Capacity Dimensioning of HSDPA Urban Network

Awais Saeed[1], Adnan A. Khan[2], Syed Ismail Shah[3], Shariq Yasin[4]

[1]Department of Electrical and Computer Engineering, Centre For Advance Studies in Engineering (CASE) Islamabad, Pakistan
[2] Department of Electrical Engineering, Military College of Signals, National University of Sciences and Technology, Pakistan
[3] Chairman, Pakistan Telecommunication Authority, Pakistan
[4] Senior Consultant, Central Asian Forum, Pakistan
[1]chawaissaeed@yahoo.com, [2]adnankhan@mcs.edu.pk, [3] ismail@ieee.org, [4]shariq@3gca.org

Abstract**:** Capacity dimensioning is performed before launching a cellular network, which includes coverage estimation and forecast of throughput. Cellular companies in developing countries like Pakistan are only providing 2G services, while 3G services are still in process of being launched. Although a lot of research has been done on 3G services in developed countries but there is very little knowledge regarding practical aspects of planning and optimization of 3G networks in third world countries like Pakistan. This research paper includes a thorough analysis of factors that affect capacity of 3G networks, including radio propagation models. Various propagation models are studied and propagation constants of Standard Propagation Model are tuned according to topography of Islamabad. The performance analysis of these propagation models is done using Matlab and results are verified through planning tool Atoll and field measurements. Based on analysis of these results capacity dimensioning, in terms of number of sites, is carried out for an urban network of Islamabad.

Keywords**:** 3G mobile communication, Pathloss, Linkbudget, Standard Propagation Model, Coverage Prediction, Drive test**.**

1. Introduction

In recent years the world has witnessed tremendous growth in mobile communications. This was possible due to development of successive generations of the mobile phone industry. 2nd Generation (2G) systems focused on provide voice services where as the data services still remained a big challenge. Due to low data rates 2.5 Generation (2.5G) systems were developed and Enhanced Datarate for GSM Evolution (EDGE) was evolved [1]. Due to growing demands of high speed data rate 2.5G systems were not enough to cope up the requirements of high speed internet. As the number of mobile subscribers grew tremendously and different applications (video, internet services) were developed, it was realized that the future mobile systems should provide high capacity, optimized coverage and efficient resource utilization. People also wanted high volume of data to be continuously available on their mobile phones. Thus 3G systems were launched in order to increase the capacity of existing 2G systems. For the standard customer video streaming, TV broadcasts, video calls, video clips and new music services became a reality. Similarly for a businessman high speed tele working, video conferencing and real time financial information are the added advantages of a 3G system [2, 3, 4].

In the International Telecommunications Union (ITU), third generation networks are called International Mobile Telecommunications2000 (IMT-2000), and in Europe these are known as Universal Mobile Telecommunications System (UMTS). WCDMA has emerged as the mainstream air interface solution for the third-generation networks. The frequency bands for UMTS standards are 1885–2025 MHz for uplink and 2110–2200 MHz for downlink. There are various releases for UMTS networks. In release 5 and 6 of UMTS, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) significantly increased the data rates up to 14 Mbps [5].

Capacity dimensioning is a key aspect of any system. The dimensioning of 3G networks is quite a challenging task. Benchmarking the results of theoretical and field measurements is an important aspect in this regard. Before launching a network, forecast of end user throughput and number of Node B sites is done in the planning phase. There are many factors that affect the capacity of 3G system. e.g. cell breathing, location of the user, application of data, adaptive modulation schemes, interference and appropriate radio propagation models [6,7,8,9]. These factors should be taken into consideration while dimensioning a network. If these factors are not taken into account appropriately a difference can be observed between the predicted and field values of coverage and throughput [10].

The most important factor that can affect the capacity of 3G system is radio propagation model. If an appropriate propagation model with tuned propagation constants, is not used then quality of service of an end user can degrade once the network is operational. This problem area is studied in this paper and suggestions are given to address this issue.

The main objective of this paper is to design a network, in terms of number of Node B sites, which can accurately fulfill the data requirements for a HSPDA dense urban network of Islamabad using appropriate propagation model. Another objective of this work is to do performance analysis of various propagation models using Matlab and performance verification using planning tool Atoll and field measurements. Based on analysis of these results, capacity dimensioning is carried out of an urban network of Islamabad.

This paper is organized as follows. Section 2 presents analysis of capacity of WCDMA systems and factors affecting it. Section 3 explains the importance and details of various propagation models used in wireless communication systems. In section 4 performance analysis of various propagation models is done. Pathloss and capacity, in terms of users, is calculated for these propagation models. Section 5 deals with performance verification of results using planning tool Atoll. In section 6 these results are verified by field measurements. Here number of sites are also proposed for a HSDPA network of Islamabad. Section 7, concludes this paper and describes the directions to extend this work in future.

2. Capacity of WCDMA Systems

Capacity is very important aspect of 3G networks. It can be defined as number of users that can be supported by a particular sector of a Node B. In terms of network dimensioning capacity means the number of sites that are required to be launched in any network in order to meet a certain threshold of QoS e.g. throughput, cell coverage etc. In order to commercially launch a 3G network, an estimation of end user throughput is done in the planning phase of network dimensioning. There are many key factors due to which the design and optimization of WCDMA system is different from traditional GSM 2G systems [11]. These factors are defined below. The theoretical calculation of capacity of WCDMA system, in terms on number of users is also shown. The important mathematical notations used throughout in this paper are shown below for a quick reference.

Table 1. Description of important mathematical notations

Notation	Description
E_b / N_0	Bit energy to noise power density level
W / R , PG	Processing gain
α	Voice activity factor
f	Operating frequency MHz
d	Distance between transmitter and receiver
h_B , H_{tx}	Height of base station
h_M , H_{rx}	Height of mobile station
$PLfs$	Free space pathloss
V	Diffraction loss parameter
$K4$	Multiplying factor of diffraction loss
$K(clutter)$	Correction coefficient of clutter attenuation
$EIRP$	Effective isotropic radiated power
$L(db)$	Outdoor pathloss

2.1 Location of subscriber and adaptive modulation

In 3G system the location of any user plays a vital role in determining the end user throughput. Users enjoy accessing the internet independent of their physical location by making use of new applications [8]. In HSDPA the modulation schemes are changed on a per-user basis, depending on signal quality and cell usage. The initial scheme is QPSK, but in good radio conditions 16QAM and 64QAM can significantly increase data throughput rates. As most of the users are indoor users and radio conditions vary significantly due to multi path fading components; the end user throughput is adversely affected if the signal strength Received Signal Code Power (RSCP) is not satisfactory. Thus location of user and modulation scheme plays a pivotal role in dimensioning of a HSDPA system. As shown in [6] the coverage radius for an outdoor user is 200 meters more than that of an indoor user.

2.2 Application of Data

In order to plan and run networks efficiently, the need of the hour is to understand the data traffic statistics of various users [8]. Majority of the users in a WCDMA system are data centric as compared to voice centric. The type of application varies from user to user. As shown in [6] different users use different data services like video telephony, streaming, ftp, http, e mail, mms etc. Each of these applications require different data rate. Generally reading an email requires low data rate as compared to downloading a movie. So the end user throughput will vary in case of different scenarios of data applications. Similarly the numbers of users also play a significant role in determining the throughput of a cell.

2.3 Cell Breathing

Cell breathing is the constant change in the range of a geographical area covered by a cellular transmitter based on the amount of traffic being currently used by that transmitter. With the increase of activated terminals and high speed services, interference is increased. As a result the coverage area of a cell is decreased and blind spots occur [11]. Thus drop of a call occur at the edge of a cell and users at the boundary of the cells are deprived of high speed internet services. If there are users having low data requirements then the coverage area of the cell will increase as compared to the scenario when there are users having high speed data requirements [6].

2.4 Interference

In WCDMA systems; each user contributes to interference in the uplink direction. More number of users will result in high interference and as a result the throughput will decrease. Similarly if the output power of the system is higher, the network interference will be increased which directly affects the end user experience. As shown in [9], high number of users results in high Block Error Rate (BLER) and as a result of this end user throughput is degraded.

2.5 Admission Control

The admission control implements the admission or rejection of the requested service according to the availability of resource. Based on the radio measurements the admission control will sustain the system stability first and then try the best to satisfy the new calling service’s request. Admission control is the only access entry for the incoming services and it’s strategy will directly affect the cell capacity and stability, e.g. call loss rate, call drop rate. As a result of this feature a user having weak signal strength will not be allowed to access to the network. In two different scenarios, one voice centric and other data centric; it can been seen that number of rejected users are more in case of the later scenario as compared to the earlier one [6].

2.6 Radio Propagation Model

The most important factor that affects the capacity is an appropriate propagation model. These models calculate the pathloss at a particular distance between transmitter and receiver.

2.7 Capacity of WCDMA system in terms of number of users

The capacity of a WCDMA system in terms of number of users is shown below. The bit energy to noise power density level is given by E_b / N_0. The numerator is obtained by dividing the chip rate W with the information bit rate, R. The denominator is simply SNR.

E_b / N_0 is given by:

$$E_b / N_0 = \frac{W / R}{(N - 1) + \eta / S} \quad (1)$$

Where W / R is the processing gain, η is the back ground thermal noise, *S* is the received power of user and *N* is the number of users. The processing gain determines coverage radius of a cell. The above equation can also be written in terms of capacity and the number of users as following:

$$N = 1 + \frac{W / R}{E_b / N_0} - \frac{\eta}{S} \quad (2)$$

This means that in the total bandwidth *W*, the number of users is reduced by the inverse of per user SNR. The capacity can be increased by decreasing the interference due to other users and by introducing voice activity factor α . The voice activity factor means that if a user is not speaking during conversation the output of the coder is decreased and unnecessary transmissions can be reduced. Similarly the interference due to other users is decreased by using antenna sectorization approach. By making use of these two techniques the capacity of the system is enhanced.

E_b / N_0 becomes:

$$E_b / N_0 = \frac{W / R}{(N_s - 1)\alpha + \eta / S} \quad (3)$$

Here N_s shows the number of users for each sector and the interference is via one antenna. The received power of first user at the Node B is as follows:

$$S = S_1 - L_p - U \quad (4)$$

Where S_1 is the power of user 1; L_p is the path loss at a distance d between mobile and Node B, and U is the shadow fading margin. From the above mentioned equations the number of users at a particular distance can be found [12,13].

3. Radio Propagation Models

Propagation models focus on predicting the received signal strength at a given distance from the transmitted power. These propagation models forecast the coverage area of a cell. In addition to this, they provide a great help to mobile network planning engineers as they provide the cell coverage area while minimizing the interference. More over many localized parameters of a particular area like antenna heights, terrain profiles, clutter maps, clutter type etc are also incorporated in propagation model [14]. In order to accurately dimension a network; choosing an appropriate propagation model is very important. The propagation model calculates path loss of a particular signal. Path loss is reduction in power of a signal as it travels via space. This information is very important in order to determine the coverage, placement and optimization of a Node B [15]. Without propagation predictions the parameters like coverage estimation can only be obtained by extensive field measurements which is time consuming and expensive.

Various type of propagation models include empirical, theoretical and site specific models. Empirical models are derived from extensive field measurements. The input parameters for these models are quantitative like dense urban, urban etc and operating frequency as well. These models can be used for specific environments. For example empirical model for macro cell cannot be used for indoor propagation modelling. These models are easy and efficient to use.

Theoretical models are derived assuming ideal conditions. For example the over roof top model is derived using physical parameters assuming uniform heights and spacing of the buildings. Site specific models are based on numerical methods e.g. ray tracing model. The disadvantage of these models is the computational complexity. Different empirical propagation models are described below:

3.1 Free Space path loss model

This model measures the attenuation when a signal is transmitted. Free Space Path Loss (FSPL) model assumes an ideal condition that there is one clear line of site (LOS) between a sender and transmitter. H.T. Friis calculated the equation for this model [16].

$$PLfs = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \quad (5)$$

d is in kms, f is in MHz

3.2 Okumura Model

Okumura model was developed for the city of Tokyo, Japan. This is ideal for cities with many urban structures but not very tall buildings. The model can be used for the operating frequency up to 1920 MHz. Okumura did extensive drive test measurements with different clutter types, frequency range, transmitter and receiver height and power of the transmitter. The signal strength decreases as the distance is increased from Node B. The pathloss is given by following equation

$$P_L = PLfs + Amn(f, d) - G(hb) - G(hm) - Garea \quad (6)$$

Where *PLfs* is free space path loss given by equation 5, *Amn(f,d)* is the median attenuation relative to free space, *Garea* is the gain due to the type of environment. *G(hb)* and *G(hm)* are the antenna height gain factor for Node B and Mobile Station respectively [16].

$$G(hb) = 20\log_{10}(hb/200) \quad for 10m < hb < Km$$
$$G(hm) = 20\log_{10}(hm/3) \quad for hb < 3Km \qquad (7)$$
$$G(hm) = 10\log_{10}(hm/3) \quad for 10m < hb < 1000m$$

Here the equation of FSPL is used with addition and subtraction of some correction factors. It can be said that this model is also based on ideal conditions and is not used for practical solutions.

3.3 Okumura-Hata Model

The Hata model is used to predict the radio propagation in built areas. It incorporates the information of the Okumura model and develops it further to include the effects of scattering, reflection, diffraction caused by the buildings of city. The Hata Model for Urban Areas is formulated as following [17]:

$$L_u = 69.55 + 26.\log_{10} f - 13.82\log_{10} h_B - C_H + [44.9 - 6.55\log_{10} h_B]\log_{10} d \qquad (8)$$

For small or medium sized city C_H is,

$$C_H = 0.8 + (1.1\log_{10} f - 0.7)h_M - 1.56\log_{10} f \qquad (9)$$

and for large cities,

$$C_H = \begin{cases} 8.29(\log_{10}(1.54h_M))^2 - 1.1, if 150 \le f \le 200 \\ 3.2(\log_{10}(11.75h_M))^2 - 4.97, if 200 < f \le 1500 \end{cases} \qquad (10)$$

Where

L_u = Path loss in Urban Areas. Unit: decibel (dB)

h_B = Height of Node B Antenna. Unit: meter (m)

h_M = Height of mobile station Antenna. Unit: meter (m)

f = Frequency of Transmission. Unit: Megahertz (MHz).

C_H = Antenna height correction factor

d = Distance between the base and mobile stations. Unit: kilometer (km).

3.4 Cost-Hata Model

One of the most famous classical propagation models for 2GHz band is Cost 231 Hata model. Cost 231 is improved version of Hata model. It is used for frequency range up to 2000 MHz. It is available for urban, sub urban and rural areas [14]. The path loss is as under:

$$PL = A + B\log_{10}(d) + C \qquad (11)$$

Where

$$A = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m)$$
$$B = 44.9 - 6.55\log_{10}(h_b)$$

C=0 dB for medium sized city and suburban area with moderate tree city or C =3 dB for metropolitan centers. The effective transmitting antenna height in meters is ranging from 30 m to 200 m and the effective mobile (receiver) antenna height is ranging from 1 m to 10 m, d is the separation distance in km. The mobile antenna correction factor is given by

$$a(h_m) = 3.2[\log_{10}(11.75h_m)]^2 - 4.9 \qquad (12)$$

This path loss model does not give good results for surrounding structures and topology.

3.5 Stanford University Interim Model (SUI) model

For the frequency below 11GHz; IEEE 802.16 Broadband Wireless Access working group calculated the standards containing the channel model developed by Stanford University, namely the SUI models [15,18]. The main equation is shown below

$$PL = A + 10\gamma\log_{10}(d/d_o) + Xf + Xh + S \quad for d > d_o \qquad (13)$$

Statistical procedure is used to calculate the variables path loss exponent γ and the weak fading standard deviation S is defined. The value of S is between 8.2 and 10.6 dB. Various parameters are defined as below:

$$A = 20\log_{10}(4pido/\lambda) \qquad (14)$$

The path loss exponent is defined by the following equation

$$\gamma = a - b * hb + (c/hb) \qquad (15)$$

d_o is reference distant which is 100m, γ > 5 for indoor propagation, hb is the height of Node B in meters ranging from 10 to 80 meters. The constants a,b,c are the related to topology of terrain. Propagation constants for different terrains are defined in table 2.

Table 2. Propagation constants for SUI model

Model	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b(1/m)	0.0075	0.0065	0.005
C(m)	12.6	17.1	20

Xf is frequency correction factor and Xh is the correction for receiver antenna height. These are mentioned below:

$$Xf = 6\log_{10}(f/2000)$$
$$Xh = -10.8\log_{10}(hr/2000) \quad \text{for terrain type A and B}$$
$$Xh = -20\log_{10}(hr/2000) \quad \text{for terrain type C} \qquad (16)$$

3.6 COST 231 Walfish-Ikegami (W-I) Model

This model is a combination of J. Walfish and F. Ikegami model. COST 231 project further developed this model. Now it is known as COST 231 Walfish-Ikegami (W-I) model. This model is suitable for flat areas [16]. For LOS conditions the equation is given as

$$PL1os = 42.6 + 26\log_{10}(d) + 20\log_{10}(f) \quad (17)$$

For NLOS [19] the pathloss is given as below

$$PLNLos = PLfs + Lrts + Lmsd \quad (18)$$

Where $PLfs$ is given be equation 5, and $Lrts$ is diffraction from roof top to street and is given by:

$$Lrts = -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log\log_{10}(h_{roof} - h_{mobile}) + L_{ori} \quad (19)$$

Here w is the width of street and h_{roof} and h_{mobile} are heights of building and mobile respectively. L_{ori} is a function of the angle of the antenna relative to street and is given as follows:

$$L_{ori} = -10 + 0.354\varphi for 0 < \varphi < 35^o \quad (20)$$

$Lmsd$ gives diffraction loss as a result of multiple obstacles.

$$Lmsd = Lbsh + k_a + k_d \log(d) + k_f \log(f) - 9\log(b) \quad (21)$$

Where for $h_{base} > h_{roof}$

$$Lbsh = -18\log(1 + h_{base} - h_{roof}) \quad (22)$$

Where k_a =54, k_d =18, b is inter building distance which is taken to be 50m. For metropolitan cities K_f is defined as:

$$K_f = -4 + 1.5(f/925 - 1)$$

The following assumptions are made for this propagation model:

h_{base} =30m, h_{roof} =15m, φ =30, h_{mobile} =1.5m

3.7 Ericsson Model

One propagation model is also proposed by network planning engineers of Ericsson. This is modified version of Okumura Hata model and has some more parameters that can be tuned. The path loss equation is as follows [16,18].

$$PL = a_0 + a_1\log_{10}(d) + a_2\log_{10}(hb) + a_3\log_{10}(hb)\log_{10}(d) - 3.2(\log_{10}(11.75hr)^2) + g(f) \quad (23)$$
$$G(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2$$

Table 3. Propagation constants for Ericsson model

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12	0.1

3.8 Standard Propagation Model (SPM)

In 3G network planning, the standard propagation model (SPM) is used to define the local environment in a precise way. SPM is derived from well known Cost 231 Hata model. The Cost 231 model is limited to Node B's antenna height greater than 30 m. It cannot be used for very short distances where the height of the neighbouring obstacles is higher than the height of Node B. SPM provides solution to this problem by including two main parameters the clutter loss and diffraction loss [10,20]. The diffraction loss can be calculated depending upon the height and distance of obstacles between transmitter and receiver. If the height of obstacle is below LOS, then the diffraction loss will be less as compared to a scenario where the height of obstacle is above LOS [12]. Similarly the clutter loss also depends on the topography of any city. Higher value of clutter loss is taken for a city with very high building structures and vice versa. The pathloss of SPM is given by the following equation:

$$L-model = K_1 + K_2\log(d) + K_3\log(H_{tx}) + K_4 \cdot DiffractionLoss + K_5\log(d)\cdot\log(T_x) + K_6(H_{rx}) + K(clutter)f(clutter) \quad (24)$$

Where

K_1: constant offset (dB),

K_2 : multiplying factor for log (d).

d: distance between the receiver and the transmitter (m).

K_3 : multiplying factor for log (H_{tx}).

H_{tx} : effective height of the transmitter antenna (m).

K_4 : multiplying factor for diffraction loss.

$DiffractionLoss$: loss due to diffraction over an obstructed path (dB) and is calculated using Fresnel Diffraction Parameter V [12] as follows:

$$V = h\sqrt{[2(d1 + d2)/\lambda(d1 + d2)]} \quad (25)$$

Where $d1$ is the distance of transmitter to the obstacle and $d2$ is the distance of receiver to the obstacle. λ is the wavelength and h is defined as the difference between height of obstacle and height of the receiver.

K_5 : multiplying factor for log (H_{tx}) log (d)

K_6 : multiplying factor for H_{rx} .

H_{rx} : effective mobile antenna height (m).

$K(clutter)$: Correction coefficient of clutter attenuation

$f(clutter)$: weighted average of losses due to clutter.

The values of these propagation constants are tuned as per the topography of Islamabad and are shown in table 4.

Table 4. Tuned values of propagation constants of SPM

Area Profile	K 1	K 2	K 3	K 4	K 5	K 6	K clutter
Urban	16.4	44.6	5.83	0.5	-6.55	0	1

The detailed procedure adopted for tuning of these constants is described in section 5.4

4. Performance analysis of various propagation models

Performance analysis of various propagation models is done using a single link WCDMA transmitter and receiver system in Matlab. Capacity calculation in terms of number of users is also done for each propagation model. The block diagram of WCDMA system is shown in Figure 1

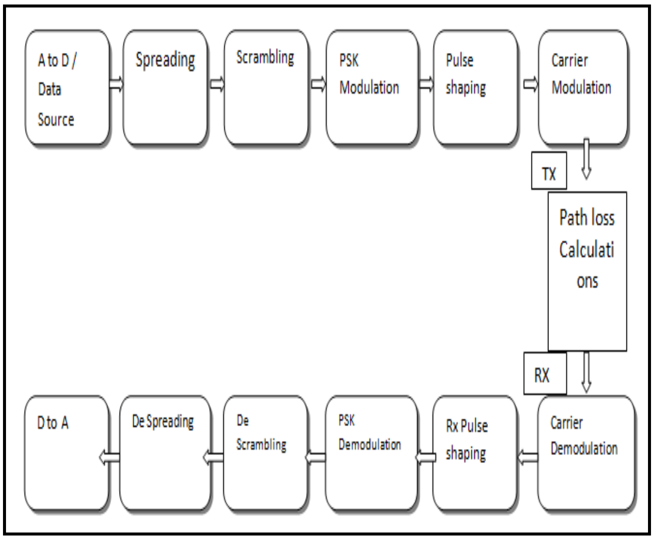

Figure 1. Simulated single link WCDMA system

A standard procedure for achieving A/D conversion is to use the American Standard Code for Information Interchange (AASCII) representation of characters [21]. The AASCII code uses 8 bit representation for each character and thus provides binary representation of up to 256 characters. Each character is mapped to a decimal value in the range of 0 to 255.

In UMTS, spreading is done using Walsh codes which have the property of being perfectly orthogonal. These codes are generated using Hadamard matrix. These belong to family of OVSF (Orthogonal Variable Spreading Factor codes). The modulated data bits and the code bits are commonly referred to as chips. These are organized in the form of a code tree [22].

After channelization; the scrambling codes are used to distinguish different users of a single cell in the uplink and different cells in the downlink direction. They are generated via combination of two m sequences called Gold codes [2] which are not orthogonal. Gold codes have low level of both auto and cross co relation. This characteristic makes them good for separating transmissions. There is 218-1 downlink scrambling codes used to distinguish different cells.

After channelization [23] and scrambling, the transmitted signal is modulated using 8-PSK modulation scheme. As per the specifications of WCDMA, root raised cosine filter with roll off $\alpha = 0.22$ is used for pulse shaping in the frequency domain. The baseband signal is converted to physical signal which can be transmitted through the antenna for a specific carrier frequency. Here the carrier frequency is 2110 MHz which is the downlink frequency of UMTS. In this paper, pathloss is calculated for various propagation models using this carrier frequency. Pathloss results of various propagation models explained in section 3 are shown below:

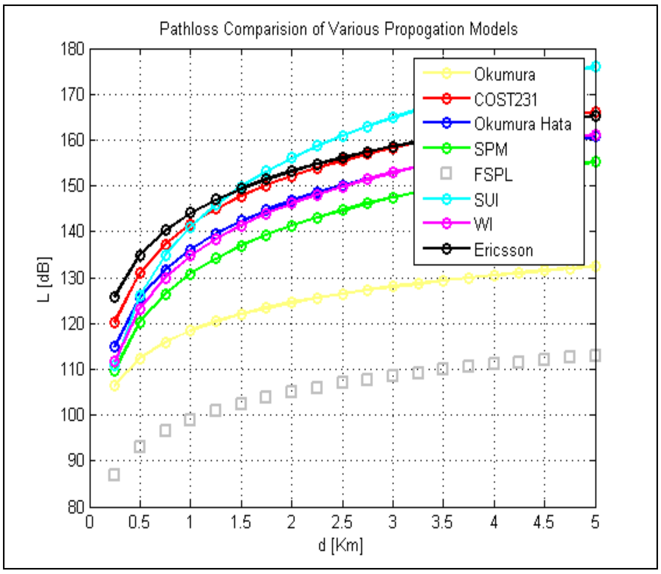

Figure 2. Path loss of various propagation models

As seen above, FSPL gives the lowest value of path loss among all models. This is due to the fact that FSPL assumes ideal conditions with no affect of reflection or diffraction. Similarly Okumura model also gives low value of FSPL as the basic equation of FSPL is used and some correction factors are added. Other than these two ideal models, SPM gives the lowest value of path loss among all other propagation models. Thus SPM is the best suited model among all propagation models for WCDMA network operating in 2100 MHz band.

Using Equation 3, capacity is calculated for each propagation model in terms of number of users. The calculations are done both for voice and data services. The service activity factor for voice is taken as 0.67 and for data is taken as 1.0 [13].

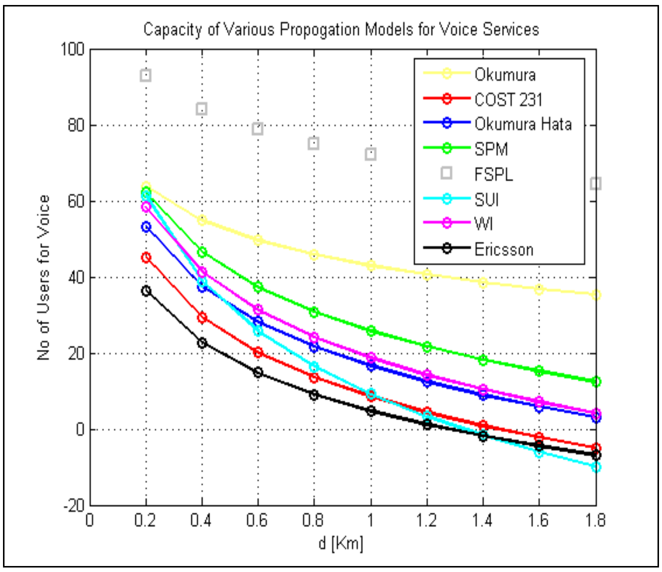

Figure 3. Capacity of various propagation models for voice services

It can be seen from figure 3 that SPM gives most number of users among practically used propagation models. It means that high capacity is obtained by using SPM as compared to other propagation models.

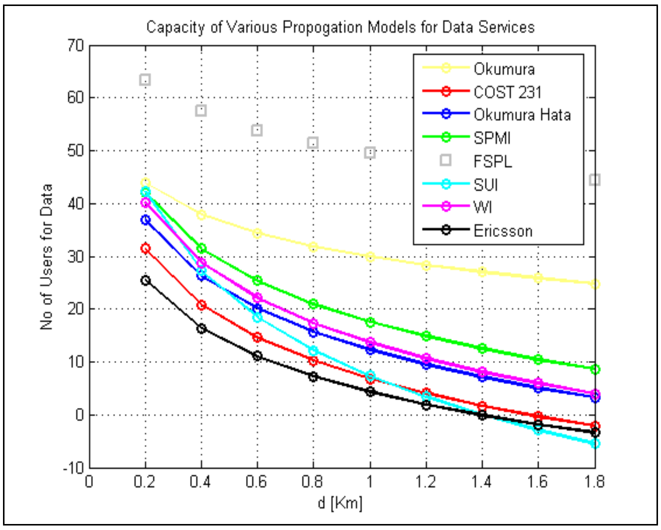

Figure 4. Capacity of various propagation models for data services

It is also observed that the offered numbers of users are more for data services in comparison to voice services. This is due to the fact that the value of voice activity factor is higher for data services as compared to voice services and is inversely proportional to the number of users.

5. Performance verification using Atoll

In this section performance verification of results of Matlab is done using planning tool Atoll.

5.1 Link Budget of WCDMA

Designing a link budget is a fundamental step in network dimensioning of WCDMA system. Link budget is to estimate the coverage capability of a system by reviewing all kind of influence factors in the propagation path of the forward or reverse link. It also means to obtain the maximum propagation loss allowed in the link under certain call qualities. The parameters of link budget are incorporated in Atoll which are also used in tuning of SPM and capacity calculations for WCDMA network. The link budget of HSDPA is shown in Table 5 and the parameters are given below.

The EIRP is given as

$$EIRP = P_t + G_t - Bodyloss - Feederloss \quad (26)$$

Thermal Noise is given as

$$Thermal\ Noise = KTB \quad (27)$$

Where

K= 1.380650x10E-23 Boltzmann's constant

T: absolute temperature(= Celsius temperature+273.15)

B: Receiver bandwidth, the bandwidth for UMTS system is 3.84MHz.

Processing gain is defined as:

$$Processing\ Gain = Chip\ rate/\ Bite\ Rate\ (Wc/Rb) \quad (28)$$

Chip rate is 3.84Mcps for UMTS services. Different services have different processing gain thus their coverage is different. E_b / N_0 is the energy per bit to noise spectrum density. Values of E_b / N_0 are defined in 3GPP specifications. Similarly the receiver sensitivity is given as

$$RxSensitivity = KTB + N_f + E_b / N_0 - PG \quad (29)$$

Various margins (Interference margin, noise figure, feeder loss etc) are used in link budget at the receivers' end. Some of these margins are added where as some of these are subtracted in the commutated equation. The combined value of margin is defined as follows:

$$\begin{aligned} Margin &= AntennaGain + SoftHOGain - \\ &(InterferenceMargin + Feederloss + Bodyloss \\ &+ PCheadroom + Shadowmargin) \end{aligned} \quad (30)$$

The outdoor pathloss is given as

$$L(db) = EIRP - RxSensitivity + Margin \quad (31)$$

The indoor pathloss is given as

$$\begin{aligned} Lindoor(db) &= EIRP - RxSensitivity + Margin \\ &- PenetrationLoss \end{aligned} \quad (32)$$

Table 5. Link Budget (Downlink) for HSDPA network using data rate 600kbps

Category	Parameter	Value
Transmitter's end	TX Power	37
Transmitter's end	Antenna Gain	18
Transmitter's end	Body Loss	0
Transmitter's end	Feeder Loss	2.8
Transmitter's end	EIRP	52.2
Receiver's end	Thermal Noise	-107.99
Receiver's end	PG	8.016
Receiver's end	Eb/No	6.19
Receiver's end	Noise Figure	7
Receiver's end	Interference margin	6
Receiver's end	Antenna gain	0
Receiver's end	Feeder Loss	0
Receiver's end	Body Loss	0
Margins	PC Headroom	2
Margins	Soft HO Gain	3
Margins	Shadow Fading margin	8.7
Calculations	Path Loss (Outdoor)	140.36
Calculations	Penetration Loss	20
Calculations	Indoor Path Loss	120.36
Calculations	Cost Hata- Coverage Area (km)	0.2517
Calculations	Okumura Hata- Coverage Area (km)	0.3586
Calculations	SPM-Coverage Area (km)	0.502

By equating the path loss obtained from link budget and pathloss of each propagation model; the coverage radius of each propagation model can be calculated. Using three sector approach; the coverage area, in square km, of a particular sector can be calculated by the below mentioned equation:

$$S = 9/8\sqrt{3}R^2 = 1.95 \times R^2 \quad (33)$$

The total number of proposed sites can be calculated by dividing the total area that is desired to be covered, with the coverage area of one sector *S* [13]. The detailed link budget [7] of downlink for HSPDA network can be seen in table 5. This link budget is calculated for an average data rate of 600kbps. It means that this data rate will be provided once the user is at the boundary of any cell. This also called the cell edge throughput. In case of downlink the transmitter is node B and the receiver is the mobile station.

5.2 Importance of radio network planning tool

Radio network planning tools are very important in design and optimization of any network. These tools are used before launching a network. The results of these tools can be used for optimization purposes as well. These planning tools use path loss prediction models, physical parameters of the equipment at the Node B and localized information of a particular area. As a result the probability of serving of a certain Node B at a particular point can be determined. In this paper Atoll has been used to run prediction based on SPM model. Atoll is multi technology wireless network design and optimization software. It gives support to wireless operators throughout the network lifecycle from network design to densification and optimization. It has a user friendly Graphical User Interface (GUI). It is a licensed tool that can only be used if it is commercially purchased [10].

5.3 Calibration of Atoll Package

To setup Atoll; clutter classes, digital models, roads, heights are given as an input. The integration and setup of Atoll is a big challenge. The integration begins with defining of geographical area. As described in [24] various parameters like clutter, heights, vector data are incorporated in the planning tool. Table 6 shows the simulation settings for Pakistan.

Table 6. Important Parameters of Atoll

Parameter Name	Value of Parameter
Ellipsoid	WGS-84
UTM Zone	42N
Other Parameters	Clutters, Heights and Vectors of Pakistan

Clutters can be defined as classification of areas e.g. dense urban, rural, forests, open etc. The values of clutter losses are given below.

Table 7. Indoor and clutter penetration losses

Clutter Class	Clutter Loss (dB)	Indoor Loss (dB)
Open	-4	0
Inland water	-13	0
Forests	-2	0
Parks	-6	0
Village	-8	0
Industrial	-1	0
Agriculture	-10	0
Airport	-2	0
Roads	-2	0
Rural	-10	0
Urban	2	20
Dense urban	3	20
Buildings	4	20
Residential	2	20

As seen above the highest clutter loss is given to the clutter classes of high buildings and dense urban area. Similarly extra indoor propagation loss of 20 dB is also given to those clutter classes where most of the users are inside the buildings e.g. residential and dense urban etc.

5.4 Tuning of the propagation constants of SPM according to the topography of different cities

As described in section 3.8, two parameters; Kclutter and Diffraction loss play critical role in SPM. These two parameters are tuned as per the topographic area of Islamabad. A higher value of Kclutter is taken for cities having high rise buildings. As most areas of Islamabad are plain and there are not many high rise buildings; the value of Kclutter is taken to be 1. In Islamabad the average height of Node B is 30 meters which is higher than the average height of buildings (10 meters). In this case the height of obstacle will be lower than LOS. The diffraction loss will be very little in such scenario [12]. Thus the value of K4 is tuned to 0.5. The value of diffraction loss will be quite high for a city having high rise buildings like Karachi. Similarly the value of clutter loss will also be high in such cities. The value of clutter loss varies from 1 in cities with no buildings to 3 in cities with many high rise buildings. Similarly “Hilly Terrain Correction Factor” is taken into consideration while dimensioning a network for a city with hilly terrain like Muzaffarabad. The values of other propagation constants are independent of any area and remain unchanged in various tuned models [10,25]. The default values of these constants are used in this study.

5.5 Coverage and throughput prediction plots of single site

Coverage and throughput prediction comparison is plotted for a single site using Atoll. Prediction means the forecast of expected signal strength (SS) and throughput at a particular point or area. The clutter effect is also incorporated while taking prediction of coverage and throughput. The analysis is done for three different propagation models; Cost Hata, Okumura and SPM. The coverage is shown with different colours in these coverage plots, e.g. [-60, 0 dBm] coverage range is shown by green colour, [-60,-70 dBm] is shown by light green, [-70,-80 dBm] is shown by yellow, [-80,-90 dBm] is shown by orange and [-90,-110 dBm] is shown by red colour. Green range shows that signal strength is excellent where as red colour shows that signal strength is quite weak. The coverage plots for three propagation models are shown below which are Cost 231, Okumura Hata and SPM:

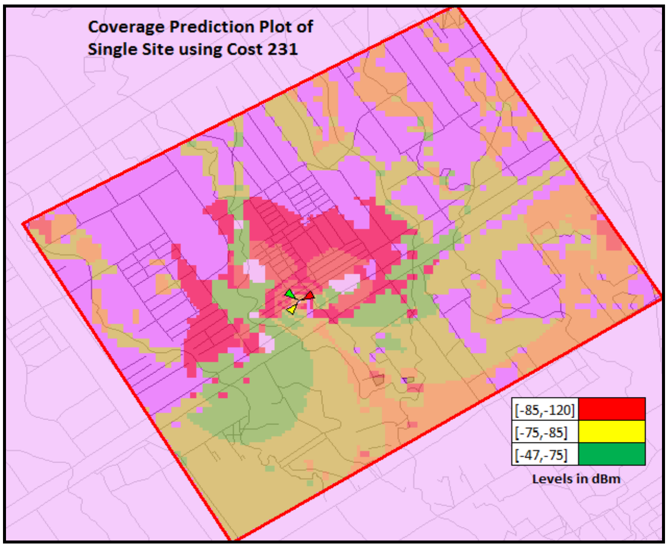

Figure 5. Coverage plot of single site using Cost Hata

Figure 5 shows that by using Cost 231, weak coverage is observed very near to the site. It is also observed that many areas are not fully covered as well. The coverage plots for other propagation models are shown below.

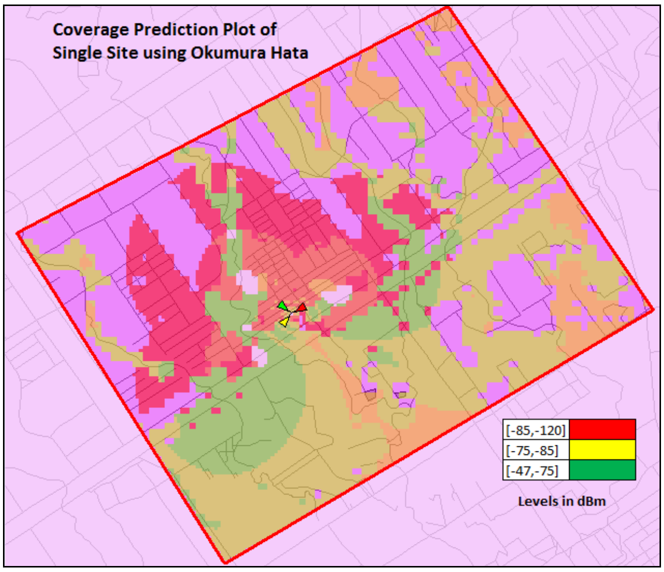

Figure 6. Coverage plot of single site using Okumura Hata

Okumura Hata also shows very weak coverage probability as shown in Figure 6.

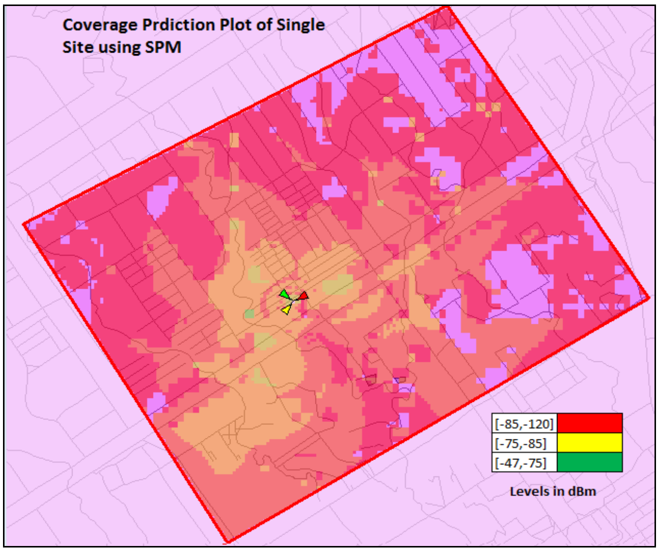

Figure 7. Coverage plot of single site using SPM

Figure 7 shows that the coverage forecast of SPM is far better as compared to other propagation models. SPM shows coverage in almost complete area and gives good coverage in range [-60,-70 dBm] near to the site. In case of other propagation models it is observed that many areas are not covered and weak coverage is also observed very near to the site.

Detailed analysis of coverage is also done for various clutter classes. Two clutter classes are taken into considerations in this study; residential and buildings. In order to compare the results, histograms are plotted for each clutter class that show the distribution of signal level in dBm for each range; e.g. [-60, 0dBm] shows that the received signal strength lies between 0 and -60 dBm. Here x-axis shows the ranges of signal strength and y-axis show the percentage of samples for each range.

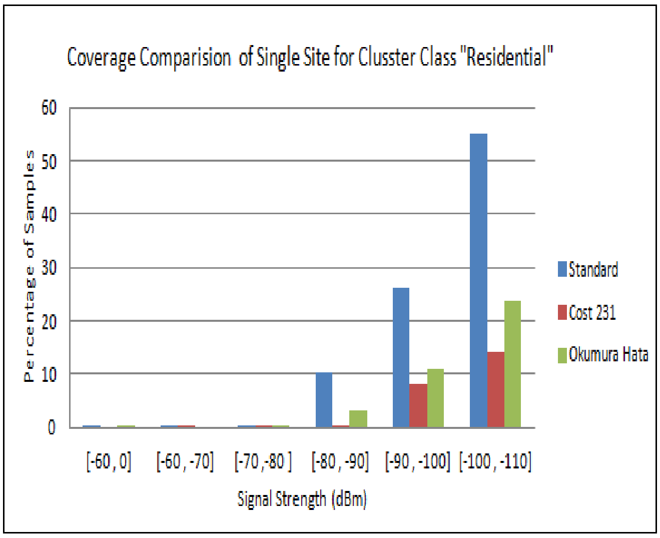

Figure 8. Coverage comparison of single site for clutter class residential

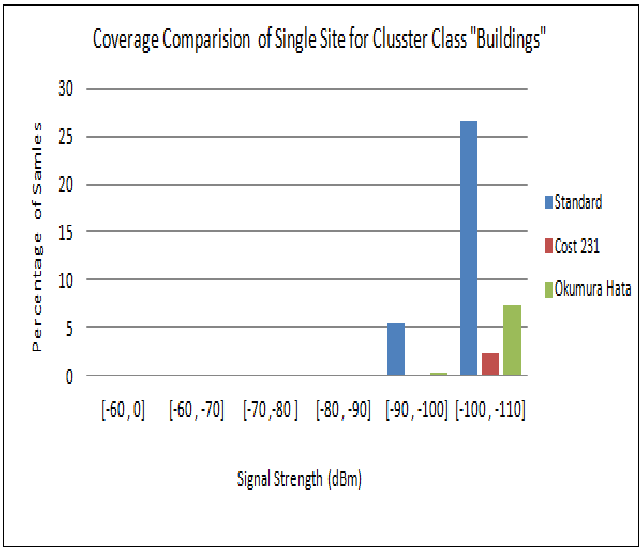

Figure 9. Coverage comparison of single site for clutter class buildings

Figure 8 and 9 show the limitations of Cost 231 and Okumura Hata while predicting the coverage for indoor clutter classes like residential and buildings. SPM gives better coverage forecast for these clutter classes as compared to other two propagation models.

The forecast of throughput is also done in this paper. The throughput is shown with various colors in the below mentioned graphs. Throughput in the range of 9Mbps to 12 Mbps is shown with various shades of green color. Whereas the throughput in the range of 1Mbps to 8Mbps is shown with various shades of blue color.

As depicted in the below mentioned figures 10,11,12; it is observed that as compared to Cost Hata and Okumura Hata, SPM gives better forecast of throughput. This is due to the fact that the coverage forecast of this model is also better as compared to other models.

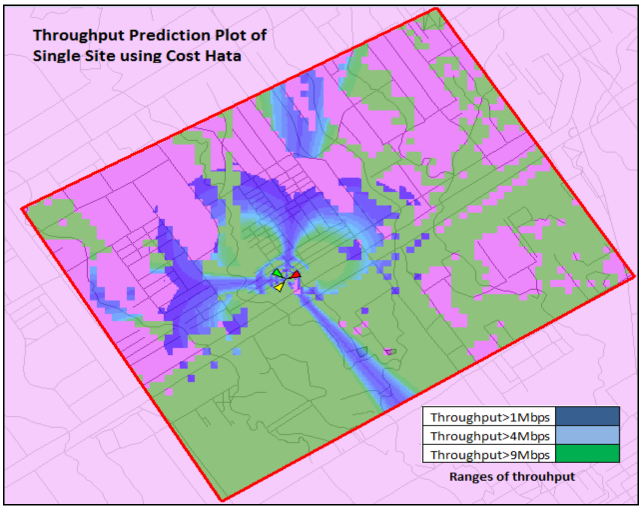

Figure 10. Throughput plot of single site using Cost Hata

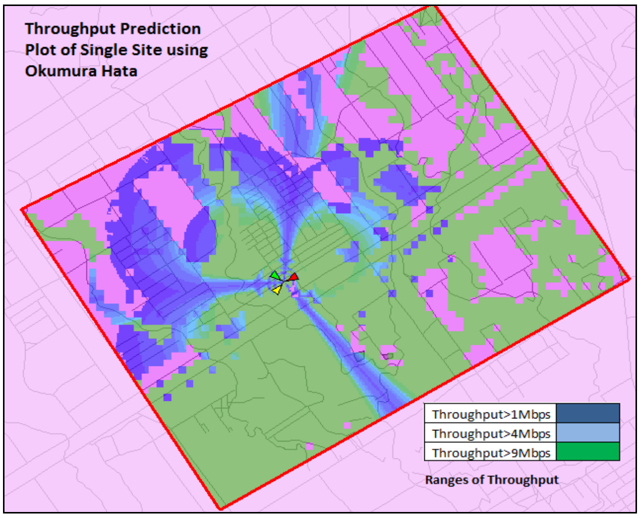

Figure 11. Throughput plot of single site using Okumura Hata

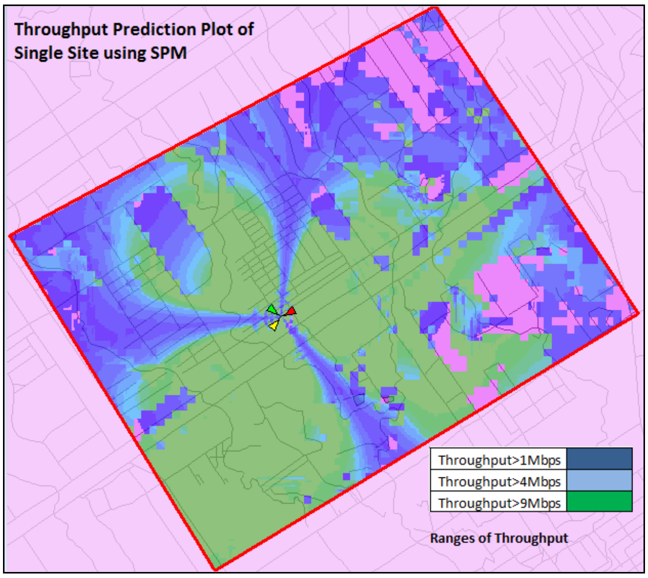

Figure 12. Throughput plot of single site using SPM

5.6 Coverage and throughput prediction plots of multiple site network

The prediction analysis of a single test site is not enough to reach to a final conclusion about performance of any propagation model. As 3G sites are not yet deployed so existing GSM sites are chosen as reference sites for site location [26]. There are 82 existing GSM sites in area of 84.22 square kilometer of Islamabad. Same methodology of plotting these results is adopted which was used for a single site network. It is observed that for both coverage and throughput, performance of SPM is far better than other propagation models. Coverage comparison is done for different clutter classes on same pattern as it was done for a single site. Same ranges are used defined in section 5.5

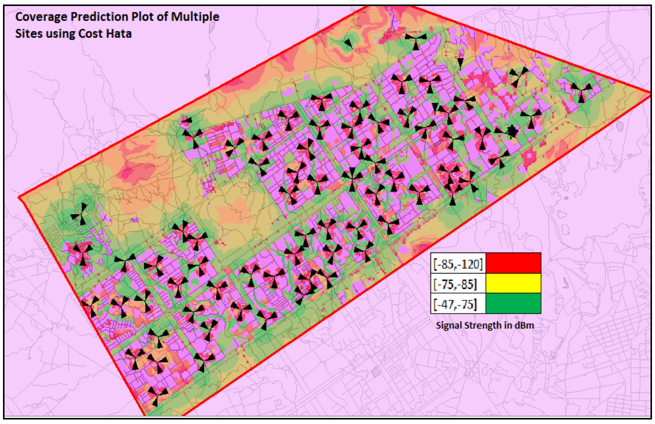

Figure 13. Coverage plot of multiple sites using Cost Hata

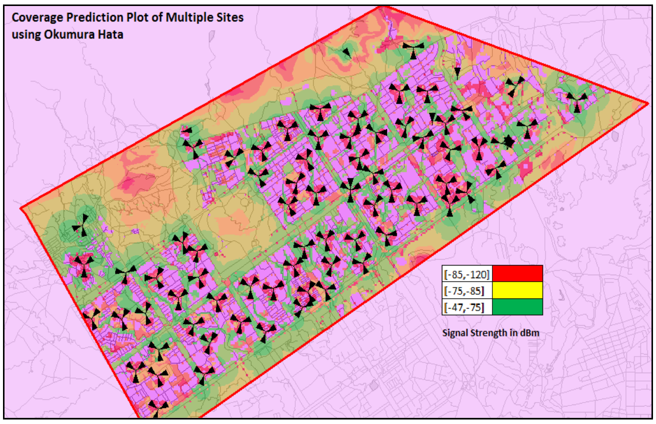

Figure 14. Coverage plot of multiple sites using Okumura Hata

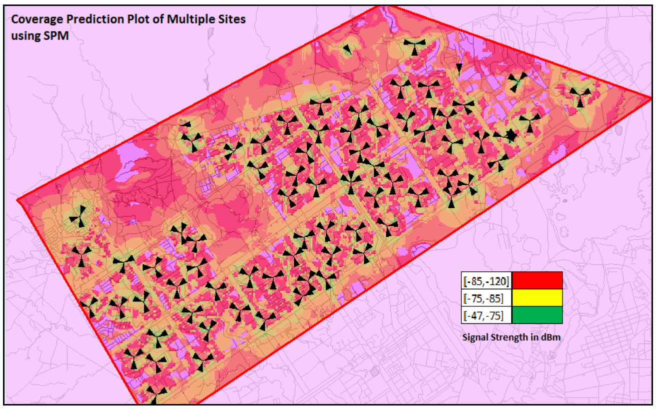

Figure 15. Coverage plot of multiple sites using SPM

As seen in figures 13 and 14 Okumura Hata and Cost 231 propagation models provide very limited coverage in dense urban areas. In comparison to this, SPM gives far better results especially for dense urban areas as shown in figure 15. It is also observed that despite coverage forecast is improved by using SPM, there are still some areas that are not covered. This implies that the existing infrastructure of GSM sites needs to be increased.

Coverage comparison for multiple sites is also done for different clutter classes on same pattern as it was done for a single site. Same clutter classes are taken into considerations here which are residential and buildings. It is observed that SPM has given better results for coverage and throughput for a multiple site network as well. The results are shown below.

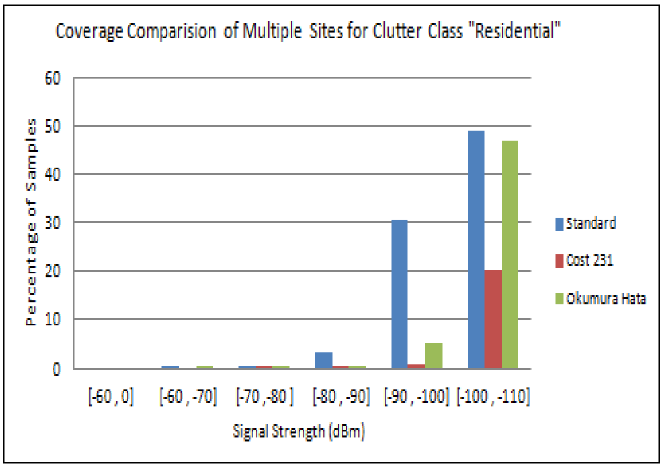

Figure16. Coverage comparison of multiple sites for clutter class residential

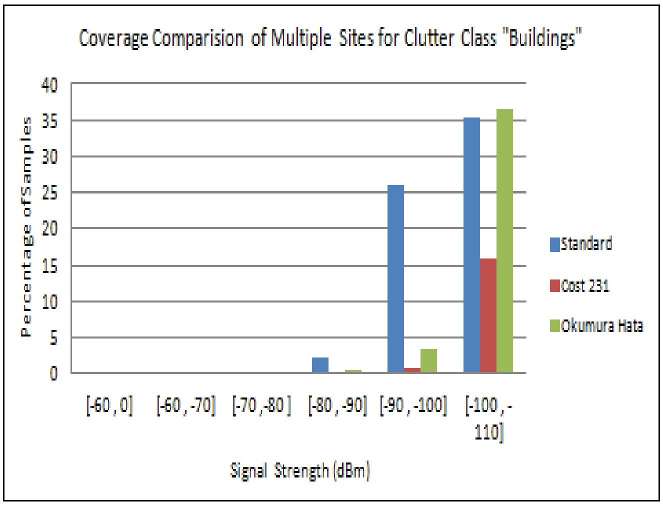

Figure 17. Coverage comparison of multiple sites for clutter class buildings

The prediction plots of throughput for multiple sites network are shown below. It is observed that due to better coverage forecast by SPM, better forecast of throughput is also observed as compared to other propagation models. Thus it can be concluded that SPM gives better results as compared to other propagation models for a multiple sites network.

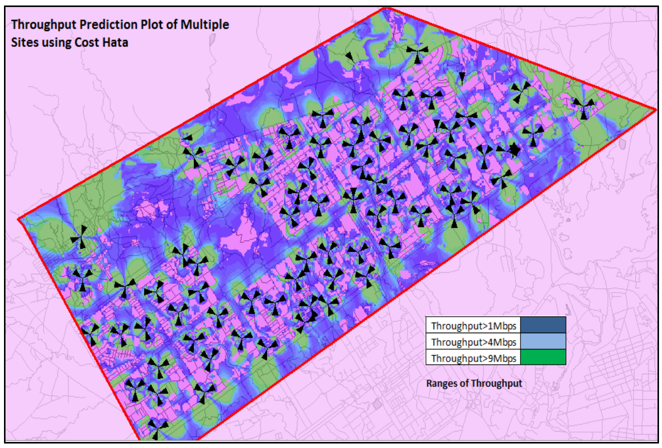

Figure 18. Throughput plot of multiple sites using Cost Hata

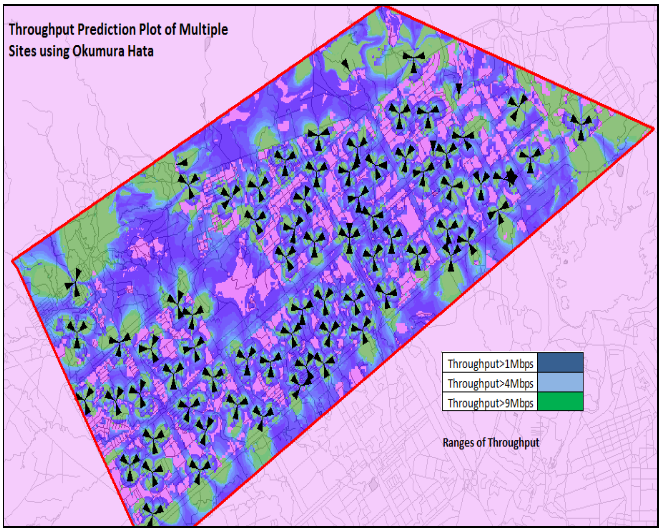

Figure 19. Throughput plot of multiple sites using Okumura Hata

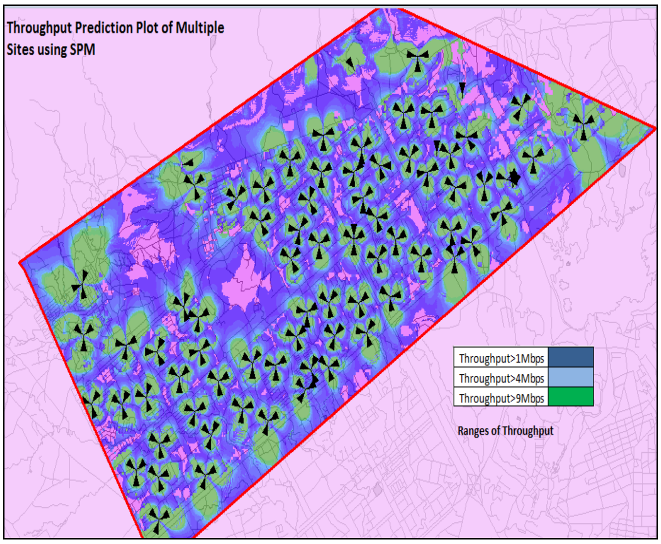

Figure 20. Throughput plot of multiple sites using SPM

6. Performance verification by field measurements and dimensioning of capacity for HSDPA urban network

Performance verification for results of Matlab and Atoll is done by taking field measurements using drive test equipment. In order to analyse the effect of indoor penetration loss on coverage; the drive test is done for a building having five floors. Coverage plots are taken for each floor. The value of signal strength (RSCP) is noted for each point and an average value of the signal is calculated for each floor. Here same colour coding is used that was used to plot prediction of coverage i.e. green color shows better coverage while red color shows weak coverage. The drive tests results are shown in the following plots. Coverage plots of first three floors are shown for reference.

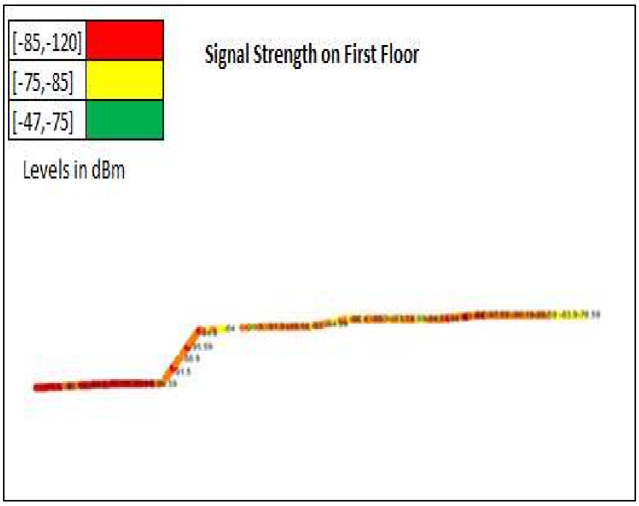

Figure 21. Coverage plot of indoor drive test for 1st Floor of a building

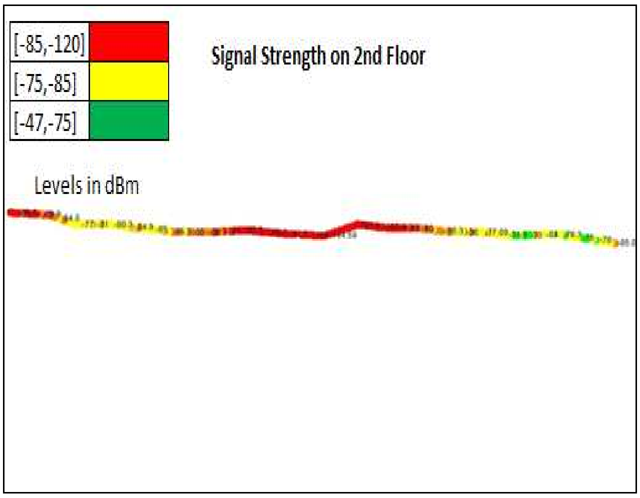

Figure 22. Coverage plot of indoor drive test for 2nd Floor of a building

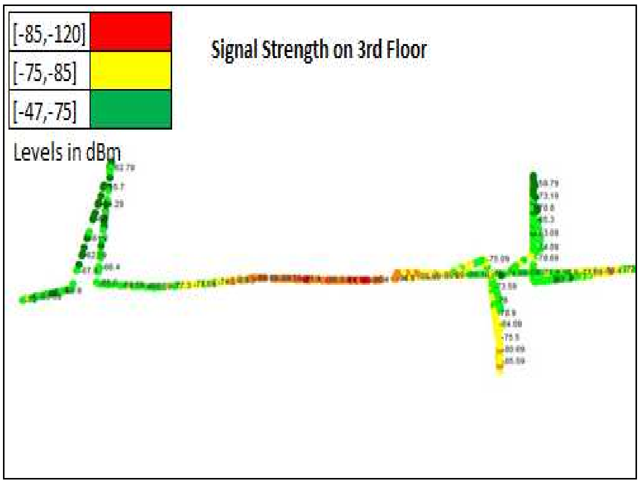

Figure 23. Coverage plot of indoor drive test for 3rd Floor of a building

Drive test results are plotted in the form of histogram as seen below. Here the average received level is noted as -81dBm.

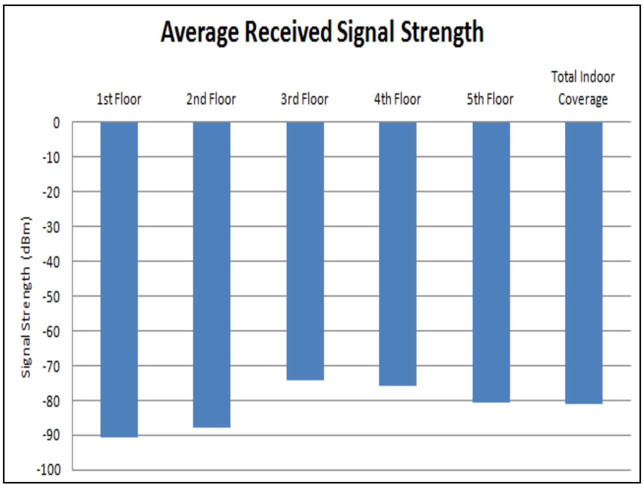

Figure 24: Received signal strength of drive test

The difference between the predicted coverage forecast for various propagation models and the drive test results are is shown below.

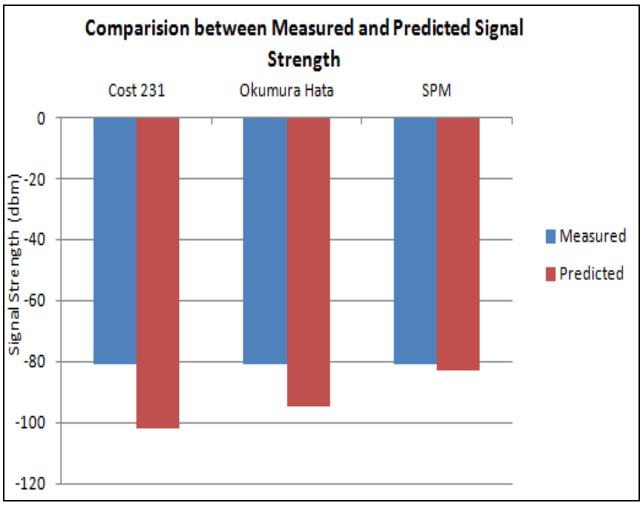

Figure 25. Predicted and field measurements of signal strength for propagation models

As seen above the difference between the predicted and the measured values of received signal strength is minimal for SPM. The other two propagation models do not show good results. To summarize, it can be said that SPM gives better results in terms of predicting the coverage and throughput both for a single site and existing GSM network of 82 sites. These results are also replicated in drive test where the performance of SPM is much better than other propagation models.

Based on these results, the capacity requirement for an urban network of Islamabad is calculated and is shown in table 8. The coverage radius for each cell is calculated using path loss of three propagation models Cost 231, Okumura Hata and SPM. Number of sites are calculated for each propagation model for an area of 84.22 square kilometers using equation 33. The calculations have been made for 600 kbps which is the cell edge data rate.

Table 8. Number of sites for various propagation models

Propagation Model	Cell Coverage Area (km)	Number of Sites
Cost Hata	0.2518	681
Okumura Hata	0.3586	335
SPM	0.502	180

It can be seen that Cost Hata and Okumura Hata models have over dimensioned the network. Whereas SPM gives reasonable number of sites that can be deployed in an urban network of Islamabad which are 180. The proposed number of sites are compared with the existing number of 3G sites for various cities similar to Islamabad e.g. Damam, Bahrain etc. It is observed that proposed network topology is giving accurate results. In order to further improve the indoor coverage, femto cells can be installed which provide the cost efficient solution [3]. Femto cells are low power cells that provide good indoor coverage with in the distance of few meters. These are deployed in residential, buildings and enterprise areas.

7. Conclusion

In this paper a detailed dimensioning of network capacity is carried out for an urban network supporting HSPDA. The tuning of propagation constants of SPM is done according to the topographical information of Islamabad. Performance analysis of various propagation models is carried out using Matlab, Atoll and field measurements. Analysis shows that SPM gives the best results among all propagation models. The difference between field measurements and theoretical results is minimal for SPM as compared to other propagation models. Based on these results, the optimized numbers of sites for an urban network of Islamabad are proposed. However these results can be used for any urban city of Pakistan having same topography like Islamabad. In this research, suggestions are also given to tune the values of propagation constants of SPM for other cities of Pakistan e.g. a metropolitan city like Karachi and a hilly city like Muzaffarabad.

With the prospects of launching 3G services in Pakistan in near future, this paper is a valuable research that provides thorough analysis of potential problems of launching a commercial network. Based on the analysis carried out, it is suggested that for a dense urban network of 84.22 square kilometers of Islamabad at least 180 sites are required in order to provide seamless coverage and capacity of HSDPA network.

This work is based on the analysis of capacity dimensioning of HSDPA urban network. Results of analysis and comparison of various propagation models are shown. This research work can further be extended in many ways. However, these future directions require a commercially operational 3G network. The proposed values of SPM in this study can be verified once the network is deployed where the effect of loading and interference can be seen.

References

[1] R. Surender, G. Sivaradje and P. Dananjayan "Performance Comparison of UMTS/WLAN Integrated Architectures with Dynamic Home Agent Assignments" International Journal of Communication Networks and Information Security (IJCNIS), Vol 1 No 3, December 2009

[2] M. R. Karim and M. Sarraf "WCDMA and cdma2000 for 3G networks", 2002

[3] K. D. Nguyen, Haong Nam Nguyen, Hiroaki Morino and Iwao Sasase "Uplink Channel Allocation Scheme and QoS Management Mechanism for Cognitive Cellular-Femtocell Networks" International Journal of Communication Networks and Information Security (IJCNIS), Vol 6 No 1, April 2014

[4] M. Zeeshan , S. Ahmed "A Robust Carrier Frequency Offset Estimation Algorithm in Burst Mode Multicarrier CDMA based Ad Hoc Networks" International Journal of Communication Networks and Information Security (IJCNIS), Vol 4 No 3, December 2012

[5] H. Holma and A. Toskala, "WCDMA for UMTS-HSPA Evolution and LTE" Fourth Edition Nokia, Finland, 2008

[6] M. Antunes, L. M. Corriea "Impact of HSDPA Implementation on UMTS Capacity and Cell Coverage" 4th European Wireless conference at Prague, pp. 1-5 22-25 June, 2008

[7] R. P. F. Hoefel and G. Braz, "Throughput and Coverage Analysis of WCDMA and HSDPA networks" Fifth International Conference on Digital Communications at Athens, pp 70-76 13-19th June, 2010

[8] M. Laner, P. Svoboda, S. Schwarz and M. Rupp "Users in Cells: a Data Traffic Analysis", Wireless Communications and Networking Conference (WCNC) at Shanghai, pp 3063 - 3068 on 1-4th April,2012

[9] C. M. H. Noblet, R. Rueda, J. M. Garcia, "Enabling UMTS end to end performance analysis" 5th IEE International Conference on 3G Mobile communication technologies, pp 29-33, 2004

[10] M. Amro, M. A. Landolsi, S. A. Zummo "Practical Verifications for Coverage and Capacity Predictions and Simulations in Real World Cellular UMTS network" International Conference on Computer and Communication Engineering , Kuala Lumpur, pp 3-5, 3-5 July 2012

[11] S. Datta, M. A. Imran and C. Tzaras "Uplink Coverage –Capacity Estimation Using Analysis and Simulation" Fourth Advance International Conference on Telecommunications, Athens, pp 151-156, 8-13 June 2008

[12] T. S. Rappaport "Wireless Communication Principles and Practice" Second Edition , Dec 2001

[13] T. M. Rao and A. S. Piato "Coverage and Capacity Calculations for a CDMA Cell in Different Radio Environments, International Conference on Computer as a tool" EUROCON at Belgrade pp 441-444 on 21-24Nov, 2005

[14] J. Chebil, A. K. Lwas, Md. R. Islam and A. H. Zyoud "Comparison of Empirical Propagation Path Loss Models for Mobile Communications in the Sub urban Area of Kuala Lumpur", 4th International Conference on Mechatronics (ICOM) , Kuala Lumpur pp 1-5, 18-19 May 2011

[15] M. F. Iskander and Z. Yun, "Propagation Prediction Models for Wireless Communication Systems" IEEE Transactions on Microwave Theory and Techniques, Vol 50, No 3 pp 662-673 March 2002.

[16] V. D. Nimavat and G. R. Kulkarni " Simulation and Performance Evaluation of GSM Propagation Channel under the Urban, Suburban and Rural Environments" International Conference on Communication, Information and Computing Technology, Mumbai, pp 1-5 Oct19-20 2012

[17] J. S. Seybold "Introduction to RF propagation" John Wiley and Sons 2005

[18] J. Milanovic , S. R. Drlje and K. Bejuk "Comparison of propagation models accuracy for WiMAX on 3.5GHz",14th IEEE Conference on Electronics, Circuits and System at Marrakech, pp111-114, 11-14 Dec 2007

[19] N. Shabbir, M. T. Sadiq, H. Kashifm, R. Ullah "Comparison of Radio Propagation Models for LTE network ", International Journal of Next Generation networks (IJNGN) Vol3,No.3, September 2011

[20] P. Zhao, Y. Zhang, S. Zhou, Y. Hu "A New Method of Obtaining Slow fading Characteristics from CW test and its Implementations in Radio Planning", IEEE International Conference on Communication Technology and Applications at Beijing, pp 279-283, 16-18 Oct,2009

[21] B. A. Forouzan "Data Communication and Networking", 4th Edition by 2008

[22] J. P. Romero, O. Sallent, R. Agusti and M. A. Diaz-Guerra "Radio Resource management strategies in UMTS", John Wiley and Sons, Ltd 2005

[23] S. C. Yang, "CDMA RF System Engineering" Artech House Publishers, 1998

[24] L. Horton and R. F. Smith "Capacity Optimization for 3G Wireless Networks" Brandon 40th Southeastern on System Theory University of New Orleans New Orleans, LA USA, pp 164-168, 16-18 March, 2008

[25] M. S Rani, S. V. V. R. K Behra, K. Suresh "Comparison of SPM and SUI Radio Propagation model for Long Term Evolution (LTE)" International Journal of Advanced and Innovative Research (IJAIR) 1(6):221-228, 2012

[26] F. I. Mahmoud and S. A. Mawjoud "Planning and design of WCDMA network compatible with existing GSM system in Mosul city" 5th International Multi-Conference on Systems, Signals and Devices at Amman, pp 1-6, 20-22 July 2008