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Development of a Modified Link Budget for Low Earth Orbiting (Leo)-Based Land Mobile Satellite Communications System

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Abstract: **In this paper, a modified link budget model for Low Earth Orbiting (LEO)-based land mobile satellite communications system operating at Ku, K and Ka frequency bands is presented. The model takes into account the effect of additional loss due to Doppler frequency shift. Effect of losses due to Doppler frequency shift on satellite link budget was investigated at different satellite orbits (LEO, MEO and GEO). The results obtained show that at maximum satellite converge angle and central frequencies for Ku, K and Ka bands, the Doppler frequencies for LEO (780 km) are: 325.50 kHz, 423.20 kHz and 726.90 kHz; for MEO (20000 km) we have 88.33 kHz, 114.80 kHz and 197.30 kHz; while GEO (35786 km) stood at 55.26 kHz, 71.84 kHz and 123.40 kHz. Comparative analyses between the conventional and the modified link budget at Ku, K and Ka bands was carried out thereof. The results showed that the Carrier to Noise density ratio $\left({}^{C}/_{N_0}\right)$ at Ku frequency band dropped by 58% (from 31dB without Doppler shift to 13dB with Doppler shift). Similarly, at K band, the ${}^{C}/_{N_0}$ dropped by 62% (from 54dB without Doppler shift to 20dB with Doppler shift). At Ka band, 55% drop of ${}^{C}/_{N_0}$ (from 85dB without Doppler shift to 38dB with Doppler shift) was also observed. With these, it could be concluded that Doppler shift is most pronounced at LEO orbit and therefore, should not be ignored during satellite link budget analysis; because it will give the designer an insightful view as to the amount of margins required for most efficient communication link design.**

Key words: Carrier to Noise Density ratio, Doppler Frequency Shift, K, Ka and Ku frequency band, Land mobile satellite communications link budget, Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO)

SECTION I
1.0 INTRODUCTION

Since the launch of the first world known satellite – SPUTNIK - in 1957, the world has made a tremendous progress in the course of advancing the frontiers of Space science and engineering. The use of Space environment, as many nations now recognize the strategic value and practical benefits of space asset, led to active and aggressive pursuit of space capabilities (Qingchong, 1999 and Ray, 2000). Achieving effective utilization of abundant resources that space science and technology presented could be well categorised into Global Navigation Satellite Systems, Metrological and Terrestrial System, fixed communications satellites and Low Earth Orbit Satellites Systems. LEO satellites have very wide scientific applications such as but not limited to; remote sensing of oceans, analyses of Earth's climate change, Earth's imagery with high resolution and astronomical purposes (Ajayi, 2007). Low earth orbit satellites are also used for data relay and navigation as well as low-cost store-and-forward communications systems (Ajayi, 2007). This technology is currently being used for communicating with mobile terminals and with personal terminals that need stronger signals to function. Unfortunately, Satellite systems operating in LEO are inevitably affected by orbit perturbation such as Doppler frequency shift during signal transmissions between the satellite and earth stations (Ogundele, 2010). The Doppler frequency shift poses the problem of receiving higher or lower frequencies than the original transmitted frequency. The concept of Doppler frequency shift is applicable to the land mobile radio, including digital cellular transmission link (Gataullin et al., 2010). Here, the cause of Doppler effect could be due to the movement of a mobile unit or natural and constructed obstacles (Levano, 1988 and Gataullin et al., 2010). Natural calamities like torrential rains, raging storms, heavy snowfall e.t.c also cause significant Doppler effect in wireless communication (Kausik et. al, 2007). A satellite link margin prediction model used for evaluation of the performance of ASTRO Malaysia was developed by (Khairi, 2009). In (Nikolaos Tsakalozos et al., 2010), Doppler effect in both a classical and a relativistic setting were derived the input-output model by considering Doppler effect as a channel in itself and not necessarily as impairment. (Andrew et al., 2010) investigated methods of exploiting the communication link of small satellites that are required to use fixed data rates. In conjunction with global pass coverage analysis, the methods presented can help designers plan for optimal placement of ground stations and the optimal fixed data rate to use for the ground stations planned. In the work of (Shkelzen et al (2011), antenna noise temperature for Low Earth Orbiting satellite ground stations at L and S Band under the worst propagation case for a hypothetical satellite ground station implemented in different cities of Europe was presented. A software based application for satellite link budget analysis at Ka band was developed by (Mebrek et al., 2012). (Marie Rieche et al., 2014) worked on the modeling of land mobile satellite channel considering the terminal's driving direction based on the channel between a satellite and a mobile terminal. In (Snehasis et al., 2014), a data sheet approach to computing the performance and link budget of LEO satellite (Iridium) for communications operated at the

frequency range 1650 - 1550MHz was presented. Similarly, (Snehasis & Barsha 2014) presented a data sheet approach to calculating the performance and link budget of LEO satellite (Sky Bridge) communication operated at Ku band frequency range (12-14) GHz.
In a LEO satellite system, Doppler shift can be introduced in the both uplink and downlink reasons being that if not accounted for during link budget, it can invariably lead to comparatively weak signal or sometimes complete signal loss.

The rest of the paper is organized as follows: section II presents the review of the pertinent theoretical background. Section III explains the methods and materials used. Results and analysis and presented in section IV. Finally in section V, we present the conclusion.

SECTION II
2.0 CLASSICAL LINK BUDGET ANALYSIS

A link budget is simply the addition and subtraction of gains and losses in a radio link. When the gains and losses of various system components are summed together, the result is an estimation of the system performance in the real world (Maral, 2002). To arrive at an accurate answer, every component or factor that contributes to gain or loss must be included. Detailed reviews of these factors are provided in the following subsections:

2.1 Effective Isotropic Radiated Power (EIRP)

EIRP describes the combination of a transmitter power and antenna gain in terms of an equivalent isotropic source with power P_t watts, radiating uniformly in all directions (Pratt, 2003). EIRP is expressed mathematically as (Pratt, 2003):

$$[EIRP]_{Uplink} = [p_{hpa}] - [tfl]_{Uplink} + [G_{es}] \quad (2.1)$$

Where: $[p_{hpa}]$ = transmitted power, $[tfl]_{uplink}$ = transmitter to antennae line loss (feeder loss) and $[G_{es}]$ = transmit antenna gain.

2.2 Total Transmission Path Loss (tpl)

The transmission path loss or $[tpl]$ is the summation of all the losses and it is defined as (NIIT, 2007);

$$[tpl] = [fsl + pl + aml + aal + Gal + Rl + fl + sl + tp] \quad (2.2)$$

Where: fsl = free space loss, aml = antenna misalignment loss, pl = polarization loss and aal = atmospheric absorption loss, Gal = gaseous absorption loss, Rl = rain attenuation, fl = attenuation caused by clouds and fog, sl = loss due to snow and tp = tropospheric attenuation.

2.3 Antenna Gain

Antenna gain in dB for satellite applications is usually expressed as the dB value (Louis, 2008);

$$G(dB) = 10\log\left(109.66 f^2 d^2 \eta_A\right) \quad (2.3)$$

Where; d = Physical diameter of the antenna, f = Carrier wave frequency.

2.4 Link Power Equation

The received power P_{ri} is commonly referred to as carrier power; because most satellite links use either frequency modulation for analog transmission or phase modulation for digital transmission (Ogundele, 2010). To compute the received power at the satellite receiver input, the isotropic power gain of the satellite antenna $[G_{sat}]$ and any receiver feeder losses $[rfl]$ must to be taken into account (Adria, 2010);

$$P_{ri} = [EIRP] - [tpl] + G/T - [rfl] \ dBW \quad (2.4)$$

Where; $EIRP$ = Effective Isotropic Radiated Power, tpl = Transmission path loss

G/T = Satellite antennae gain to temperature and rfl = Receiver feeder loss.

2.5 Figure of Merit

The figure of merit (G/T ratio) is another parameter of interest in link budgeting used to specifying the system performance (Dennis, 2001).

$$[G/T]_{Uplink} = [G]_{sat} - [T_s] (measured\ in\ dBK^{-1}) \quad (2.5)$$

Where, G = Antenna gain of the satellite and

T_s = System noise temperature.

2.6 Carrier to Noise Density Ratio

Carrier to noise density ratio $\left(\frac{C}{N_O}\right)$ is the ratio of the average wideband carrier power to noise density (Ogundele, 2010).

$$\left[\frac{C}{N_o}\right] = [EIRP] - [tpl] + [G]_{sat} - [T_s] + 228.6\ (dB) \quad (2.6)$$

It is worthy to note that in conventional approach to satellite link budget analysis, the effect of Doppler frequency shift is neglected as it can be seen in equations (2.6). Furthermore, a complete communication system consists of an uplink and downlink; and the overall C/N_0 ratio is the combine effect of these two (Vijitha et al, 2011). The carrier to noise ratio component of the uplink gives the carrier to noise power ratio for the link from the transmit terminal to the satellite receiver, and the carrier to noise ratio component of the downlink gives the carrier to noise power ratio for the link from the satellite antenna output to the ground receiver (Vijitha et al, 2011). The overall C/N_0 is expressed as: (Vijitha et al, 2011).

$$\left[C/N_0\right]_{Total} = \left[\frac{C}{N_0}\right]_{Uplink} + \left[\frac{C}{N_0}\right]_{Dowlink} \quad (2.7)$$

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2.6.1 Energy-Per-Bit to Noise Density

$$\left[E_b/N_o\right]=[Pt]+[Gt]-[tpl]+[Gr]+228.6-[T_s]-[R_b] \quad (2.8)$$

SECTION III

3.0 METHODOLOGY

i. Selection of key parameters.
ii. Development of a mathematical model of Doppler frequency shift
iii. Development of a modified model of a satellite link budget by including Doppler effect
iv. Simulation of the modified link budget at Ku, K and Ka bands using MATLAB R 2014a version.
v. Comparison between the simulated modified and conventional link budgets at Ku, K and Ka bands.
vi. Validation

3.1 Selection of the Satellite Transmitter Power

The power necessary for the transmission of a signal with a given level of quality depends on the method of modulation, satellite size and power limits. The high power amplifier (HPA) in an earth station facility provides the RF carrier power to the input terminals of the antenna that, when combined with the antenna gain, yields the equivalent isotropic radiated power (EIRP) required for the uplink to the satellite. The output power ratings of different HPA (KPA, SSPA and TWTA) are provided in Table 3.1. For the purpose of this research work, Traveling Wave Tube Amplifier (TWTA) is used due to its linearity, efficiency and reliability. The TWTAs also gives the widest bandwidth, with the best power consumption at a cost effective price when compared to KPA and SSPA.

Table 3.1: Power ratings of HPA (KPA, SSPA and TWTA) operating at Ku, K and Ka-bands (www.ATIcourses.com)

Type of Higher Power Amplifier (HPA)	Frequency Band (GHz)	Output Power (W)	Gain (dB)
KPA	Ku	10W-60W	45dB
	K	10W-100W	80dB
	Ka	15W-250W	80dB
SSPA	Ku	10W-100W	60dB 60dB
	K	10W-120W	60dB
	Ka	10W-120W	
TWTA	Ku	10W-700W	40Db
	K	10W-700W	40dB
	Ka	10W-700W	40dB

3.2 Development of a Mathematical Model of Doppler Frequency Shift

Doppler frequency shift could be best computed from the geometry of the satellite dynamic in orbit. In order to accurately calculate the Doppler frequency shift, a relative velocity between satellite and ground terminal is required. Figure 3.1 shows a typical representation of a satellite dynamics in orbit.

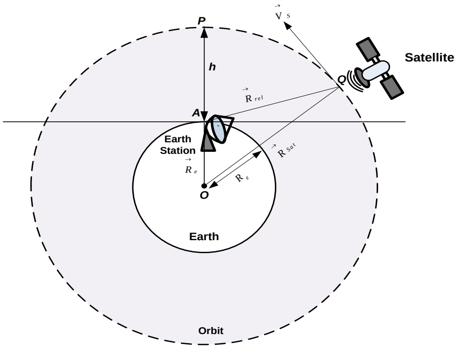

Figure 3.1: Typical Representation of Satellite Dynamics in an Orbit (Naser et al., 2001)

To compute the relative velocity of the Earth's terminal and the satellite, the ground station and the satellite velocity vectors must be in the same coordinate reference frame (Naser et al., 2001). If $\vec{R}_e$ and $\vec{R}_{Sat}$ are the position vectors of the user terminal or Earth's station terminal and satellite respectively, then relative position of the satellite and Earth's terminal is given by (You et al., 2000):

$$\vec{R}_{rel} = \vec{R}_{Sat} - \vec{R}_e \quad (3.1)$$

The relative velocity of the satellite and Earth's terminal is given by;

$$\vec{V}_{rel} = \frac{d\,\vec{R}_{rel}}{dt} = \frac{d\left(\vec{R}_{Sat} - \vec{R}_e\right)}{dt} \quad (3.2)$$

Equation (3.2) can further be expressed in terms of magnitude and direction by as;

$$\vec{V}_{rel} = \vec{V}_S \cdot \hat{\vec{R}}_{rel} \quad (3.3)$$

Where $\hat{\vec{R}}_{rel}$ is the position vector of $\vec{R}_{rel}$ given by;

$$\hat{\vec{R}}_{rel} = \frac{\vec{R}_{rel}}{\left|\vec{R}_{rel}\right|} \quad (3.4)$$

During Doppler effect, the received and transmitted signal frequencies are related by the following equation (Gataullin et al., 2010);

$$f_r = f_t \pm f_{ds} = f_t \pm \frac{\left|\vec{V}_{rel}\right| f_c}{C} \quad (3.5)$$

Where:

f_r and f_t are the received and transmitted signal frequencies respectively.

f_c is the carrier wave frequency.

f_{ds} is the Doppler shift frequency.

$\left|\vec{V}_{rel}\right|$ is the magnitude of the relative velocity between the satellite and the Earth's terminal, C is the velocity of electromagnetic wave. It can be deduced from equation (3.5) that the Doppler shift frequency is given by (Gataullin et al., 2010);

$$f_{ds} = \pm\frac{\left|\vec{V}_{rel}\right| f_c}{C} \tag{3.6}$$

f_{ds} = Doppler shift frequency, $\vec{V}_{rel}$ = relative velocity of the satellite and the Earth's terminal sometimes called relative radial velocity between the satellite and the Earth's, f_c = Carrier frequency and C = Velocity of electromagnetic wave. The ambiguous sign in equation (3.6) explains the scenarios where the satellite is either ascending towards horizon or receding below it with respect to the position of the Earth's terminal. Figure 3.2 shown below is the modification of figure 3.1 and was used to develop the appropriate mathematical representation of Doppler shift as the satellite sweeps over the orbit in an elliptical path.

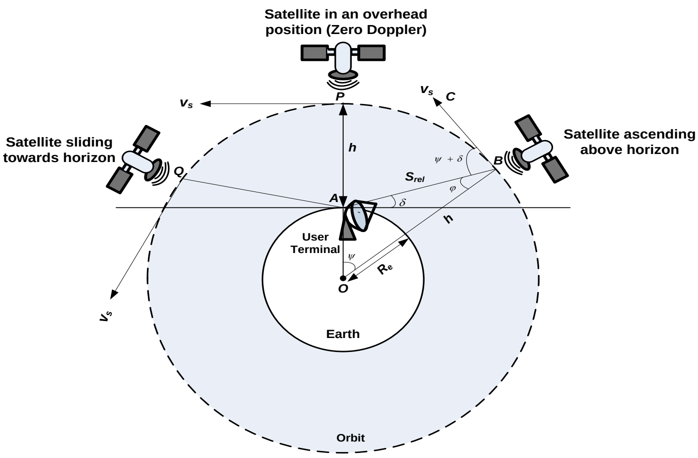

Figure 3.2: Geometrical Representation of Satellite Orbital Dynamics

Applying sine rule to ΔAOB, (δ) and (φ) are related to Earth radius (R_e) and height of the orbit (h) by the following equation;

$$\frac{\sin(90^0+\delta)}{R_e+h} = \frac{\sin\varphi}{R_e} \tag{3.7}$$

Hence, $$\sin\varphi = \frac{R_e\cos\delta}{R_e+h} \tag{3.8}$$

Similarly, $$\varphi = 90^0 - (\psi+\delta) \tag{3.9}$$

Using equations (3.8) and (3.9), the satellite coverage angle ψ will be;

$$\psi = \cos^{-1}\left(\frac{R_e\cos\delta}{(R_e+h)}\right) - \delta \tag{3.10}$$

Where $(\psi+\delta)$ is the angle between the satellite and the line joining it with the Earth's terminal.

To compute the relative velocity between the satellite and the Earth's terminal, a radial vector component of the satellite velocity ($\vec{V}_{rel}$) in the direction relative to the Earth's terminal is obtain by the transformation of satellite velocity V_s along line AB (lining joining the satellite and Earth's terminal).

$$\vec{V}_{rel} = V_S\cos(\psi+\delta) \tag{3.11}$$

Where V_S is the satellite orbital velocity. Using equation (3.10), equation (3.11) becomes;

$$\vec{V}_{rel} = V_S\sin\varphi \tag{3.12}$$

Substituting equations (3.8) and (3.12), the satellite radial velocity relative to the Earth's terminal becomes;

$$\vec{V}_{rel} = \frac{V_S R_e\cos\delta}{R_e+h} \tag{3.13}$$

With equations (3.13) and (3.6), the Doppler shift frequency is written as;

$$f_{ds} = \frac{V_S R_e f_c\cos\delta}{C\left(R_e+h\right)} \tag{3.14}$$

It can be seen from equation (3.14) that the Doppler shift is zero when the grazing or elevation angle, δ is equal to 90^0. In this position, the satellite is directly overhead the Earth's terminal. The relative distance between the satellite and the Earth's terminal S_{rel} is calculated from the cosine rule using ΔAOB as;

$$S_{rel} = \left[R^2{}_e + \left(R_e+h\right)^2 - 2R_e\left(R_e+h\right)\cos\psi\right]^{1/2} \tag{3.15}$$

Similarly, S_{rel} can be calculated from sine rule as;

$$\frac{S_{rel}}{\sin\psi} = \frac{R_e+h}{\sin(90^0+\delta)} \tag{3.16}$$

$$\cos\delta = \left(\frac{R_e+h}{S_{rel}}\right)\sin\psi \tag{3.17}$$

Using equation (3.17), equation (3.14) is further expressed as;

$$f_{ds} = \frac{V_S R_e f_c\sin\psi}{CS_{rel}} \tag{3.18}$$

The magnitude of the velocity of satellite in orbit is calculated from law gravitation as (Carassa, 1989 and Valdoni, 1990);

$$V_S = \frac{2\pi\left(R_e + h\right)}{T} \quad (3.19)$$

Where T is the satellite orbital period. The period of the satellite can be calculated from Kepler's equation as (Valdoni, 1990);

$$T = 2\pi\sqrt{\frac{\left(R_e + h\right)^3}{\mu_L}} \quad (3.20)$$

Equation (3.19) can also be written as;

$$V_S = \sqrt{\frac{\mu_L}{\left(R_e + h\right)}} \quad (3.21)$$

Where

$\mu_L = 398\ 600\, km^3 \sec^{-2} = 3.896\times10^{14}\, m^3 \sec^{-2}$

(Kepler's constant).

It can be seen from equations (3.15) through (3.21) that the Doppler frequency shift depends on both the relative velocity and distance between the satellite and Earth's terminal, the frequency of the carrier signal, the height of the orbit and the period of satellite on the orbit.

Doppler frequency shift can be expressed in dB using equation (3.18) as follows;

$$\left[f_{ds}\right] = \left[10\log\left(V_S R_e f_c \sin\psi\right)\right] - \left[10\log\left(CS_{rel}\right)\right]\ (dB) \quad (3.22)$$

3.3 Development of a Modified Model of a Satellite Link Budget with Doppler Effect

The modified model of link budget is obtained by adding the Doppler equation in decibel to the classical link budget equation (2.6). The modified link budget equation is expressed as;

$$\left[\frac{C}{N_o}\right]_{Modified} = \left[EIRP\right] - \left[fsl + pl + aml + aal + Gal + Rl + fl + sl + tp\right] - \left[f_{ds}\right] + \left[G\right]_{sat} - \left[T_s\right] + 228.6 \quad (3.23)$$

Where;

$$\left[f_{ds}\right] = \left[10\log\left(V_S R_e f_c \sin\psi\right)\right] - \left[10\log\left(CS_{rel}\right)\right]\ (dB)$$

and; $\left[tpl\right] = \left[fsl + pl + aml + aal + Gal + Rl + fl + sl + tp\right]$

Therefore equation (3.23) becomes;

$$\left[\frac{C}{N_o}\right]_{Modified} = \left[EIRP\right] - \left[tpl\right] - \left[f_{ds}\right] + \left[G\right]_{sat} - \left[T_s\right] + 228.6 \quad (3.24)$$

As an illustration, Doppler effect was calculated at minimum grazing or elevation angle and the corresponding maximum satellite coverage angle, ($\delta_{\min} = 20.07^0$ *and* $\psi_{\max} = 8^0$) (Carassa, 1989) using the following values: $V_S = 7377.57\, ms^{-1}$, $R_e = 6378 km$, $h = 780 km$, $f_c = (15.0GHz, 19.5GHz\ and\ 33.5GHz)$ and $S_{rel} = 2480.54 km$. Using these values and equation (3.18), the Doppler frequency shift for Ku, K and Ka bands in LEO were respectively calculated as: f_{dsku}=325.483kHz, f_{dsk}=423.129kHz and f_{dska}=726.914kHz. The corresponding values of these frequencies in decibel are: $\left[f_{dsKu}\right] = 55.125\ (dB)$, $\left[f_{dsK}\right] = 56.265\ (dB)$ and $\left[f_{dsKa}\right] = 58.615\ (dB)$. With these values, modified link budget equations at Ku, K and Ka bands can be respectively written as;

$$\left[\frac{C}{N_o}\right]_{Modified(Ku)} = \left[EIRP\right] - \left[tpl\right] + \left[G\right]_{sat} - 55.125 - \left[T_s\right] + 228.6\ (dB) \quad (3.25)$$

$$\left[\frac{C}{N_o}\right]_{Modified(K)} = \left[EIRP\right] - \left[tpl\right] + \left[G\right]_{sat} - 56.265 - \left[T_s\right] + 228.6\ (dB) \quad (3.26)$$

$$\left[\frac{C}{N_o}\right]_{Modified(Ka)} = \left[EIRP\right] - \left[tpl\right] + \left[G\right]_{sat} - 58.615 - \left[T_s\right] + 228.6\ (dB) \quad (3.27)$$

The modified equation for energy per noise density, $\left[\frac{E_b}{N_0}\right]$ using equations (2.8) with the Doppler Effect becomes;

$$\left[E_b/N_o\right] = \left[Pt\right] + \left[Gt\right] + \left[Gr\right] - \left[tpl\right] - \left[f_{ds}\right] + 228.6 - \left[T_s\right] - \left[R_b\right] \quad (3.28)$$

The overall link budget equations taking into account the effect of Doppler in terms of $\frac{C}{N_0}$ and $\frac{E_b}{N_0}$ for both uplink and down link can be written as;

$$\left[C/N_o\right]_{Up\,link} = \left[Pt\right]_{ET} + \left[Gt\right]_{ET} + \left[Gr\right]_{Sat} - \left[tpl\right] - \left[f_{ds}\right] + 228.6 - \left[T_{Sat}\right] \quad (3.29)$$

$$\left[C/N_o\right]_{Down\,link} = \left[Pt\right]_{Sat} + \left[Gt\right]_{Sat} + \left[Gr\right]_{ET} - \left[tpl\right] - \left[f_{ds}\right] + 228.6 - \left[T_{ET}\right] \quad (3.30)$$

$$\left[E_b/N_o\right]_{Up\,link} = \left[Pt\right]_{ET} + \left[Gt\right]_{ET} + \left[Gr\right]_{Sat} - \left[tpl\right] - \left[f_{ds}\right] + 228.6 - \left[T_{Sat}\right] - \left[R_{b\uparrow}\right] \quad (3.31)$$

$$\left[E_b/N_o\right]_{Down\,link} = \left[Pt\right]_{Sat} + \left[Gt\right]_{Sat} + \left[Gr\right]_{ET} - \left[tpl\right] - \left[f_{ds}\right] + 228.6 - \left[T_{ET}\right] - \left[R_{b\downarrow}\right] \quad (3.32)$$

The total carrier to noise density ratio is the summation of equations (3.29) and (3.30). Similarly, the summation of equations (3.31) and (3.32) yields the total energy bit to noise density ratio. The two parameters are expressed as;

$$\left[C/N_o\right]_{Total} = \left[Pt\right]_{ET} + \left[Gt\right]_{ET} + \left[Gr\right]_{sat} + \left[Pt\right]_{sat} + \left[Gt\right]_{sat} + \left[Gr\right]_{ET} - \left[T_{sat}\right] - \left[T_{ET}\right] - 2\left(\left[tpl\right] + \left[f_{ds}\right]\right) + 457.2 \quad (3.33)$$

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$$\left[{E_b}/{N_o}\right]_{Total} = [Pt]_{ET} + [Gt]_{ET} + [Gr]_{sat} + [Pt]_{sat} + [Gt]_{sat} + [Gr]_{ET} - [T_{sat}] - [T_{ET}] - 2([tpl] + [f_{ds}]) - [R_{b\uparrow}] - [R_{b\downarrow}] + 457.2 \tag{3.34}$$

The modified total path loss is thus;

$$[tpl]_{Total} = [tpl] + [f_{ds}] \tag{3.35}$$

SECTION IV

4.0 RESULTS DISCUSSION

4.1Variation of Carrier to Noise Density Ratio with Transmission Path Loss

In order to investigate the effect of Doppler frequency shift on the carrier signal, the overall carrier to noise density ratio was plotted against the total transmission path loss at Ku, K and Ka bands with and without the Doppler frequency shift. This relationship is depicted in Figures: 4.2, 4.3 and 4.4; which were obtained using equations: (2.6), (2.7), (3.33), (3.23) and the data in Table 3.1.

4.1.1 Variation of Carrier to Noise Density Ratio with Transmission Path Loss at Ku-Band

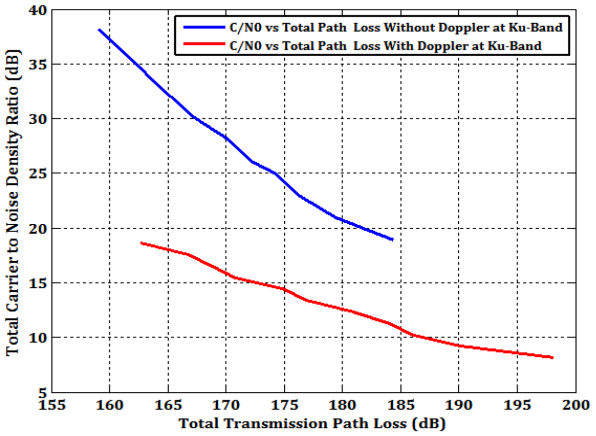

Figure 4.2: ${C}/{N_0}$ against the Transmission Path Loss at Ku-Band

From Figure 4.2 it can be seen that there is considerable decrease in carrier to noise density ratio. When the Doppler frequency shift was introduced, an appreciable decrease in ${C}/{N_0}$ was observed. At 158 dB transmission path loss for instance, the ${C}/{N_0}$ without the Doppler effect is 38 dB. This value reduces by 41.67% (19 dB) with the inclusion of Doppler frequency shift. Similarly, the same scenarios were observed at both K and Ka bands (see Figures 4.3 and 4.4).

4.1.2 Variation of Carrier to Noise Density Ratio with Transmission Path Loss at K-Band

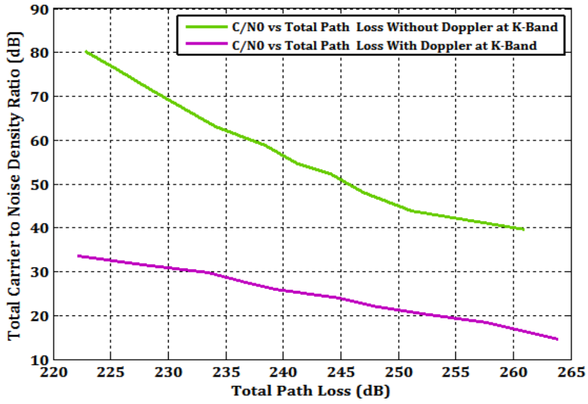

Figure 4.3: ${C}/{N_0}$ against the Transmission Path Loss at K-Band

From Figure 4.3, excluding the Doppler frequency shift, carrier to noise density ratio decreases from 80dB to 40dB with corresponding increase in the total transmission path loss from 223dB to 261dB as indicated by the green line graph. With the inclusion of Doppler frequency shift however, a significant lowering of the value is seen with the carrier to noise density ratio plummeting from 33dB to 17dB (58.75% at 223dB transmission path loss and 57.5% at 264dB transmission path loss).

4.1.3 Variation of Carrier to Noise Density Ratio with Transmission Path Loss at Ka-Band

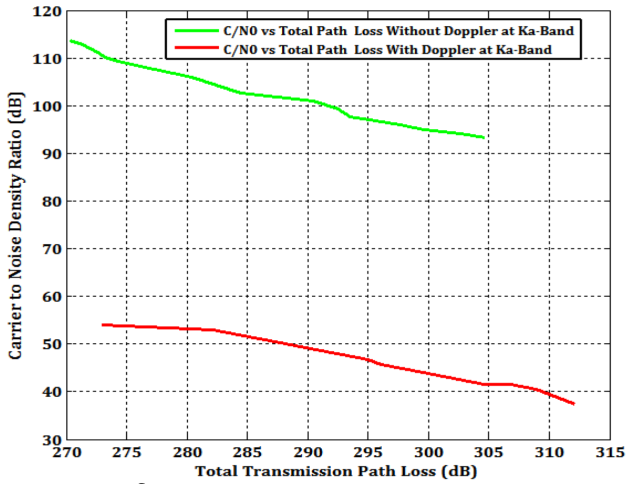

Figure 4.4: ${C}/{N_0}$ against the Transmission Path Loss at Ka-Band.

As it is illustrated in Figure 4.4 the carrier to noise density ratio decreased from 110dB at 271dB transmission path loss to 94.05dB at 304.9dB transmission path loss without the effect of Doppler frequency shift. When Doppler frequency shift was included, there was a significant fall in ${C}/{N_0}$ by 50.9% and 56.4% at 273dB and 312.9dB respectively.

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4.2 Modified Link Model Validation

The modified model developed was validated through comparison with the work of Snehasis & Barsha (2014). The graphical plots obtained thereof were shown in Figures 4.5, 4.6 and 4.7. These figures further confirmed that with the inclusion of impairment due to Doppler frequency shift, there was a significant decline in carrier to noise density ratio when compared with the corresponding values obtained without the Doppler frequency effect (using conventional model).

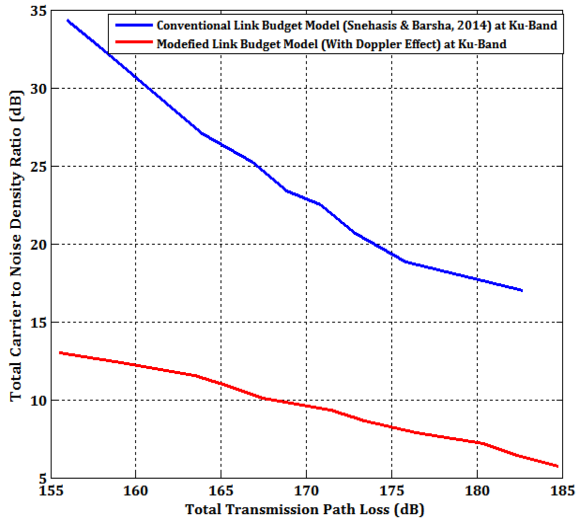

Figure 4.5: Variation of C/N_0 with Transmission Path Loss at Ku-Band

From Figure 4.5, it can be seen that at transmission path of 160dB for example, the Carrier to Noise density ratio C/N_0 for Ku frequency band dropped by 58% (from 31dB without Doppler shift to 13dB with Doppler shift).

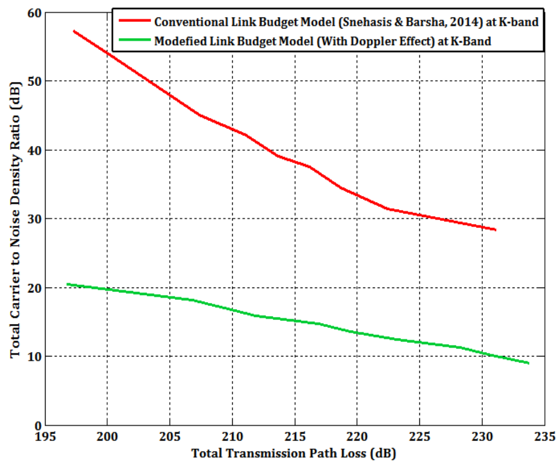

Figure 4.6: Variation of C/N_0 with Transmission Path Loss at K-Band

At K band, a considerable reduction in carrier to noise density ratio, C/N_0 is seen. The C/N_0 for K frequency band dropped by 62% (from 54dB without Doppler shift to 20dB with Doppler shift).

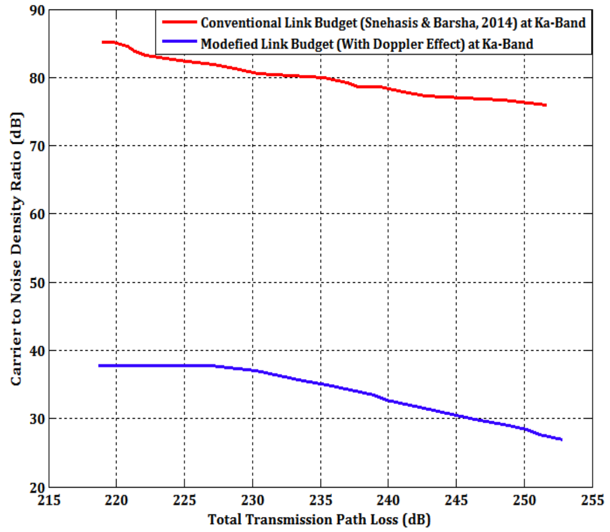

Figure 4.7: Variation of C/N_0 with Transmission Path Loss at Ka-Band

The results at Ka band follows a similar pattern when compared with that observed in the Ku and K band. The C/N_0 for Ka frequency band dropped by 55% (from 85dB without Doppler shift to 38dB with Doppler shift).

SECTION V
5.0 CONCLUSION

A detailed approach to the development of modified link budget for land mobile satellites communication systems was presented. The model took into account the additional impairment due to Doppler frequency shift, which is often neglected in the conventional satellite link budget model. The effect of losses due to Doppler frequency shift on satellite link budget was investigated at Ku, K and Ka bands.

Comparative analyses between the conventional (without Doppler shift) and the modified link budget (with the inclusion of Doppler shift) at Ku, K and Ka bands was achieved thereof. The results obtained show the Carrier to Noise density ratio C/N_0 for Ku frequency band dropped by 58% (from 31dB without Doppler shift to 13dB with Doppler shift). The C/N_0 for K frequency band dropped by 62% (from 54dB without Doppler shift to 20dB with Doppler shift). The results at Ka band follows a similar pattern when compared with that observed in the Ku and K band. The C/N_0 for Ka frequency band dropped by 55% (from 85dB without Doppler shift to 38dB with Doppler shift). It can be seen from the results obtained that with Doppler shift, Carrier to noise density ratio is worse when compared to the values obtained by snehasis and Barsha.

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