International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-6, June 2015

Aircraft Wireless Network Analysis Model

Fairoza Naushad, Kesari Sai Srikanth, Kasthala Anusha

***Abstract*— Satellite Communications on an aircraft involves Line Of Sight (LOS) and Beyond Line Of Sight (BLOS) communications. An aircraft communicates with a Ground Station or an aircraft in its line of sight using LOS communications. It uses BLOS communication via a Satellite when both the aircrafts are beyond the line of sight. A need of analysis is present for the selection of important parameters like frequency band, size of the antenna, power, modulation technique to be used which offers the best suited performance for satellite communications in aircraft environment.**

So, the aim is to develop a generic wireless network simulator model with line of sight and beyond line of sight communication capabilities. The simulator shall be used to analyze the aircraft wireless network requirements in order to finalize the aircraft communications system specifications. It evaluates UHF and Ku band's performances when used on an aircraft for satellite communications. The parameters of interest are Data Rate, Bandwidth, Atmospheric attenuation, Gain provided by the antenna at a given antenna size. Matlab Simulink is used for this purpose for BLOS communications and Network Simulator-2 for LOS communications. These simulation results will be analyzed to calculate the link budget of radio wave propagation and feasibility of the network. Finally a decision can be made on the choice of frequency band, size of antenna required and other parameters based on the results obtained, without being actually implemented on the real aircraft.

This tool will help in generating specifications of communication system with weight, size and power constraints on a fighter aircraft. This is very useful analysis tool for ab initio design of a communication system with audio, data and picture transmission for both Line Of Sight and Beyond Line Of Sight.

Size, power and weight are important parameters in finalizing the communication system specifications for a fighter aircraft. It will be useful to tune the communication system so as to meet the required performance under the given constraints of size, weight and power budgets.

***Index Terms*—Matlab, Simulink, NS2, Geo Stationary Satellite, UHF and Ku band.**

I. INTRODUCTION

Communication systems are of two kinds, wired and wireless communications. Wired communications will be based on a wired media between the transmitter and receiver.

In wireless communications, certain protocols define how the wireless communication should interface the transmitter to receiver.

Fairoza Naushad, Scientist / Engineer "E", Aeronautical Development Agency (Ministry of Defence, Govt. of India), Avionics Systems, Bangalore, Karnataka, India, Mobile No: +919449045521.

Kesari Sai Srikanth, Project Assistant-1 Aeronautical Development Agency (Ministry of Defence, Govt. of India), B.Tech in ECE, Department of Electronics and communication Engineering, Bangalore, Karnataka, India, Mobile No: +919066868208.

Kasthala Anusha, student (Trainee), M.Tech DECS, Department of Electronics and communication Engineering, JNTU Anantapur/Madanapalle Institute of Technology and Science (MITS), Madanapalle, Andhra Pradesh, India, Mobile No: +919972033093.

A satellite provides wireless communications at Line of sight and Beyond Line Of Sight to the receiver. The need is to develop a tool to facilitate the simulation of wireless networks which can be used to create the required user defined network containing an aircraft and satellite along with the ground station.

In aviation communications, satellite systems are widely used and advantages of satellite communication in aviation are connected with possibility of operation with many aircrafts at long distances for information exchange and with independence of communication expenses on distances to aircraft. In military application, wireless communications both Line Of Sight and Beyond Line Of Sight enables NCW(Net Centric Warfare) capability for sharing target data information and it is very important for mission success. Operation of satellite communication link is very sensitive to its parameters and even small alterations of these parameters can cause a change in data rate, size of the antenna, power required and ground coverage of satellite system. For this reason it is important to develop models of real satellite communication channels and analyze the results using different parameters of operation.

There is a scope for obtaining better performance on upgrading the frequency of operation in satellite communications. Today, satellite transponders are available in various frequency bands like UHF, Ku bands etc., A trade off study has to be done on whether UHF can provide the required data rates for the next generation audio-video transmission or upgrading to Ku band is a better choice. For this purpose, a Matlab simulink tool is developed to create a satellite-aircraft model with all communication systems for Beyond Line Of Sight communications. Network Simulator 2 is used to simulate the Line Of Sight propagation link.

A theoretical analysis of the effect of frequency on all the communication parameters like the antenna size, atmospheric attenuation etc. is done and is compared to the actual implementations. Merits and Demerits of the frequencies of UHF, Ku bands for satellite communications are presented. Finally, tradeoffs for selection of a suitable frequency are also presented with calculations which are cross verified using the tool.

II. INTERDEPENDENCE OF COMMUNICATION PARAMETERS

A. Antenna Size and Frequency of Operation

The size of the antenna used for the communications is related to the frequency of operation by the basic gain equation;

The gain of the antenna is inversely proportional to the square of the wavelength as;

$$G = \frac{4\pi \, Ae}{\lambda^2} \qquad (1)$$

provided, Ae is constant.

where G is the Gain of the antenna, Ae is the effective aperture area , λ is the wavelength of operation.

Considering the case where gain required to be constant, we can have relation between size of the antenna and wavelength as Ae α λ^2 since λ=c/f , where c is the velocity of light which is a constant;

$$Ae \ \alpha \ \frac{1}{(\text{frequency})^2}$$

To conclude, Antenna size is inversely proportional to the frequency of operation.

B. Data rate and Gain Of Antenna

The relation between data rate and the Gain of Antenna (related in turn to frequency of operation) is as given in (2);

$$\frac{C}{No} = R + \frac{Eb}{No} \quad (2)$$

Where $\frac{C}{No}$ is the average Carrier power to Noise power density.

R is the Data Rate at which the transmission and reception are being done.

$\frac{Eb}{No}$ is the Energy per bit to the Noise Ratio.

$\frac{C}{No}$ is calculated for a given receiving element as follows;

$$\frac{C}{No} = P_T + G_T - Attn + G_R - k - T \quad (3)$$

where No = kT which is the Noise Power

P_T = Transmitted Power

G_T, G_R = Gains of transmitting and receiving antennae

k is Boltzmann constant = -229 dBW/Hz/K

T is the Receiver noise temperature

Comparing (2) and (3), the Data Rate is directly related to the Gain of the Antenna which in turn is mainly effected by the size of the antenna and the size of the antenna varies with the frequency of operation. Therefore "Increasing the Gain increases the Data Rate" for a given Ae (Aperture Area).

C. Atmospheric Attenuation and Frequency Of Operation

In satellite communications, the signal has to pass through a large distance in the atmosphere to reach the satellite and to reach the base station. Hence the sensitivity of the signal towards atmosphere has to be considered as a major factor. The atmospheric attenuation is generally referred to as Free Space Loss (FSL) given by;

$$FSL = (^{4\pi d}/_{\lambda})^2 \quad (4)$$

since $= c/f$, where c is the velocity of light which is a constant; FSL α (frequency)^2

Hence larger frequencies to experience more attenuation than the smaller frequencies.

C. Gain and Antenna Size

The gain of the antenna is directly proportional to the square of the antenna element radius as;

$$G = \frac{4\pi\, Ae}{\lambda^2}$$

provided the wavelength of operation is constant.

Considering a circular dish antenna, the physical area (Ap) would be πr^2 and aperture area(Ae) is given by

Ae = (Efficiency) X (πr^2)

Hence, G α r^2

since for a given antenna Efficiency is fixed.

So, even with a lower frequency of operation, if the size of the antenna is increased, larger Gain can be obtained from the antenna.

D. Bandwidth versus Data Rate

According to Shannon's theorem, data rate and bandwidth are related by;

$$\text{Data rate} = \text{BW X} \log(1 + S/N) \quad (5)$$

where S/N is the signal to Noise ratio.

Since desired Signal to Noise ratio of a link is constant, if the Band Width of operation is increase, there will be a proportional increase in the Data Rate.

i.e., Data rate α Bandwidth

Hence a frequency band providing larger bandwidth can be able to provide higher data rates which make advanced applications like video streaming possible on the aircraft.

III. Theoretical Analysis

Theoretical analysis is carried out considering UHF frequency at 300MHz and Ku frequency at 12 GHz.

A. Atmospheric Attenuation

UHF is an excellent candidate frequency to contact a satellite because it can penetrate the atmosphere and ionosphere with little attenuation as mentioned in (4).

For a geo stationary satellite, distance from the ground will be 36000km. Consider the frequency at 300MHz, we get the FSL value as;

$$FSL = \left(\frac{4\Pi d}{\lambda}\right)^2 = \left(\frac{4\Pi df}{c}\right)^2 = 173.1357 \text{ dB}$$

The Free Space path Loss is experienced more by a Ku Band signal when compared to an UHF signal which is;

$$FSL = \left(\frac{4\Pi d}{\lambda}\right)^2 = \left(\frac{4\Pi df}{c}\right)^2 = 205.1725 \text{ dB}$$

at f = 12GHz

It can be seen that a difference of 32dB can be saved when using UHF band instead of Ku band.

B. Data Rate

Data rate analysis is done for a antenna size of 35 cm for both UHF and Ku bands using (2) and (3) as,

For an antenna operating in UHF at 300 MHz assuming an EIRP of 18dBas in [2], for a BER of 10^{-6} the value of Energy to Noise ratio $\frac{Eb}{No}$ is 12 dB for QPSK as in [10].

$$\frac{C}{No} = P_T + G_T - Attn + G_R - k - T$$

Here $P_T + G_T$ = 18dB;

Attenuation = 171.5dB

Received Gain G_R = 10 dB

Boltzmann Constant k = 229 dB and

Noise Temperature = 31 dB

$$\frac{C}{No} = 18 - 171.5 + 10 - (-229 + 31) = 54.5$$

R_{UHF} = 54.5 - 12 = 42.5dBHz = 11.2kbps.

For an antenna operating in Ku band at 12GHz of 35cm providing a gain of 30 dB at an EIRP 50dB as in [1]

operating at a Temperature of 1300K. Data rate for a given Bit Error Rate of 10^{-6} is;
Here $P_T + G_T = 50$ dB;
Attenuation = 206 dB
Received Gain $G_R = 30$ dB
Boltzmann Constant k = 229 dB and
Noise Temperature = 31 dB

$$\frac{C}{No} = 50 - 206 + 30 - (-229 + 31) \;= 72 \text{ dB/Hz}$$
$$\frac{C}{No} = R + \frac{Eb}{No}$$
$R_{Ku} = 72 - 12 = 60$ dBHz = 1 Mbps

Hence it can be observed that Ku band antenna offers better data rates when compared to a UHF antenna of the same size.

The above values are obtained for a transmission without any channel coding. So, when channel coding is involved, for better Bit Error Rate, the effective data rate will be reduced. This will be at a percentage of 57.14% in the simulation.

C. Gain of the Antenna

From the antenna gain equation, $G = \frac{4\pi \, Ae}{\lambda^2}$
Considering a antenna element of size 35 cm and efficiency of 0.55, the gain that can be provided by;
A Ku band antenna at 12 GHz is 30dB
An UHF antenna at 300MHz is -1.715 dB
For the UHF antenna to give a gain of 30dB, an antenna of 1400cm is to be used, which is not feasible in space constrained application like fighter/commercial aircrafts.

D. Rain Fade

Rain fading effects the frequencies above 10GHz, which is proportional to the amount of the rainfall. Only those regions with highest rainfall such as tropical forest region and where there is high incidence of thunder storms would make Ku-Band tend less practical.

India accounts a rain rate of 18mm/hr and 23mm/hr for North and South regions respectively, at which the worst case specific attenuation per Km is taken as 1dB/km for 23mm/hr (considering an availability of 99.97%).

The percentage of availability means that the given region will not exceed the rain rate of 23mm/hr for 99.97% of the year. If suitable dB-margin is maintained, rain fade effect can be overcome.

For a cloud height of 5Km, hence considering 5km of rain fade affected region, the worst case rain fade can be 5dB. Consider a rain fade of 5dB effecting a transmission link operating at a Ku band frequency of 12GHz, the range obtained and power received at such frequency compared to UHF link unaffected by rain fade for a fixed antenna size of 35cm will be; (Assuming a receiver sensitivity of -140dB, for a transmitted power of 100W.)

Maximum Range $d = \sqrt{\frac{Pt*Gt*Gr*(\lambda)^2}{(4\pi)^2*Pr*(RainFade)}}$ from Friis equation. For a fixed antenna of size 35 cm; a Ku band antenna operating at 12 GHz, the gain of transmitter is 30dB and for a UHF antenna operating at 300MHz the gain of the transmitter is -1.16dB. For maximum possible range, Received power is substituted to be the receiver sensitivity i.e., least possible received power.

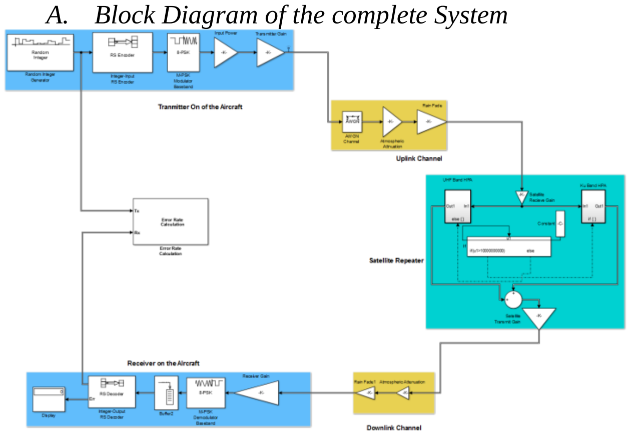
According to the above equation, Ku antenna terminal is capable of transmitting signal for a distance of 9,65,240km whereas UHF antenna of the same size can be able to transmit to a maximum range of 42,896km. At these values, Ku Band can provide a data rate of 1Mbps where as UHF antenna can support 1kbps data rate.

Hence, provided the size of the antenna is fixed, Ku band performs better than UHF despite the Rain fade.

IV. SIMULATION OF BLOS COMMUNICATION LINK IN MATLAB-SIMULINK

The following section details the simulink model developed to simulate the Aircraft to Satellite communication scenario. Matlab Simulink is used to simulate BLOS communication network whereas NS-2 is used to simulate the LOS communication network.

A. Block Diagram of the complete System



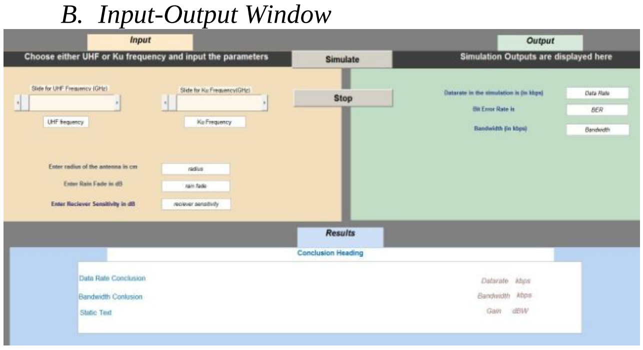
The complete model consists of a Simulink block attached with a GUI to receive inputs from user and display simulation results.

The above figure shows the top level block diagram of the model where an aircraft transmitter, receiver and satellite repeater are present along with Uplink, Downlink channels.

Separate block for Data Rate calculation is defined which receives inputs upon completion of the simulation and calculates data rate as per (2) and (3).

A block is also provided for Error Rate calculation which displays the number of bits transmitted and number of errors occurred along with the Bit Error Rate.

B. Input-Output Window

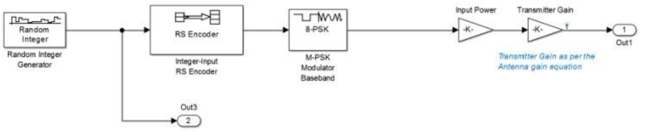


A input-output window is generated using Matlab GUIDE tool which initializes the simulation by getting inputs from the user from the input block. The user has to input frequency of operation from the slider, radius of the antenna in cm, the rain fade value in dB and receiver sensitivity in dB has to be input in the textboxes provided.

'Simulate' push button starts the simulation of the specified simulink model by using the parameters specified above. During the simulation, output parameters are copied to workspace to be displayed at the end to the user.

'Stop' push button stops the simulation and displays the results along with the conclusions derived from the simulation.

C. Transmitter on Aircraft

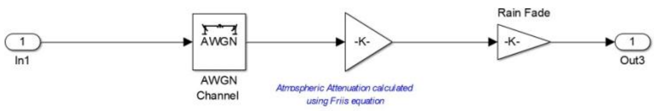


The transmitting antenna on the aircraft is simulated to provide high gain at low space requirement. Hence, a dish antenna is chosen with an efficiency of 0.7. The modulation chosen is 8-PSK for this purpose which provides better Bit Error Probability. A Random Integer Generator simulates integers at a frequency of the operating frequency chosen by the user from GUI. Framing is performed at 4 samples per frame the sampling time is chosen to be 1/(2 x carrierfreq).

Channel coding is necessary for better performance of the link in terms of error detection and correction. Block Coding is chosen which implements Reed Solomon(RS) coding with a codeword length of 7 bits. Coding efficiency is 57.14%.

The transponder provides a gain which is calculated based on the antenna gain equation (1) to which the transmitted power is fed as the input.

D. Uplink Channel

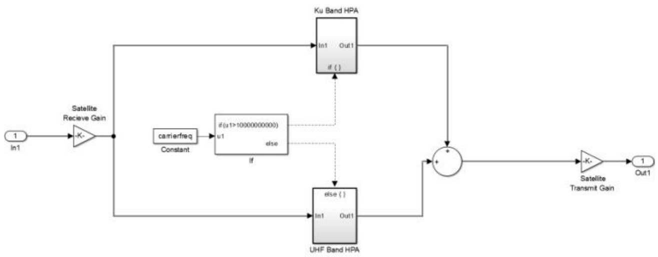


A model which mimics the properties of the free space channel between the aircraft transponder and the satellite is simulated based on Friis Equation.

An AWGN channel is used to simulate the channel behavior to which Free Space Loss(FSL) is added according to (4), which is the atmospheric attenuation experienced by the signal while travelling from the aircraft to the satellite.

In case of Ku band signal, Rain Fade is added to the signal which is given as an input by the user.

E. Satellite Repeater

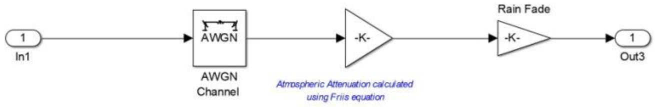


A Satellite repeater receives the signal, and provides sufficient gain to the signal so that it is susceptible by the receiving station either on Earth or on the aircraft.

For this purpose, along with the Satellite receiving and transmitting antennas, High Power Amplifiers (HPA) is present which improves the signal power at a larger scale. A decision box is present at the Satellite repeater input which chooses the gain which has to be provided for UHF and Ku band respectively.

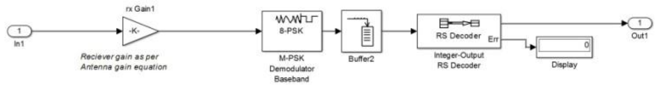
The satellite also performs down conversion of the frequency which is done to avoid interference between the uplink and the downlink signals. Down sampling at a rate of 6/7 is chose for this purpose.

F. Downlink Channel



A similar channel which is present in the uplink is present at the downlink path. This has an AWGN channel which is added with the atmospheric attenuation which is calculated according to the Friis equation.

G. Receiver on aircraft



A receiver whose sensitivity is as specified by the user is used to detect the signal on the aircraft. It initially has a gain block which has a similar gain value present in the transmitting end (to validate reciprocity).

The amplified signal is provided to a 8-PSK demodulator which demodulates the signal. Then the signal is buffered again to form frames of 4 samples per frame. Reed Solomon decoding is used at the receiving end which produces the raw message signal.

V. Simulation of LOS Communication Link in Network Simulator 2

Network Simulator 2 is used for simulation a wireless network which is limited to Line Of Sight communications between aircrafts and aircraft to ground station.. It was chosen since a large number of readily available reference models were present for Line Of Sight communications. It makes use of Free Space model where the transmitter and receiver communicate with the channel being free space.

The NS2 model consists of a transmitter with Omni-directional antenna operating at 10 GHz frequency. The carrier sensing range of the receiver is set to 500 meters with a transmit power of 100 Watts. The simulation bandwidth is set as 512 kb and the distance between the transmitter and receiver is set to be 100 meters. UDP (User Datagram Protocol) is used as the transport layer protocol with a traffic source, Constant Bit Rate (CBR) generator used to simulate data to be transmitted.

The simulation is done with a transmitter and a receiver operating at 10GHz frequency with receiving ranges of 250m and 160m respectively. A transmit power of 100Watts is used. Using the network simulator model, the test results are analyzed using appropriate codes to determine the received power and the bit error rate.

The Ns-2 file generates a NAM (Network Animation) file which visualizes the model which is generated and a trace file which keeps a track of all the data that is transmitted with the details of the delivery, time of arrival, transport protocol used, and delivery of the packet.

A script is written in AWK language to analyze the trace file and important results like Packet Delivery Ratio, Time delay, effective bandwidth, Number of packets sent, number of packets dropped, and the number of packets received during the simulation.

In the simulation, for better approximation, randomness is induced to the movement of the wireless transmitter and the receiver.

VI. Test Cases and Results

Beyond Line Of Sight Communication results :

The simulink model is used to run different test cases whose results are tabulated as below.

Case 1 :

Parameter	***Result***
Frequency	300 MHz
Size of the antenna	35cm
Rain Fade	0 dB
Gain by transponder	4.2 dBW
Data Rate	18.76 kbps
Bandwidth	9kHz

Case 2:

Parameter	***Result***
Frequency	500 MHz
Size of the antenna	35 cm
Rain Fade	0dB
Gain by transponder	8.6 dBW
Data Rate	52.11 kbps
Bandwidth	24.5kHz

Case 3:

Parameter	***Result***
Frequency	12 GHz
Size of the antenna	35cm
Rain Fade	5 dB
Gain by transponder	36.2 dBW
Data Rate	0.949 Mbps
Bandwidth	0.425 MHz

Case 4:

Parameter	***Result***
Frequency	16GHz
Size of the antenna	35cm
Rain Fade	5 dB
Gain by transponder	38.78 dBW
Data Rate	1.68 Mbps
Bandwidth	0.75 MHz

Line Of Sight Communication Results :

Parameter	***Result***
Distance	100 m
Transmit Power	150W
Bandwidth	512kb
Datarate	200kb
Frequency	10GHz
Received Power	-60dB
Packet Delivery Ratio	99.6%

VII. Conclusion

It is observed from the results of test cases that were run, at a given antenna size, input power, Ku band antenna provides better gain and data rates when compared to UHF band antenna.

The Ku band propagation which is limited by atmospheric attenuation and rain fade can be provided with an extra power which makes it much feasible than UHF propagation where data rate and gains are lesser.

Hence, a Ku band transponder can achieve high data rates with small receiver element requirement which makes it a better choice when compared to UHF band for aircraft application where antenna size is constrained.

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Fairoza Naushad Obtained B.E in Electrical and Electronics Engineering and done her specialization M.S. in Avionics Systems. Presently , She is working as Scientist/Engineer 'E' in Aeronautical Development Agency, Bangalore. She is a Associate member of Aeronautical Society of India and Institution of Engineers, India.

Kesari Sai Srikanth completed B.Tech in Electronics and communications and Presently, He is working as Project Assistant-1 in Aeronautical Development Agency.

Kasthala Anusha pursuing M.Tech degree in Digital Electronics and Communication Systems, Department of Electronics and Communication Engineering in Madanapalle Institute of Technology and Science in Madanapalle, Andhra Pradesh, India.