VOD AND LIVE TV CHANNELS FOR AIRCRAFT BROADBAND NETWORKS

A Thesis by

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The following faculties have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Electrical Engineering.

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DEDICATION

This thesis is dedicated to my parents, friends and teachers who have supported and encouraged me throughout my life

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ABSTRACT

Broadband aircraft communications have come long way from web surfing to the very recent live TV channels by the Qatar airways. This thesis has gone one step further by analyzing the possibility of video on demand and live TV channels using single antenna for IFE options provided by the aircraft. With TVOD (true video on demand), passengers have the option to select a movie or TV channel from content which are hosted in the ground server at any time with the start, pause and stop functionality. As opposed to the prescheduled programs which are already in place. The research work defines the challenges, complete architecture, products and the emerging technological solutions in implementing the VOD and live TV channels through Ku band satellite IP communication. In addition, cost analysis and ways to efficiently use the bandwidth is also discussed. The proposed architecture's performance is analyzed with the help of frequency sharing introduced in this thesis. The channel capacity and throughput for various parameters are calculated using the mathematical model.

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CHAPTER 1

INTRODUCTION

Broadband over mobile satellite services is an emerging and rapidly growing field in satellite broadband communications. However in 2000, broadband communication for aeronautical purposes was limited to a certain extent due to various factors like expensive satellite bandwidth and bulky antennas for aircrafts. Later, many aircraft companies enhanced their In-flight entertainment systems according to their market demands and passengers' needs. Major IFE companies like Matsushita, Rockwell-Collins Passenger Systems (RCPS), Sextant and Sony Transom (recently acquired by Rockwell-Collins) provide a wide variation in their systems' capabilities, ranging from simple overhead video to very complex audio and video-on demand systems to the newest direct broadcast satellite systems. Recently, Quatar airways have taken a stride by adding live channels to the list of in-flight entertainment options available on its routes.

All these inventions wouldn't have become possible without the sophisticated equipments like broadband antennas, Vsat networks, Ku band transponders and modems. Broadband antennas are definitely a boon to broadband aircraft satellite communications. They are available in very small sizes which would not have ever been dreamed of in the past. Commercially available antennas like Rantec, DBS-2400 and MIJET are equipped with lot of built in features which suits for the Ku band satellite communication. For aircrafts, where broadband is not an easy task, antennas are the key factors to provide the reliable and fast transmission. If we dig it further, recent innovations in equipment alone did not make it feasible. New system architecture and relevant technological solutions are worth mentioning in the emergence of aircraft broadband communication. Many technological solutions like higher order modulations, modern coding techniques and multiple access schemes, have fulfilled the stringent requirements for broadband communications.

Though there are many kinds of frequency band available for satellite communication, in the 1990's L band was the communication pathway for different mobile environments providing basic connectivity. Though it had its own merits of small antenna size and low or no attenuation due to rain [1], offering broadband services over it had major problems.

In 2003, researchers started analyzing Ku band for broadband mobile services. The Ku band operates at 11-14 GHz frequency which has more bandwidth to offer when compared to L band. Ku band for fixed satellite services has been explored and Ku band services are already in place where DSL, Dial up internet is virtually impossible. However, Ku band requires big antennas with precision pointing and increased coverage area for aeronautical and maritime environments [1]. The credits go to researchers for their innovation in small sized aircraft antenna to utilize the full advantages of the Ku band. Also, the other major influencing factor is the total cost associated in delivering broadband services on Ku band.

However, air traveler's IFE options using broadband services are limited to a certain extent. Forget about the lost baggage, tasteless food and confined seats, more disturbing is the fact that the list of IFE options available for the passengers in the long-haul aircraft. Nobody would like to sit idle in a long journey. Passengers have the option of watching prerecorded TV shows, movies and listening to songs. Certainly not enough for long journeys, especially repeated shows make it even worse.

This paper involves implementing Movies on demand and live TV channels using single high-tech steerable small sized aircraft broadband antennas. Movies and live TV channels are shown already in few aircrafts. However, current techniques involve watching a few movies and videos which are stored in their local cabin servers. This paper follows a different approach which involves integrating both using a single antenna, transmitted from the ground station. Video on demand is available in various forms both through cable and internet. In aircraft's IFE, the movies are locally stored the in Cabin File server's Digital media servers, used in audio and video-on-demand systems. They store and deliver digital audio and video to the SEB (Seat Electronic Box). So the options are handcuffed to the limited storage capacity of the internal servers.

This thesis analyzes the challenges, complete architecture, products, and the emerging technological solutions in implementing the VOD and live TV channels through satellite IP communication. In particular, increasing the channel capacity with the help of a new technique called frequency sharing is analyzed. A question which suddenly comes to everyone about this implementation is: do we have enough bandwidth to accomplish it? So Link budget with modulation techniques, coding techniques which will help to consume less bandwidth and power are also discussed. The nightmare about satellite communication is expensive satellite bandwidth. Hence, it is also analyzed in detail.

The rest of the document is presented as follows: Chapter 2 discusses the existing technologies and related papers. Chapter 3 discusses the proposed system architecture, cost analysis and technological solutions. Chapter 4 discusses a mathematical model for the link budget. In particular, channel capacity is analyzed in detail with higher order modulation coding. Chapter 5 describes the substantiation of the mathematical model with simulations and results. And finally, Chapter 6 will discuss the conclusions and future work which could be done.

CHAPTER 2

LITERATURE REVIEW

This chapter completely analyzes the existing system architecture, technologies and relevant papers on this research. The section 2.1 discusses a research paper which analyzes the issues in satellite communication. The section 2.2 analyzes existing VSAT networks. Section 2.3 describes the research paper on Ku band for mobile satellite services. Section 2.4 describes the research paper on in flight entertainment. Section 2.5 analyzes the different modulation techniques and coding used in advance satellite communication. The section 2.6 explains the research paper on the necessity of broadband communication in aircraft. The final section analyzes the white paper of time division duplex and satellite duplex methods.

2.1 Satellite Communications in the Global Internet: Issues, Pitfalls, and Potential TCP/IP over Satellite:

The researchers from Hughes lab Dante De LuciaIn and Yongguang Zhang have addressed the issues and challenges in satellite communications in global internet in this paper, which gives the deep insight in to TCP/IP over satellite [2]. In today's fast paced environment, internet has become an essential part in daily life. Researchers have started deploying commercial products in earth's geosynchronous orbit so that Internet can be made omnipresent. The advantages of using internet via GEO satellites are high bandwidth, less cost, undeterred communication, Simple Network topology and the most important, broadcast and multicast services [2]. Despite all these added advantages there is a major challenge; the latency present in communication. GEO satellites incur a latency of 250ms to 400ms (approx). This latency caused by GEO satellites is approximately 10 times more than the regular point to point connection. This latency is negligible for bulk data transfer, but highly affects applications that require frequent handshakes and acknowledgement mechanisms such as the TCP. The TCP control mechanisms [2] are as follows:

Window Size - Window size is the amount of data that can be sent on the network without being delayed for the acknowledgement. The present standard window size for TCP is 64KB. But satellite links have larger bandwidth so TCP over satellite links require a window size more than 64KB. In order to have a better utilization of the bandwidth TCP-LW (Large Window) [2] is implemented in satellite networks.

Bandwidth Adaptation - TCP manipulates the window size depending upon the congestion. As congestion increases the window size is decreased in TCP and vice versa. The downside is the adaptation is proportional to the latency. In satellite links the latency is high hence this adaptation is not very effective.

Selective Acknowledgement - In general, TCP has a cumulative acknowledgement scheme. In this scheme when a data segment is lost, the sender has to retransmit from the lost data segment irrespective of subsequent data which received correctly. Alternatively TCP-SACK (Selective Acknowledgement) can be used for satellite communications [2]. In TCP-SACK when a segment is lost, the sender is immediately informed about the lost segment. Unlike the regular TCP it doesn't have to wait for the timeout and TCP triggers an immediate retransmission.

Slow Start - Initially TCP has to determine the available bandwidth. So the TCP starts with an initial window size of one segment which is 512 bytes and thereby increasing the window size with each successful transmission of the segment. The approximate total time for the TCP slow start period is $RTT*\log_2(B/MSS)$; [2] where *RTT* is the Round Trip Time, *B* the available bandwidth and *MSS* the TCP segment size. The increase in window size is exponential but the high bandwidth and latency of satellite links will take a significant amount of time.

Congestion Avoidance - There are two main approaches for the congestion avoidance, one is RED (Random Early Detection) and the other is TCP Vegas [2]. In RED, the TCP sender receives an implicit notification about the congestion because the packet is dropped earlier than normal. Hence the window size is reduced before any serious congestion occurs. In TCP Vegas, based on the recently observed RTT the sender has to foresee the congestion and reduce the window size correspondingly.

TCP for Transactions: TCP uses a three-way hand shake and slow start to avoid congestion. In order to reduce the impact of latency at the beginning of TCP connection, T/TCP (Transaction TCP [2]) is used. T/TCP bypasses the three-way handshake and slow start, efficiently designed to enhance the behavior. This is achieved by using the cached information from previous connections.

Approaches for performance improvement:

Although T/TCP, TCP-SACK, RED, TCP Vegas improve the performance, techniques such as *Split-TCP* and *TCP Spoofing* [2] improve TCP performance in satellite links without having to change the TCP structure.

Split-TCP: In Split-TCP the end-to-end TCP connection is broken down into two or three segments. The middle segment will span the long latency whereas the other segments will span the low latency. Splitting the connection separates the effect of latency. Hence TCP can speed up the slow start and will have a normal window size. However for successful transmission the middle segment has to implement the T/TCP.

TCP Spoofing: TCP Spoofing is similar to that of Split-TCP, but instead of splitting the connection an intermediate gateway is used. The intermediate gateway sends a premature acknowledgement to the sender instead of waiting for the actual acknowledgement. The gateway caches the segments in its buffer. When the gateway receives a negative acknowledgement from the receiver it is not forwarded to the sender but the gateway retransmits the segment from its buffer. However this might not work for applications that run on end-to-end semantics.

2.2 VSAT Networks:

In the present internet world high performance is gravely desired. Due to which the design of the Earth Station is complicated. Also the size of the Earth station increases thereby increasing the maintenance work. The optimal solution for this problem was Very Small Aperture Terminals (VSAT) [3]. VSAT's are small, simple and cheap bidirectional earth stations that can be installed at the end user's premises. The key fact is; the VSAT uses a lower performance microwave transceiver and a low gain dish antenna.

A star based topology is implemented where the Earth Station acts a central node and the Satellite acts as a broadcast medium. When the VSAT nodes have to communicate they have to transmit the data to the satellite. The satellite regenerates the signal and transmits it to the Earth Station. [3] The downside of the star topology is that when two VSAT's try to communicate at the same time the downlink is slower compared to the uplink.

2.3 Ku Band for Mobile Satellite Services:

"The Ku band revolution by Antonio" Arcidiacono, Daniele Finocchiaro, Sébastien Grazzini"[1] gives a very good background abound the use of Ku Band in Mobile Satellite Services. The L band has been the communication pathway for different mobile environments providing basic connectivity. Though it has its own merits of small antenna size and low or no attenuation due to rain [1], offering broadband services over it has major problems.

The author [1] discusses the limitations of it and the system design modeled to specific environments on using Ku band for broadband mobile services. The Ku band operates at 11- 14 GHz frequency band which has more bandwidth to offer when compared to L band. However, it needs big antennas with precision pointing and increased coverage area for aeronautical and maritime environments [1]. Also, the other major influencing factor is the total cost associated in delivering broadband services on Ku band. The paper [1] also discusses the optimization of cost on different segments such as system components, technology and operating cost which ensure that offering broadband services to mobile environments is a lucrative business model. The system components must be easy to install with the ability to support different applications on the same hardware for additional features and maintenance operations. The critical elements of the technological solution like antenna and modems must be reliable and efficient, while communication channel techniques should provide reasonable performance with a minimum quality of service.

Basically, broadband applications demand high bit rate and need to be made compatible with modulation and coding techniques existing in satellite communications. The paper [1] identifies two major issues and the technical methods to resolve the same. The first problem of interference of signals generated to and from the adjacent satellites can be avoided for the return signals by implementing one of the Spread Spectrum techniques like Code Division Multiple Access (CDMA). CDMA modulates the carrier signal with unique code waveform and spreads it to the available bandwidth. Secondly, to optimize the link for different coverage scenarios, the paper [1] considers using Adaptive Coding and Modulation (ACM) or Variable Coding and Modulation (VCM) for the forward links. These techniques in association with Dynamic Link Assignment (DLA) enable better performance of throughput even in the worst scenario.

Broadband services demand a fair amount of quality of service and a suitable transport mechanism that handles congestion the mechanism reliably. The TCP/IP stack is well developed for wide applications but still needs specific modification in mobile environments such as TCP acceleration and methods to make it functional on satellite links which have large delay and are affected by various errors. Prioritizing traffic based on end user needs and management of available bandwidth will be the key to a successful business model. This paper also discusses the various existing services offered by aircraft. They are as follows:

- Inmarsat Swift 64 provides internet with the speed of 64Kbps for the corporate jet market
- Connexion by Boeing (CBB) proposed high speed internet access using Ku-band. But the business model from the service is far from being proven.

- I-4/B-GAN with Inmarsat I-4 built a Broadband Global Area Network in 2005 with the bit rate up to 432Kbit/sec.
- Qatar Airways implemented seven live TV channels in 2007 in its aircraft. It's an award winning concept. Since it is a satellite broadcast, it is available only in the Middle East and Europe.

Basically, a few movies are shown in all aircrafts which are stored in their HDD array.

2.4 In-Flight Entertainment

"In flight entertainment: The Sky is the limit by Gerald Lui-Kwan" [4] is a very interesting research paper which discusses about the In-Flight Entertainment. Boeing envisioned itself into the commercial venture with the significant project termed as Connexion by Boeing (CBB) to provide broadband services on airplanes on the Ku band along with customized network architecture In Flight Entertainment [4] to offer services throughout the aircraft. The system is composed of variety of appliances that can range from providing simple video transmission to complex audio- and video-on-demand features. The entire system is distributed across the aircraft in three zones Head end, Zone end and Seat end (as described in [4]) with appropriate telecommunication and network equipment to deliver the broadband services. The head zone consists of system control panel, cabin control along with the entertainment system controller and telecommunication unit. It is operated by the ground and cabin crew for in-flight operations to maintenance operations. One of the critical components is the cabin file server that logs all line replaceable units' activities and is used for hosting application software programs that are required for real time IFE operations. The audio and video controllers with associated interface can provide both analog and digital stream with necessary data bus interface. The data is provided by on board audio and video on demand digital servers and their numbers are influenced by its own data stream bandwidth.

One such kind of deployed server is Lufthansa Technik's Audio and Video on Demand (AVOD) Server that is part Lufthansa Technik Ethernet IFE system [5]. It is certified by different standards which offer 512 Gigabytes of storage with capability of serving multimedia traffic to 100 clients. It offers several software applications that provide various options for the entertainment system.

Figure 2.1 Lufthansa's AVOD server

The zone end is the distribution area for this traffic to end peripherals in seat end. They are kind of bridged devices of respective data bus interface like Ethernet or Token ring or IEEE 1394. The components of seat end zone deliver the functionalities to the end user for utilizing these broadband services.

2.5 Waveforms in advance satellite communication

"Waveforms in advance satellite communications" by Mark Dankberg [6] gives a deep insight about the waveforms involved in satellite communications. This paper discusses the most modern techniques for data handling capacity for existing and future satellite communications. Other than the most general parameters like dish size, power amplifier output, etc. Three new technologies have come up that can increase the data rates over satellite links. They are

1. PCMA

2. Turbo Codes
3. 8 – PSK

This paper primarily focuses on these techniques with respect to continuous, steady state two way symmetric data circuits.

Turbo Coding:-

The main advantage of turbo codes is that it reduces the power required for completing a link at a given rate of data. The current existing turbo codes with reasonable block size and complexity can achieve near to Shannon's channel capacity [6]. But turbo codes can also be advanced upon and worked on to produce higher data rates.

High Order Modulation: -

There are two kinds of high order modulation and they are 8-PSK and 16 –QAM. The main advantage of this is that it can increase the bandwidth efficiency of the data link to a significant extent. 8–PSK may generally be applied with saturate power amplifiers at the earth station or at the satellite transponders [6]. Combining this high order modulation with turbo coding provides increased bandwidth efficiency at lower power usage and less complexity.

PCMA: -

The main advantage of PCMA is, it can double the available bandwidth for links that are either band limited or power limited. It is a signal cancellation technique that allows both directions of the data links to re-use the same frequencies. They have discussed it in detail with the following diagram. The net result is that using PCMA a full duplex circuit will occupy only half the bandwidth that it would without PCMA.

PCMA would cancel the original signal transmitted by each terminal, but in practice that rate is not achievable [6]. Each side's self transmitted signal is not cancelled, but is suppressed by a certain amount.

Comparison:-

In this section, the paper talks about combining and using various combinations of the above mentioned techniques. It is clearly seen that the techniques with PCMA show higher efficiency than any other technique. This also leaves behind a lot of economic advantage [6] .In conclusion; all the three techniques prove efficient in all senses.

2.6 Aircraft Communication – Broadband is the future

"Aircraft Communications- Broadband is the future" a research paper from Boeing [10] a leading aircraft industry analyzes the importance and needs for broadband communication in aircrafts. The main agenda is aviation needs like safety, security, efficiency of flight, sustainability and passenger satisfaction with the flight. Broadband allows the facilitation of the aviation agenda by allowing the aircrew and passengers to make use of it. The paper also explains how the broadband is possible in aircrafts. Ku band secondary allocation for mobile satellite services was included in the agenda of the World Radio Conference-2003. It also explains about allocating the frequency range without harmful interference. After allocation, it requires continuing effort to maintain the spectrum as the other users may like to use the existing allocation, or the existing users would like to expand their spectrum [10]. So the ITC-R monitors and allocates the frequency after analyzing the interference factors. The paper also emphasizes the need for combined effort between Civil Aviation Organization (ICAO) and the ITU-R to make the broadband communication possible in aircrafts.

2.7 Advantages of TDD in broadband applications

2.7.1 Time Division Duplex (TDD)

The white paper "Advantages of Time Division Duplex (TDD) for Broadband Wireless in Last-Mile Applications" by Proxim Wireless[7] gives clear and distinct advantages of using Time Division Multiplexing over Frequency division Multiplexing on Wireless Broadband Applications .TDD is defined as a method which uses a single frequency channel. In this method, the transmitter and the receiver are both assigned to the same frequency but different time slots. The data stream is broken down into frames and each frame is assigned a time slot. This will allow both the uplink and downlink traffic to use the same medium and only a part of bandwidth to be used. In order to switch or transition between the uplink and the downlink frames, guard periods are used in the frames. Several inferences have been made in this paper. In internet type traffic, since the time slots are assigned dynamically, the operator can calculate the percentage of downlink traffic vs. uplink traffic. TDD uses the guard period to separate downlink and uplink thereby preventing loss of spectrum allotted for guard band. The guard period is used for synchronization and to accommodate the delays when switching from downlink to uplink and vice versa. We can infer that due to dynamic allocation of time slots, only a negligible amount of spectrum is wasted for asymmetric operations such as last-mile applications [7].

2.7.2 Frequency Division Duplex (FDD):

The white paper [7] continues to discuss the disadvantage of using FDD in broadband wireless communications. FDD is defined as a method which uses a single time slot. In this method, the transmitter and the receiver are both assigned to the same time slot but different frequencies. The uplink and the downlink traffic will transmit at the same time, but the uplink and downlink traffic will use different frequencies. FDD is used when applications require equal bandwidth for both uplink and downlink traffic. The following inferences can be made from the paper. FDD uses symmetric transmission channels i.e. 50% for the uplink traffic and 50% for downlink traffic. Hence, using FDD for asymmetric operations like internet access will result in wastage of bandwidth. In order to separate the uplink traffic from the downlink traffic a guard band is used. The guard band must be two times the size of the uplink or downlink channel. Hence, half of the spectrum is lost. We can also infer that once a channel bandwidth has been allotted it cannot be changed. Unused spectrum in the allotted channel bandwidth will be wasted [7].

2.8 Conclusion

From the discussions in the paper we can infer that TDD is best suited for asymmetric operations like internet access which has bursty traffic [7]. Using TDD, the service providers can allocate the percentage of bandwidth based on the traffic in each direction. Also, TDD effectively uses the spectrum. FDD will be implemented effectively where both the uplink and downlink traffic require an equal amount of bandwidth. Operations like enterprise data transfer will opt for FDD.

CHAPTER 3

ARCHITECTURE AND TECHNOLOGIES USED TO IMPLEMENT VOD AND LIVE TV CHANNELS IN AIRCRAFT

The main constraints for any aircraft to provide live TV channels or video on demand are the bandwidth, costly servers and bulky antennas. However, this proposed scheme analyzes the new products and system architecture which would be able to provide broadband applications such as movies and live TV channels over internet using relatively lesser bandwidth. Frequency ranges, antenna specifications, complete system architecture, working and cost analysis will be described in this chapter.

3.1 Movies (Video on Demand)

As of now, many aircrafts provide the option of watching movies which are stored in their internal HDD array. There are fewer movies for the economic class, whereas there are quite more for business class passengers. Now, with the revolution in Ku band, it is quite possible to get the movies from the ground station. There are many sources to get the get movies from for the ground station. The best possible way would be getting it from some web servers, which allow users to watch it online. Having said that, the next billion dollar question would be, are they legal? Do they have proper digital copyrights? So, the easiest and legally safest way would be getting the movies from any online DVD rental store.

Figure 3.1 Aircraft Broadband Satellite Communications [20]

This research work suggests, if an aircraft company can make a contract with any of the movie rental stores which have big collection of online movies, then an aircraft company would virtually have very large collection of movies and TV shows, distributed in various servers. The appropriate satellite uplinks and downlinks at different servers to transmit the data to the aircraft's antenna. The movies will be downloaded to the local cabin server based on the passenger's request. For an instant, one passenger has requested a movie, so it will be downloaded to the cabin server. After a while, another passenger is requesting a same movie. So this time he should be able to watch the movie which is stored in the internal server. His request should not go to ground station for it. It should go to internal server. It is one way of efficiently using the allocated bandwidth.

But, movies will not be stored forever. Just like renting a DVD from a movie store, we will return it after watching a movie. So, the movie has to be internally stored for a while and then it should get automatically deleted. This is because we are renting and watching it through online. But if a movie gets deleted after a single request, then when two users request same movie, each time the request has to go to ground station. This is definitely not an efficient way of utilizing bandwidth and will add overhead. So, movie has to be kept at least for a full journey of flight. And then, it should be completely wiped.

3.2 Live TV channels:

Qatar Airways has added live satellite television to the list of IFE options available on its routes. Boeing's Connexion offers few news and sports channels through internet for viewing on a laptop PC rather than being provided direct via satellite to the seat-back TV [8].

But this paper discusses watching live TV channels streamed through satellite IP and using only one single antenna to accomplish it along with movies on demand. If satellite broadcast is used like Qatar airways, then live TV channels will be transmitted in different range of frequencies and movies will be at another range. Receiving live TV channels in mobile satellite service is not an easy task to accomplish. So TV channels over satellite IP is recommended for this approach. The complete communication process from the ground station to antenna of the aircraft is analyzed in the following chapters.

3.3 Communication process from the ground station to Antenna of the aircraft:

This section explains how data is transferred from the ground station to the satellite transponders and then to the antenna of the aircraft by step by step process:

This diagram just shows how data is transferred from the satellite mode of communications to the network via a router [9].

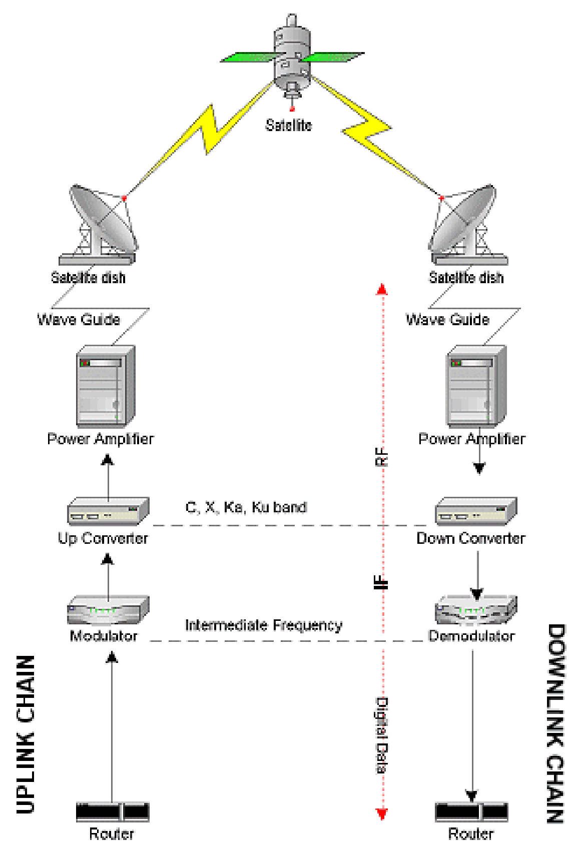

Figure 3.2 Satellite IP communication [9]

1) Digital data from the router should be sent to the modulator, which converts it into a modulated signal in the intermediate frequency range according to our specifications. This architecture considers frequency range of (60-120 MHz). Like

in most satellite applications, 8-PSK modulation can be used with turbo codes, as they are ideal for the efficient bandwidth usage with low power consumption.

2) Then, the intermediate frequency signal is passed through an up converter. It mixes the intermediate frequency with a Ku band frequency range to produce a final frequency which carries the modulated data. Next, signal is fed in to the filters to remove the unwanted noises. Like in any communication network, the signal has to be amplified using a power amplifier [9].
3) Then, the amplified signal is fed in to the dish using a wave guide. A feed horn placed at the dish emits the ku band radio transmission into the satellite transponders revolving in the earth's orbit [9]. Then the signal is picked by the high steerable antenna of the aircraft.
4) The signal is then transmitted to a Viasat modem, the signal will be demodulated and it will be fed to the cabin file servers or video file servers which are already placed in the aircraft. Viasat modem is chosen for this approach, because of its salient features. Now according to the passenger's movie request, files downloaded in the CFS are first sent to the Area distribution boxes which are placed in different cabins of the aircraft. They are connected to the CFS via a high speed data bus used by ATM and Ethernet.

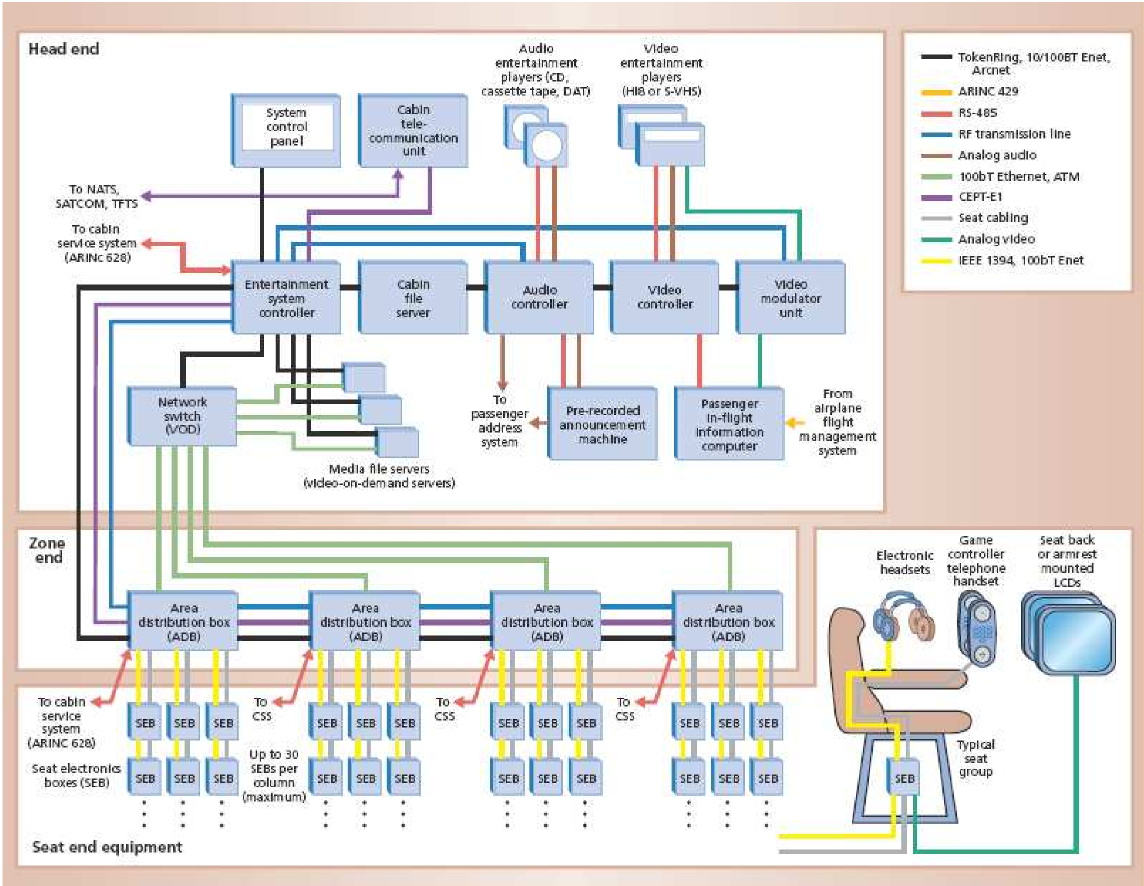

Figure 3.3 Aircraft's interior network architecture [4].

5) The data is distributed from the area distribution box to the individual SEB (Seat Electronic Boxes). They are connected to ADB using copper based IEEE 1394, which are already deployed in many of the aircrafts.

6) Earlier passengers will be given two options viz live TV channels and live movies. The complete process is explained completely in the following chart:

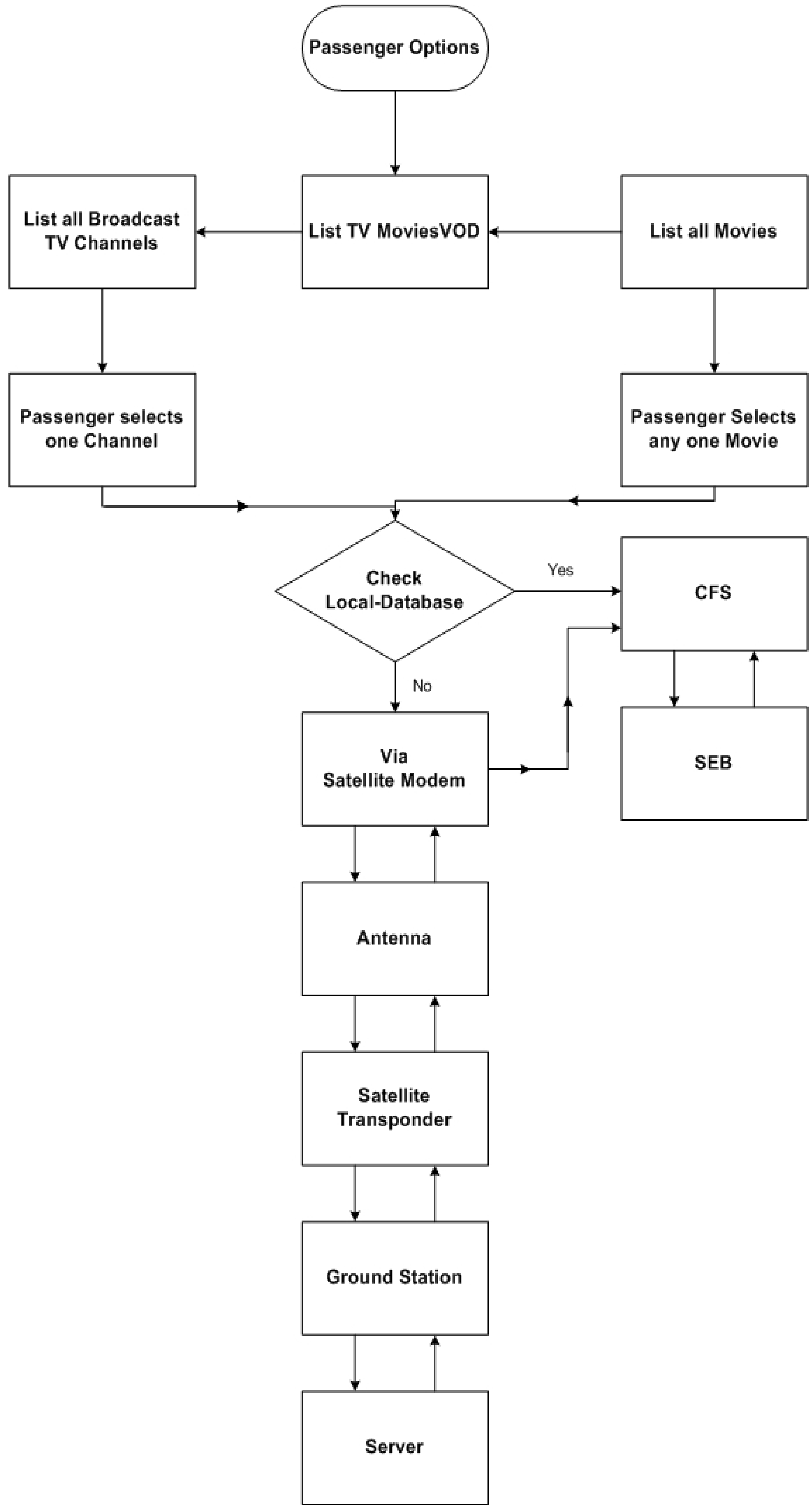

Figure 3.4 Flowchart of the system architecture

As explained in the flow chart, an internal search is carried out before sending the request to ground station. The probability of two or more passenger's watching the same movie is low, but given an option of 5 to 6 live TV channels, the probability of the same live TV channel being watched by many passengers is very high. So, a request will not be sent to the ground station at all. A request will reach the ground station only when passengers request a TV channel which is not being watched by any of the passengers. So, approximately 25 percent of the time, a user's request is served from the Cabin file server itself. Hence, the available bandwidth is used efficiently.

3.4 Advantages of Proposed technique:

- Passengers will have the option of watching movies and TV shows from a huge database along with 6 to 7 live TV channels.
- Installation and maintenance cost is relatively cheap and it is affordable by any aircraft company.
- Due to the frequency sharing technique, it requires less bandwidth than any other broadband application currently offered by aircraft companies. Acquiring a satellite segment is very costly and not an easy task. So, frequency sharing would definitely be an added advantage.
- Existing devices which are already used by aircrafts are utilized for this approach. Installing any new device is not an easy task, as it directly affects the weight of the aircraft, but no separate device will be installed in the aircraft, which adds an advantage to its other features.

The following section analyzes the efficient frequency allocation and introduces a new concept called frequency sharing.

3.5 Frequency allocation used in this technique:

Broadband applications for aircrafts require an allocation of radio frequency to provide the mobile satellite service. The International Telecommunication Union Radio communications Sector (ITU-R) is the organization which maintains the international co-operation among the Member States of the Union for the improvement and use of radio frequency spectrum and satellite orbits. They also manage co-ordination among users to avoid and eliminate interference [10].

Ka, L, S and Ku-bands are widely used for the satellite communications. Ka-band is not used widely due to technical limitations. Whereas the L-band is limited with the capacity of 30 megabytes per second (Mbps) for all users combined. So, in a 450 aircraft environment, the bit rate per aircraft would only be around 200 kilobytes per second (kbps). The limitation remains the same for S-band [11].

Ku-band frequency range is selected due to its advantages:

- More bandwidth up to 36–72 mbps, and with the help of individual satellites it can be pushed around 1–2 gigabytes per second (Gbps) [11].
- Less interference and comparatively low cost.

The Ku-band is available from the frequency range 10.7 GHz - 14.5 GHz. So, the available frequency has to be efficiently used in order to accommodate more uses. Since our technique uses two way communications, uplink and downlink frequencies need to be assigned. So, a passenger's request has to be notified to the ground station using a downlink frequency, and the requested data will be sent to the aircraft using the uplink frequency. The next section explains the way the downlink and uplink is shared in this technique.

3.6 Downlink and Uplink Frequency sharing:

A passenger's request has to reach the ground station and the requested movie has to reach the aircraft's antenna. More channel capacity is needed for uplink than the downlink. In the case of downlink, it is only the user request and acknowledgements. It is more like an asymmetric service, with a constant unequal flow of data in both directions. So most of the time, the downlink will be free. Instead of wasting the downlink, this technique utilizes the channel when it is free. So with one frequency band, a links capacity is doubled by allocating most of the time slots in one direction. So whenever there is a need, the downlink is actually used dynamically using dynamic channel allocation. Rest of the time, it is used for uplink. The main advantages of this method are as follows:

- Channel is efficiently used without wasting.
- More numbers of users are served in an allocated channel.

This technique is very similar to Time Division Duplex where a common carrier is shared between the uplink and downlink. To avoid interference, the uplink and downlink time slots are separated by guard periods. The TDD technique provides the option of allocating the channel dynamically and the operator can define the percentage of UL and DL traffic [7]. So, a few techniques are borrowed from TDD for the frequency allocation used in this approach. This is one way of efficiently using our bandwidth among a few other ways discussed in this chapter.

3.7 Antenna used for Ku band satellite communication:

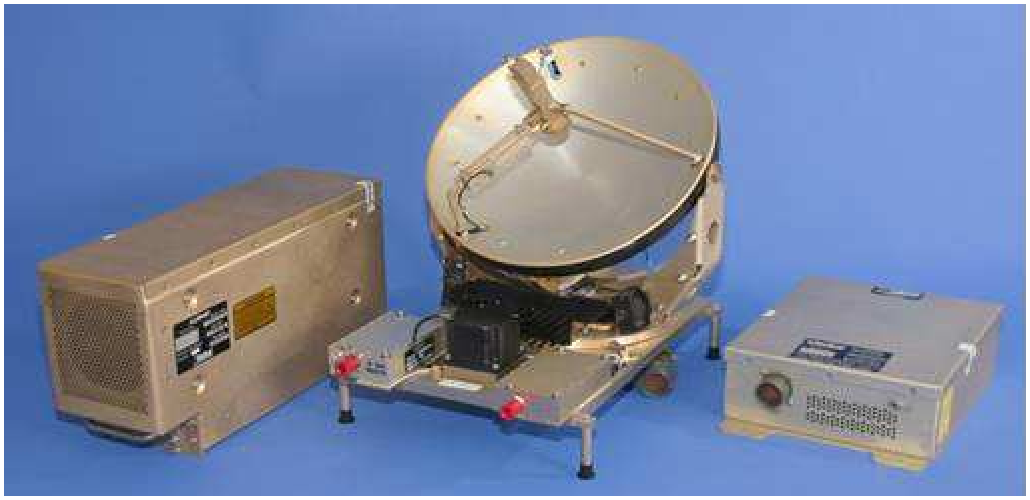

Figure 3.5 The complete onboard system for the ARINC service on business jets: the Viasat modem, the RANTEC tail-mount antenna, and the antenna control unit [1].

Figure 3.6 DBS-2400 low profile ku band aircraft antenna [12]

Design and characteristics of the antenna play a major role in any kind of satellite communication. High-tech steerable antennas and satellite transponders are chosen for this approach, as it involves receiving signals from a moving satellite transponder to an antenna. This is not an easy task to be obtained. "Dish antennas typically need to be aligned to within one degree of the satellite to get a signal, so keeping the antenna pointing in the same place while the aircraft moves require complex calculations "[8]. Antennas are available with an antenna control unit to align them with the receiving signals, since the antenna has to grab the signals while on the move, it has to be properly tuned to the downlink and uplink frequency. In the proposed technique, downlink frequency will be used for uplink also. Favorably, the antennas like Starling's ComPA, Rantec tail-mount antenna, DBS-2400 and Mijet [13] are capable of configuring TDMA/TDD which is very similar to the technique discussed in the paper. The following table lists the specification of various Ku band antennas used for broadband applications:

TABLE 1

KU BAND ANTENNA SPECIFICATIONS

Ku band Antenna	Diameter/Height (in inches)	Transmit/Receive rate (in Mbps)
Starling's ComPA	16/4	512/(4-7)
Rantec tail-mount antenna	11.1/13.5	512/(4-7)
DBS-2400	25/4	512/10
Mijet	30/6	1.25/(10-15)

An aircraft antenna's weight and size have to be considered properly before installing into any aircraft. The size and weight of the system are very important because they directly reflect on the drag of the aircraft and the fuel consumption, so the antenna chosen for the approach is carefully considered to have less weight.

3.8 TCP acceleration:

TCP encounters serious problems due to the high delay in satellite networks. Satellite delay is around 500ms RTT, so even when the link is available, it will not be used efficiently. Performance Enhancing Proxies (PEPs) are devices to improve the end-to-end performance of TCP. They use a TCP spoofing technique to break up the end to end locations into small endpoints with gateways. In this way, gateways at the end points act like the end location and send the Ack packet, so the window time interval is reduced and the server sends more packets. Finally, the Ack packet from the end location is discarded at the gateway. Therefore, the TCP acceleration technique increases the maximum efficiency of a satellite link and increases throughput and bandwidth.

Another issue with TCP/IP in satellite communication is the congestion, so some kind of quality of service has to be deployed to manage the available bandwidth [1]. In our case, live TV channels are more time sensitive than live movies, so priority has to be given to live traffic in case of congestion. The modems and ground station implement bandwidth management according to the traffic at the terminal level. In the proposed case, it is most unlikely that the bandwidth is utilized completely all the time. Since frequency sharing is used, congestion will occur only when all the users are trying to watch the movies and TV channels simultaneously. So congestion should be treated very normally for this approach to some extent.

3.9 Cost Analysis:

For implementing any design, cost analysis is very critical. Regardless of the technical revolution, innovations will not get noticed without proper cost analysis. To that end, this section discusses the implementation costs of the complete architecture. However, the discussion is restricted to the implementation of the connectivity domain.

The total cost of the implementations can be divided in to three main categories as follows:

- Cost of aircraft antenna
- Cost of satellite segment
- Cost of ground station

They are analyzed individually in the following sections.

3.9.1 Cost of Antenna:

The main cost of this design on the aircraft is completely dominated by the antenna's cost. Having said that, installation itself is a significant part and it requires many considerations and complex calculations before installing. The proposed design makes use of the ku band antennas which are already in service such as RANTEC tail-mount antenna, DBS-2400 Low profile Ku-band antenna system, Starling's CoMPA (coherent multi-panel antenna) etc. Installation cost of the antenna is not going to be an issue in this design. Moreover, the antennas specified above are reliable and cheap.

3.9.2 Cost of satellite segment:

The cost of the satellite segment mainly depends on the bandwidth required to fit in all the users' request. The more we use the more we pay, so efficient ways have to be deployed in order to use the bandwidth economically. In addition, the same satellite segment should be shared by a large amount of users. The proposed design uses frequency sharing between the uplink and downlink allocations. So cost for the bandwidth allocations is comparatively lower than the other applications. Companies like Busy access, sky casters have already started giving these sorts of applications at low cost. The following table describes the various plans offered by sky casters and their monthly charges [14]:

TABLE 2

Plans offered by Sky casters [14]

Service Level* Download/ Upload	VSAT Systems 1.5Mbps/ 384Kbps	VSAT Systems 2.04Mbps/ 512Kbps	VSAT Systems 2.04Mbps/ 640Kbps	VSAT Systems 2.50Mbps/ 768Kbps	VSAT Systems 2.5Mbps/ 1.02Mbps	VSAT Systems 3.07Mbps/ 1.5Mbps
Service Plan Monthly Price	$149.00	$199.00	$249.00	$399.00	$499.00	$999.00
Committed Information Rate (CIR)*	1.02 Mbps/ 128 Kbps	1.02 Mbps/ 256 Kbps	1.5 Mbps/ 384 Kbps	1.5 Mbps/ 512 Kbps	2.04 Mbps/ 768 Kbps	2.04 Mbps/ 1.02 Mbps
Throughput Allowance	1GB	2GB	3GB	5GB	6GB	12GB

From the table, it is evident that the cost of the satellite segment is comparatively low from any aircraft's company perspective. Moreover as mentioned, this technique involves using downlink frequency for uplink requirements. Approximately 25% of the time, the user's request will not go the ground station. It's a complete dedicated link for only video. Hence, cost of the satellite segments is not going big concern.

3.9.3 Cost of ground station

The cost of ground station is mainly dominated by the installation cost and the ground satellite costs. Many ku band antennas are available for low prices in the market. Ground antennas should be simple, efficient and cheap, and it should be compatible with the aircraft's antenna too. Major requirements for any ground antenna are as follows:

- It should not grab noise from the adjacent satellite transponders

- While transmitting, it should not interfere with the same as per the ETSI regulation.
- The tracking algorithm and mechanics are very important, not to lose some signal strength (db) due to poor tracking accuracy [1].

Consideration of all above requirements proper ground station antenna should be done. Existing antennas available in the market with the price is listed as follows [15]:

TABLE 3

Ku-Band Ground Antenna Cost

Ku-Band Dish antenna	Price cost
1.2 Meter Offset Ku-Band Dish	$165
1.1 Meter Offset Ku-Band Dish	$129
Winegard DS207676cm Offset Ku-Band Dish	$69
75 cm Offset Ku-Band Dish	$49

The simulation and results are explained in the upcoming chapter. From the above cost analysis, it is evident that the prices for the Ku band antenna and installation cost are easily affordable by any aircraft company.

CHAPTER 4

MATHEMATICAL MODEL

4.1 Introduction

In this chapter, a mathematical model to find the link capacity of the satellite link by using frequency sharing is calculated along with the link budget. In the first section, a mathematical model is proposed to determine the link capacity of uplink communication. First, it is calculated from earth station to the transponder, and then from the transponder to the aircraft's antenna. The frequency sharing technique was explained in the previous chapter to utilize bandwidth. Based on that, link capacity for the high traffic uplink is calculated in the following section.

4.2 Channel Capacity:

Channel capacity is calculated separately for earth station to transponder and then from transponder to aircraft antenna.

4.2.1 Earth station to satellite transponder:

Channel capacity is defined by the well known Shannon Capacity equation:

$$C = B \log_2 (1 + SNR) \text{ (b/s)} \quad (1)$$

Where B = Bandwidth in (Hz) and SNR = Signal to Noise ratio.

Due to frequency sharing, the downlink is utilized for the uplink purposes most of the time, so the channel capacity for uplink will be the summation of two channel capacities.

$$C_{uf} = B_1 \log_2 (1+SNR_1) \quad (2)$$

$$C_{df} = p\,(B_2 \log_2 (1+SNR_2)) \quad (3)$$

Where C_{uf}=Channel capacity of uplink using Uplink frequency.

C_{df}=Channel capacity of uplink using Downlink frequency and

p = percentage of the Down link traffic.

The main intention of frequency sharing is to efficiently transmit the data in bandwidth constrained networks. In order to utilize the channel capacity fully, SNR should be as low as possible. This is because it is inversely proportional to the channel capacity and it depends mainly on the following factors:

- ➢ Earth Hub parameters
- • Antenna size.
- • Power Amplifier and
- • Noise temperature.
- ➢ Transponder parameters
- • EIRP
- • G/T
- • Antenna Gain
- • Flux density
- • Power amplifier.
- ➢ Modulation Technique and
- ➢ Coding techniques

So based on the above factors, SNR is calculated in the following sections.

4.2.1a Calculation of SNR_1 for C_{uf}:

SNR is a signal to noise ratio or to be more precise carrier power to noise power. SNR is expressed in terms of C/N in the further documents. In order to find C/N, C/No has to be computed first, which is nothing but carrier power per unit Bandwidth. And C/N is carrier power in whole bandwidth. Then, the carrier power received at the receiver is the summation of power of transmitter, Transmitting antenna's gain and receiving antenna's gain. Noise is not taken in to account yet. Therefore, carrier power can be found by the well known equation as follows:

$$\text{Carrier Power} = G_{Rx} + P_{Tx} + G_{Tx} - \text{Losses} \qquad (4)$$

Where G_{Rx} = Receiving antenna's gain, PTx =Transmitter Power and G_{Tx}=Transmitting antenna's gain. In the above equation, P_{Tx} and G_{Tx} can be combined into one single term called EIRP. EIRP is amount of transmitted power, which is basically the power from the amplifier and antenna's gain which further amplifies the power. In the above equation, these values can be replaced with EIRP [16].

$$\text{Carrier Power} = G_{Rx} + EIRP_{Gs} - \text{Losses} \qquad (5)$$

So far, the carrier power received in the satellite transponder is calculated. In order to find C/No, Noise (No) received should be calculated. Noise is calculated by the following equation:

$$N = kTBn \qquad (6)$$

Where K= Boltzmann's constant = 1.38×10^{-23} Joules/Kelvin

So combining the signal power and power, we get

$$C/N = G_{Rx/T} + EIRP_{Gs} - \text{Losses} - K - Bn \qquad (7)$$

As mentioned earlier, C/No is per unit bandwidth and C/N is for complete bandwidth. So

$C/No = GRx_{/T} + EIRP_{Gs}$ - Losses - K- Input Back Off (8)

Types of Losses for Ku band satellite communication.

Free Space Loss:

This is considered to be the major loss in satellite communication, because signal is attenuated as it travels more distance. Geo-stationary satellites are placed at the attitude of 36,000Km, and then the signals have to travel to the aircrafts. This is a lot of distance and yields fair chances for the signal to get attenuated [16]. It is estimated by the following equations:

$\text{Free Space Loss}_{(\text{in dB})} = 32.4 + 20 \log(d) - 20 \log(WL)$ (9)

Where d = distance and WL= Wave length.

Rain Attenuation:

The main disadvantage of the Ku band frequency range is that the signal suffers attenuation due to rain. It can vary from place to place depending upon the rain intensity level. Hence, Earth station has to carefully chosen depending upon the annual rainfall range of the place. The average value of 2dB is considered for this approach [16].

Free space loss and rain attenuation are the main factors which attenuates the signal to greater extent. Other losses like gaseous absorption are very small for Ku band frequency, so they are not considered for this approach. Likewise, antenna misalignment loss is not considered also. Assuming the fact that the antennas are properly aligned to transmit and receive the signal with the maximum gain, the final C/No equation is expressed as follows:

C/No = EIRP (ES) + G/T (SR) - K - Rain attenuation - Free space loss - Input Back Off(decibels) (10)

Input Back off

Usually, the earth station has a fixed antenna's gain and power amplifier value. However, sometimes it transmits the data with some reduction from the fixed value, which is termed as input back off. So the maximum EIRP is not attained always [16]. As a result, the IBO is accounted for along with the losses and subtracted from EIRP in Eq (10).

Relationship between C/No and C/N

C/No is the carrier power per unit bandwidth where as C/N is for whole usable bandwidth. So in decibels,

$$C/N = C/No - 10 \log (B) \qquad (11)$$

Modulation and coding techniques used in the modem are not taken into account yet. Basically, C/N is used for analog signals and Eb/No is for digital signals. As the research work deals with digital signals, Eb/No has to be computed. The following section describes the relation between C/No, C/N and Eb/No along with the modulation techniques and coding techniques.

Eb/No Calculation

Eb/No is the bit energy per noise density for a signal. The Bit error rate is always expressed as a function of Eb/No. Eb/No always depends on the type of coding and modulation technique used.

$$Eb/No = C/No - 10 \log10 \text{ (FEC Code Rate)} - 10 \log10 \text{ (bits/symbol)} \qquad (12)$$

C/No is calculated from eq10.

Where FEC = Coding rate = R

FEC = 1 if no coding used.

Bits/ Symbol [10]:

- Bits/symbol = 2 for QPSK
- Bits/symbol = 3 for 8-PSK
- Bits/symbol = 4 for 16-QAM

Coding and modulation techniques used for this approach are explained in the following section briefly. Then, the SNR is calculated from all the calculated results.

Coding

Though there are different types of coding available, turbo codes is chosen for this approach, since it produces low signal to noise ratio compared to the other conventional coding techniques. Also, it is very suitable for low power links as well. Coding is evaluated with different code rates viz 7/8 and 3/4 [16]. It is often represented by the following equation:

R = K/M

Where K is the total message bits and M is Message and parity bits.

Coding Gain:

Higher Order modulation:

In modems, bit rates are often represented in the form of symbols. When one symbol represents more than three bits it is often referred as higher order modulations. 8-PSK, 16-QAM and QPSK combined with turbo codes are analyzed for this approach. One disadvantage of the higher order modulation is that it consumes more power than the normal modulation techniques.

Hence, the calculated Eb/No from the eq 12 is substituted in eq 13 to find the SNR.

$$C/N = SNR = Eb/no + \log (Rb) - \log (B) \quad (13)$$

Now C/N = SNR is substituted in the equation in 2 to find the channel capacity to get C1.

$Cuf = B_1 \log_2 (1+SNR_1)$.

Calculation of SNR2 for C_{df}:

SNR_2 is calculated by the same way like SNR_1, but instead of uplink frequency, downlink frequency has to be used to find the capacity. It is again the capacity of the uplink with the downlink frequency due to frequency sharing. The same modulation technique, coding, same earth station parameters are considered to calculate the SNR2.

$C_{df} = p (B_2 \log_2 (1+SNR_2))$

P is the percentage of the uplink traffic used with the downlink frequency. It will vary randomly according to the downlink's usage. And while the downlink usage is none, it will be used completely for uplink's traffic. Whenever there is a need for downlink traffic, it will be assigned dynamically with the help of guard bands.

Now the summation of Cuf and Cdf gives the total capacity of the satellite link from earth station to transponder. The next section explains about the link budget and capacity of the satellite link from transponder to the aircraft antenna.

4.2.2 Satellite transponder to aircraft's antenna.

Channel capacity and SNR mainly depends on the satellite transponder parameters such as EIRP, G/T, Antenna Gain Flux density and the aircraft antenna's parameters. Higher order modulation along with turbo codes are used for calculating the channel capacity from earth station to transponder. More power is required to operate the modem with higher order modulations, which will not be a good practice at the satellite transponders, as they are power constrained. Therefore, the signal which is received at the modem is demodulated and modulated again with the QPSK, which is applicable for power constrained networks like transponders and aircraft antennas. QPSK sends two bits per symbol whereas higher order modulation sends more than three bits per symbol. In this way, channel capacity will be reduced to some extent than from earth station to transponder. However, if a satellite transponder has enough power to transmit the data with higher order modulation, then 8-PSK and 16-QAM will be efficient. Both cases are considered and analyzed in this approach.

Equations will be the same as they are discussed in the section 4.2.1, except the parameters. Likewise, C/N, C/No and Eb/ No are calculated with different parameters. Frequency sharing is also taken into account. The C/No equation with different parameters will be:

$C/No = EIRP_{(ST)} + G/T\ (_{AR}) - K - \text{Rain attenuation} - \text{Free space loss (decibels)}$ (14)

- $G/T\ (_{AR})$ = Aircraft antenna's gain / Temperature in Kelvin
- K = Boltzmann's constant = 1.38×10^{-23} Joules/Kelvin
- $EIRP_{(ST)}$ = EIRP of the satellite transponder.

Free space loss is the signal attenuation pertinent to the distance traveled. Free space loss is calculated from the geostationary satellite transponder to the aircraft's antenna. The distance traveled will be comparatively less than the FSL of the earth station to the transponder. Other losses like rain attenuation and gaseous absorption would be the same as the section 4.2.1.

From the eq 14 Eb/No, SNR and Channel capacity using uplink frequency and down link frequency for uplink are calculated subsequently.

BER

Bit error rate is the ratio of the errors to the total number of bits sent in a time interval. It is also defined as the function of Eb/No and error function [16]. The error function depends upon the various modulation methods used. It is expressed in the following equation:

For QPSK= BER =1/2Erfc $(eb/no)^{1/2}$

For 8-PSK= BER =1/4Erfc $(eb/no)^{1/2}$

For 16-QAM= BER =1/8Erfc $(eb/no)^{1/2}$

TCP and Bit rate

Bit rate or total channel capacity can be calculated as discussed in channel capacity topic. But while using TCP as the transport protocol, the calculated channel capacity for single request can not be completely utilized. TCP window size is not enough to allow a single request to utilize the available channel capacity [19]. The maximum TCP window size is 65, 535 bytes per request, but the available bit rate is in Gbps with and without frequency sharing. TCP throughput is calculated by the well known formula [19]:

Throughput = Window size / RTT

RTT is the round trip time in the satellite channel. And the RTT in an error free channel is 560ms. So the maximum throughput for any satellite channel is limited to 117, 027 bytes/ second. Therefore single TCP connection cannot fully utilize the available satellite bandwidth [19]. But a satellite link can be shared among many flows. So even for window limited environment where full channel speed can not be achieved, channel capacity can be fully utilized by multiple file transfers. Hence almost all the passengers request can be served even if they initiate the file transfer simultaneously. Indeed with reasonable buffer capacity.

Simultaneous file transfers.

Video content is available in many formats like Divx, CD, and DVD. But arguably DVD video format is best in terms of quality. But the tradeoff is it needs more storage capacity than any other video formats. An average DVD file size for a two hour would be in Giga bytes, though there are plenty of encoding mechanisms available to shrink it. At the same time, similar decoder is needed in the aircrafts seat boxes. So the paper just considers the DVD file size to calculate the simultaneous transfers. The formula to calculate the simultaneous transfers is as follows:

No of simultaneous transfers = Bit rate or Channel capacity / Throughput.

So number of simultaneous transfers for different window sizes and its throughput is explained in the next chapter with subsequent simulation and results to substantiate the mathematical model.

CHAPTER 5

SIMULATION AND RESULTS

This chapter discusses the simulations and results obtained based on the mathematical model derived in the chapter 4. The rest of the chapter is arranged as follows: Total capacity is analyzed separately of the satellite link from earth station to transponder and transponder and earth station. The channel capacity, Eb/No and BER with the different modulation schemes and coding rate suitable for power and bandwidth constrained links are discussed with graphs. Earlier mathematical equations are implemented in MATLAB and results are obtained and analyzed.

5.1 Channel capacity of earth station to transponder:

The following table lists the parameters considered for the calculation purposes.

TABLE -4

CHANNEL CAPACITY PARAMETERS

Satellite transponders parameters EIRP:-50 db Transponder type: - Ku band transponders. Modulation: - QPSK, 8-PSk, 16-QAM. Coding:-Turbo Code. Input Back Off & Output Back Off :-0 for video [17] G/T:-21.3 K:- -228.

Earth station parameters Modulation: - QPSK, 8-PSk, 16-QAM. Coding:-Turbo Code (R=7/8). Modem: - CDM-600(Turbo codec and 8-psk modem). Input Back Off & Output Back Off:- 0 Sampling rate or Information rate:- 47.48 (in db) [17] G/T:- 21.3 K: - -228.
Aircraft Antenna parameters(Rantec Antenna) Transmit frequency:- 10.5 -12.5 GHZ Receive Frequency:- 14 - 145.5 GHZ EIRP:- 49 (in db) Modulation: - QPSK, 8-PSk, 16-QAM. Coding:- Turbo Code (R =7/8) Modem:- Viasat Modem Input Back Off & Output Back Off:-0 G/T:- 21.3 K: - -228.

5.2 Total capacity with and without frequency sharing:

Graph -1

The mat lab results are obtained with the parameters considered in the above table. The graph is the capacity of the uplink without frequency sharing for all different modulation techniques. For the Ku band frequency, maximum capacity obtained is 11.6Gbps for 16- QAM, which will not fit in the request of all the users. In particular, video data requires more than that.

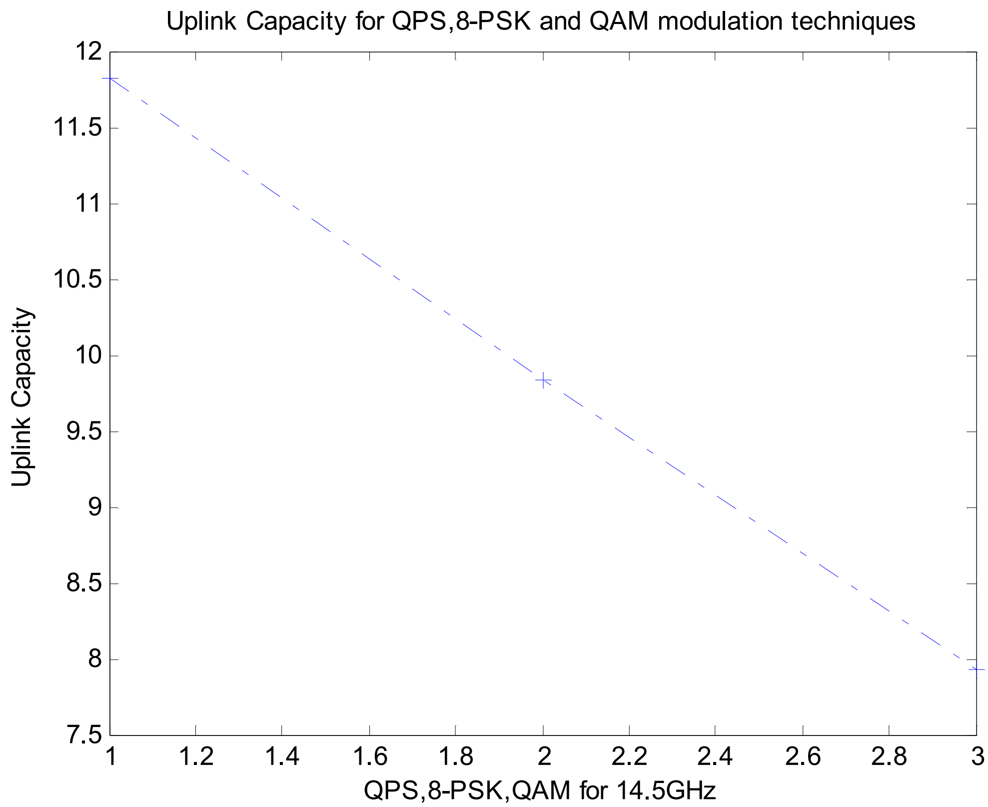

Figure 4.1 Uplink Capacity Graph from Earth station to transponder

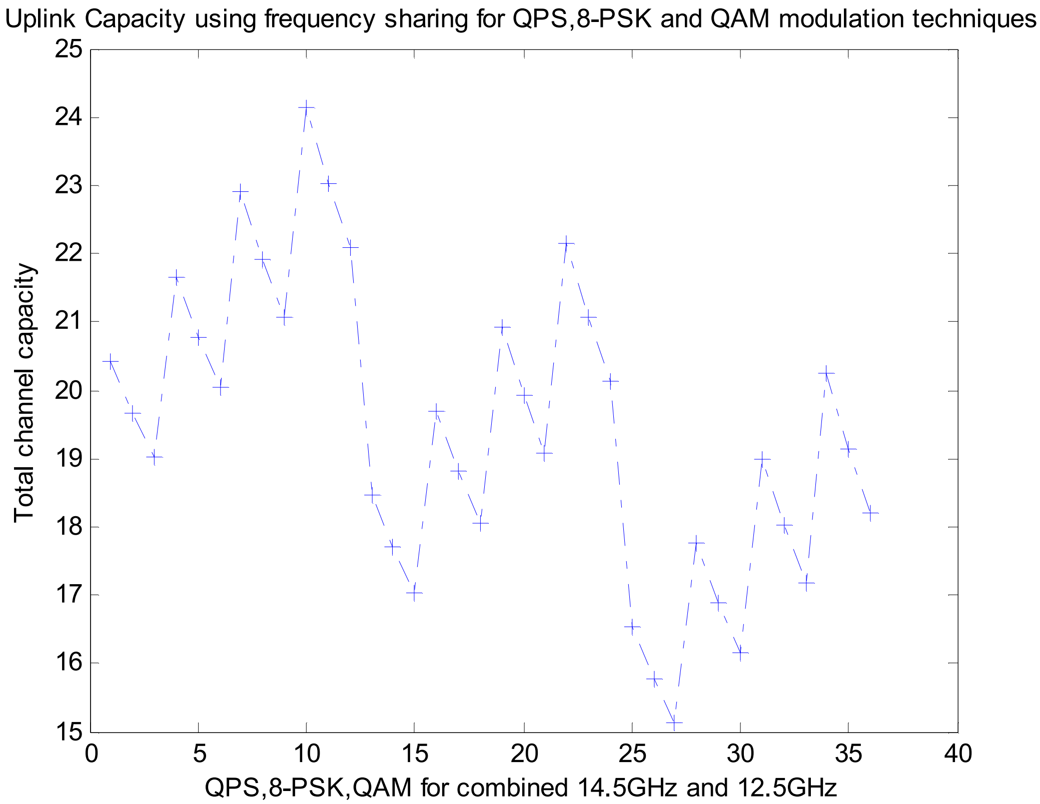

Figure 4.2 Uplink capacity from earth station to transponder with frequency Sharing graph

Graph-2 is the MATLAB result obtained with frequency sharing where downlink's frequency is utilized for uplink's purposes. It is quite evident from the graph that the channel capacity is double the capacity without frequency sharing. The maximum channel capacity 24Gbps is obtained by 16-QAM. However, 16-QAM and 8- PSK are higher order modulations which will consume more power.

As explained in chapter 3 and 4, turbo codes are used for coding at the coding rate of 7/8. Though there are lots of linear codes available, but turbo codes give the lowest error rate. It is quite clear from the graph that the Eb/No value changes with and without turbo codes. The coding gain is approximately 1db, which would definitely increase the SNR value, but certainly will decrease the Probability of error rate.

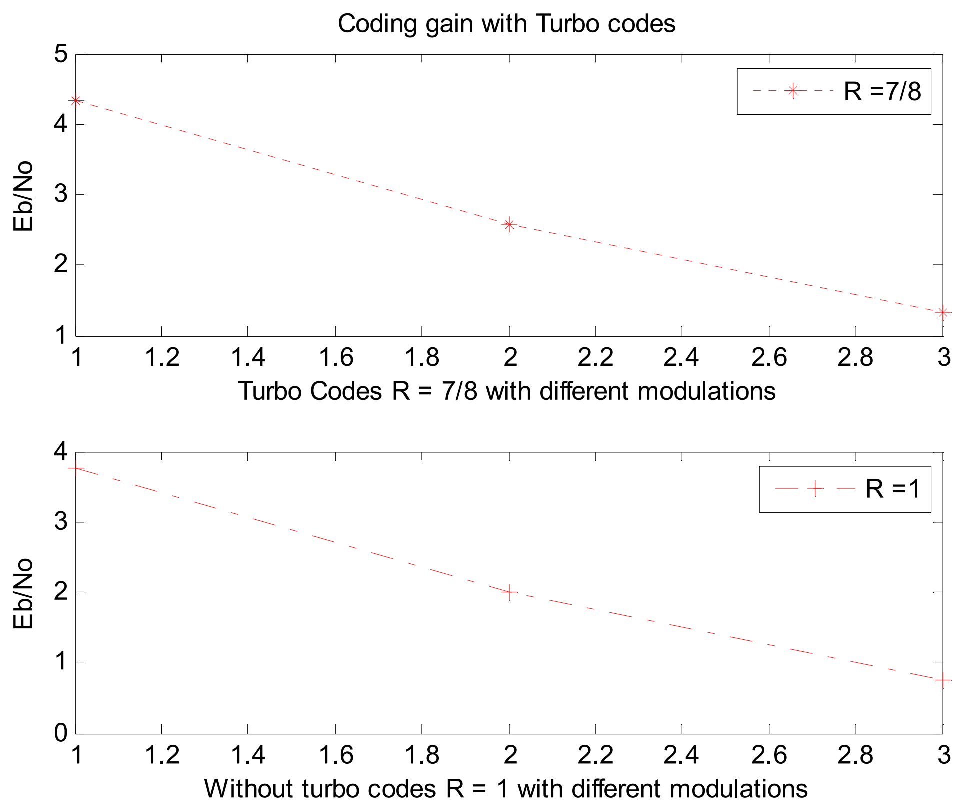

Figure 4.3 Turbo Codes graph

Channel capacity from Transponder to aircraft antenna.

Though the transponder properties remain the same, the aircraft antenna's parameters are considered for calculation purposes instead of those of the earth station. Higher order modulations are very useful for bandwidth constrained networks, but the transponder will not have sufficient power to cope with the 8-PSK and 16-QAM modulations. Though results are plotted for three modulations, QPSK would be an ideal choice to transmit the data from transponder to the aircraft's moving antenna

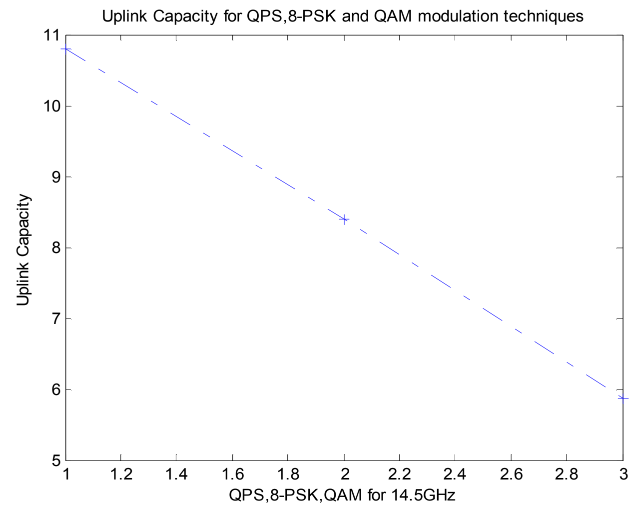

Figure 4.4 Uplink capacity from transponder to antenna graph

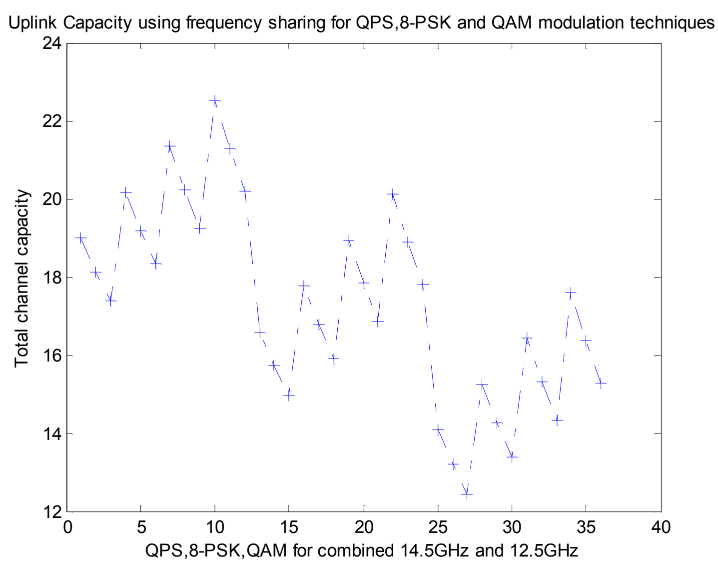

Figure 4.5 Uplink capacity with frequency sharing from transponder to antenna Graph

So without frequency sharing, the total capacity is around 6Gbps for QPSK modulation, which will result in more congestion in satellite links. However, with frequency sharing, the capacity is double fold to 17Gbps; it certainly answers the question of sufficient bandwidth. Frequency sharing will be suitable only for asymmetric traffic where either uplink or downlink occupies less traffic. In our case, uplink usage will be more as the movie content should reach the ground station. Downlink will only have the user request and acknowledgements, which certainly will not occupy much of bandwidth. At maximum, downlink will use 30% of the available capacity. The remaining 70% will used for uplink's purposes.

Simultaneous File transfers

The total capacity with frequency sharing is 17 Gbps. For a single file transfer, channel capacity will not be fully utilized, as it mainly depends on the TCP/IP window size. The window size has to be selected carefully as it directly depends on the total response time. Bigger the window size, faster the file transfer. TCP stacks have to be adjusted properly [19].

Though the larger windows are not necessary for multiple transfers in a shared link, it is a key factor in satellite links to reduce the response time as the propagation delay is comparatively more than the terrestrial links. And with the frequency sharing, bandwidth available is in Gbps. Hence larger windows are absolutely necessary to reduce the response time. It also can be adjusted depending upon the number of users.

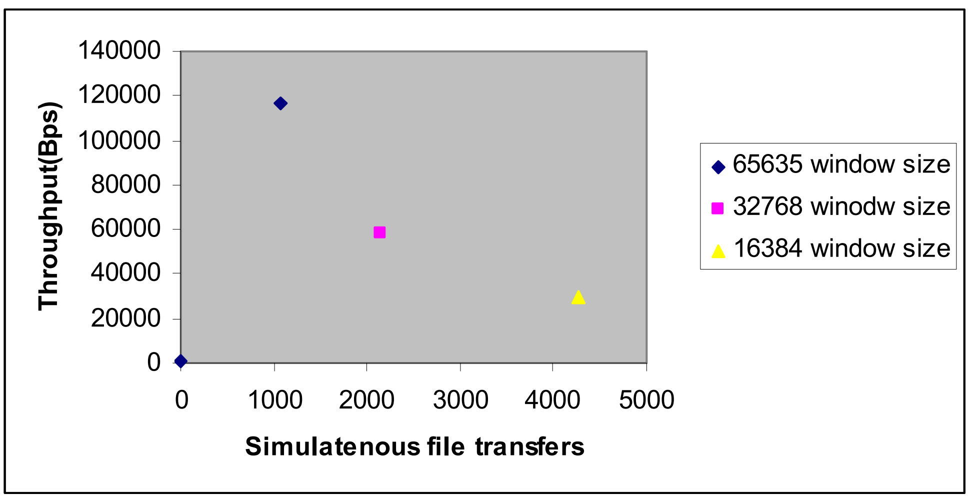

Figure 4.6 Simultaneous File transfers Vs Throughput

So the above graph is plotted with the three different window sizes and its corresponding throughputs. Future work and results have been analyzed in the next chapter.

Conclusions and Future Work

This thesis analyzed a basic prototype for implementing VOD and Live TV channels through Ku band communication for aircraft. Emerging new products and the latest technological solutions have also been analyzed to implement the same. The simulation results show that the channel capacity is approximately double fold with the frequency sharing technique along with the proper modulation and coding techniques. And the effective throughput for different window sizes has also been analyzed to find the number of simultaneous file transfer. So depending upon the number of passengers, appropriate window size can be selected. Hence, Frequency sharing techniques would be very ideal for multimedia applications like VOD and live TV. It can also be used in any kind of asymmetric service, where a constant unequal flow of data in both directions is required. VOD and live TV channels would definitely be a boon to IFE options, and since it is offered at a reasonable price, aircraft companies would not hesitate to implement it. More importantly, they are offered with the existing system architectures, which will make the implementation easier.

The thesis described the prototype model. Handoff between different geographical coverage areas will definitely occur. Therefore, continuity of the connections should be guaranteed and specified by the Network operation center, in collaboration with some onboard equipment. For example if an aircraft flying from Chicago to Frankfurt, Germany, handoff has to be successfully established with the European range of Ku band frequencies. As specified above, NOC will take care of it. Connectivity will not be lost.

Delay and free space loss will increase linearly with respect to increase in the distance from the main server. In order to minimize the delay and free space loss, mirror servers have to be implemented in the flight route of other geographical locations. However, this will give rise to another issue related to handoff. For example, a passenger is watching a movie from the main sever. Almost 60% of the movie is downloaded to the Cabin file server. During handoff, the aircraft's antenna is configured to reach a mirror server in order to minimize the delay and FSL. The mirror server has to transmit the correct sequence of data to maintain the continuity of the content. It has to be notified by the main server or the aircraft antenna to do the same, which is not covered in this research work. It is worth being discussed in a separate research topic.

PCMA (Paired carrier Multiple Access) is not discussed in this research work, which definitely increases the channel capacity to a great extent. The two different modulations has been considered in this paper, one from earth station to transponder and then from transponder to aircraft station. So PCMA will not scale well in this system architecture, so future work should also include single modulation for the whole process along with PCMA.

REFERENCES

List of References

[1] Broadband Mobile Satellite Services: The Ku band revolution by Antonio Arcidiacono, Daniele Finocchiaro, Sébastien Grazzini
http://www.eutelsat.com/products/pdf/broadbandMSS.pdf

[2] Satellite Communications in global internet: issues, pitfalls, and potential by Yongguang Zhang, Dante De Lucia, Bo Ryu, Son K. Dao- Hughes Research Laboratories, and USA.
http://www.isoc.org/inet97/proceedings/F5/F5_1.HTM

[3] Satellite Data networks, VSAT networks by Rizwan Mustafa Mir, CIS Department at OSU.
http://www.cse.wustl.edu/~jain/cis788-97/ftp/satellite_data/index.htm#VSAT

[4] In flight entertainment: The Sky is the limit by Gerald Lui-Kwan Oct, 2000
http://ieeexplore.ieee.org/iel5/2/18966/00876295.pdf?arnumber=876295.

[5] Lufthansa's techlink- Audio Video demand server.
http://www.lufthansatechnik.com/applications/portal/lhtportal/lhtportal.portal;JSESSIONID_LHTPORTAL=JKj5GkPRYBKQKkmJKwrmwTBlSRfMgvfmDrmyS1rjZdZTPCjkNYQC!1742279836?_nfpb=true&_pageLabel=Template5_6&requestednode=358&node=358&action=initial

[6] Waveforms in advance satellite communications by Mark Dankberg.
http://whitepapers.zdnet.co.uk/0,1000000651,260030513p,00.htm

[7] Advantages of Time Division Duplex (TDD) for Broadband Wireless in Last-Mile Applications by Proxim Wireless.
http://www.mms-ag.de/pdf/systems/FDD_TDD_WiMAX_Position_Paper_FINAL.pdf

[8] Live TV in-flight on Qatar Airways by Martin Williams August 9, 2006
http://www.pcadvisor.co.uk/blogs/index.cfm?blogid=4&entryid=337.

[9] http://www.inetdaemon.com/tutorials/telecom/satellite/uplink_chain.shtml.

[10] Aircraft Communications- Broadband is the future by Connexion by Boeing℠
http://www.touchbriefings.com/pdf/12/avia031_t_CONNEX.PDF

[11] Connecting to the sky by Peter Berendsen ATP/CFII Boeing 747, MD11.
http://www.starling-com.com/imgs/uploads/office%20in%20the%20sky.pdf

[12] DBS-2400™ Low profile Ku- Band Antenna System
http://www.titan.com/products-services/abstract.html?docID=9

[13] Starling, Changing the rules in Airborne Connectivity

http://www.starling-com.com/ShowDoc.asp?MyMenu=3&Link=1&MenuID=262

[14] Sky casters satellite internet service levels.
http://www.skycasters.com/broadband-satellite-compare/compare.html

[15] http://www.satelliteone.com/bigdish/antennas/ku_antennas.html

[16] Link Budget Equations – Intuitive guide to principles of communication by Charan Langton
http://complextoreal.com/chapters/linkbud.pdf

[17] Performance analysis of Vsat networks using KU band by vuong, Zimmerman, Shimabukuro, Mar 1998.
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel1/35/25/00000450.pdf

[18] Performance of Satellite links, TCP/IP by Technology Development Group, Loral CyberStar, Inc.
http://www.adec.edu/nsf/tcpip-performance.pdf

[19] RFC 2488- Enhacing TCP Over Satellite Channels using Standard mechanisms by M.Allman, Nasa Lewis / Streling Software, D.Glover, Nasa Lewis, L.Sanchez. http://www.faqs.org/rfcs/rfc2488.html

[20] Starling's core technology, CoMPA™ (Coherent Multi-Panel Antenna), is implemented in our first products, the MIJET and MiniMIJET antenna systems.
http://www.starling-com.com/ShowDoc.asp?MyMenu=3&Link=1&MenuID=262