

Maximizing Throughput of The GEO Satellite At C/Ku Bands

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Research Article

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Abstract

The need for broadband data has increased speedily but in underserved rural areas, the mobile connectivity of 3G and LTE is still a significant challenge. By looking at the historical trend, the data traffic and the internet are still expected to grow in these areas [1]. The next generation of satellites is trying to decrease the cost per MB having the advantage of higher throughput and availability. To maintain the performance of the link, choosing an appropriate frequency is evident. A multi-beam satellite system can fulfill the demand and performance over a coverage area. The high throughput satellites (HTS) fulfill this requirement using C and Ku bands. In this paper, we present the benefits of using Ku-band on the user site and the composite of C and Ku bands on the gateway site. This configuration has proved to be a cost-efficient solution with high performance over the traditional straight configuration. The data rate is improved five times both on upstream and downstream as compared to the existing available FSS system. Moreover, it has got an advantage to Ku-band user that they would enjoy the significant improvement in the performance without upgrading their systems.

I. Introduction

The new generation of satellites is high throughput satellites (HTS). It has many times more throughput of the traditional FSS satellites allocating the same amount of frequency on orbit [2]. The throughput of these satellites is high by taking advantage of frequency reuse and multiple spot beams. The cost per bit is reduced irrespective of spectrum choice [3]. ADS is replaced by FTTH for access performance as a new standard. [4]. Throughput in this scenario is information delivery speed (bits/sec) which depends upon:

Bandwidth (MHz): It is increased by using frequency reuse phenomena.

Efficiency (bits/sec per MHz): This is the amount of error-free information in the allocated bandwidth, which can be achieved by using spot beams.

One of the fundamental differences in the architecture of HTS and traditional satellites is the use of multiple spot beams for the coverage of a specific desired location, unlike the previous wide beams. These spots beams have two major benefits [5].

High Gain (Transmit/Receive): The directivity in spot beams is high so the gain is higher compared to traditional wide beams. A narrow beam results in increased power due to which user terminals become smaller and higher order modulation becomes possible, thus higher data rate transmission per unit is achieved.

Frequency Re-Use: The desired service location can be covered by multiple spot beams. The same frequency band and polarization can be used by several beams which mean an increase in the capacity of the satellite system for a specific frequency band allocated to the system. Four color schemes are the best settlement between performance and system capacity however three and seven color scenario is also be implemented for frequency reuse [6]. Dividing no of spots of spots beam antenna by no of colors

gives the frequency reuse factor of spot beam antenna. The capacity of spot beam antenna is frequency reuse factor times more than a large contour single beam.

This capacity increase is attained without raising DC power and RF but just with a little amendment in the satellite [7]. In Single feed per beam SFB antennas the multiple beams are produced by a single horn. Active or passive lenses and single oversized designed reflector are used to produce overlapping spot beams to evade holes in the coverage area [8]. Multiple spot beam antennas MSB uses arrays of small horns to generate beams so using only one reflector overlapping spots can be achieved which pointer reduction in cost and mass.

High throughput satellites (HTS) system is classified into different generation according to its capacity.

The first generation of HTS gives around a few tens of Gbits/s while the 2nd HTS generation produces one hundred Gbits/s approximately e.g. KA-SAT, Via Sat 1, Echo-star etc. [6]. Several hundreds of Gbit/s will be offered by the third generation. It will boost the capability of the system and optimization of the satellite and system resources, providing quality close to fiber to the home [7] [8][9]. KA-SAT is the new generation satellite of Ka-band of HTS system. It provides services for broadband and TV broadcasting as well [9]. It has 82 spots covering a large area using frequency-reuse factor 20-times. This system uses small user terminals for Asymmetric digital subscriber line (ADSL). Its capacity is over 90 Gbit/s. It was the first HTS Ka-band satellite launched with this much capacity on 26 Dec 2010 and its commercial operation was started on 31 May 2011[10].

ii. High Thoughtput Satellite Systems

The High throughput Satellite (HTS) system consists of two kinds of major links.

Forward Link of HTS: It maintains communications from a gateway to the user terminal. It includes uplinks satellite and downlink of user link. Data is transmitted from gateway to user terminal via forwarding link.

Return Link of HTS: It supports communication from the user terminal to the gateway. It includes uplink of the user link, satellite, and downlink of the feeder link. Data is transmitted from user to gateway via return link.

A multi-spot antenna configuration is used to serve the service area of the user. The service area is formed by contiguous cells [11]. The circular beam provides the performance of each cell. These cells are usually established on systematic polygons. The performance of each cell is determined by EIRP, G/T, downlink C/I and uplink C/I. The use of several spots for an area boosts the antenna gain per beam which results in improvement in the following [9]. Uplink Performance i.e. G/T (It is the figure of merit of satellite receiving system) and capacity return. Downlink Performance, increased antenna gains either it increases the forward capacity or reduce the repeater RF power requirement. Since there are several cells so frequency reuse with on a given polarization is possible several times. For frequency reuse, each cell is

separated sufficiently so that intersystem interference is controlled. Usually, a 4-color scheme with 250 MHz assigned per color is used for ordinary frequency reuse scheme, Quarter of the available frequency capacity is utilized by each color the colors can be red, green, yellow and blue. To reduce the number of gateways, several cells are associated with each gateway so both the polarization can be used by frequency plan. It means a gateway frequency plan that consists of many channels on each polarization. Using 2.0 m parabolic dish antenna, 16 beams of 0.75° spots beams can be created [12].

iii. Forward Link Of Hts

It is the path of the signal from the gateway to the user is called a forward link. As the downlink (user) service area is decomposed into hexagonal cells thus key elements of the exploration concentrated on the output of the cell. In the case of HTS, consider a cell is a hexagon which is totally bounded by a circle. The effective isotropic power (EIRP) can be stated as a function of the normalized region [9].

$$EIRP_{\beta} = EIRP_{PK} - \beta (\theta/\cos\theta)^2 \quad (4.1)$$

$$EIRP_{PK} = P_{TWT} - L_{O/P} - L_{ant} + D_{PK}$$

Where,

P_{TWT} is the Traveling Wave Tube (TWT) RF power in dBw

$L_{O/P}$ is the Repeater Output Losses in dB

L_{ant} is the Antenna Losses in dB

D_{PK} is the Peak Directivity in dBi

A. Forward Downlink C/I

In this case, the interference arises at the end terminal in the cell. It gets the signal proposed to it as well as also gets the signals proposed to other cells. In the four-color scheme, only between cells of the same color can receive interference. Cells of dissimilar colors are orthogonal in polarization and frequency.

Forward Link Requirements: The forward link of High Throughput Satellites normally uses variable coding of modulation (VCM) and adaptive coding of modulation (ACM) which has the capability of multi-spot coverage and can handle atmospheric conditions and different geographical locations. The DVB-S2 standard [13] is a good example of the ACM and VCM. It provides the system to improve the modulation and coding in both static and dynamic conditions. Lower coding rates and higher order modulations are utilized at the peak performance of the beam while at the edges of the beam higher coding rates and lower order modulation are used. Mod cod (Modulation and coding) is used to sustain the optimum link under a dynamic condition or rain fade. Under critical situations, the finest data rates are offered according to the link properties at a definite terrestrial area.

IV. Forward Link Budget Analysis

The forward link which is an important component of the link budget. Its performance is determined by the performance of downlink. If propagation effects are ignored, the uplink performance remains constant. The downlink is the function of an area where terminal exists in a given cell. Further interferences that degrade downlink is repeater C/I effects and inter-spot- interference (ISI) [9].

$$\left(\frac{C}{N+I} \right)_{FWD} = -10 \log_{10} \{x\}$$

$$X = 10^{-(C/N)FWD.UL/10} + 10^{-(C/N)FWD.DL/10} + 10^{-(C/I) FWD. RDTR/10} + 10^{-(C/I)FWD.DL/10}$$

Where,

$(C/N)_{FWD.UL}$ is the Uplink Carrier to Noise Ratio (C/N) in db.

$(C/N)_{FWD.DL}$ is the Downlink Carrier to Noise ratio (C/N) in db.

$(C/I)_{FWD.RPTR}$ is the Carrier to Interference Ratio due to the forward repeater in db.

$(C/I)_{FWD.DL}$ is the Downlink Carrier to Interference ratio due to the inter-spot in db.

V. Hybrid C/ku Band System

A hybrid system of C/Ku- bands of high throughput satellite system if designed will be the optimal system to increase the throughput of a conventional satellite system in tropical areas and overcome the atmospheric effects. This improvement increases the performance without the requirement to upgrade the user terminal site.

For a satellite link, the total C/N is represented by [14]

$$(C/N)_{Total} = \{ [(C/N)_{DL}]^{-1} + [(C/N)_{UpL}]^{-1} + [(C/N)_{IBI}]^{-1} + [(C/N)_{ASI}]^{-1} \}^{-1}$$

Where,

$(C/N)_{UpL}$ = Uplink carrier to noise ratio of the satellite due to thermal noise

$(C/N)_{DL}$ = Downlink carrier to noise ratio of the satellite due to thermal noise of the terminal

$(C/I)_{ASI}$ = (C/I) carrier to interference ratio due to adjacent satellite interference

$(C/I)_{IBI}$ = (C/I) carrier to interference ratio due to inter-beam interference from frequency reuse in other beams. The values for $(C/I)_{IBI}$ and $(C/I)_{ASI}$ normally are 18dB [15]

$$(C/N)_{\text{forward}} = \{0.032 + [0.91(C/N)_{\text{DL}}]^{-1}\}^{-1} \quad (5.1)$$

$$(C/N)_{\text{Return}} = \{[0.032 + 0.91(C/N)_{\text{UpL}}]^{-1}\}^{-1} \quad (5.2)$$

$$(C/N)_{\text{DL}} = \text{EIRP} + G/T - K - B - \text{FSPL} \quad (5.3)$$

Vi. Performance Of Forward Link

It is used to transmit information from the gateway to the user terminal, the customer premise equipment (CEP) should be simpler and less expensive. Ku and Ka are the two bands more suitable for this purpose. To compare the performances of these two bands the values of EIRP, FSPL, G/T, and K is assumed as follow.

i. For Ku-Band:

$$\text{EIRP} = 57.76 \text{ dBW}$$

$$\text{FSPL} = 205.15 \text{ dB}$$

$$G/T = 20.27 \text{ dB/k}$$

$$K = -228.6 \text{ dBW/0K/Hz}$$

Bandwidth of signal being transmitted $B = 83.97 \text{ MHz}$

Using equation (5.3)

$$(C/N)_{\text{DL}} = 17.51 \text{ dB}$$

For forward link Putting these values in equation (5.1) the result is $(C/N)_{\text{forward}} = 12.88 \text{ dB}$

Spectral Efficiency (Bit/Hz) = 3.48 bits/Hz

ii. For Ka Band:

$$\text{EIRP} = 57.76 \text{ dBW}$$

$$\text{FSPL} = 209.58 \text{ dB}$$

$$G/T = 20.27 \text{ dB/0K}$$

$$B = 83.97 \text{ MHz}$$

$$K = -228.6 \text{ dBW/0K/Hz}$$

Putting these values in equation (5.3)

$$(C/N)_{DL} = 13.08 \text{ dB}$$

Putting this value in equation (5.1)

$$(C/N)_{\text{forward}} = 10.65 \text{ dB}$$

Spectral Efficiency = 2.93 bit/Hz

Table 1.1 Forward Link Performance

	Ku	Ka
TWTA (Watt)	150.0	150.0
EIRP (dBW)	57.760	57.760
FSPL (dB)	205.150	209.580
G/T (dB/0K)	20.270	20.270
(C/N)DL (dB)	17.510	13.080
(C/N)forward (dB)	12.88	10.65
Spectral Efficiency (bit/Hz)	3.48	2.93

From the above results, it is clear that "Ku Band" forward link is 2 dB better than "Ka-Band" and spectral efficiency is also better than "Ka". So, for equal cost and same coverage areas "Ku" band forward link performance is better than Ka.

Vii. Performance Of Return Link

a. For Ku Band

$$\text{EIRP} = -13 \text{ dBW/Hz}$$

$$G/T_{\text{sat}} = 13.5 \text{ dB/0K}$$

$$\text{FSPL} = 207.3 \text{ dB}$$

$$K = -273$$

$$B = 44.99 \text{ MHz}$$

Uplink carrier to noise C/N due to thermal noise at the satellite using equation (5.3)

$$(C/N)_{Up} = 21.21 \text{ dB}$$

Putting this value in equation (5.2)

$(C/N)_{\text{Return}} = 13.95 \text{ dB}$

Spectral Efficiency = 2.34 bit/Hz

b. For Ka Band

EIRP = -19 dBW/Hz

G/T_{sat} = 16.7 dB/0K

FSPL = 213.7 dB

B=45.8 MHz

K=-273 0K

Using equation (5.3)

$(C/N)_{\text{UpL}} = 11.21 \text{ dB}$

Using in equation (5.2)

$(C/N)_{\text{Return}} = 9.38 \text{ dB}$

Spectral Efficiency = 1.64 bit/Hz

Table 1.2 Return Link Performance

	Ku	Ka
Antenna VSAT(m)	0.750	0.750
BUC(Watt)	8.0	0.50
EIRP(dBW/Hz)	-13.0	-19.0
G/T	13.50	16.70
FSPL	207.30	213.70
(C/N) UpL (dB)	21.210	11.20
(C/N) Return (dB)	13.95	9.38
Spectral Efficiency (bit/Hz)	2.34	1.64

Viii. Frequency Allocation

Forward Channel:

C band range is 6465.0 MHz – 6705.0 MHz while Ku band range is 13750.0 MHz – 14100.0 MHz . The above two bands are distributed into 8 forward channels each of 125 MHz

So, C-band will be

1. 6445 – 6570
2. 6580 – 6705

And Ku-band will be

1. 13750 – 13875
2. 13885 – 14010

Now according to our design, we need Ku downlink on user site so +6045 LO for C-Ku and -1530 for Ku will be used.

Adding LO to C band as shown below:

6445	~	6570	~	6580	~	6705
+6045		+6045		+6045		+6045
<hr/> 12490		<hr/> 12615		<hr/> 12625		<hr/> 12750

C-Ku downlink range at forward gateway will become (12490MHz – 12615MHz) and (12625MHz – 12750MHz)

Now Adding LO to Ku band as shown below:

13750	~	13875	~	13885	~	14010
-1530		-1530		-1530		-1530
<hr/> 12220		<hr/> 12345		<hr/> 12355		<hr/> 12480

Ku-Ku downlink range at forward gateway will become (12220MHz – 12345MHz) and (12355MHz – 12480MHz)

Return Gateway:

The return link is divided into 8 channels of 90 MHz

For C band:

1. 3400 – 3490
2. 3500 – 3590

For Ku band:

1. 11450 – 11540
2. 11550 – 11640

Now according to our scenario, LO = 2660MHz with being added to Ku and LO = 10910 to C band.

Adding LO to C-band:

$$\begin{array}{rcccl}
 3400 & \sim & 3490 & \sim & 3500 & \sim & 3590 \\
 10910 & & 10910 & & 10910 & & 10910 \\
 \hline
 14310 & & 14400 & & 14410 & & 14500
 \end{array}$$

C-Ku return link ranges will become (14310MHz – 14400MHz) and (14410MHz – 14500MHz)

Adding LO to Ku band:

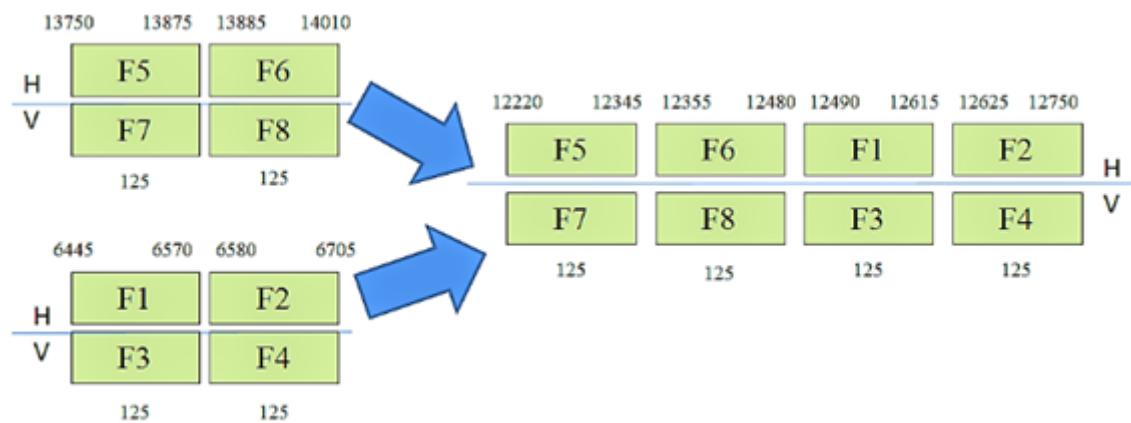
$$\begin{array}{rcccl}
 11450 & \sim & 11540 & \sim & 11550 & \sim & 11640 \\
 2660 & & 2660 & & 2660 & & 2660 \\
 \hline
 14110 & & 14200 & & 14210 & & 14300
 \end{array}$$

Ku-Ku return link ranges become (14110MHz – 14200MHz) and (14210MHz – 14300MHz).

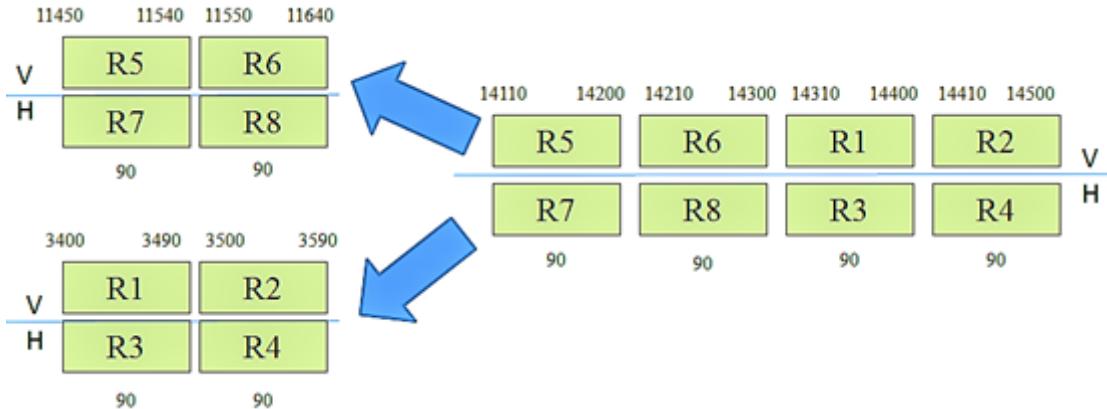
Using 2.0 m dish parabolic antenna, sixteen 0.75° spot beams can be possible covering the service area [16]. By using this scenario, the overall capacity of 10.3 Gbps can be achieved. [15].

Ix. System Architecture

The forward link is divided into 8 forward channels of 125 MHz and reverse link is divided into 8 channels of 90 MHz Horizontal and Vertical Polarizations and bands distributions are shown in the above figures according to the LOs defined above. This system architecture improves the system capacity and throughput of the system.



Forward Link Architecture



Reverse Link Architecture

X. Conclusion

From the Link Budget calculations, the maximum data rate in downstream is 20 Mbps and in upstream 2 Mbps in FSS while in HTS the downstream data rate is up to 100 Mbps and the upstream data rate is 10 Mbps for EIRP of 40dBW and 8dB/K G/T. It means our proposed system improved the data rate significantly five times. Since in this system the frequency used in one spot beam can be utilized several times in the whole location and as much smaller the beam spot, the higher the data throughput which means low cost per megabit. Hybrid multi-spot beam satellite performs much better than the fixed-satellite service (FSS) both on receive and transmit. It improved the system without too much equipment changing cost, so it is good news for satellite operators to accommodate more HD channels. This system is envisaged to be more beneficial for existing Ku-band users e.g. TV channels because they are already using Ku band and very little changes will be required to upgrade the Ku-band terminal to overcome the weather obstacle in communication in tropical areas to a greater extent.

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