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Cell Coverage Area and Link Budget Calculations in GSM System

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Abstract

The initial establishment of a Wireless system is very expensive and time consuming process. Due to this it is require to develop a mathematical model before establishment of such type of systems. The Calculation of path loss, link budgets etc are in the part of wireless system designing. Radio propagation is profoundly site specific and varies considerably depending on topography, frequency of operation, speed of mobile terminal, interface sources and other dynamic factor. To predict signal coverage and achieve data rates, it is important to characterize radio channel through key parameters and a mathematical model. In This paper we discussed the parameters which are affecting the communication performance and the coverage range of the cell. The coverage starts within the cell, by estimating the affecting parameters on the signal power level in the uplink and downlink at the practical circumstances that means at the mobile station at the cell boundary, or in a high fading region, taking into consideration the factors causing fading and other losses is the signal power.

Keywords: Global system for Mobile Communication (GSM), path loss, link budget, coverage area, Base Transceiver Station (BTS).

I. Introduction

The provision of wireless telephony network in a serving area requires planning and design in the most effective manner. In the design process the service providers generates a set of system requirements concerning the type of the desired system (e.g. Global system for Mobile Communication GSM, Code Division Multiple Access CDMA etc.), The main principle inside cellular network is replacement of a single high power transmitter by many small power transmitters and In this case each low power transmitter covers a small area or small range called a cell. Cellular networks are completely based on the technique of frequency reuse, so that the narrow radio spectrum will get maximum use, as shown in Fig.1. In cellular radio networks, A small area is covered by one base station and other base stations are installed with small overlapping areas. Neighboring cells require using different frequencies to evade interference, but the same frequency can be reused in distant cells. The entire coverage area is splitter into many small hexagonal cells so that to increase the capacity of entire network and a decrease in the reuse of frequency [2].

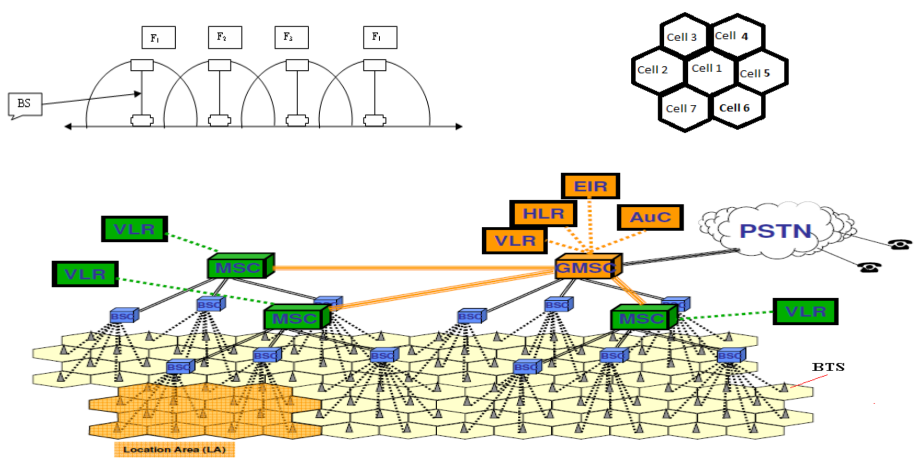

Fig. 1 Concept of cell and frequency reuse[11]

SIM Subscriber Identity Module	HLR Home Location Register
MS Mobile Station	VLR Vistor Location Register
BTS Base Transceiver Station	EIR Equipment Identity Register
BSC Base Station Controller	AC Authentication Center
MSC Mobile services Switching Center	PSTN Public Switched Telecomm Network
VLR Visitor Location Register	ISDN Integrated Services Digital Network

Propagation models mainly focus to predict the received signal strength within some range from the transmitter, as well as the variation in the received signal strength in a close spatial proximity to a particular location. Propagation models which predict the signal strength for a random transmitter- receiver (T-R) separation distance are very useful in calculating the radio coverage area of a transmitter. on the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distances are called small-scale or fading models. Propagation models are also useful for predicting signal attenuation or path loss. Calculated path loss information is useful for controlling system performance or coverage to achieve perfect reception [1-4].

II. Coverage Area

A cellular network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. These cells joined together provide radio coverage over a large geographic area. This radio network enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission. The cell and network coverage depend mainly on natural factors such as geographical aspect/propagation conditions, and on human factors such as the landscape (urban, suburban, rural), subscriber behavior etc. The ultimate quality of the coverage in the mobile network is measured in terms of location probability. For that, the radio propagation conditions have to be predicted as accurately as possible for the region. Three main mechanisms that impact the signal propagation are depicted [5].Those mechanisms are:

- *Reflection*. It occurs when the electromagnetic wave strikes against a smooth surface, whose dimensions are large compared with the signal wavelength.
- *Diffraction*. It occurs when the electromagnetic wave strikes a surface whose dimensions are larger than the signal wavelength, new secondary waves are generated. This phenomenon is often called *shadowing*, because the diffracted field can reach the receiver even when shadowed by an impenetrable obstruction (no line of sight).
- *Scattering*. It happens when a radio wave strikes against a rough surface whose dimensions are equal to or smaller than the signal wavelength.

There are two ways in which radio planners can use propagation models. They can either create their own propagation models for different areas in a cellular network, or they can use the existing standard models, which are generic in nature and are used for a whole area. The advantage of using their own model is that it will be more accurate, but it will also be immensely time-consuming to construct. Usage of the standard models is economical from the time and money perspective, but these models have limited accuracy.
The empirical models uses Existing equations obtained from results of several measurement efforts. Some of the path loss models are as follows [6]:

a. Simplified Path Loss Model
b. Stanford University Interim (SUI) Model
c. Okumura's Model
d. Hata Model
e. COST231 Extension to Hata Model
f. ECC-33 model
g. Walfisch- Bertoni Model
h. Longley rice model
i. Egli Propagation Model
j. Bullington model
k. Epstein-Peterson model

The above mentioned all the models are designed by calculating field data in different environments. Path loss determine the cell ranges. For GSM there are three cell ranges:

- Large cells, cell radius is 1 Km and normally it exceeds 3 Km.
- Small cells, cell radius 1 Km - 3 Km.
- Microcells: of radius in the range of 200 m – 300 m. The propagation in the above three cell sizes is determined by diffraction and scattering [1].

Additional loss called indoor loss (penetration loss) which varies greatly depending on type of material, architecture (numbers of windows), floor within building, etc. [9]. The figures 2,3 and 4 shows the path loss variation with cell radius and with the help of calculation of path loss in different areas we can determine the coverage area.

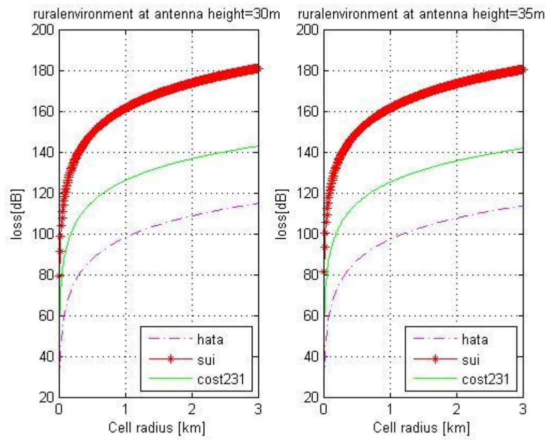

Fig. 2 The variation of path loss with cell radius in rural environment at different antenna height

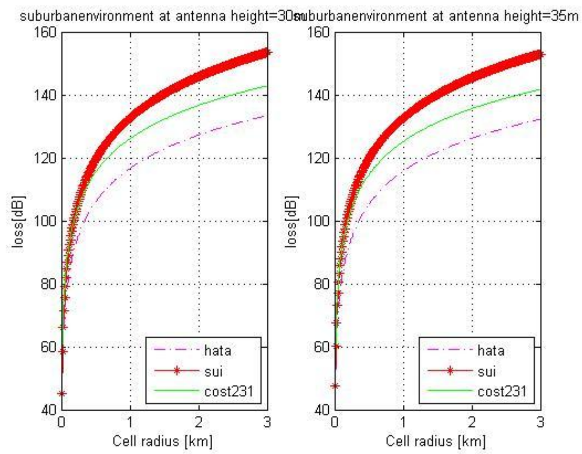

Fig. 3 The variation of path loss with cell radius in suburban environment at different antenna height

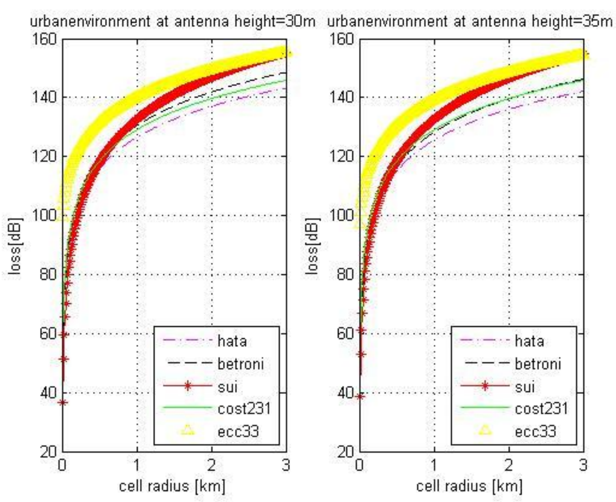

Fig. 4 The variation of path loss with cell radius in urban environment at different antenna height

III. Link Budget and its Calculations

Link budget is calculation of all the gains and losses in a transmission system. The link budget looks at the elements that will determine the signal strength arriving at the receiver. it is necessary to calculate link budget in the complete design of radio communication system. link budget calculations are used for calculating the power levels required for cellular communications systems, and for investigating the base station coverage. These link budget calculations are also used within wireless survey tools.

These wireless survey tools will not only look at the way radio signals propagate, but also the power levels, antennas and receiver sensitivity levels required to provide the required link quality. The link budget includes the following parameter [8-10].

- Transmitter power.
- Antenna gains (both transmitter antenna gain and receiver antenna gain).
- Antenna feeder losses.
- Path loss
- Receiver sensitivity

In order to formulate a link budget equation, it is required to look into all the areas where gains and losses may occur between the transmitter and the receiver. The calculation of the basic link budget is very easy.

Received power (dBm) = Transmitted power (dBm) + gains (dbm) - losses (dBm) (1)

In basic calculation of link budget equation it is assumed that the power spreads out equally in all directions from the transmitter source. The indirect meaning is that the antenna used is an isotropic source, radiating equally in all directions. This is good for theoretical calculations, But not for practical calculations. A typical link budget equation for a radio communications system may look like the following:

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{FS} - L_{FM} - L_{RX} \quad (2)$$

Where: P_{RX} = received power (dBm)
P_{TX} = transmitter output power (dBm)
G_{TX} = transmitter antenna gain (dBi)
G_{RX} = receiver antenna gain (dBi)
L_{TX} = transmit feeder and associated losses (feeder, connectors, etc.) (dB)
L_{FS} = free space loss or path loss (dB)
L_{FM} = many-sided signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)
L_{RX} = receiver feeder losses (feeder, connectors, etc.) (dB)

The objective of power budget calculation is to balance the uplink and down link. The receive signal sensitivity may be different because the mobile station and the base transceiver station has different Radio frequency architecture. The power of BTS can be adjusted to balance the whole link. The power balance (uplink and down link) decide the cell range. Here we can see two conditions those are

- The down link is greater than the uplink: It results in Range of BTS greater than Range of MS, Call dropped on uplink after initiation of handover, and Coverage area is smaller in reality than the prediction. This condition is most frequent.
- The uplink is greater than the down link: It results in Range of BTS less than Range of MS, and No coverage problem from MS to BTS.

The condition i.e the uplink > down link, is better than uplink < down link.

(A) Illustrative calculations of MS and BTS sensitivities:

It is minimum signal level at the input that leads to the signal to noise at the output, higher than a threshold Eb/No related to the modulator performance [9].

Parameter	Value
Boltzmann's constant (K)	1.38×10^{-23} J/K^0
Absolute temperature (T)	300 K^0
Equivalent noise bandwidth (B_{eq}).	200 KHz
Intrinsic characteristic of the modulator (Eb/No).	8 dBm
Noise figure	8 dBm

$$R_{MS} = 10\log_{10}(KTB_{eq}) + \frac{E_b}{N_0} + NF \quad (3)$$

Mobile station sensitivity (R_{MS}) = -120+8+ 8= -104dBm
The same as for MS but NF=-2
BTS Sensitivity= -114dBm

(B) Uplink Budget and Cell Range:

(a) Transmitting End:

$$EIRP = P_{Tx} + L_{AF} + G_{ME} \quad (4)$$

Transmitter(Mobile equipment (ME) or MS)		Parameter Value
1. Transmitter power of ME	(P_{Tx})	33dBm
2. MS or ME antenna gain (isotropic antenna)	(G_{ME})	0
3. Connector loss or Antenna feeder loss	(L_{AF})	3
4. Effective isotropic radiated power	(EIRP)	33 dBm
5. Mobile station antenna height	(h_m)	1.5m

(b) Receiving End:

$$R_s = EIRP - L_p - I_M - F_M - L_C + G_{BTS} \quad (5)$$

Receiver (BTS)		Parameter value
1. Receiver sensitivity	(R_S)	-114dBm
2. Body loss	(B_L)	3dB
3. BTS receiving antenna gain	(G_{BTS})	14dB
4. Interference margin	(I_M)	2
5. Fast fade margin	(F_M)	5dB
6. Connector loss	(L_C)	3dB
7. Base station antenna height	(h_b)	30m or 35m

Using equation (4)
EIRP=33-0-0=33dB
Using equation (5) below:

$$R_s = EIRP - L_p - I_M - F_M - L_C + G_{BTS}$$

-114 =33-L_p-2-5-3+14
Therefore L_P= 151dB

(i) Hata model

Using Hata model pathloss calculation equation

$$L_P = L_{50,urban}(dB) = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_{te}) - a(h_{re}) + (44.9 - 6.55\log10(h_{te}))\log_{10}(d) \quad (6)$$

Where,
$a(h_{re})$ is a correction factor for the mobile antenna height based on the size of the coverage area.

$$a(h_{re}) = 3.2(\log_{10}(11.75h_{re})^2 - 4.97 \text{ dB}. \quad (7)$$

h_{re}=1.5;(receiver height in meter) , f_c=900 MHz and d=Cell radius in kilometer

BTS antenna height(h_{te})=35m
$L_{50,Urban}$(dB)= 125.4949+34.7864 $\log_{10}$ d
151=125.4949+34.7864 $\log_{10}$ d
(151-125.4949)/34.7864=$\log_{10}$d
d=5.41km

BTS antenna height=30m
$L_{50,Urban}$(dB)= 126.4201+35.2249 $\log_{10}$ d
151=126.4201+35.2249 $\log_{10}$ d
(151-126.4201)/35.224=$\log_{10}$d
d=4.9865km

(ii) Cost-231 model

The path loss calculation formula is given by

$$PL=46.3+33.9\log_{10}(f)-13.82\log_{10}(h_{bs})-ah_m+(44.9-6.55\log_{10}(h_{bs}))\log_{10}d+c_m \quad (8)$$

Where $ah_m = 3.20(\log_{10}(11.75h_r))^2-4.97$, for f > 400 MHz

(9)

BTS antenna height (h_{bs})=35m
$PL=125.1107+34.7864\log_{10}d+3$
$151=125.1107+34.7864\log_{10}d+3$
d=4.5499km

BTS antenna height (h_{bs})=30m
$PL=126.0359+35.224\log_{10}d+3$
$151=129.0359+35.2249og_{10}d$
d=4.2024km

(iii) Walfisch-Bertoni model

The formula to calculate the path loss is

$$LF=89.5-10\log((\rho*(s)^{0.9})/((H_b-h_m)^2))+21\log(f)-18\log(h_b-H_b)+38\log(d); \quad (10)$$

$$\rho=\sqrt{\left(\frac{s}{2}\right)^2+(H_b-h_m)^2}; \quad (11)$$

ρ=path distance from the building edge to the mobile ,d=distance in km, hm=receiver height in meter, s=spacing between in meter, Hb=building height in meter, hb=antenna height in meter, f=freq in MHz.

BTS antenna height(h_b)=35m
$LF=122.4831+38\log_{10}d$
$(151-122.4831)/38= \log_{10}d$
d=5.6286 km
BTS antenna height(h_b)=30m
$LF=124.7320+38\log_{10}d$
$(151-124.7320)/38= \log_{10}d$
d=4.9121 km

(C) Down Link Budget and cell range

(a) Transmitting End:

$$EIRP=P_{TXB}-L_{cableB}-L_c+G_{TXB} \quad (12)$$

Transmitter(BTS)	Parameter Value
1. Out put power of BTS (P_{TxB})	44.5dBm (general value)
2. Transmitter antenna gain (G_{TXB})	18 dB
3. Cable loss (L_{CableB})	2dB
4. EIRP	
5. Combiner loss (L_c)	2dB

(b) Receiver End:

$$R_s=EIRP-L_p-B_{LM}-I_D-L_s-L_{CC}+G_{MS} \quad (13)$$

Receiver (MS or ME)	Parameter value
1. Mobile station Sensitivity (R_{SM})	-104dBm
2. Body loss (B_{LM})	3dB
3. MS receiving antenna gain (G_{BTS})	18dB
3. Interference margin (I_M)	3dB
4. Fast fade margin (F_M)	5dB
5. Connector loss (L_C)	2dB

$$R_s=EIRP-L_p-B_{LM}-I_M-F_M-L_C+G_{MS} \quad (14)$$

R_S= -104= EIRP-151-3-3-5-2+18 therefore EIRP=52

$52=P_{TxB}-2-2+18$ therefore $P_{TxB}=38$ dBm

By analysing the whole calculations we found an imbalance of ($P_{TX}-P_{TxB}$)=5dB between uplink and down link. This can be rectified or compensated by increasing the BTS power by 5 dB. Or by adding 4-6 dB to the BTS output power, so that balance is maintained in the down link also [1].

IV. Conclusions

In this paper we calculated path loss by different models in different environments like urban, suburban and rural at two different transmitting antenna heights. The result of this analysis helps the network designers at the initial level of designing a wireless network and to define the coverage area. In this paper we also discussed about link budget analysis to achieve a balance between uplink and down link received signal because MS and BTS have different RF architectures and different sensitivities. Since RF link balance depends on parameters like BTS transmitter power, BTS combiner loss and BTS receiver diversity gain. The link budget analysis decides the cell coverage area.

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