Performance Analysis of GSM Coverage considering Spectral Efficiency, Interference and Cell Sectoring

Afsana Nadia, S. K. Aditya

Abstract— In this work, the capacity and coverage area of GSM system have been studied. This paper presents the importance of using link budget calculations, determining the path loss and cell range for RF coverage planning and improving capacity using cell-sectoring. The major contribution is to estimate the coverage of GSM system which depends on BS antenna height, transmitting antenna gain, output power of BS for propagation environment such as rural, sub-urban and urban case. MATLAB has been used for simulation and performance evaluation of capacity and coverage in GSM system. Path loss for uplink and downlink has been calculated using Link Calculator software considering 3-sector antenna. Analysis reveals that coverage area improves significantly considering spectral efficiency, interference and cell sectoring. As an example, Google Earth and Radio Works software have been used to estimate the coverage area for a particular area. A 3D coverage map has been formulated using this result.

Index Terms—Cell Sectoring, GSM Coverage, Interference, Spectral Efficiency.

I. INTRODUCTION

In the early 1980s, as business was becoming increasingly international, the communications industry focused exclusively on local cellular solutions, with very few compatible systems. The problem was lack of capacity. By the early 1990s, it was clear that analog technology would not be able to keep up with demand [1]. 1G standards could not overcome all the limitation, such as, Capacity limitation, many standards throughout the world and no data transfer facilities. So the next generation (2nd Generation) cellular networks are being designed to facilitate high speed data communication traffic. The second-generation (2G) mobile cellular systems use digital radio transmission for traffic. Thus, the boundary line between first- and second generation systems is obvious: It is the analog/digital split. The 2G networks have much higher capacity than the first-generation systems. NADC (North American Digital Cellular) and DMPS are the second generation mobile systems. The D-AMPS used existing AMPS channels and allows for smooth transition between digital and analogue systems in the same area. The AMPS data rate is 48.6 kbps. But D-AMPS could not also overcome the limitations. So GSM (Global System for Mobile) was introduced.

GSM is worldwide standard that allows users of different operators to connect and to shares the services simultaneously. GSM has been the backbone of the phenomenal success in mobile telecommunication over the last decade. Now, at the dawn of the era of true broadband services, GSM continues to evolve to meet new demands. One of GSM's great strengths is its international roaming capability, giving consumers a seamless service in about 160 countries. This has been a vital driver in growth, with around 300 million GSM subscribers currently in Europe and Asia. The European realized this early on, and in 1982 the Conference of European Posts and Telegraphs (CEPT) formed a study group called the Group Special Mobile (GSM) to study and develop a pan-European public land mobile system [1].

This paper presents the impact of the spectral efficiency, interference and cell sectoring on coverage estimation in GSM. Effect of MS antenna height, BS antenna height and effect of output power of BS have been studied for different areas.

The rest of this paper is organized as follows. Section II and III contains the system capacity estimation considering interference and channel capacity estimation considering spectral efficiency respectively. Section IV describes capacity improvement using cell-sectoring. Section V and VI contains the link budget calculation and path loss and cell range calculation respectively. In section VII and VIII, coverage and BS power are estimated respectively. In section IX, Path Loss Models are presented. Section X gives conclusions for the paper.

II. INTERFERENCE AND SYSTEM CAPACITY

Interference is the major limiting factor in the performance of the cellular radio systems [2]. The two major types of system-generated cellular interference are as follows:

A. Co-channel Interference

Frequency reuse implies that a given coverage area there are several cells that use the same set of frequencies. These cells are called co-channel cells and the interference between the signals from these cells is called co-channel interference. For a hexagonal geometry [2],

$$Q = \frac{D}{R} = \sqrt{3N} \tag{1}$$

A small value of Q provides larger capacity since the cluster size N is small, whereas a larger value of Q improves the transmission quality due to the smaller level of co-channel interference [2].

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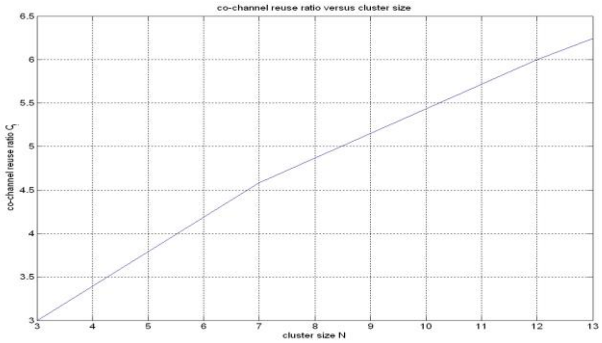

Fig. 1: Co-channel Reuse Ratio versus Cluster Size.

B. Adjacent Channel Interference

Interference resulting from the signals which are adjacent in frequency to the desired signal is called adjacent channel interference [2].

III. SPECTRAL EFFICIENCY

Spectral efficiency is defined as the ratio of the data rate in bits per second to the effectively utilized channel bandwidth [3]. With the value of B·T, the channel data rate is 271 kbps. Because the channel bandwidth is 200 kHz, the spectral efficiency of GSM is 1.36.

A. Channel Capacity

Spectral efficiency is directly related to capacity. The higher the spectral efficiency, the greater the capacity of the system. Here, capacity is defined as the number of channels per MHz per cell. For a TDMA system, the capacity is given by, For a TDMA system, the capacity is given by [4],

$$\kappa = \frac{N_{ts}(1-\chi)}{MB} \quad (2)$$

Where N_{ts} is the number of time slots per carrier, χ is the fraction of channels allocated for signaling, M is the cluster size, and B is the channel bandwidth. For the GSM system, N_{ts} is equal to 8, and B is equal to 200 kHz. With perfect power control, frequency hopping and discontinuous transmission with a voice activity factor (VAF) of ½, M is equal to 4 using omni-cells [4]. Assuming χ to be equal to 0.1, the GSM capacity is then,

$$\kappa = \frac{8\times(1-0.1)}{4\times 0.2} = 9\, channels/MHz/cell \quad (3)$$

There are a number of ways in which capacity can be increased. In GSM, this can be achieved by a smaller cluster size, sectorization, implementing channel borrowing schemes, and activity factor. In GSM, sectorization cell into of a 3 sectors will decrease the required cluster size from 4 to 3. This gives a capacity gain of 4/3.

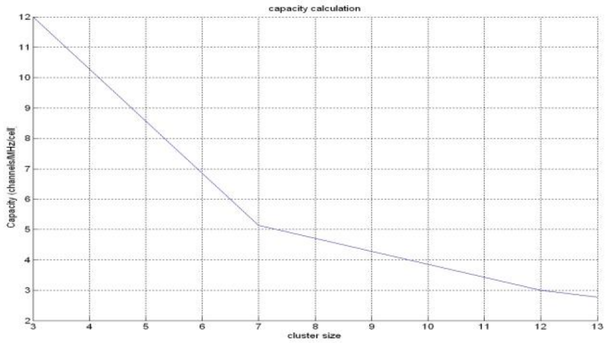

Fig. 2: Capacity Calculation.

IV. CAPACITY IMPROVEMENT USING CELL-SECTORING

The sectoring technique increases the capacity via a different strategy. In this method, a cell has the same coverage space but instead of using a single omni-directional antenna that transmits in all directions, either 3 or 6 directional antennas are used such that each of these antennas provides coverage to a sector of the hexagon [5]. There are two types of sectoring:

A. 120-Degree Sectoring

When 3 directional antennas are used, 120° sectoring is achieved (each antenna covers 120°). For example, assume n=4. Then the N=4 cluster with 120° sectors will have a worst case S/I a factor of 3 larger than the “typical” omni case value of $\sqrt{3.4}^{4}/6 = 24$, hence 72 or 18.6dB. This is nearly the same as the “typical” N=7 case ($\sqrt{3.7}^{4}/6 = 73.5$ or 18.7 dB). Yet our reuse factor jumps from 1/7 to 1/4, an increase of 75% [6], [7].

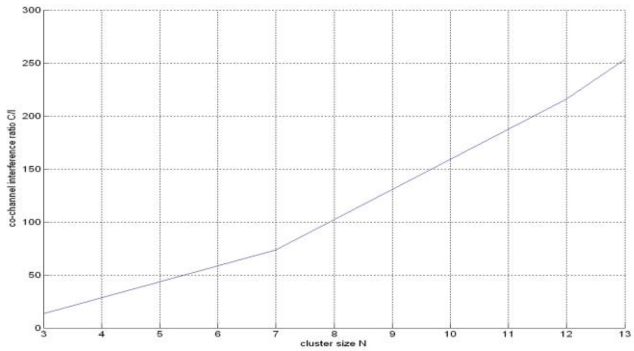

Fig. 3: Co-channel Interference Ratio versus Cluster Size.

B. 60-Degree Sectoring

When 6 directional antennas are used, 60° sectoring is achieved (each antenna covers 60°).

V. THE LINK BUDGET CALCULATION [8], [9]

The detailed radio network plan can be sub-divided into three sub-plans:

(1) Link budget calculation,
(2) Coverage, capacity planning and spectrum efficiency,
(3) Parameter planning.

A. Uplink Calculations

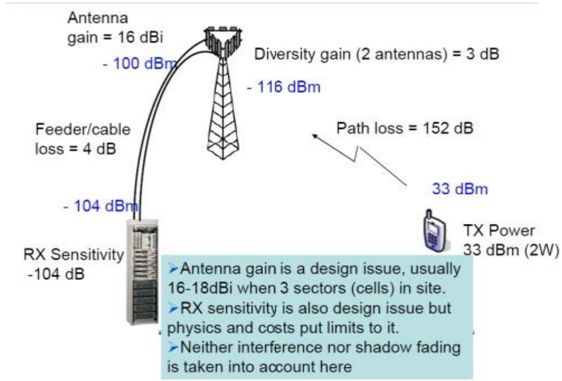

Fig. 4: Example of Link Budget Uplink Calculation.

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PL_U (Path Loss in uplink) = $EIRP_m$ (Peak EIRP of Mobile) − P_{rb} (Power Received by the base station)

$EIRP_m$ = P_{tm} (Power transmitted from the MS) − Losses + G_m

Losses = L_{cm} (cable loss at mobile) + L_{om} (any other loss)

$P_{rb} = -G_b$ (antenna gain) − Losses + B_s (BTS sensitivity)

Losses = L_{cb} (cable loss at BTS) + L_{ob} (any other loss)

$$PL_U = EIRP_m - P_{rb}$$

$$PL_U = [P_{tm} - L_{cm} - L_{om} + G_m] - [-G_b + L_{cb} + L_{ob} + B_s]$$

= [33-0-0+0]-[-16+4+0+(-104)]
= 149 dBm

B. Downlink Calculations

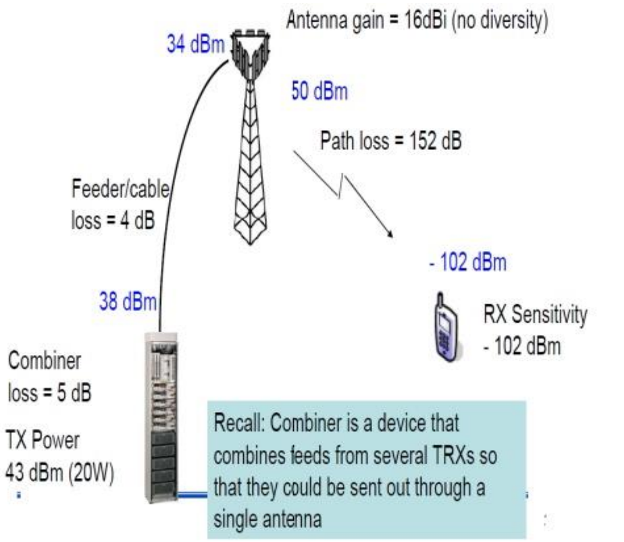

Fig. 5: Example of Link Budget Downlink Calculation.

PL_d (Path Loss in downlink) = $EIRP_b$ (peak EIRP of BTS) − P_{rm} (Power received by the MS)

$EIRP_b$ = P_{tb} (Power transmitted by BTS) + G_{tb} (antenna gain) − Losses

Losses = L_{cb} (cable loss at BTS) + L_{ccb} (combiner loss at BTS)

P_{rm} = M_s (Mobile sensitivity) + Losses − G_m (mobile antenna Gain)

Losses = L_{cm} (cable loss) + L_{om} (any other loss)

$$PL_d = EIRP_b - P_{rm}$$

$$PL_d = [P_{tb} + G_{tb} - L_{cb} - L_{ccb}] - [M_s - L_{cm} - L_{om} - G_m]$$

= [43+16-4-5]-[-102-0-0-0]
= 152 dBm

As can be seen, there is an obvious difference in the results of the uplink and downlink power budget calculations, where the downlink path loss exceeds the uplink power loss. This is an indication that the area covered by the base station antenna radiations is more than the area covered by the mobile station antenna, thereby giving more coverage in the downlink direction. Reducing the power in the downlink direction can reduce this difference but results in a loss of coverage [8].

VI. PATH LOSS AND CELL RANGE CALCULATION

In table I, pathloss and cell range are calculated for outdoor, indoor and in car by using a Link Calculator where the operating frequency is 900 MHz. Here we have got higher Pathloss (143 dB) for outdoor than indoor and in car. We have got higher range (22.9 km) for rural area in outdoor where the transmitting antenna height (40m), transmitting output power (42 dBm), transmitting antenna gain (18 dBi) and MS sensitivity (-104 dBm) are constant.

Table I. Path Loss and Cell Range Calculation

Frequency 900 MHz		Path Loss (dB)	Urban Range (km)	Sub-urban Range (km)	Rural Range (km)
Outdoor	Uplink	140	2.8	5.4	18.8
	Down link	143	3.4	6.6	22.9
In car	Uplink	132	1.6	3.2	11
	Down link	135	2	3.9	13.4
Indoor	Uplink	124	1	1.9	6.4
	Down link	127	1.2	2.3	7.9

VII. COVERAGE ESTIMATION

(i) We estimated coverage by using Goole Earth and Radio Works software. We have calculated distance (1.9 km) from Asadgate to Shaukrabad, Dhaka, Bangladesh. We have got latitude 23deg 45min 27.86sec N and longitude 90deg 22min 26.35sec E from Google Earth. From these values we have got 3D coverage map in fig. 6.

Fig. 6: 3D Coverage Map.

(ii) In Hata Model (urban), BS antenna Height, MS antenna Height, distance between base/mobile, transmission frequency are 131.233595ft, 6.56167979ft, 1.18060520mi, 900MHz respectively for large city. Finally we have got path loss/distance graph from Radio Works software.

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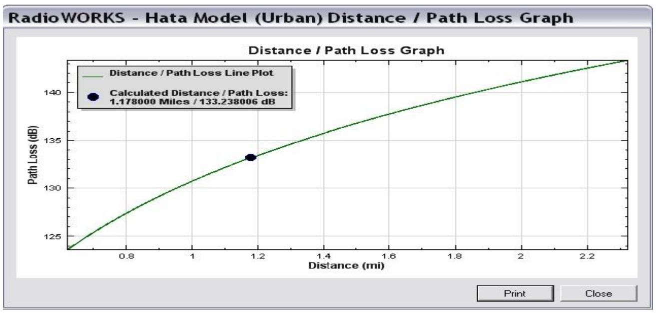

Fig. 7: Distance/ Path Loss Graph.

(iii) If we increase the transmitter power from 20W to 43W, then distance will be increased from 1.9km to 2.7859km.

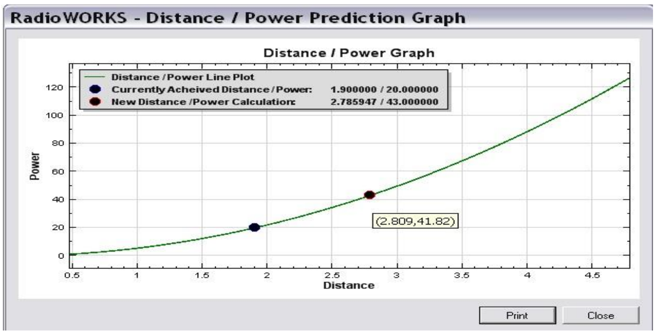

Fig. 8: Distance/ Power Graph.

VIII. BS POWER ESTIMATION

Output power of base station is found for three different areas (urban, suburban and rural areas) by using Hata-Okumura propagation model [10].

For urban areas:

$$P_{tu} = P_{r\min} + L_o + L_{pu} - G_t - G_r \quad (4)$$

For suburban areas:

$$P_{tsu} = P_{r\min} + L_o + L_{ps} - G_t - G_r \quad (5)$$

For rural areas:

$$P_{tr} = P_{r\min} + L_o + L_{po} - G_t - G_r \quad (6)$$

Parameters of these formulas:

$P_{r\min}$ = Minimum receiver sensitivity

G_t, G_r = Transmitter and receiver antenna gain

L_{pu}, L_{ps}, L_{po} = Loss for urban, suburban, open or rural areas respectively

L_o = Additional Loss Distance in km

f_c = Operating Frequency (900 MHz)

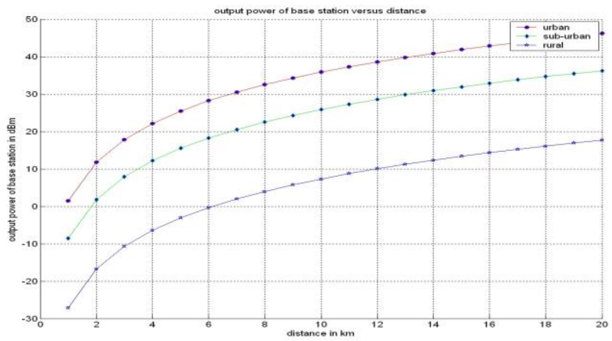

Fig. 9: Output Power of Base Station as a Function of Distance for Urban, Sub-Urban & Rural Area, at f=900MHz , h(r)=2m.

Comments and Analysis: The transmitting powers for urban, suburban and rural areas are plotted as a function of distance as shown in fig. 9. From here we can see that transmitting power increases with the increase in distance for urban, sub-urban, rural area where the receiving antenna height is fixed. Transmitting power increases more with increase in distance for urban than sub-urban and rural area. Increasing the Cell Transmit power increases downlink coverage but does not affect uplink coverage.

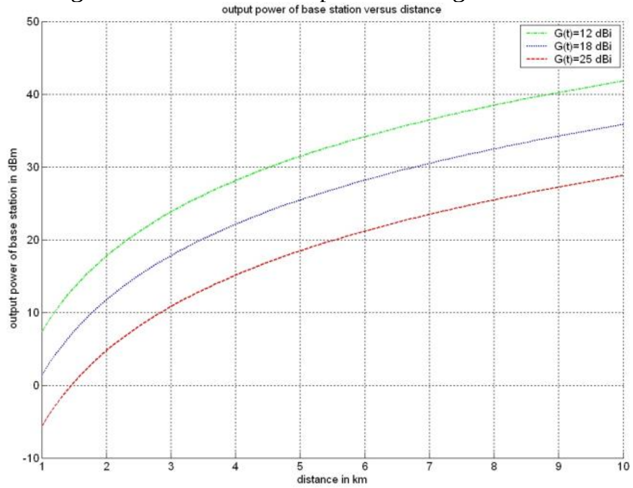

Fig. 10: Output Power of BS versus Distance for Urban Area at f = 900MHz, h(r) =2m and G(t) Varied from 12 dBi to 25 dBi.

Comments and Analysis: Fig. 10 is a plot of urban area transmitting power as a function of distance, at f = 900 MHz, h(r) = 2m and G(t) varied from 12 dBi to 25 dBi. From here we can see that decreasing transmitting antenna gain increases transmitting power for urban area where the receiving antenna height is fixed.

IX. PATH LOSS MODELS

Hata Model: The model is an empirical formulation of the graphical path loss data provided by Okumura. Hata presented the urban area propagation loss as a standard formula and supplied correction equations for other types of areas [11].

Urban Area:

$$L_{pu} = 69.55 + 26.16\log_{10} f - 13.82\log_{10} h(t) - ah(r) + [44.9 - 6.55\log_{10} h(t)]Log_{10}d \quad (7)$$

Where, L_{PU} = Propagation loss in urban area (dB)

f = The carrier frequency (150 MHz ~ 1500 MHz)

h(t) = Base station antenna height (20 – 200 m)

h(r) = Mobile station antenna height (1m → 10 m)

d = Distance (1 → 20 Km)

For small to medium city:

$$ah(r) = (1.1Log_{10} f - 0.7)h(r) - (1.56Log_{10} f - 0.8) \text{ (dB)} \quad (8)$$

For large city:

$$ah(r) = 3.2[Log_{10}(11.75h(r))] - 4.97 \text{ (dB)} \quad (9)$$

Where, ah(r) is a correction factor.

Suburban area [12], [13]:

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$$L_{ps} = L_{pu} - 2[\log_{10} \frac{f}{28}]^2 - 5.4 \quad (10)$$

Where, L_{PS} = path loss (dB) in suburban area.

Open Area [12], [13]:

$$L_{po} = L_{pu} - 4.78[\log_{10} f]^2 + 18.33 \log_{10} f - 40.94 \quad (11)$$

Where, L_{PO} = path loss (dB) in open area.

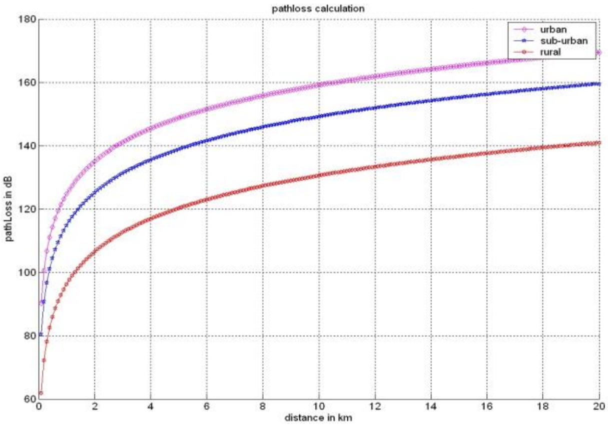

Fig. 11: Path Loss as a Function of Distance for Urban, Sub-Urban & Open Area, at f=900MHz , h(t)=40m.

Comments and Analysis: The path loss for urban, suburban and open areas using equations 7, 10 and 11 are plotted as a function of distance as shown in fig. 11. From here we can see that path loss increases with the increase in distance for urban, sub-urban, open or rural area where the transmitting and receiving antenna height are fixed. Path loss increases more with increase in distance for urban than sub-urban and rural area.

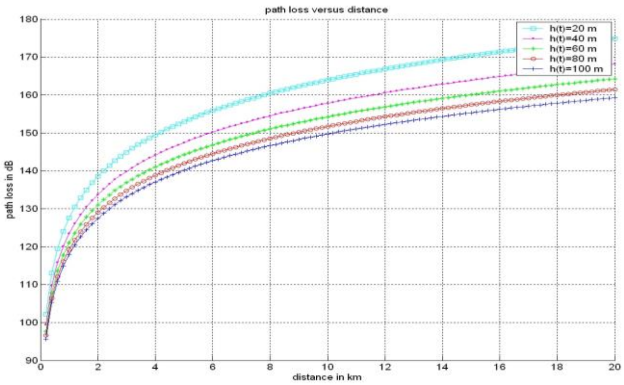

Fig. 12: Path Loss versus Distance for Urban Area at f = 900MHz, h(r) =2m and h(t) Varied from 20m to 100m.

Comments and Analysis: Fig. 12 is a plot of urban area path loss as a function of distance, at f = 900 MHz, h(r) = 2m and h(t) varied from 20 m to 100 m. From here we can see that increasing transmitting antenna height reduces path loss for urban area where the receiving antenna height are fixed.

X. CONCLUSION

In this paper, the performance analyses in coverage of GSM using interference, spectral efficiency and cell-sectoring has been simulated and evaluated for some parameters. The calculation has done for path loss and cell range with Microsoft Excel tool and Link Calculator considering 3 sectored antennas. Channel capacity and system capacity has been estimated considering spectral efficiency and interference respectively using MATLAB. Coverage has been estimated by using Google Earth and Radio Works software. 3D coverage map has been found using this result. We have estimated how path loss for different areas (such as-urban, sub-urban, and rural) is changed with the distance by the help of MS antenna height and BS antenna height using Okumura-Hata Model. In this paper output power of the base station has been also observed to increase with distance for urban, sub-urban and rural areas. This paper has shown the importance of using link budget calculations and determining the path loss and cell range for RF coverage planning.

XI. ACKNOWLEDGMENT

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REFERENCES

[1] T. S.Rappaport, “Wireless Communications”, 2nd Edition, Prentice Hall, 2002, Ch. 1, pp. 1-9.
[2] T. S.Rappaport, “Wireless Communications”, 2nd Edition, Prentice Hall, 2002, Ch. 3, pp. 67-74.
[3] Haykin, S., “Communication Systems”, 4th Edition, Willey, Inc., Newyork, 2001.
[4] Steele, R., Lee, C.C., Gould, P., “GSM, cdma One and 3G Systems”, John Wiley & Sons Ltd, Baffins Lane, Chichester, 2001.
[5] Dr. Wajih A. Abu-Al-Saud, “Improving Coverage and Capacity in Cellular Systems”, Lecture 10, EE 499: Wireless & Mobile Communications(082).Available:http://faculty.kfupm.edu.sa/EE/wajih/files/EE%20499,%20Lecture%2010.pdf
[6] Garg, V. K., and J. E. Wilkes, “Wireless and Personal Communications Systems”, Prentice Hall, 1996, ISBN 0-13-234626-5.
[7] Stutzman, W. L. and G. A. Thiele, “Antenna Theory and Design”, Wiley, 1998, ISBN 0-471-02590-9.
[8] A.R. Mishra, “Fundamentals of Cellular Network Planning & Optimisation”, John Wiley & Sons, 2004, Ch. 2, pp. 29-33.
[9] J. Lempiäinen-M. Manninen, "Radio Interface System Planning for GSM/GPRS/UMTS", Kluwer Academic Publishers, 2002.
[10] Ali Hakan IŞIK, İnan Gular, “Novel Approach for Optimization of Cell Planning and Capacity”, International Journal Of Communications, Issue 1, Volume 3, 2009.
[11] Dr. S. A. Mawjoud, “Evaluation of Power Budget and Cell Coverage Range in Cellular GSM System”, Al-Rafidain Engineering, Vol.16 No.1 2008.
[12] B. H. Walke, Mobile Radio Networks, John Wiley and Sons, 2002, pp. 44-46.
[13] K. Pahlavan and A. H. Levesque, Wireless Information Networks, John Wiley and Sons, 1995, pp.74-82.

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