antenna height on path loss

BS Antenna height (m)	Hata L_p (dB)	COST231 L_p (dB)	ECC-33 L_p (dB)
20	165.23	164.86	549.78
22	164.37	164.02	533.62
24	163.60	163.25	518.87
26	162.89	162.54	505.30
28	162.23	161.88	492.74
30	161.63	161.27	481.04
32	161.06	160.70	470.10
34	160.52	160.17	459.82
36	160.02	159.66	450.13
38	159.54	159.18	440.96

Also path loss has a relationship with received power using equation (6) [4, 5].

$$\text{Rxd (dBm)} = \text{EiRPTx} - L_{MASK} - \text{Lp} \qquad (6)$$

Where Rxd (dBm) = received power in dBm.
EiRPTx = maximum Effective Isotropic Radiated Power of the cell in dBm (that is, at the peak gain point of the antenna).

L_{MASK} = 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.

$$\text{EiRP} = P_A\text{Power} + \text{antennaG} \qquad (7)$$

Where: AntennaG = 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 Hata, cost 231 and ECC-33 at BS antenna height, one can also determine their various values for the received power (Rxd) by developing a MATLAB script using equation (6).This will give rise to Table 3.0

Table 3.0: Effect on received signal strength by varying BS antenna height.

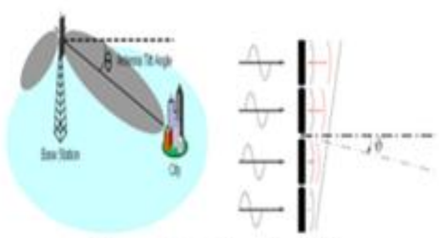
BS Antenna height (m)	Hata R_{xd} (dBm)	COST231 R_{xd} (dBm)	ECC-33 R_{xd} (dBm)
20	-533.24	-532.89	-917.81
22	-516.24	-515.89	-885.49
24	-500.72	-500.37	-855.99
26	-486.44	-486.09	-828.85
28	-473.22	-472.87	-803.72
30	-460.91	-460.56	-780.33
32	-449.40	-449.05	-758.44
34	-438.59	-438.23	-737.89
36	-428.39	-428.04	-718.51
38	-418.75	-418.39	-700.17

III. IMPACT OF ANTENNA TILT ON COVERAGE

The efficiency of a cellular network depends on its correct configuration and adjustment of radiant systems by the transmit and the receive antennas. And one of the most important system optimizations task is based on correct adjusting tilts, or the inclination of the antenna in relation to an axis. With the tilt, we direct irradiation further down (or higher), concentrating the energy in the new desired direction. When the antenna is tilted down, it is called down tilt, which is the most commonly used. If the inclination is up (very rare and extreme cases), one can call it up tilt. The tilt is used when one wants to reduce interference and/or coverage in some specific areas, having each cell to meet only its designed area.

When selecting the optimum tilt angle, the goal is to have as high signal strength as possible in the area where the cell should be serving traffic. Beyond the serving area of the cell, the signal strength should be as low as possible.

When the cell site uses a high-gain antenna, downward tilting can direct the nulls in the antenna pattern towards the horizon to prevent energy from propagating into other cells [6]. A too aggressive down tilting strategy will however lead to an overall loss of coverage. Down tilting the antenna limits the range by reducing the field strength in the horizon and increases the radiated power in the cell that is actually to be covered.
Down tilting can be done in two ways: Electrical down tilting and Mechanical down tilting as shown in figs 1(a) and 1(b) respectively.



Figures1 (a): Electrical tilt

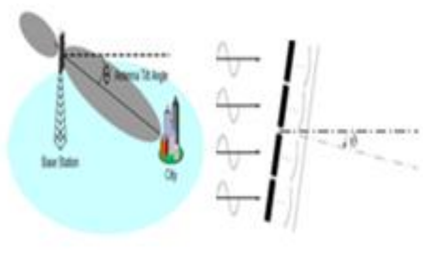


Figure1 (b): Mechanical tilt

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;
Where; opposite = Height

Adjacent=Distance
Angle = Arc TAN (Height / Distance) (8)
Note: the height and distance must be in the same measurement units.

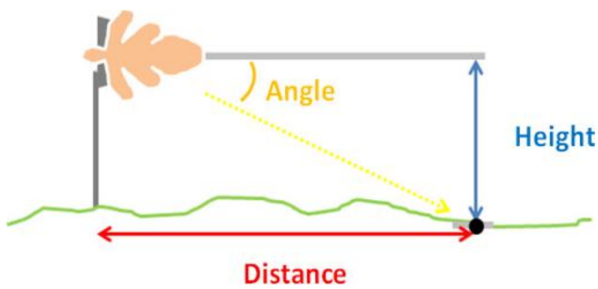


Figure1(c): Relationship between antenna height, tilt and T-R distance

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 (6) 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 4.0

Table 4.0 summarizes the impact on received signal level (coverage area) by varying the Antenna Tilt

Table 4.0: Effect on received signal strength by varying the BS antenna tilt

Tilt angle (degree)	0°	1°	2°	3°	4°	5°
Hata Okumura R_{xd} (dBm)	-248.11	-249.02	-225.13	-301.50	-250.01	-228.30
COST-231 R_{xd} (dBm)	-249.00	-249.16	-225.20	-302.03	-250.50	-229.00
ECC-33 R_{xd} (dBm)	-350.72	-340.25	-302.00	-441.15	-350.00	-290.20

IV. IMPACT OF TRANSMITTER POWER ON COVERAGE

Controlling the transmit power of the mobile and base station reduces the system interference and thus can be used to reduce the cluster size if implemented properly. In practical cellular radio and personal communication systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations. This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel [6, 7]. Power control not only helps prolong battery life for the subscriber unit but also dramatically reduces the reverse channel *C/I* in the system.

In general, there are two algorithms to control the power. First, the algorithms are based on this rule that increasing the path gain will cause the power to be decreased. In the simplest and most used kind of these algorithms, the intensity of the receiving signal is remained constant and to reach the goal path gain should be compensated completely. In another kind of this structure, only some changes of path gain will be remunerated. Both structures will cause a slight increase in the capacity. The second kind of algorithms that will be used will be designed on the quality of connection which main factor is the carrier to interference ratio (CIR).

The output power of base station is evaluated for three different areas (urban, suburban and rural areas) by using Hata-Okumura propagation model. Input values of Hata-Okumura propagation model are operating frequency, base station height, mobile station height, cell radius. Output value is base station propagation power for different areas [3, 8].

As the BTS power increases received power also increases. The Impact on received signal level (coverage area) by varying the transmitted power from 30 dBm to 46 dBm is shown in table 5.0
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 (9).

$$Pr = Pt + Gt + Gr - PL - A \qquad (9)$$

Where Pr = Received Power, Pt = Transmitted Power, Gt = Transmitted antenna gain, Gr = Received antenna gain, PL= Path loss, A= Connector and cable loss

The power received (R_{xd}) for Hata, Cost 231 and ECC-33 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 9, having known the values for other parameters in that equation(see Table 1.0); this actually gave rise to Table 5.0.

Table 5.0: Effects on received signal strength by varying transmitted power

Txd power (dBm)	Hata R_{xd} (dBm)	COST231 R_{xd} (dBm)	ECC-33 R_{xd} (dBm)
30	-135.50	-135.14	-150.05
32	-133.50	-133.14	-148.05
34	-131.50	-131.14	-146.05
36	-129.50	-129.14	-144.05
38	-127.50	-127.14	-142.05
40	-125.50	-125.14	-140.05
42	-123.50	-123.14	-138.05
44	-121.50	-121.14	-136.05
46	-119.50	-119.14	-134.05

V. PROBLEM EVALUATION

In this section the coverage of GSM network is investigated and evaluated on the basis of received signal level and its impact on network coverage and capacity by varying the BS antenna height, antenna power and antenna tilt.

The Results of the effect of varying BS antenna height on path loss is depicted by fig. 2, while the result of the effect of varying BS antenna height in received signal strength is depicted by fig. 3. Furthermore, figs. 4 and 5 shows the effects of varying the BS antenna tilt on received signal strength level and the impact of transmitted power on coverage area (Received signal strength) respectively.

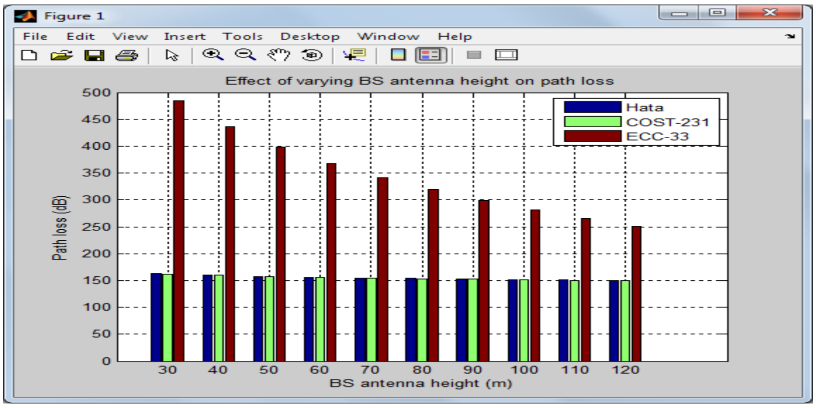


Figure 2: Bar chart showing path loss against BSAntenna height for the various empirical Propagation models

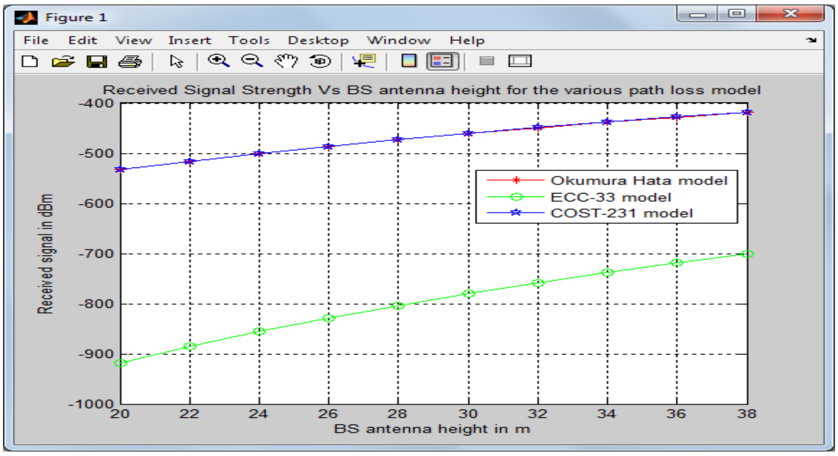


Figure 3: Plot showing received signal strength against BS antenna height for the various empirical propagation models

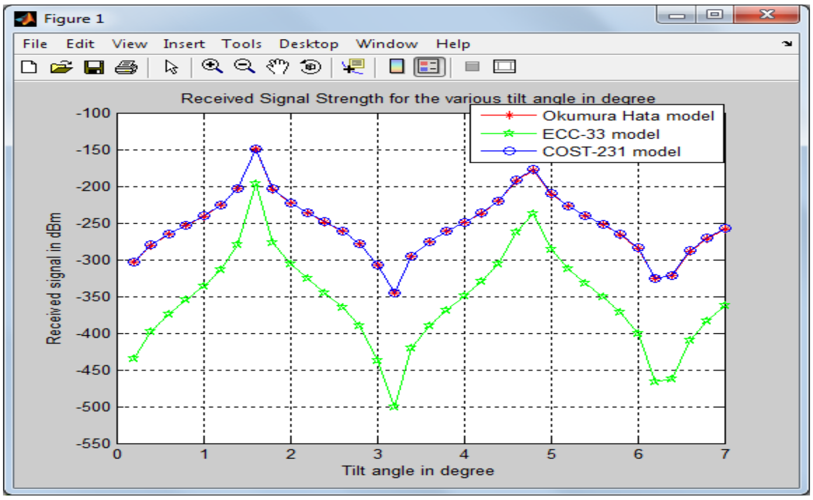


Figure 4: Plot showing the effect of tilt on Received signal level

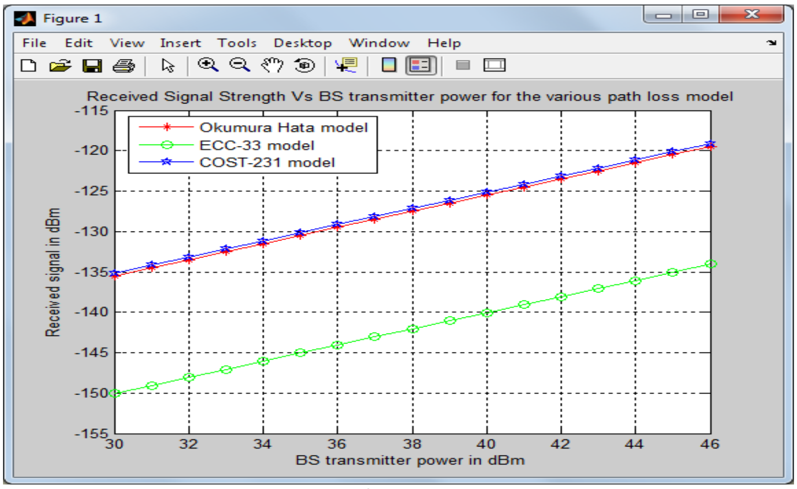


Figure 5: Coverage Prediction Plot showing the impact of transmitted power on coverage area (received signal strength)

VI. RESULT ANALYSIS

The empirical path loss propagation models are used to carry out the investigation and as shown in the figures(2-5) above, the received signal strength increases as the antenna height and power increases but higher when Hata Okumura and COST 231 propagation model are used for the path loss prediction unlike when ECC 33 model is used. Also the received signal strength is higher when the antenna tilt is optimum.

VII. CONCLUSION

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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