Optimizing down Link Capacity of CDMA Network

Ashagrie Getnet
Ethio Telecom, Head Quarter Churchill Road
Addis Ababa, Ethiopia
Email:edenashagrie@gmail.com

***Abstract*—Coverage requirement along with the traffic requirement relies on the propagation model to determine the traffic distribution. In this study the number of user as a function of the path loss value and the propagation prediction model were discussed. The analysis takes into account to improve the accuracy of signal prediction and improve the capacity based on the experimental measurements and empirical models using MSE. Performance results are presented and compared with measured value. Excellent agreement was observed and considerable CDMA capacity improvement was accomplished. Specifically, an average means square error (MSE) of 6.2 dB and 6.3 dB observed in optimized Hata and optimized Lee model respectively, which is considered low value comparing the predicted average value (10.6 dB and 11.4 dB).In addition to this the corresponding capacity improvement achieved by 11.8 % and 10 % for sample site 2.**

***IndexTerms*—Path Loss, Energy Per Bit, Mean Square Error, Signal-to-Noise Ratio, Capacity.**

I. INTRODUCTION

CDMA is a multiple-access technique, where multiple users can share the same time and frequency domains while remaining distinct in the code domain (e.g., applying the orthogonality principle) [1]. It spreads the message signal to a relatively wide bandwidth by using a unique code that reduces interference, enhances system processing, and differentiates users. CDMA does not require frequency or time-division for multiple accesses; thus, it improves the capacity of the communication system [2].

The performance of the network is affected by the propagation model chosen because it is used for interference predictions. The propagation model helps to determine where the cell sites should be placed to achieve an optimal location in the network. If the propagation model used is not effective in placing cell sites correctly, the probability of incorrectly deploying a cell site in the network is high [3]. With accurate propagation prediction and the simulation methods the network design can be fully tested before any hardware is deployed [4].

In this study first path loss prediction is improved by using measurement results considering Hata and Lee model. Mean Square Error (MSE) is used for mathematical analysis for the improvement process. Using the optimized prediction model the simulation was done and different comparison wasillustrated (i.e. CDMA signal prediction versus capacity).

II. PATH LOSS PREDICTION

The core of the signal coverage calculation for any environment is a path loss model which relates the loss of signal strength to distance between the base stations to the mobile station [5].

A. *Free Space*

Free-space attenuation is defined as the transmission loss caused by the dispersion of the energy of the wave that would occurs were the antennas to be replaced by isotropic radiators placed inside a perfectly dielectric, homogeneous, isotropic and unlimited environment where there are no obstacles between the transmitter and the receiver [6,7]

The equation for free-space attenuation (A_0) is:

$$A_0 = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (1)$$

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

$$A_o = 32.4 + 20log_{10}(f) + 20log_{10}(d) \quad (2)$$

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

B. *Hata Model*

A number of research groups have carried out measurements in outdoor environments of which the most extensive set of measurements was carried out by Okumura, et al., in the city of Tokyo. The range dependence was presented as curves of median received field strength for various parameters. Subsequently, Hata expressed these results in terms of path loss between isotropic antennas and developed curve fitted formulas which have proven to be very useful in system planning [8].

The standard formula for median path loss in urban areas under the Hata model is [1, 9]:

$$L_{urban}(dB)=69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_{re}) - \alpha(h_{re}) + (44.9-6.55 \log_{10}(h_{te}))\log_{10}(d) \quad (3)$$

The parameters in this model are the same as under the Okumura model, and $a(hre)$ is a correction factor for the mobile antenna height based on the size of the coverage area. For small to medium sized cities, this factor is given by

$$a(h_{re}) = (1.1log_{10}(f_c) - 0.7)h_{re} - (1.56log_{10}(f_c) - .8)dB \quad (4)$$

and for larger cities at frequencies f_c >300 MHz by

$$a(h_{re}) = 3.2(log_{10}(11.75h_r)^2 - 4.97dB \quad (5)$$

where

h_{ta} is the base station height in meters, hte: 30–200m
hre Receiver (mobile) effective antenna height (m), hre: 1–10m
f_c range of frequencies, 150-1500 MHz
d is the link distance in km

C. Lee Model

The Lee model is a power law model, with parameters taken from measurements in a number of locations, together with a procedure for calculating an effective base station antenna height which takes account of the variations in the terrain [10]. The simplified formula of the Lee model at the cellular frequency [11].

$$L_p = 1.14\ x\ 10^{-13}\,\frac{h^2}{h^{3.84}} \quad (6)$$

where *d* is the distance (in kilometers) between the base station and the mobile user and *h* is the height (in meters) of the base station antenna. Note that in this case, the path loss varies as an inverse power of 3.84 compared to an inverse power of 2 in free space. In other words, the path loss encountered in terrestrial mobile communication systems is worse than that seen in free space. Converting (6) into decibel form yields

$$L_p = -129.45 - 38.4\log(d) + 20\log(h) \quad (7)$$

where, again, *d* is in kilometers and *h* is in meters.

III. CDMA DOWN LINK CAPACITY CALCULATION

The demand for multimedia services is expected to increase in the wireless communication system as well. The CDMA scheme has been proposed for a next generation wireless system that will offer multimedia services [12]. The SNR is a key consideration in all communication systems. In digital communication systems, the SNR is characterized by a related figure of merit, the bit energy per noise density ratio (Eb /NO). That parameter takes into account the processing gain of the communication system, a vital consideration in spread-spectrum communications [2]. In the wireless communication system, the system capacity and resource management can be related as follow [12].

Calculating the actual Eb/N_0 and Ec/I_0 ratios essentially involves the accounting of signal and interference terms

$$\frac{E_b}{N_o} = \frac{S}{N}\frac{W}{R} \quad (8)$$

Eq. (8) relates the energy per bit Eb/N_0 to two factors: the signal-to-noise ratio S/N of the link and the ratio of transmitted bandwidth W to bit rate R. The ratio W /R is also known as the processing gain of the system [13]. The capacity is tied to a flexible resource-power-and is said to be soft-limited. In other words, if the required Eb/N_0 is lowered, the transmit signal power allocated to each user is reduced, and the number of users can be increased [2].

Assume that the system possesses perfect power control, which means that the transmitted powers of all mobile users are actively controlled such that at the base station receiver, the received powers from all mobile users are equal. Based on this assumption, the SNR of one user can be written as

$$\frac{S}{N} = \frac{1}{M-1} \quad (9)$$

where M is the total number of users present in the band. Substituting (9) in to (8) we get:

$$\frac{E_b}{N_o} = \frac{S}{(M-1)}\frac{W}{R} \quad (10)$$

Now consider effects of Loading the target cell is said to be loaded by users from other cells. Equation (10) is modified to account for the effect of loading:

$$\frac{E_b}{N_o} = \frac{S}{(M-1)}\frac{W}{R}\left(\frac{1}{1+\eta}\right) \quad (11)$$

The inverse of the factor (1+η) is known as the frequency reuse factor Fr

$$Fr = \left(\frac{1}{1+\eta}\right) \quad (12)$$

Consider effects of Voice Activity factor (υ): Thus, (11) is again modified to account for the effect of voice activity [13].

$$\frac{E_b}{N_o} = \frac{S}{(M-1)}\frac{W}{R}\left(\frac{1}{1+\eta}\right)\frac{1}{\upsilon} \quad (13)$$

Let consider other factor and the downlink Coverage Calculation can be written as

$$P_L = 10\ log\left[\frac{x.Pt}{(1+C_{sho})M}\right] - 10log\left[\frac{\gamma_t N_0 W}{\frac{W}{R} - \gamma_t \upsilon\left(\frac{M(1+C_{sho})-1}{Fr}\right)(1-\theta)}\right] + G_{sho} \quad (14)$$

where: Gsho the soft handoff gain , Csho Soft handoff capacity overhead , θ Orthogonality factor, Pt base station transmit power , x Percentage of base station power allocated to traffic channels and $\gamma_t$required Eb/No [2, 13, 14].

IV. SIMULATION ASSUMPTIONS AND DATA FITTING

A. Simulation Assumption

TABLE I. PATH LOSS SIMULATION PARAMETER

Parameter	Value
BTS transmit power	10 w for Site 1 & 2 15 w for Site 3
Antenna Gain	17 dBi
Log-normal fade margin (dB)	5.4 dB
BTS height	25 m for site 1 & 2 27 m for site 3
MS Height	1.5 m

Multi-user diversity gain (dB)	2 dB
BTS Cable loss (dB)	2 dB
BTS Jumper loss	0.4 dB
Other Loss +body Loss	3 dB

TABLE II. CAPACITY SIMULATION PARAMETERS

Parameter	Value
Frequency Band	850 MHz
Spread Rate (W)	1228800 Hz
Data Rate (R)	9600
Required $E_b/N_o=\gamma_t$	7 dB
Soft-handoff gain (Gsho)	1 dB
Soft handoff capacity overhead (Csho)	0.18
Percentage of base station power allocated(x)	0.8
noise over the full bandwidth (NoW)	4.89779E-12
Voice activity factor	0.3
Frequency reuse factor(Fr)	0.8
Orthogonality factor(θ)	0.8

TABLE III. FELD MEASUREMENT DATA

Distance(M)	Site 1 (Rx value dB)	Site 2(Rx value dB)	Site 3 (Rx value dB)
200	-51	-52	-48
400	-57	-54	-51
600	-64	-56	-57
800	-69	-57	-77
1000	-78	-61	-80
1200	-79	-73	-84
1400	-71	-86	-86
1600	-75	-89	-87
1800	-86	-92	-89
2000	-83	-92	-93

B. *Data-Fitting Methods in Path-Loss Modeling*

An empirical model like the Long-distance path loss models is based on measurements. The most straightforward approach to data fitting is the least squares approach. Consider the linear case

$$yi = ax_i + b + e_i \quad (15)$$

where: e_i represents the measurement error.

In order to find the best parameters a and b , a natural cost function is the overall cumulative error

$$J(a,b) = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N}(y_i - ax_i - b)^2 \quad (16)$$

which is to be minimized with respect to a and b. It is straightforward to solve the analytical expressions for the optimal a and b [15].

The MMSE error equation for the dB power measurement is

$$F(\gamma) = \sum_{i=1}^{n}[M_{measured\ (di)} - M_{model}(di)]^2 \quad (17)$$

where M measured (di) is the path loss measurement at distance di, and M models(di) the selected path loss based. The standard deviation:

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}[M_{measured\ (di)} - M_{model}(di)]^2 \quad (18)$$

C. *Link Budget Calculation*

The path loss between a pair of antennas is the ratio of the transmitted power to the received power, usually expressed in decibels. It includes all of the possible elements of loss associated with interactions between the propagating wave and any objects between transmit and the receive antennas [10]. Measurements of the received power taken at a specified location between transmitter and receiver have shown the received power to be a random variable with certain distributions [14].The study is focused on downlink since forward link is the more critical link due to the asymmetric characteristic of the network. The receiver power in terms of antenna gain can be calculated in (20) [16].

$$P_r = P_t + G_t + G_r - (32.44 + 20\log d + 20\log f) - Ls + Gd \quad (19)$$

where

P_r = received ower in dBm

P_t = transmitted power in dBm

G_t = transmitting antenna gain in dBi

G_r = receiving antenna gain in dBi

Ls = loss (Cable loss, Connector loss, body loss ...)

Gd = different gain (diversity gain, . .)

IV. SIMULATION RESULTS

From this study; the data was collected through drive test in three CDMA sites located in Addis Ababa (see Table III). The path losses for various models are calculated using (3), (4), (7), (19) and Table III. The path loss in (dB) versus distance platted in a logarithmic scale. The optimized model was obtained by applying (16) - (18) and Table I (See Figure 1 -3).

Using the result of optimized models, Table II and (12) - (14) the capacity simulation carried and the result is shown Figs. 4, 5 and 6.

A. *Path Loss Simulation*

Comparing the field measurements the mean square error (MSE) of Hata model and Lee Model were 14 dB and 14.3 dB respectively. However in the optimized down link model the

MSE in optimized Hata and optimized Lee model become 8.6 dB and 8.6 dB respectively (Fig. 1).

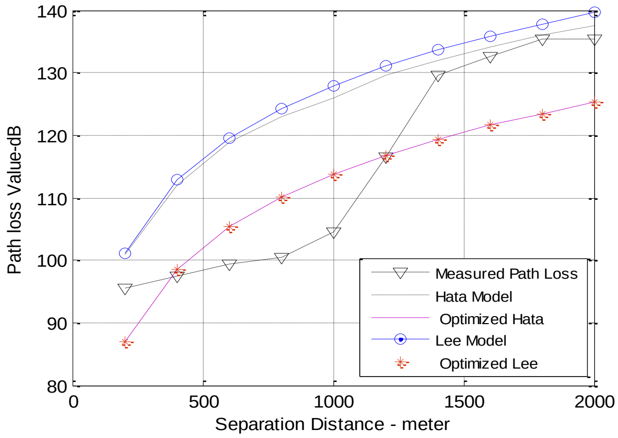

Fig.1. Path Loss Comparison in Site 1

Decreasing this MSE value in (3) and (7) the optimized models were found. The optimized Hata model is given as below

Lurban (dB)=55.55 + 26.16 log10 (fc) – 13.82 log10 (hre) – α(hre) +(44.9-6.55 log10 (hte))log10(d) (20)

Similarly the optimized equation for Lee models is given:

$$L_p = -143.75 - 38.4\log(d) + 20\log(h) \qquad (21)$$

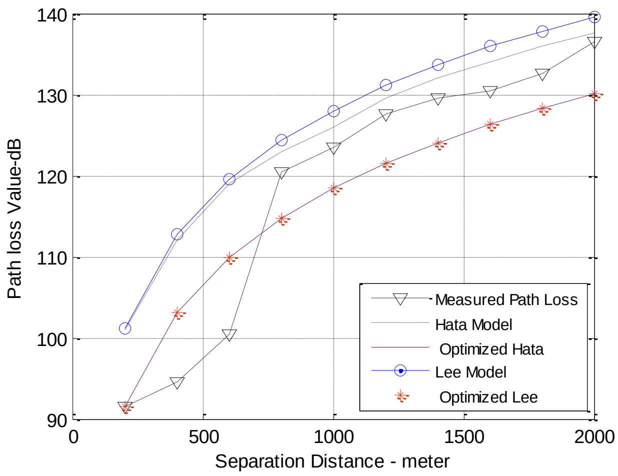

Fig. 2. Path Loss Comparison in Site 2

Considering the path loss comparison in Fig. 2 the MSE in optimized Hata model is 6.7 dB and MSE for Optimized Lee model 6 dB which are accepted value for signal prediction. It indicated that the path loss prediction accuracy better than the existing predication models.

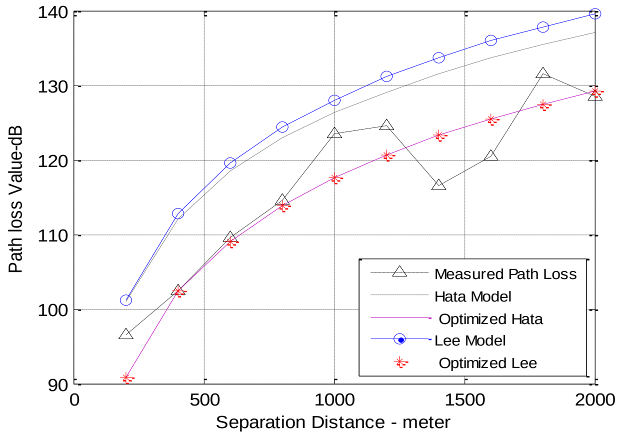

Fig. 3. Path Loss Comparison in Site 3

Capacity is affected by like propagation conditions in real environments. Improved existing path loss prediction model provides the optimal solution to use the resource effectively with good quality of service. Fig. 3 illustrates the modified path loss value lower than other prediction path loss value. The MSE decreased by 4.9 dB and 6.4 dB in the optimized Hata and optimized Lee Models respectively.

B. *Capacity Simulation*

Fig. 4 illustrates the number of user as a function of the distance between the serving BS and MS. The top curve corresponds to what is obtained when Using optimized (modified) Hata Model. An interesting result is that the number of user increased an average of 17.8 % and 16.9 % for the optimized Hata and optimized Lee model respectively.

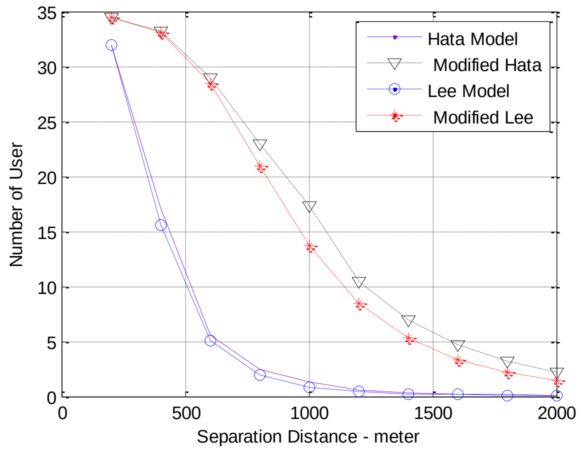

Fig. 4. Number of Subscriber in different signal prediction Models (site 1)

The downlink capacity depends on the maximum path loss. The more accurate path loss provides more capacity in the system. As shown Fig.5 the number of user increase at d=400 m by 13 and at d=600m by 15. This result indicates, coverage and capacity are planned together for effective resource utilization.

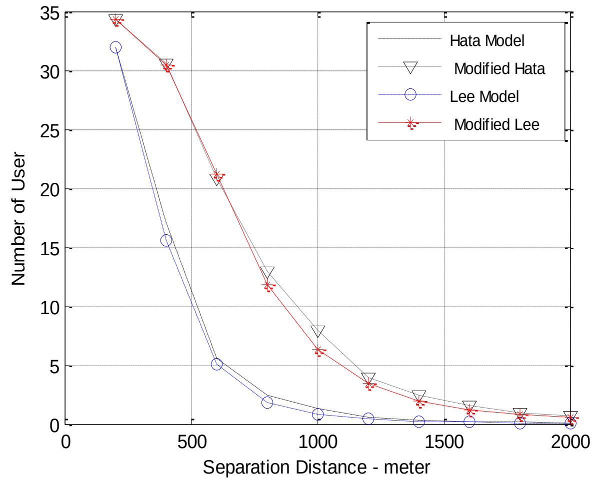

Fig. 5. Number of Subscriber in different signal prediction Models (site 2)

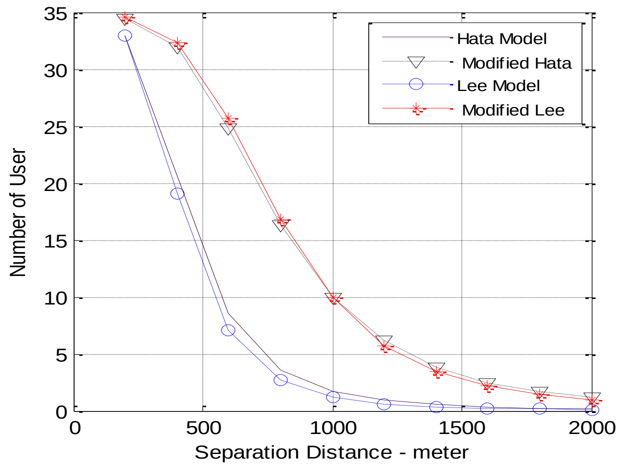

Fig. 6. Number of Subscriber in different signal prediction Models (site 3)

The decrease MSE is significant to improve CDMA network capacity, see Fig. 6; the graph shows the number of subscriber increase both optimized Lee and Hata models. In this respect having at 500 m radius the number of user increased by 12.

V. CONCLUSION

The study illustrate that a properly optimized prediction model reduce the MSE between the measured data and predicted path loss. On the other hand capacity is affected by the amount of path loss that can be tolerated in order to cover a given area. Hence, it is necessary to implement the optimized propagation prediction models to achieve better performance in a given coverage and capacity parameter. The result shows that the value of MSE decreased by 4.4 dB and 5.1 dB for the optimized Hata and optimized Lee Model respectively. In addition to this the number of CDMA voice user increased by an average of from 97 to 139 and from 59 to 132 after optimizing the Hata and Lee models respectively. The result indicates that, optimizing down link performance is one of the methods for capacity improvement. It can also help the operator to meet user's requirements with economical investment and better quality.

ACKNOWLEDGMENTS

I would like to thank my wife Dr. Alemnesh Woldeyes for her valuable comments and continuous encouragement.

REFERENCES

[1] A. Goldsmith, Wireless Communications, Cambridge University Press, 2005, pp. 42-42
[2] J. B. Groe and L. E. Larson, CDMA Mobile Radio Design, London:Artech House, Inc.,2000, pp.21,28-32,40.
[3] V. K. Garg, Wireless Communications and Networking, USA: Elsevier Inc., 2007, pp. 66.
[4] A. W. Graham, Nicholas C. Kirkman and P. M. Paul, Mobile Radio Network Design in the VHF and UHF Bands a Practical Approach, England: John Wiley & Sons Ltd, 2007, pp. 49.
[5] K. Pahlavan, Principles of Wireless Network: A Unified Approach, New Jersey: Prentice Hall PTR, 2002, pp. 45-65.
[6] H. Sizun, Radio Wave Propagation for Telecommunication Applications, Germany: Springer-Verlag Berlin Heidelberg, 2005, pp. 54.
[7] J. Boccuzzi, Signal Processing for Wireless Communications, USA: McGraw-Hill Companies, Inc., 2008, pp. 349.
[8] R. Janaswamy, Radiowave Propagation and Smart Antennas for Wireless Communication, USA, Kluwer Academic Publishers, 2001, pp. 82.
[9] J. M. Hernando and F. Pérez-Fontán, Introduction to Mobile Communication Engineering, London: Artech House, 1999, pp.158.
[10] S. R. Saunders, Antennas and Propagation for Wireless Communication Systems, 2 nd ed., England: John Wiley & Sons Ltd, 2007, pp. 89-92,170-178.
[11] S. C. Yang, CDMA RF System Engineering, USA: Artech House, Inc, 1998, pp.14-18, 75-83,256-257.
[12] K. Kim and I. Koo, CDMA Systems Capacity Engineering, USA: Artech House, Inc., 2005, pp.18-25.
[13] S. C. Yang, 3G CDMA 2000 Wireless System Engineering, USA: Artech House, Inc, 2004, pp. 159-169, 172-176.
[14] M. A. Abu-Rgheff, Introduction to CDMA Wireless Communications, USA: Elsevier Ltd, 2007, pp.340-349,382-385.
[15] H. Koivo, Systems Engineering in Wireless Communications, United Kingdom: John Wiley & Sons Ltd., 2009, pp. 75.
[16] R. Blake, Wireless Communication Technology, pp. 227