

A SYSTEMATIC EVALUATION OF LINK BUDGET FOR EFFECTIVE 900MHz GSM COMMUNICATION SERVICES

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Abstract

This paper describes the various basic parameters necessary to determine a high level link budget for radio communication operating at 900MHz spectrum band. It considers a typical Lagos terrain by using the Okumura and Hata prediction model in calculating the path loss between a transmitter and mobile receivers. In this paper, the rain attenuation calculation from the updated ITU model was incorporated into the link budget to improve GSM communication during rainfall. These parameters can be used to predict a reliable communication ranges for the design and implementation of future GSM communication systems.

Keywords: 900MHz Spectrum Band, Prediction model, Link-budget, Path loss, Rain attenuation, Communication ranges, GSM Communication.

1.0 Introduction

The need for effective propagation of radio signal from a transmitter to numerous and sensitive mobile receivers cannot be underestimated, as this adequately depends on an accurately prepared link budget which gives an account for all the gains and losses from a transmitter through a medium (free space, cable, waveguide etc) to a receiver.

Successful design of radio communication links involves many factors such as the various losses, antenna power and gain. However, it is the first step an engineer will consider in order to determine the feasibility of any given GSM communication system. A link budget calculation is also an excellent means to understand the various factors that must be traded off to realize a given cost and level of reliability for a communication link [1].

The prediction of propagation loss is a central question in the planning and preparation of a radio link budget and the number of approaches and statistical model are available for the prediction and calculation of transmission loss in different condition [2]. In this paper we consider the preparation of link budget parameters for 900MHz GSM communication in different terrain (urban, suburban and rural).

Section 2.0 of this paper briefly discussed some mechanism through which radio signals are propagated. The parameters for effective determination of Link budget were explained in section 3.0. Section 4.0 narrates the radio wave propagation models necessary for effective evaluation of radio link budget while section 5.0 clearly explains link calculations and results. An effective calculated sample link budget for an urban terrain in Lagos is given in section 6.0. Finally, the conclusions were enumerated in section 7.0.

2.0 Radio Wave Propagation Mechanism

In radio propagation, electromagnetic waves suffer several effects that results in power loss and these effects are:

- **Reflection and refraction:** This actual characteristic depends on the polarization of the incident wave and there can also be a 180 degree phase shift in the reflected component. Propagating wave impinges on the object that is larger as compared to the wavelength (e.g. the surface of the earth, tall building, and large wall etc). This results into large scale fading [3].
- **Diffraction:** This occurs when electromagnetic waves hit the edge of an obstacle; a secondary wave is propagated into the shadowed region. An excess path length results in phase shift and Fresnel zone (shadow region) relates phase shift to the position of obstacle. This results into small scale fading.
- **Scattering:** When objects are smaller than the wavelength of the propagating wave (e.g. foliage, street signs, rain droplets, small concrete walls, lamp posts), the incoming wave is scattered into several weaker outgoing signals. This also results into small scale fading [4] & [5].

3.0 Parameters for Determination of Link Budget

The link budget parameters are as follow:

- Transmitter Output Power: cost will be affected by transmitter output power and power amplifier efficiency. Battery consumption may limit the maximum output power and safety consideration may limit the Effective Isotropic Radiated Power (EIRP).
- Transmitter Feed-line Losses: Low-loss cable or wave guides are more expensive
- Connector Losses: losses associated with the feeders connectors
- Combiner Losses: in some cases, diplexers are used to connect feeder cable with a transmitting antenna.
- Transmit Antenna Gain: Higher-gain antennas are more expensive and may not be practical for portable and mobile users.
- Path Loss: This may be a system design parameter (e.g. cell size). For land mobile applications we can use statistical models such as Okumura-Hata.
- Other propagation losses: These may need to be considered in some application.
  a. Log-normal shadowing (land mobile)
  b. Diffraction losses (obstructed paths)
  c. Atmospheric absorption (at high frequencies)
  d. Outdoor-to-indoor (base outside, user indoor)
- Receiver Antenna Gain: The same gain/cost consideration with transmitter antenna. In some cases a higher receiving antenna will also reduce interference.
- Implementation Losses: Some link budgets include an implementation loss to account for distortion, inter-modulation, phase noise and other degradation introduced by real receivers and transmitters.[6]

4.0 Radio Wave Propagation Models for GSM Services

Over the decades, various propagation models have been developed to estimate the propagation path loss at various mobile stations' distances from a base transceiver station to a mobile transceiver.

a. Free space loss model:

The free space model assumes an ideal situation where there are no obstacles that could cause reflection, diffraction or scattering within the line-of sight between the transmitter and receiving stations. Thus the attenuation of the radio wave signal is proportional to the distance from the transmitter.[6]

The receiver power density, at a distance "d" from the transmitter, is expressed as:
$D = P_t A_t / 4\pi d^2$
Where: A_t – BTS Transmitter antenna gain
$A = \lambda^2 A_r / 4\pi$ - Effective area of the receiver antenna

The receiver power density can also be written as:
$D = P_r / A$
Where: $Pr = P_t A_t A_r (\lambda /4d)$
Path Loss, $P_L = 10 \log (P_t / P_r)$
We know that f is in MHz (10^6Hz) and d is Km (10^3m)
$P_L = 32.44 + 20 \log (f) + 20\log (d)$

Practically, the ideal situation upon which this model was derived is quite realistic. Radio wave signal power attenuation depends largely on the frequency band and terrain types between the transmitting and receiving antenna. The propagation path loss varies according to the terrain type and this should be given serious consideration in propagation path loss modeling. This is done using the correction factor for each terrain. A more realistic path loss model is the Okumura and Hata model for macro cells in rural and suburban areas.

The most common practical propagation models for frequency band of 900MHz are:

b. Okumura Model:

Okumura developed an empirical model that is derived from extensive radio propagation studies in Tokyo. It is represented by means of curves with which is applicable for urban areas. For other terrain, Okumura has provided correction factors for three types of terrain:

- Urban Area: Built up city or large town with large buildings and houses with two or more storey, or larger villages with close houses and tall, thickly grown trees.
- Suburban Area: Village or highway scattered with trees and houses, some obstacles near the mobile but not very congested
- Open Area: Open space, no tall trees or buildings in path, plot of land cleared for

300–400 m ahead, e.g. farmland, rice fields, open fields. It also corresponds to rural area, countryside kind of terrain [4] & [6].

c. Hata Model:

This is an empirical prediction method of graphical path loss data provided by Okumura. It is important to note that estimation is easier in this model, but it is limited to frequency of 150MHz to 1500MHz, receiver distance of 1 to 20Km, transmitter antenna height of 3 to 200m and receivers' antenna height of 1 to 10m. Hata presented the urban propagation loss as a standard formula and supplied correction equations for other types of areas.

- **Urban Area** [5]:

$L_U = A + B \log_{10}(f) – 13.82 \log_{10}(h_t) – a(h_r) + [44.9 – 6.55 \log_{10}(h_t)] \text{Log}_{10} d$

Where:

$A = 69.55$, $B = 26.16$ (for frequency of 900MHz)

L_U = Propagation loss in urban area decibel (dB)

f = frequency in Megahertz (MHz)

h_t = Transmitter antenna height in meter (m)

h_r = receiver antenna height in meter (m)

d = distance between transmitter and receiver

$a(h_r)$ = receiver correction factors

Correction factor for small to medium city is written as:

$a(h_r) = (1.1 \log_{10} f – 0.7) h_r – (1.56 \log_{10} f – 0.8)$ (dB)

For large city, the correction factor is written as:

$a(h_r) = 3.2 [\log_{10} (11.75(h_r))]$ (dB)

- **Suburban area** [6]**:**

The path loss formula for urban is modified as:

$L_{SU} = L_U – [\log_{10} f/28]^2 – 5.4$

Where:

L_{SU} = Path loss (dB) in suburban area

- **Open area** [7]**:**

The path loss for suburban is also modified as:

$L_O = L_U – 4.78[\log_{10} f]^2 + 18.33 \log_{10} f – 40.94$

Where:

L_O = Path loss (dB) in an open area

d. Rain Attenuation Using the Updated ITU Model:

The ITU rain attenuation model is given in Reference 8 of the compendium. The first step is applying the ITU model for a given availability on a horizontal or nearly horizontal communication link is to determine the 99.99% fade depth. The standard approved relation governing rain attenuation in every country of the world is clearly written in the proceedings of the ITU. The rain rate attenuation measured in dB is expressed below:

$\text{Attenuation}_{(0.01)} = k.RR^{\alpha}dr$ (dB) [6]

Where: RR = The 99.9% Rain Rate for the rain region (mm/hour). $K.RR^{\alpha}$ = This is the specific rain attenuation (dB/km)

d = This is the link distance (km) r = This is the factor given as $1/1+ (d/d_o) = (0.998)$

d_o = This is the Effective Path Length (km)

$d_o = 35e^{-0.015RR}$ (km)

k = 0.324, RR = 95 (For Lagos metropolis in Nigeria), α = 0.95 and d = Unknown (i.e. there is no specific value assigned).

The parameter d_0 is the effective path length and r is called the distance factor. The values of k and α are gotten from two ITU publications page 838.1 and page 837.1 respectively. Then, the value of d is assumed to be 7.2 km [7], [8], [9], [10], [11], [12] & [13].

5.0 Results of Systematic Evaluation of Link Budget

The objective of evaluation is to balance the uplink and down link. Since the MS and the BTs have different RF architecture, the receive signal sensitivity will be different. BTs power can be adjusted to balance the link. The power balance (up link and down link) will also decide the cell range. The followings scenarios are very important in the process of evaluating an effective link budget. They are:

a. When the down link is greater than the uplink (limitation of the MS output power and BTs receivers sensitivity) it results in the followings:
   - Range of BTS must be greater than Range of MS.
   - Call dropped on uplink after initiation of handover.
   - Coverage area is smaller in reality than the prediction.
   - This is the most frequent case.
b. When the uplink is greater than the down link.
   - Range of MS must be greater than Range of BTS.
   - No coverage problem from MS to BTS.

If the uplink is greater than the down link, it is better than uplink to be less than the down link.
For link calculation, general link budget equation is written as:

$$S_{RX} = EIRP + \sum G - \sum L - L_{\text{Path loss}} + T_x \qquad \text{(1)}$$

Where:
EIRP: Effective Isotropic Radiated Power (dBm)
T_x: Transmitter power (MS or BTS) in dBm
G: Gain of different equipment (dB)
L: Loss of different equipment (dB)
S_{RX}: Receiver Sensitivity (MS or BTS) in dBm
Both the mobile station and base station serves as a transceiver station depending on the flow of communication from the transmitter to the receiver. This can be an uplink (MS transmit, BTS receives) or down link (BTS transmit, MS receives) [7].
Regarding MS sensitivity S_{MS},
Equation (1) can be rewritten for MS sensitivity as:

$$S_{MS} = 10\log_{10}(KTB) + E_C/N_O + NF \qquad \text{(2)}$$

Where:
K = Boltzmann's constant (1.38×10^{-23} J/°K).
T = Ambient temperature (300 °K).
B = Equivalent Noise bandwidth (200 KHz).
E_c/N_o = Intrinsic characteristic of the modulator (8 dB).
NF = Noise figure of receiver (10 dB).
$S_{MS} = -120\text{dBm} + 8\text{dB} + 10\text{dB} = -102\text{dBm}$
In the case of BTS Sensitivity S_{BTS}, there is a change in NF whilst the calculation adopts same rule.
The same calculation applies as in MS but NF for BTS = 8 dB
Therefore, the equation can also be written as:
$S_{BTS} = -120\text{dBm} + 8\text{dB} + 8\text{dB} = -104\text{dBm}$

a. For downlink budget calculation

Equation (1) can be expanded as follows:

$$S_{RX} = EIRP + G_{MS} - I_{DM} - L_{SM} - L_{MCC} - L_{PL} - L_{BL} \qquad \text{(3)}$$

Where:
S_{RX} = MS Sensitivity (-102dBm)
G_{MS} = MS Antenna Gain
I_{DM} = Interference Degradation Margin (3dB)
L_{SM} = Log Normal Shadowing Margin For 90% Coverage Area (5dB)
L_{MCC} = MS antenna cable and connector loss (0dBm)

L_{BL}= 3dB antenna (body loss)
L_{PL} = Propagation / Path Loss
$EIRP = P_{BTS} - L_{CFI} - L_{AFC} + G_{BTS}$ ………………………… (4)

Where:
P_{BTS} = Output power of BTS.
L_{CFI} = Combiner / filter / isolator loss (4dB).
L_{AFC} = BTS transmitter antenna feeder / connector loss (2dB).
G_{BTS} = BTS transmitter gain (dBi)

b. For uplink budget calculation

Equation (1) can be expanded as follows:
$S_{RX} = EIRP + G_{BTS} - I_{DM} - L_{SM} - L_{ACC} - L_{PL} - L_{BL}$ ………….. (5)
Where:
S_{RX} = BTS Sensitivity (-104dBm)
G_{BTS} = BTS receiving Antenna Gain (dB)
I_{DM} = Interference Degradation Margin (3dB)
L_{SM} = Log Normal Shadowing Margin For 90% Coverage Area (5dB)
L_{ACC} = BTS antenna cable and connector loss (dBm)
L_{BL}= 3dB antenna (body loss)
L_{PL} = Propagation / Path Loss
$EIRP = P_{MS} - L_{AFC} + G_{MS}$ ………………. (6)
Where:
P_{MS} = Output power of MS.
L_{AFC} = MS transmitter antenna feeder / connector loss (0dB).
G_{MS} = Mobile antenna gain (0 dBi)

c. For rain attenuation calculation

Now, calculating the rain attenuation for Lagos metropolis as a case study of this paper, we have

$Attenuation_{0.01} = 0.324 \times (95)^{0.95} \times 7.2 \times 0.998 = 176.135$ (dB) [13] …. …………… (7)

6.0 Effective Sample Link Budget for Lagos Metropolis

A corrected sample of link budget for Lagos metropolis is shown in table 1 below. However, table 1 shows a link budget taken from a 900MHz GSM specification which incorporates the rain attenuation result calculation in order to enhance effective GSM communications during rainfall.

Table 1: Effective Calculated Sample Link Budget

System scenario		Cluster scenario	indoor
Frequency band	900MHz		
Environment	Urban		
Cluster scenario	Indoor		
Down link (DL) Data		Uplink (UL) Data	
BTS Max. transmit power (dBm)	46	MS max. transmit power (dBm)	33
BTS combiner loss (dB)	7	BTS combiner loss (dB)	0
7/8 Feeder length (m)	50.00	7/8 Feeder length (m)	50.00
5/4 Jumper length (m)	0.00	5/4 Jumper length (m)	0.00
½ Jumper length (m)	5.00	½ Jumper length (m)	5.00
Feeder connector loss (dB)	0.50	Feeder connector loss (dB)	0.50
BTS Feeder and connector loss (dB)	3.08	BTS Feeder and connector loss (dB)	3.08
BTS Antenna Gain (dBi)	18.00	BTS Antenna Gain (dBi)	18.00
Effective Isotropic Radiated Power EIRP (dBm)	53.93	BTS antenna diversity gain (dB)	3.00
MS sensitivity (dBm)	-102.00	BTS Sensitivity (dBm)	-104.00
Noise correction (dB)	2.00	Noise correction (dB)	2.00
Actual Environment sensitivity (dB)	-100.00	Actual Environment sensitivity (dB)	-108.00
Maximum path loss (dB)	153.93	Maximum path loss (dB)	158.93
Body loss	0.00	Body loss	0.00
Standard development of slow fading (dB)	8.00	Standard development of slow fading (dB)	8.00
Expected area coverage probability	98%	Expected area coverage probability	98%
Corresponding edge coverage probability	94%	Corresponding edge coverage probability	94%
Expected shadow fading margin (dB)	12.2	Expected shadow fading margin (dB)	12.2
Cluster loss (dB)	25	Cluster loss (dB)	25
Allowed Down Link Propagation loss (dB)	292.87	Allowed Up Link Propagation loss (dB)	297.87
Allowed propagation loss satisfying link budget		292.87dB	
Rain attenuation loss for Down Link (dB) 176.14		Rain attenuation loss for Up Link estimate (dB) 176.14	

MS antenna height (m)	1.5
BTS antenna height (m)	30
Twice environment correction (dB)	0
Coverage radius (Km)	0.51

7.0 Conclusions

Based on the results in 5.0, it show that for effective communication between mobile station and the base station, more emphasis must be made concerning the medium and the various losses attached to it, and that must be absolutely considered in preparation of a quality link budget. The rain attenuation loss must be given priority because of its significance while communicating during the period of rainfall.

The link budget which includes all gains and losses from baseband input to baseband output should be given maximum consideration: Choice of propagation model suitable for the terrain profile of the cell must be a priority. Time dispersion (multipath) is a major issue in live network and can be reduced by cell site location and installation of sectorized antennas.

The concluding remark for a good link budget is that both the uplink and downlink must be considered, and the link must be designed in such a way that both the uplink and downlink receive signal balances.

However, the effective link budget calculation decides the cell coverage range in any urban centre and megacity like Lagos in Nigeria.

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