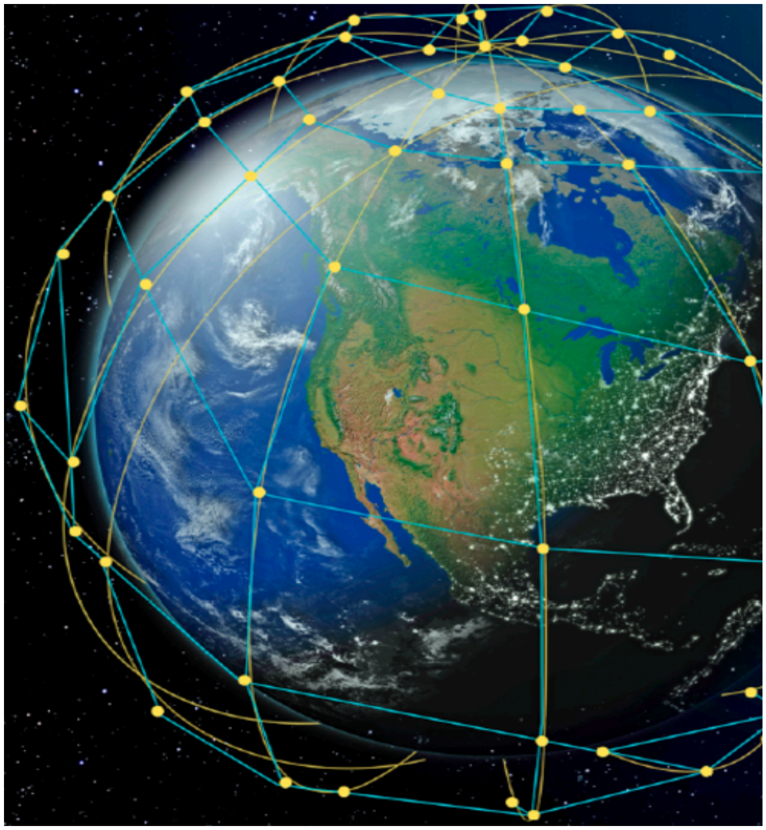


Understanding Satellite Networks and Communication

Visalakshi Gopalakrishnan - W0976426

Wireless Mobile Multi Media Networks – COEN 332
Spring 2017

This report is submitted to Dr. Keyvan Moataghed of Santa Clara University, for the partial fulfillment of requirements for the **Wireless Mobile Multi Media Networks** course (**COEN 332**)

Table of Contents

List of Figures

Audience

This project mainly focuses on basics of satellite communications and networks, transport protocol over Satellite and relationship between Satellite and terrestrial networking. This report is for graduate student and IT professionals who wish to gain familiarity with this technology.

This report is also useful for business enterprise that wishes to expand their content delivery to wider areas using satellite technology.

Pre-requisite: The reader should have a basic understanding of computer networks, network communication and basic routing protocols. They should also have some knowledge about the basic working of satellite network.

Chapter 1: Introduction

Area of reach of content delivery is no longer an issue with the Satellite communication, as it plays an important role in broadband, high definition television and global Internet services. Due to the high area coverage, satellite network will continue to play an important role in Multi Media transport due to its aim to support many applications and services that are available to users in the terrestrial network.

Due to the architecture of Satellite and the way the satellite links interact with the terrestrial links, some of the standard protocols do not perform optimally and will have to be conformed to support efficient connection and transmission of media between both the links.

In spite of the challenges and many practical constraints like cost and complexity, research is ongoing and recent developments in satellite network now support global access and services such as Voice over IP, Multi-Media, video-conferencing as such as Skype, Digital Video Broadcasting and IPv6 over satellite.

The paper will discuss briefly basics of satellite network and the interworking of satellite network with terrestrial networks. It will also discuss transport protocol like ATM, TCP and RTP over satellite and IP protocol over satellite. The paper will also briefly review services like DBS and VoIP over satellite.

1.1 Overview of chapters:

The reminder of the paper is organized in the following order:

Chapter 2: Discuss basics of satellite network, different types satellite orbit LEO, GEO and HEO, services provided by satellite like BSS, FSS and MSS and challenges in satellite network

Chapter 3: Gives overview of different components of satellite network, the topology of satellite based on number of hops, the link between satellite in same orbit and between different orbits (ISL). The chapter also discusses intra-plane and inter plane handover between satellites.

Chapter 4: Gives briefly discuss concepts of SDH protocols for transfer of multiple digital bit streams, IP and ATM protocol over satellite and ISDN services over satellite. Readers wishing to gain in depth knowledge about topics in this chapter should also read chapters 5 and 6.

Chapter 5: This chapter discusses ATM over satellite in detail. The chapter discusses in detail the function of ASIU, the cell transport method, errors, transport control and interworking of LAN/MAN using ATM over satellite

Chapter 6: This chapter will discuss TCP/IP over satellite, the limitations of TCP protocol, TCP acceleration to improve throughput over satellite and improve security by implementing TCP acceleration through VPN

Chapter 7: This chapter will discuss multimedia over satellite and challenges in multimedia transmission. This chapter will also review DVB and DVBS systems, the advantages and disadvantages of DVB system.

Chapter 8: This chapter will conclude the paper and provide readers with the author's opinion on the future of satellite network and communication.

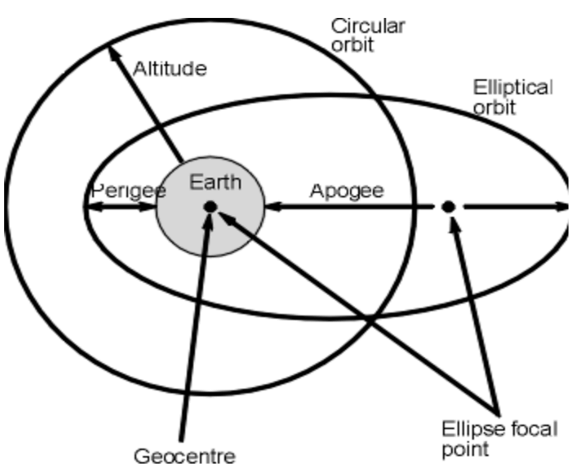
Chapter 2: Overview of Satellite Networks

In this chapter we will discuss different satellite orbits, the application and the services provided by satellite communication and the challenges faced by the satellite communication.

2.1 Satellite Orbit:

Satellite communication gives wide area coverage covering majority of earth's surface and giving access to widely dispersed users without geographical boundaries.

Once Satellite is launched in space, it hardly requires any power. A satellite's orbit is a calculated path that takes into account of Earth's rotation, satellite's speed and the gravitational pull of Earth on that satellite. The satellite functions because of the balance between both the forces. Engineers design the path keeping in mind the functionality of the satellite and the application they serve. Higher location satellites are popular for applications such as broadcasting and communication where as satellite closer to Earth are used for mobile applications.



Satellites orbit Earth in one of two of the following path [3]

- **Circular Path**: The distance of the Satellite path remains the same from the Earth all the time.
- **Elliptical Path**: The path of the Satellite changes in distance from the Earth

Figure 1: Satellite Orbit Path

Types of Satellite:

- **Low Earth Orbit (LEO) Satellites:**

As name suggest they are the closets to Earth approximately 200 KM - 1200 KM altitude and therefore their coverage of Earth surface is lesser than higher altitude satellites. More satellites are required to cover the Earth's surface and this could potentially lead to collision and therefore extreme care has to be taken in design of their path, as collision could potentially increase space debris. However the advantages of the their location supersedes the potential harm. Because of their low altitude they provide smaller attenuation and signal delay. The RTT (Round Trip Time) for radio signals is much lower. Placement of satellite in low orbit is relatively less expensive and even though they may reduce delay and loss, they have a complex system of communication links between Earth terminal and themselves due to their speed. They are mostly used for direct broadcast, communication and mobile applications.

- **Geostationary Earth Orbit (GEO) Satellite:**

GEO's are used for communication, broadcast and relay system. GEO can provide wide area coverage because of their distance from Earth. They travel at the same speed as Earth, completing one orbit path at the same that the Earth completes one rotation. It takes GEO 24 hours to complete one orbit path. Since they travel as same speed at Earth, they in the same location relative to Earth. Antennas in ground can aim with relative ease at GEO's and once aimed do not need to rotate to maintain connection. Another advantage is GEO's coverage of Earth. They can cover almost 42% of Earth's surface. Although it's advantageous to have satellites in relatively same position, because of the distance there is delay in transmission and losses in communication. GEO can only be above equator, which means other satellites have to be launched to take care of Polar Regions.

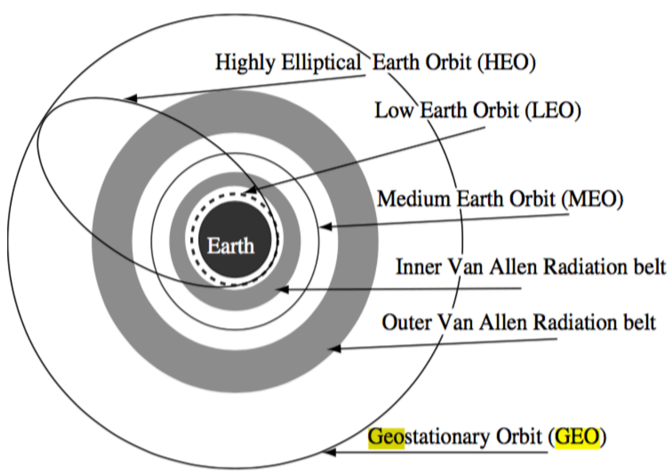


Figure 2: Different Satellite Orbits

- **Highly Elliptical Orbit (HEO) Satellites:**

As name suggests they follow the curve of an ellipse, and because of the shape of their orbit, they spend most of their time near apogee moving slowly. They provide the most coverage of any point on earth and are not limited to equatorial orbits like GEO or LEO, as a result they have the capacity to provide high altitude and polar region coverage. Polar areas are significant for HEO's.

2.2 Applications and Service of Satellite Network:

Satellite communication services are categorized as follows:

- **Broadcast Satellite Service:**

BSS or Broadcast satellite service provides distribution of high resolution video and audio through satellite. It is a radio communication service in which signals are transmitted and general users are the intended direct recipients through television antennas. They are commonly referred as Direct Broadcast (DBS) Satellite. Once positioned properly, DBS systems are used for direct broadcast of television and Internet services to all the residence residing within its area of coverage. To receive media, the residence is equipped with satellite dish and receiver that receives signals and decodes them for the user to use the services. Though DBS is primarily used for direct broadcast of high definition video and audio, they are also used for weather monitoring, data transmission and satellite phones.

- **Fixed Satellite Service:**

Fixed satellite services or FSS implement point-to-point communication through satellite between fixed stations. VSAT (Very Small Aperture Terminal) is an application for fixed satellite services. They offer services such as telephone calls and television broadcasting. They have low power and require larger dish antenna for reception. They have less power than DBS.

- **Mobile Satellite Service:**

Mobile Satellite Service or MSS are communication satellite for use with mobile telephones and is implemented using point-to-point communication. Telephone communication via MSS is similar to ground communication system, except that the repeaters are placed in orbit instead of earth. They are of three types - AMSS (Aeronautical MSS), LMSS (Land MSS) and MMSS (Marine MSS). If designed and spaced properly, these satellites can give good coverage and can link any two mobile devices. They are interconnected with ground cellular network. AMSS provide communication between ground segment and user segment in space (aircraft) via satellite. As name suggest MMSS can provide communication between marine equipment and ground via satellite. Coverage good and contiguous as long as the MSS infrastructure is well planned, but can be spotty in countries where the satellites are not spaced properly.

2.3 Challenges of Satellite Communications

- **Propagation Delay**

Since signal has to travel from ground station to satellite and back, propagation delay in satellite communication depends upon the orbit the satellite is orbiting. For GEO satellites, for one-way signal such as inter continental [5] television broadcast, this delay may not be that obvious or apparent but for two way communication, the delay becomes significant since the effective round trip affect communication especially when the signals are transmitted from ground to satellite and back to ground over longer distance. The double hop delay though not in any way dangerous can give poor user experience. However for LEO satellite the delay between sending and receiving packets are relatively low due to shorter distance and the position of satellite relative to user. In practice LEO system can experience delay like GEO because of multiple hops between multiple satellites before the call reaches the user segment.

- **Noise**

Performance for any communication system is affected by the amount of noise in the receiving system called noise floor. Greater the noise, greater the signal strength is required to offset the loss of signal in noise. There are two types of noise - antenna noise that is unrequired microwave radiation, solar and cosmic rays picked by the antenna and the other noise is called impulse noise that is generated at the receivers end. Other significant noises that can impact signal transmission include cross talk from adjacent parts of communication system. Signal processing techniques have to be efficient and advanced to extract signals well below the noise level.

- **Hazards**

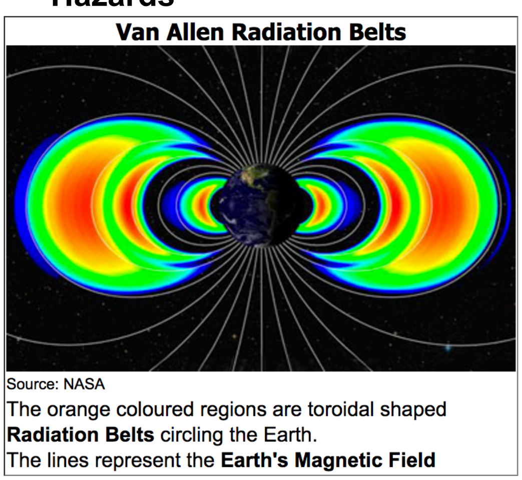


Figure 3: Van Allen Radiation Belts

Van Allen Radiation belt is a region of highly charged [5] particles that move at the speed of light. These particles encircle the earth and are responsible for damage to solar cells, circuits, and sensors and shorten life span of satellites. They posses threat to satellite systems and the damage range from minor anomalies to major satellite circuit damage and potentially failure of satellite system. To avoid such mishap, satellites should be designed orbit in a path that avoids the Van Allen Belts.

- **Temperature, Weather and terrestrial limitation**

Satellites operate in extreme condition with high temperature varying from -150C to 150C depending on their position. They could get extremely hot if under direct sun and extremely cold as they move away from sun. A high temperature fluctuation poses structural fatigue in satellite body and impact electrical components. Weather can also affect reliability of communication and frequency handled by satellites. Loss of signal can result from thermal noise by sun if the satellite is under direct sun. Snow, rain and storm can impact transmission and sometime can even halt service. Terrestrial blockage in form of high mountains, high tree foliage can cause significant blockage in transmission.

- **Collision with space debris**

Space debris in form micrometeorites, inactive satellite and space rockets, disintegrated parts of other space systems pose a major collision threat to satellite infrastructure especially since number of available slots is limited amongst many satellites sharing the same orbit and sometimes the service it provides requires it to be more clustered than other over certain ground target area. The issue becomes more of a problem in GEO, where the number slot is limited with many GEOs sharing the same orbit. The space debris pieces may be small but since they are travelling at high speeds can cause major damage.

Chapter 3: Satellite Architecture

This chapter essentially discusses components that make up satellite architecture and the topology of satellite network based on number of hops. The chapter also discusses handovers between satellite and between satellite-earth stations

3.1 Brief overview of components of Satellite communication:

Satellite communication system consists of bus (tracking system, operations and resource management) and its subsystem of payload consisting of the transponders and the antenna. The Satellite system is supported in ground through ground stations consisting of ground antennas or hub.

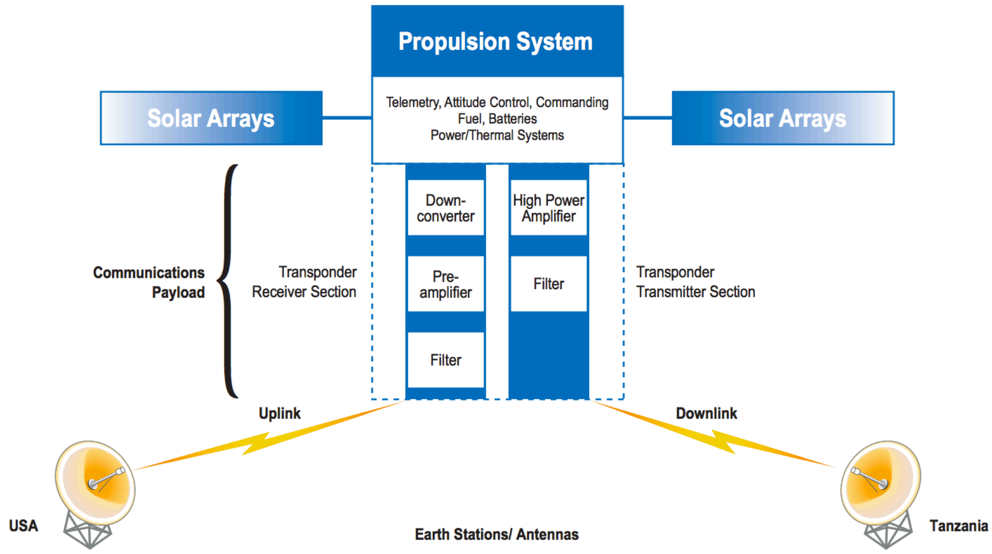


Figure 4: Representation of Satellite

- **The Bus**

Bus basically consists of the components that support the equipment in space.

- Consists of tracking system or station keeping that help maintain satellite in its orbit. The effects of lunar, solar and planetary gravity tent to push a satellite from its path
- Solar panels provide power and batteries take over when the satellite is not under direct sun
- Fuel monitoring system that track the use of fuel. On fuel consumption the satellite is commissioned out of service and usually burn on entering the earth's atmosphere or just wander in space as space debris
- A control system to push it back in orbit if it loses path
- Altitude and space control unit to ensure antenna is directed and pointer towards ground station

- **Payload**

The payload consists of:

- Transponders: As defined by Wikipedia [7]-*Transponders are series of interconnected units that form the communication channel between the receiving and the transmitting antenna's.*

They transfer signals between various ground stations that are far apart. They consists

[7] of input band limiting device, input low noise amplifier (They amplify weak signals because of distance between ground and satellite), frequency translator (Responsible from translating frequency of signal received from sender to the frequency of signal sent to receiver)

- Antenna: Antenna's create footprint of area of coverage. They require repeaters to receive, amplify and transmit signals from and to ground station

- **Ground Station**

Ground station consists of the hub with or without multiple VSAT's. The job of the ground station is to transmit high frequency microwave signals. Some ground stations are only be receivers while most are receivers and transmitters of signal. A high receiving and transmitting antenna is required because signals can become weak when they have to travel long distance. Earth stations have sophisticated technology to ensure that the link between the satellite and the ground antenna is maintained at all times and is optimized. The antenna is connected to an Indoor Unit that then connects to either actual ground devices or LAN or any other form of ground network infrastructure.

- **Signal transmission principle**

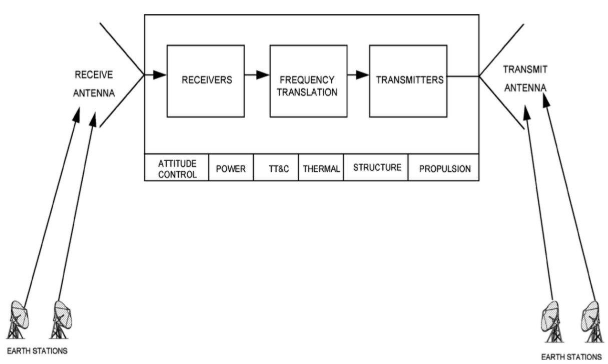


Figure 5: Bent-Pipe Principle

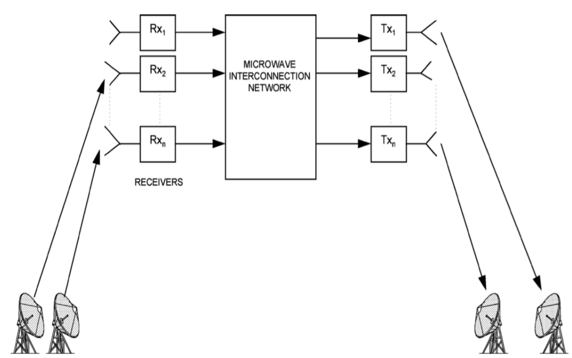


Figure 6: Spot-Beam Principle

The two principles in practice for transmission of signals from ground station are Bent-Pipe and Spot-Beam. In Bent-Pipe multiple ground stations direct the radio signals towards a single large receiving antenna on the satellite. The repeaters on the antenna receive uplink signals, amplifies the signals, translate the signals into the frequency required for the downlink, amplify it again and then direct it to the desired ground station. Bent-Pipe does not modulate or demodulate the signals and has a pre-determined receiving and transmission stations. Whereas on the other hand Spot-Beam principle facilitates the use of smaller ground terminals by allowing directed transmission of radiated radio frequency. The spot beam could be fixed or made steerable and depending upon the interconnection network at different times can provide different path between uplink and downlink beams.

3.2 Satellite topology based on hops

Satellite topology depends upon how many hops are required for a signal to travel from sender to destination without losing signal strength and also depends on applications they serve.

- **Single Hop Satellite Connection**

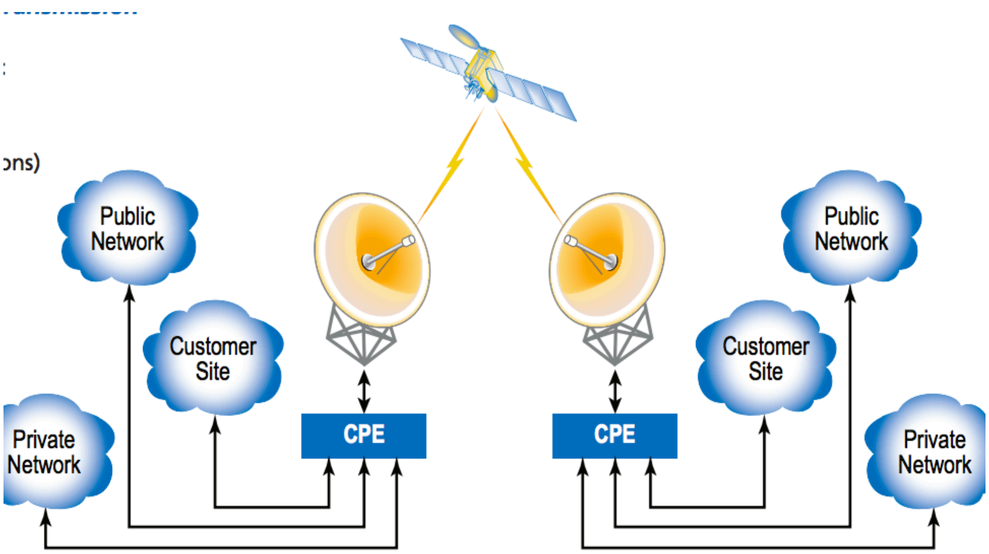


Figure 7: Single Hop satellite topology

The ground station could be fixed or mobile. In the simplest form a satellite could support one direction or two direction transmissions between two ground stations. This setup is primarily used for broadcast transmissions like television. More advanced topology is the Point-To-Point transmission for duplex transmission between two ground stations and can support applications such as VoIP, Data, IP transport and T.V broadcast. Point-To-Multi-Point transmission is a little different as it allows transmission from on big hub to multiple small ground stations like VSAT. Even though multiple ground stations are involved, end-to-end connections are routed through satellite only once ie: single hop. Used for business applications, Video, Audio and Direct - to Home Internet. It is also used for mobile ground stations such as in maritime applications or special event.

- **Multi Hop Satellite Connection**

In multi hop due to the distance between ground stations end to end connection or transmissions of signals are routed more than once through a network of ground and satellites nodes. In single hop, VSAT are widely used and central large ground hub is required to strengthen the signal. In situations where the distance between the end terminal and the hub is too large to connect with a single hop, multi hops between ground terminals and/or multiple satellites are required to make connection.

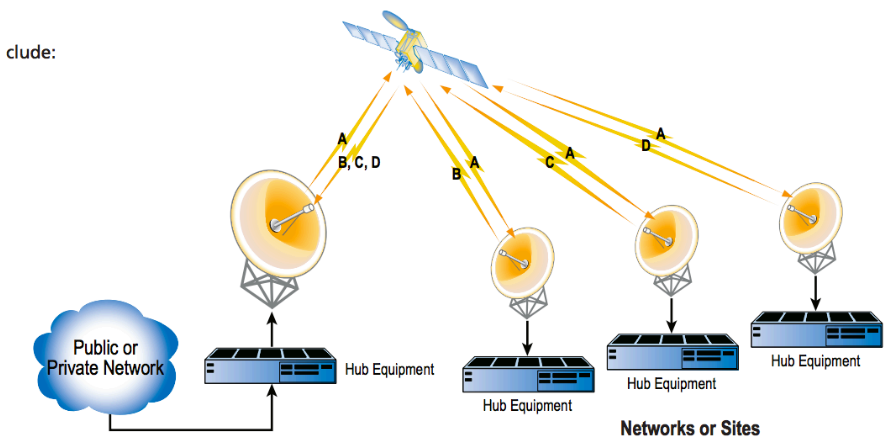


Figure 8: Multi-Hop satellite topology

Two kinds of technology are used for multi-hop communication. Star network, there will be a central ground hub with Network Management System to monitor and control all the network components. Signal is sent to the satellite, which amplifies the signal and then beams it back to the ground station. In this topology, the satellite network is the focus and forms a star with ground hub. This topology can support single hub or multiple hubs that are interconnected. In Mesh Network, the ground stations can communicate with each other through a network of satellites and/or ground terminals. This topology supports application from high definition multi-media transmission to distance learning.

3.3 Inter-Satellite Links and Handover between Satellites

- **Inter Satellite Link (ISL)**

To cover wide area either the ground terminals have to be increased or the more space segments have to be launched. Increasing space segments is advantageous as the satellites can communicate with each other without increasing space to earth traffic by replacing the number of hops between terminal and satellite from source to destination.

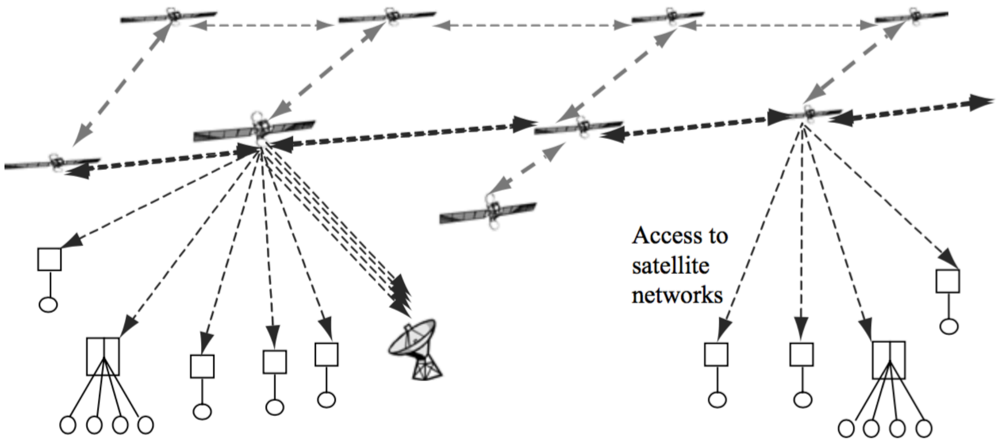


Figure 9: ISL's between satellites

On the other hand transfer between satellites require complex processing, switching and routing technologies. The line of vision between antenna's is relatively easy if they are in the same plane, however if the satellites are orbiting in the different plane, tracking the satellite to maintain connection becomes complex as satellites in different orbits have different velocities and the tracking mechanism that position antenna's rotation have to be constantly monitored.

- **Handovers in Satellite**

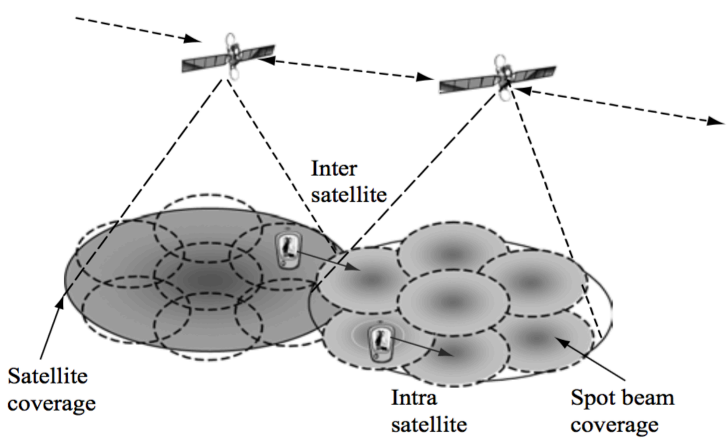


Figure 10: Handover between satellites

Handovers in satellite are needed to maintain links between satellites from source to destination. When a beam or satellite cannot accept handover because it has no idle circuit, the link gets broken and the connection is terminated. This event is called handover failure.

There are two types of handover:

- **Intra-plane handover:** This handover happens between satellites in the same plane or same orbit. When a subscriber moves from one boundary to next, the gateway that has this subscribers area code and the location of the current satellite will inform the current satellite to prepare to handover to the new area's satellite at the same time will send message to the new satellite to prepare to accept handover. If the handover happens successfully, the gateway will send massage to the station to synchronize with the new satellite and its frequency.
- **Inter-plane satellite:** It is similar to above except the handover happens between satellites in different orbits. Inter-plane handover happens if the subscriber moves away from the area of coverage of the intra-plane satellites. It could also happen that the current intra-plane could not provide the required channel or it could be possible that the coverage within the plane is not possible because of the nature of terrain.

Handovers have to done efficiently and in a timely manner otherwise delay in handover can significantly degrade service.

Chapter 4: Concept of on-board switching, SDH, ISDN in satellite networks

This chapter will briefly discuss on-board switching, SDH time division multiplexing technology, IP and ATM over SDH satellite network and ISDN services over satellite network. Chapter 5 and 6 will discuss in detail ATM over Satellite and TCP/IP over satellite networks

4.1 On-board Switching:

The traffic generated in user network depends upon the different services used by the user and the satellite network should have the capacity to support these user services like fax, telephone, Data, ISDN, B-ISDN etc.

Terrain network can support user traffic that requires high bandwidth, voice, video and multi-media services. Satellite network should take in to account of end-to end user requirements as well as signaling and channeling of the protocols of the terrain network.

A carrier suitable for telephony channel over satellite has to be created conducive for satellite radio transmission on allocated frequency band and channel. Satellite use on-board switching to transmit satellite to their destination on earth.

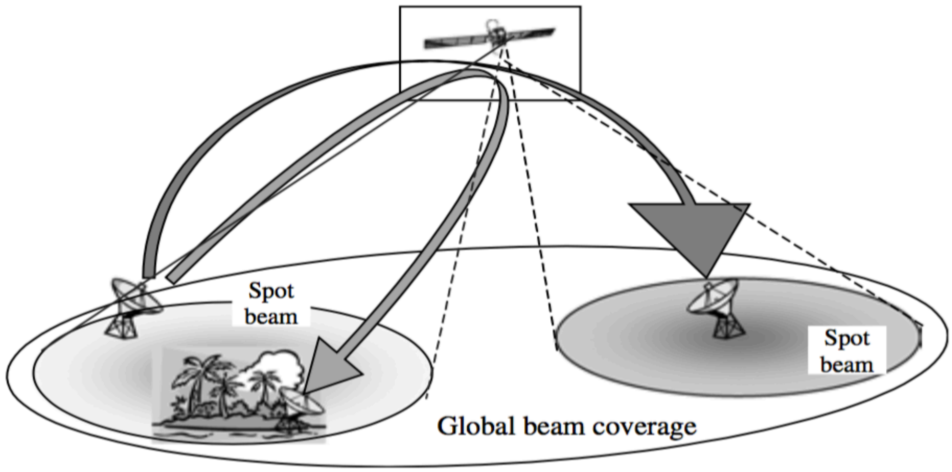


Figure 11: On-board Switching

Using satellite's on-board switching all the channels transmitted from the earth's station can be switched to their destination using different spot beams. If on-board switching was not used, the signals need to be separated at the earth station and transmitted using different bent-pipe or all the connections between earth stations have to done using a single global beam. However using multiple spot beams has its advantage. It can allow earth stations to transmit different channels to different destinations using different spot beams without the overhead of separating these channels at the terminal. Another advantage of having on-board switching is that it can replicate signals and sent to different destination using different spot beams.

4.2 Synchronous Digital Hierarchy (SDH)[14]:

SDH is a time division multiplexing technology that frames and synchronizes data at the physical level. It is capable of large payload but at the same carry low speed signal. SDH was developed to handle interfaces between network equipment and international standard transmission hierarchy. SDH has the capacity to increase available bandwidth, makes network more flexible to allow services such video conferencing and multi-media transmissions, improved network adaptability by using existing network.
Point to note - SDH protocol is processed on board while the protocols of data link (layer 2) and transport layer (layer 3) are processed in ground station

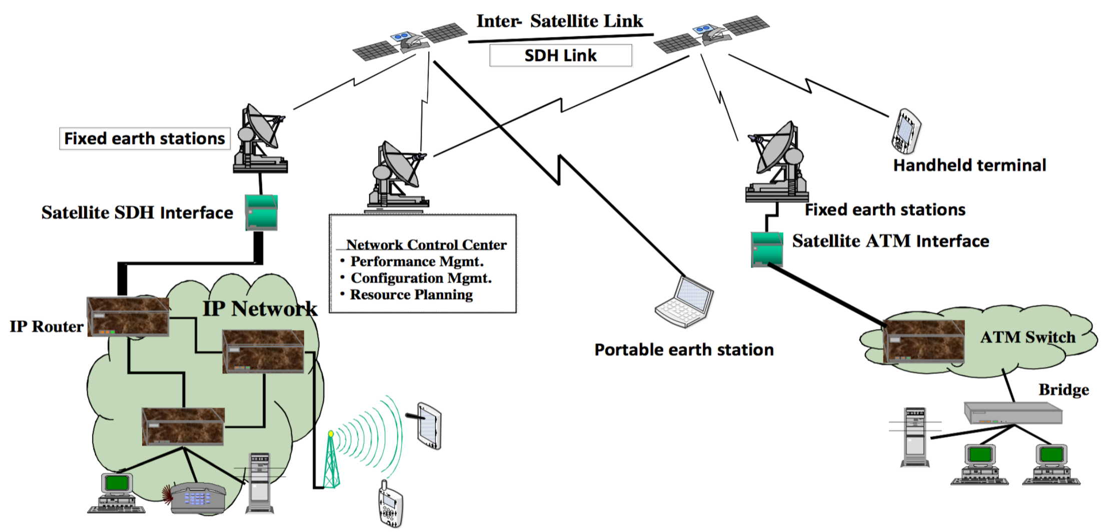


Figure 12: Satellite-SDH network model

Standards for suitable data rate transmission for SDH transmission over the satellite has been defined by International Telecommunications Union. The ground segment of satellite network consists of the ATM and IP networks. Resource management and resource allocation for satellite networks are handled by NCC. The satellite network also allows transmission of ATM and IP packets, uplink and downlink, multiplexing and de-multiplexing of STM-16 data streams and QoS.

- **IP over SDH satellite network:**

IP is a layer 3 protocols that is responsible for transmission of data at the network layer between different transport protocols. Routers in the layer 2 of the protocol stack is responsible for routing of IP packets between end users based on the IP address in the datagram. Because of ever-increasing demand for Internet based services, satellite can play an important role because of their wide area reach.

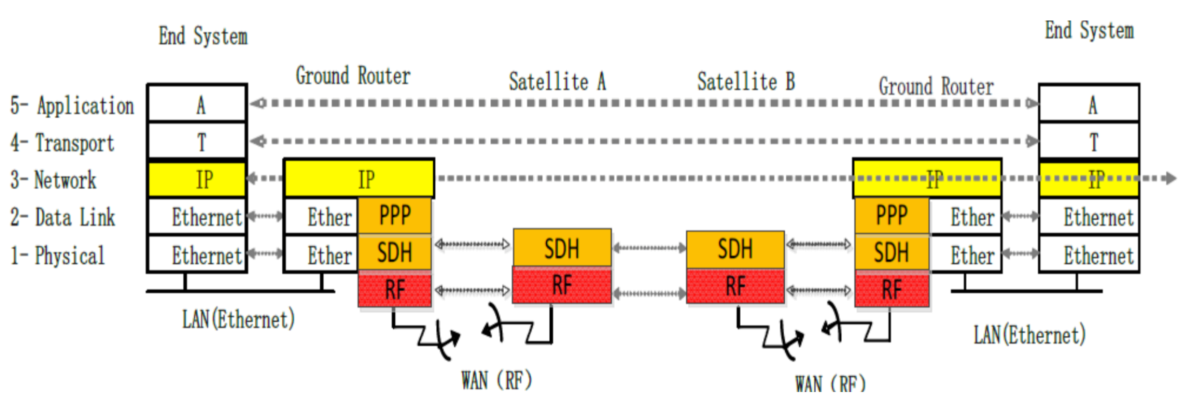


Figure 13: IP over satellite SDH network

Protocol stack diagram for IP over satellite SDH network shown in figure 13. Layer 3 and above are responsible for IP packet transmission between end users and has no knowledge about the layers below it. Layer 2 is responsible for routing and has SDH device. IP packets are encapsulated into STM-16 frame so that they can be transmitted over satellite. It is a connection-oriented service that carries IP protocols over Point-to-Point protocol. PPP is a duplex protocol that is in layer 1 that supports transmission over copper, fiber optics and satellite links. In nutshell SDH virtual containers contains mapping to PPP frame and are responsible for transmission of IP packets that are encapsulated in that PPP frame.

- **ATM over SDH satellite**

ATM is a fixed cell protocol, capable of transporting services such as video, audio and data. It is a connection-oriented service with cell switching and multiplex protocol that support circuit switching over packet switching. It provides scalable bandwidth to support various services. Figure 14 shows the ATM stack over SDH protocol. SDH mode of transfer is STM-1 frame of 155 Mbps. ATM cells in SDH payload are delineated using the (HEC) header error check of ATM cell.

The ATM cell consists of fixed 53 octets size. The SDH uses the first 5 bytes to see if it is the header or not. If it is indeed the header the SDH adds the remaining 43 bytes to find the end of the cell. It repeats the same process multiple times to find the cell boundaries. If correct cell boundaries are not found it shifts the window and tries again. The ATM cells are encapsulated in the STM-1 frame and transmitted over the satellite.

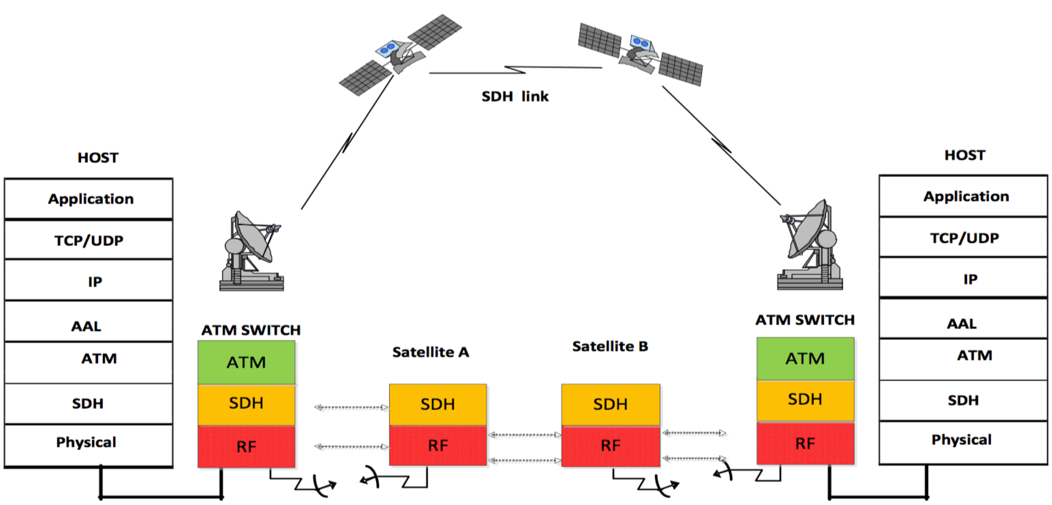


Figure 14: ATM protocol stack over satellite SDH network

4.3 ISDN over Satellite

*[According to **Wikipedia** - ISDN is a set of communication standards for simultaneous digital transmission of voice, video, data, and other network **services** over the traditional circuits of the public switched telephone network. It was first defined in 1988 in the CCITT red book.]*

Satellite transmission network differ from traditional network when considering capabilities for ISDN services. Satellite transmission errors, propagation delays effect ISDN services and have to considered. ITU-T defines standards and requirements for effective ISDN service transmission over satellite links.

Distance plays an important factor in propagation delays. Longest possible end-end connection between two end-to-end ground terminals is 27,500 Km [1]. For distance travelled. ITU-T has defined allowable performance degradation of 30% from low-to-medium grade segments and 30%-40% for high-grade segments shared between two end-to-end users. From user to local exchange, 30% of degradation is shared between them and from local exchange to international exchange 40% is shared between two segments. In terms of distance low-to-medium each segment accounts for 1250 Km and high-grade segment account for 12,500 [1] and ISDN is used over satellite links accounts for 12,500 Km. Earth station also account for link variation because of satellite movement. In practice, closer the satellite network and the ground terminal better is the performance and propagation delay is minimum.

Satellite supporting ISDN service at the minimum should support bear services that require adequate capacity to support channels ranging from 64 Kb to 1920 Kb [1]. Satellite supporting data communication should support all of ISDN packet mode bear services. Satellite network in addition should support secondary ISDN services such as support from multiple subscribers.

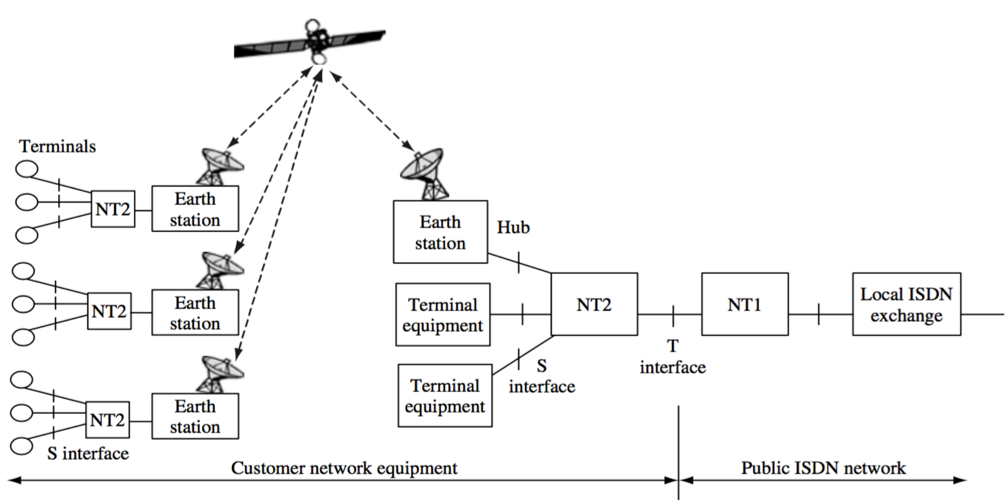


Figure 15: Multi-Node ISDN service

It should be able to support single node distributed ISDN or multi-node distributed ISDN service. In multi-node each private ISDN consisting of ground segment, network terminal and multiple users is connected to public ISDN via a hub. Routing between terrestrial and satellite circuit is governed by standards set by ITU-T, number satellite links used in the connectivity, distance between end users for better transmission quality, QoS and number of hops.

Chapter 5: Satellite ATM networks

This chapter will discuss in detail the concepts discussed in chapter 4 and is based on paper Satellite ATM Networks: A Survey by Ian F. Akyildiz and Seong-Ho Jeong, Georgia Institute of Technology [15].

Satellites satisfy the need of both developing and developed nations. In developing nations it can provide a better communication infrastructure and can reach remote areas, whereas in developed nations it can provide better quality of services, high transmission rates and multi-media services.

ATM over satellite was based on the following advantages:

- ATM services over satellite can give wide area coverage and can provide accessibility to remote and inaccessible areas
- Satellite network can match ATM network requirement of bandwidth on demand. Satellite communication systems have a very flexible bandwidth on demand capabilities and can provide PPP, multicast and fast network setup
- New subscribers can easily added to existing setup by installing an ATM device at the subscriber's location
- It can provide fault-tolerance in event of fiber failure or network congestion by rerouting through a different satellite channel on demand

However there are many obstacles it has to overcome and the following sections shall discuss.

5.1 Satellite ATM network and Cell transport method

As seen in figure 14 and in Figure 16, ASIU - ATM Satellite Interworking Unit plays an important role in the interworking between ATM network and Satellite networks. It is the key link between the ATM component and the satellite component and its primary function are to support all the function required for transmission of information between both components.

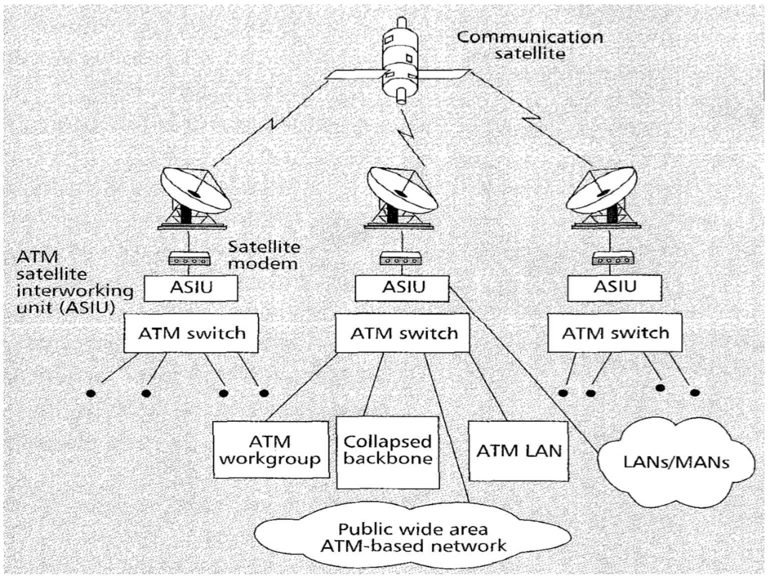


Figure 16: Satellite ATM architecture

ASIU is responsible for network bandwidth allocation, resource management, error and traffic control, synchronization and call monitoring. For ASIU to function optimally it has to support existing protocols such as SONET/SDH/PDH and PLCP. It has to also select appropriate satellite link access scheme to send information through channel.

When SDH/SONET/PDH/PLCP frames arrive at the ASIU, the ASIU's function is to extract the ATM cells from the frame and classify the cells according to their traffic class. Each of the classified cells is then placed in buffer according to the priority assigned and transmitted over appropriate satellite link. The extracted ATM cells also have to be checked for errors by ASIU. The incoming data from satellite has multiple errors because of noise in environment, weakening of signals etc. The bit error ratio of satellite should be comparable to the bit error ratio of the optical fiber link that which is the transport medium for ATM.

Satellite bandwidth is a limited resource shared by many ground terminals. ASIU's primary goal also includes efficient bandwidth management. It has to efficiently allocate bandwidth at run-time based on the user services requirement. Based on ATM cells traffic classification, ASUI should be able to provide support for appropriate link access scheme to provide high bandwidth satellite channel usage. DAMA scheme is adopted by ASIU to provide bandwidth to earth station that it actually needs, versus predicting what it may need. Another aspect that influences performance is the quality of links. The satellites not only need to be of high quality but they need to be cost efficient too.

- **Cell Transport Method**

ATM cells are transported using SDH/PDH and PLCP protocol. The concepts of SDH and PDH are discussed in chapter 4. This chapter will discuss the feasibility of these protocols in detail

- **PDH and SDH**

PDH was designed to carry digital voice. The function of the multiplexer was to check the stream at the highest clock it could support and if no bits were there in the input buffer, will add bits to stuff the signal and send message to the de-multiplexer that the bits have been stuffed and it needs to drop those stuffed bits. This means that PDH has redundant function of adding and dropping stuffed bits. But SDH on the other has a more sophisticated multiplexer. Instead of stuffing bit, pointers are used in the overhead to point the start of payload. Transfer is through optical fiber therefore accurate clock is transferred with the signal end to end. ATM cell transmission using SDH is optimum as pointers can directly point to beginning of payload and the redundant function of calculating, adding and dropping the stuff bits is avoided. But sufficient care has to be taken to ensure the pointers point to the right payload as pointers pointing to wrong payload can result in the entire block being erroneous. ASIU should employ techniques to spread errors and monitor performance.

- **Physical Layer Convergence Protocol (PLCP)**

Each ATM cell in this protocol is preceded by four bytes of the PLCP protocol as seen in figure 17

PLCP payload	Framing	POI	POH	PLCP	
A1	A2	P11	Z6	1st ATM cell	
A1	A2	P10	Z5	2nd ATM cell	
A1	A2	P9	Z4	3rd ATM cell	
A1	A2	P8	Z3	4th ATM cell	
A1	A2	P7	Z2	5th ATM cell	
A1	A2	P6	Z1	6th ATM cell	
A1	A2	P5	X	7th ATM cell	
A1	A2	P4	B1	8th ATM cell	
A1	A2	P3	G1	9th ATM cell	
A1	A2	P2	X	10th ATM cell	
A1	A2	P1	X	11th ATM cell	
A1	A2	P0	CI	12th ATM cell	Trailer
1 byte	1 byte	1 byte	1 byte	53 bytes	13–14 nibbles

A1, A2: PLCP framing bytes
P0–P11: Path overhead identifier (POI)
POH: Path overhead
Z1–Z6: Reserved byte (growth byte)
X: Unassigned byte
B1: PLCP bit-interleaved parity-8 (BIP-8)
G1: PLCP path status byte
C1: Cycle/stuff counter

Figure 17: PLCP protocol stack

First two bytes consist of A1, A2. They are the framing octets similar to framing pattern used in SDH/SONET. The other two bytes are POI (Path Overhead Indicator) and POH (Path Overhead). POI is used to indicate POH and POH are used to define bytes used to identify frames that are interleaved and used for stuff/cycle protection. PLCP frame overhead is interleaved for transmission. If the PLCP frame is not interleaved, it is susceptible to burst in errors.

5.2 Satellite access link methods and Error Control

There are three basic access methods FDMA, TDMA, CDMA. However these schemes have to be modified to support ATM over satellites.

- **FDMA - Frequency Division Multiple Access:** In this method total bandwidth is divided equally and each earth station is allocated a dedicated bandwidth. Since each station has its own dedicated bandwidth, there are no external signal interferences, errors or collision. It work well for small satellites with low power, however is it not flexible because bandwidth have to separated and not all bandwidth will be used optimally.

- **TDMA - Time Division Multiple Access:** It is similar in theory as FDMA except instead of frequency the sub channels are divided into equal time slots among all stations. Each station then get their turn based on round-robin concept and is allowed to use the entire bandwidth during that time slot. TDMA support packet traffic but the time slots have to coordinate between stations and satellite and this would make it complex and synchronization of clocks is critical.

- **CDMA - Code Division Multiple Access:** The transmissions from earth are spread over time-frequency plane by code transformation [15].

- **MF-TDMA - Multi-frequency TDMA:** It is modified TDMA. Instead of using a single frequency for time slot allocated, in MF-TDMA each station can transmit multiple frequency for that time slots. This makes the satellite network more flexible than a conventional TDMA, improves speed of transmission, results in smaller antenna and effective usage of bandwidth

- **DAMA - Demand Assignment Multiple Access:** Sometimes bandwidth allocated is not used entirely resulting in wastage of an useful resource. This method allows dynamic allocation of satellite power and bandwidth based on network need for a particular user service. Some services could require higher bandwidth but not all the time. Smaller amount of satellite power and effective usage of bandwidth makes this a better access method.

- **DAMA with MF-TDMA:** In order to achieve even better efficiency DAMA can be combined with MF-TDMA. This process requires call set-up method, negotiation of bandwidth allocation between terminals and satellite through the Master Control Station (MCA) of the satellite network. ON successful completion of negotiation and call set up, certain amount of dedicated bandwidth and memory is allocated for that time slot for the reminder of the connection.

Error Control

Burst error is a critical and well-observed error in satellite environment due to various satellite links. Convolutional codes are used to compensate for channel noise. HEC in ATM corrects single bit, but cannot handle burst errors in header and therefore can result in significant packets/cells to be dropped. ATM employs three basic algorithm to handle errors namely ARQ, stop-wait, Go-Back N and selective repeat. The first two algorithms are used for connection oriented services in the terrestrial network but are not effective in satellite network because the sender could be left waiting for an ACK due to link delay. Go-Back N is better than stop-wait as the sender is not waiting for any acknowledgement can start transmission but however on receiving an NAK due to error, the sender will have to resent the prior N cells resulting in delay and degradation of service and will not work in satellite environment.

Satellite has to adapt the existing algorithm to enhance satellite link reliability and efficient error correction. FFC code is employed as inner code over satellite link and along with Reed Solomon code (RS), the error-correcting algorithm works well and is capable of handling error.

5.3 Congestion Control

Transmission delay due to congestion can have an impact on the services provided by the ATM. Real time services like voice and video are sensitive to propagation delay and waiting time for acknowledgement. As long as the delay is controlled and original time could be recovered at the destination the impact on the service could be limited combined with high connectivity satellites. Where as certain services like data are not sensitive to delay but they require error free and reliable transport protocol. In order to support real time services various congestion scheme are employed.

- **Selective Cell Discard:** In this method, cells are discarded based on whether CLP bit is set to 1 or 0. Cells with CLP bit set to 0 are not discarded. Although this is efficient at preventing congestion, on reliable connection dropping of cells will lead to retransmission that will then cause substantial delay in satellite ATM network.

- **EFCI - Explicit Forward Correction Indicator:** The information regarding congestion is sent to the source from the destination. The cell on reaching destination is examined to see of the congestion bit is by the router and if so is sent to the higher layer with that information. The higher layer then informs its peer entity of the congestion in the route. This though effective on ground network is hardly appropriate in satellite network due to at least one propagation delay is required.

- **BECI - Backward Error Correction Indicator:** Works better than EFCI in ground network but again is inefficient in satellite network as the congestion could happen on the destination side or on the end of the propagation leg.

- **Buffering and Virtual Connection Prioritization:** Buffering can reduce congestion by buffering cells but it is at cost of delay of cells reaching destination. Data sensitive to delay should be separated from those that are not by prioritizing it in the buffer queue. Prioritization can be made effective by allocating various links for different VC connection with different VC priority.

5.4 LAN/MAN interworking with satellite ATM

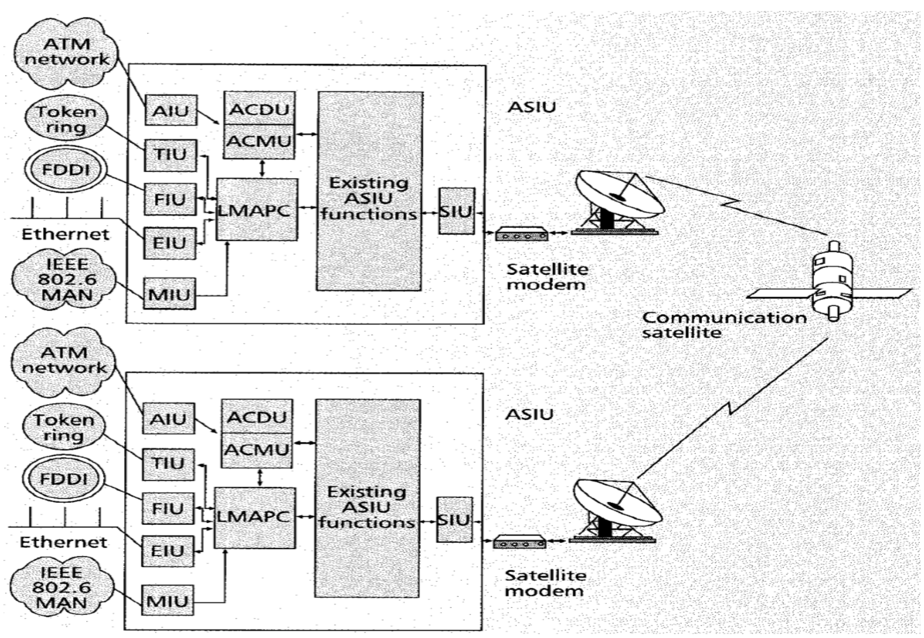


Figure 18: LAN/MAN interworking with Satellite

ASIU acts as a bridge/router between LAN/MAN and satellites as discussed in the previous chapter.

ASIU is responsible for interconnecting, error correction and management of resources. To support existing LAN/MAN infrastructure ASUI should have interfaces that support terrestrial services such as Ethernet, token ring, optical fiber, IEEE 802.6 and ability to connect to satellite with specific access method. ASIU is aware of existing network connection and is able to extract frames received and forward it to the destination. ASIU only forwards frames with unknown local LAN/MAN address over satellite and not those with known address. ASIU with capability of LAN/WAN has interfaces for all of the [14] ATM interface unit (AIU), Ethernet interface unit (EIU), token ring interface unit (TIU), FDDI interface unit (FIU), IEEE 802.6 MAN interface unit (MIU), LAN/MAN-to-ATM protocol converter (LMAPC), ATM cell multiplexer unit (ACMU), ATM cell de-multiplexer unit (ACDU), and satellite interface unit (SIU) [14].

The interfaces that interact with components of LAN/MAN such as AIU, EIU, MIU extra act like the bridge forwarding only frames with unknown address of local LAN/MAN. The filtering is done in ASIU by maintaining a table similar to routing table of local address, so that only frames with unknown address can be forwarded to the next area via satellite. The LAN/MAN to ATM Protocol Convertor (LMAPC) converts frames receives to ATM cells or vice versa. ACMU then multiplexes multiple cells into one ATM cell and forwards it to SIU. SIU then transmits the ATM cell encapsulated in STM-1 frame over the satellite.

Chapter 6: TCP/IP over Satellite

In this chapter, we will discuss limitation of satellite communication, delay due to latency, improvise TCP protocol to make more suitable for satellite network and make it more secure by using TCP acceleration along with VPN

There are two main factors that impact performance of satellite links in data transmission.

- **Throughput limitations:** TCP sender cannot send packets faster than the rate at which the receiver can accept packets. Once the TCP window is full, the sender will not send any packets until it receives acknowledgement from the receiver. Satellite has put a cap on TCP/IP throughput per RFC-793

- **Security:** TCP protocol is secure over terrestrial network, however over the satellite it is exposed to compromise. For one way broadcast such as television, the only limiting factor is the capacity of the transformer or the relay equipment. Such transmission works because the sender has dedicated bandwidth for transmission and the sender is not concerned with acknowledgments from the receiver.

6.1 Throughput limitation of Satellite Communication

For TCP protocol to work efficiently network should have low latency, maximum bandwidth availability, error detection and correction. Network should also allow retransmission in case of loss of data and efficient congestion control techniques. Two factors that affect TCP are as follows:

- **Latency:** Is the measure of time it takes for data packets to reach the destination. In satellite network it is the measure of time it takes data packets to travel from station to satellite and back. In satellite network it takes 125ms to reach satellite from earth station and another 125ms to reach earth station again. The entire Round Trip Time (RTT) will be 250ms one-way and another 250ms for it to respond. Unfortunately conventional TCP protocol is not designed for any travel time beyond 250ms.

- **Slow Start:** In TCP data transmissions between two end-users are implemented using a sliding window scheme. Sender can send all the data packets in form of bytes with the window. When the sender has exhausted the window it waits for acknowledgement number with the new window from the receiver. Failing to get that it assumes the worst and reduces the transmission rate. However in satellite network the delay in acknowledgement could be because of distance and even though there is no congestion TCP will assume the worst.

6.2 TCP Acceleration for Satellite Link

To minimize the effect of high latency and throughput limitation as discussed in the prior section TCP Acceleration technique is used. In this the technique the original TCP header is changed before transmission by the satellite modem and is called TCP Spoofing.

- **TCP Spoofing:** TCP spoofing is one type of Performance Enhancing technique that creates a communication in network as though it originates from another host. This breaks the typical TCP session from two to four as seen in the figure 19. Spoofing device on the satellite modem acknowledge the data packet it receives from the sender as though it is the receiver. TCP session proceeds as usual and on the receiver side the satellite modem suppresses the acknowledgement from the receiver. Spoofing device also contain buffer that can handle packet retransmission or lost packets between two spoofing points. This technique is not without its demerits. Spoofing can create bottleneck that can result in more packets being dropped and subsequent retransmissions. It is also not impervious to security threats.

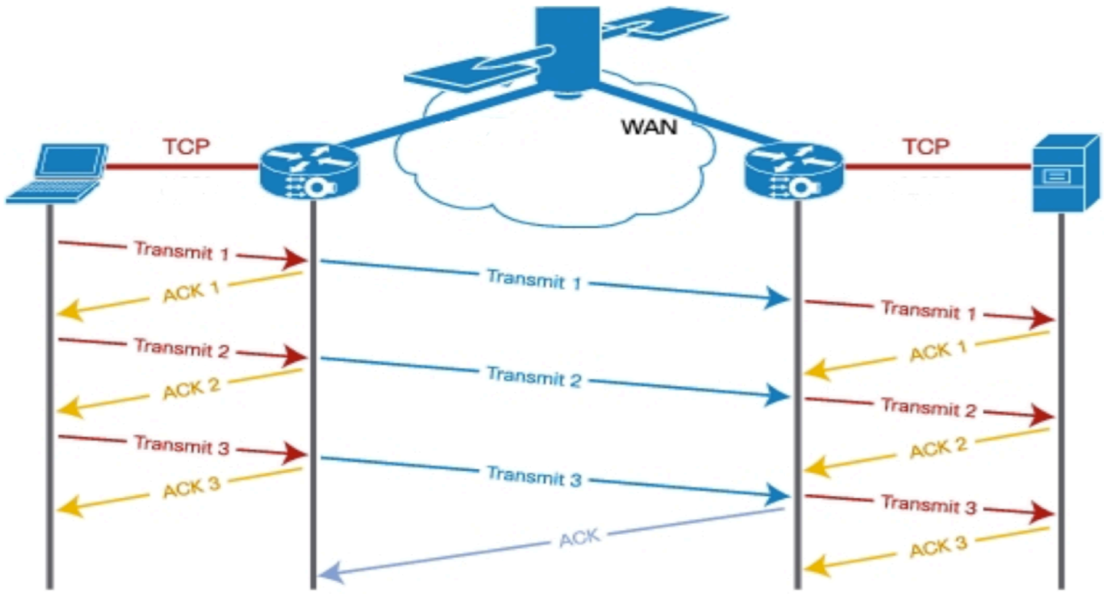


Figure 19: TCP Spoofing in satellite

6.3 Security in Satellite Communication

VPN or Virtual Private Network is most commonly used mode of transmission over insecure public IP network

VPN over satellite: VPN operate on two different transmission mode tunnel mode or transport mode. In tunnel mode the entire TCP packet is encrypted and given a new VPN header and the new encrypted data becomes the new payload to be transmitted via tunnel. This is the most secure form of data transmission. How ever in transport mode only the data is encrypted leaving the original header of the payload as is. This is less secure as the originating and destination header along with the TCP session data in text form is visible to undesirable elements.

To improve TCP over satellite we need both TCP Acceleration and VPN encryption. In TCP acceleration, the TCP header is altered but in tunnel mode of VPN the entire TCP packet is encrypted including the header. TCP acceleration will have no access to the TCP header. The only way this combination would work is to use a less secure mode i.e. transport mode of VPN where the data is encrypted but the original packet header is available for TCP acceleration to modify.

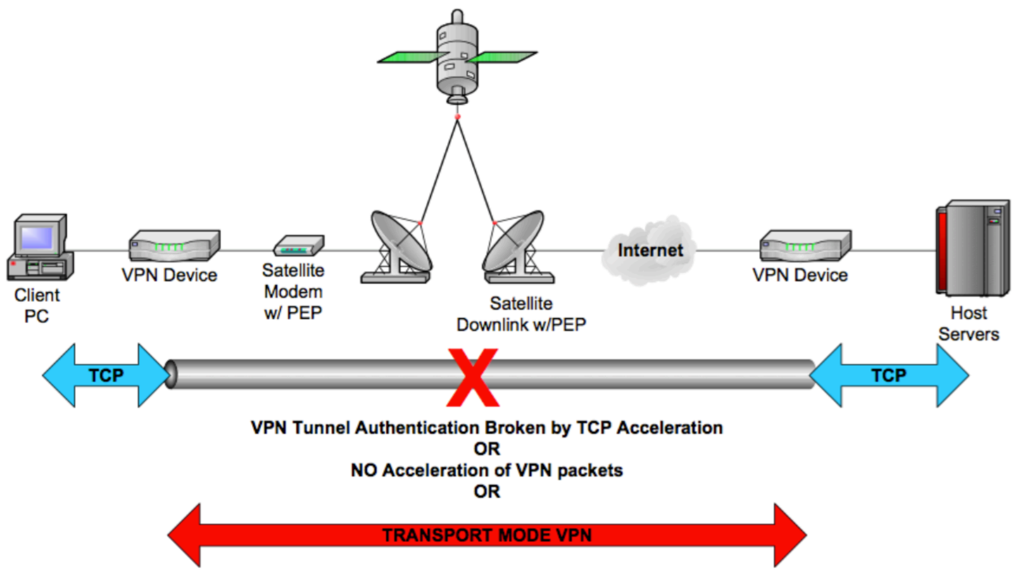


Figure 20: VPN in Satellite Communication

However this makes the data vulnerable to undesirable elements, as the header is not encrypted. Another option is then to change the header as required by TCP Acceleration and then to encrypt the entire TCP packet and tunnel it through VPN using VPN header and the accelerated TCP Packet as its new payload.

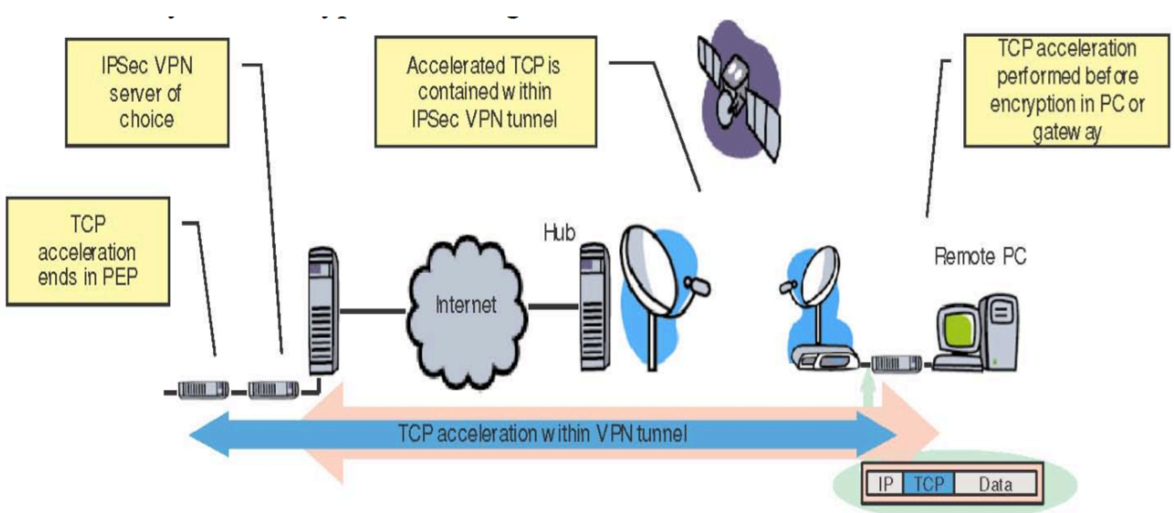


Figure 21: VPN with TCP Acceleration in Satellite Communication

Chapter 7: Multimedia over Satellite

This chapter will discuss multimedia over satellite, challenges of multimedia transmission over two different networks. This chapter will also review DVB and DVBS systems, the advantages and disadvantages of DVBS.

** This chapter is based on the research presented by Multimedia Traffic over Wireless and Satellite Networks - Floriano De Rango, Mauro Tropea and Peppino Fazio DEIS Dept., University of Calabria, Italy*

7.1 Challenges of multimedia over satellite

Satellite is no longer just a means to provide Internet access to remote areas. In developing countries satellite now provides far more advanced service that include voice, audio and high definition video.

Network in order to provide high performance multimedia service will have to satisfy certain requirements.

- Real time applications such as video/audio are extremely sensitive to time and delay will cause degradation of services. They also need to be of superior quality without out any jitters or blurriness. They require high band width one way in case broadcast and are usually unidirectional
- Data oriented transmission are not that sensitive to time but the transmission have to be secure and data integrity has to be maintained.
- However certain services are not only sensitive to response time but also require higher bandwidth, high QoS, high data integrity and security. Services such as web applications, web transactions, file sharing. Query and response should be faster for user experience.

Given the nature of multi-media services, TCP though can assure congestion free, reliable and secure transmission but cannot guarantee throughput, where as with UDP the service is faster, but the it is not connection oriented, no assurance that the data will be in the same order transmitted and the congestion is left up to the user application to handle. With the Internet services getting advanced probably UDP could be mode of transport for at least the real time application at the cost of quality but at a lower cost per consumer.

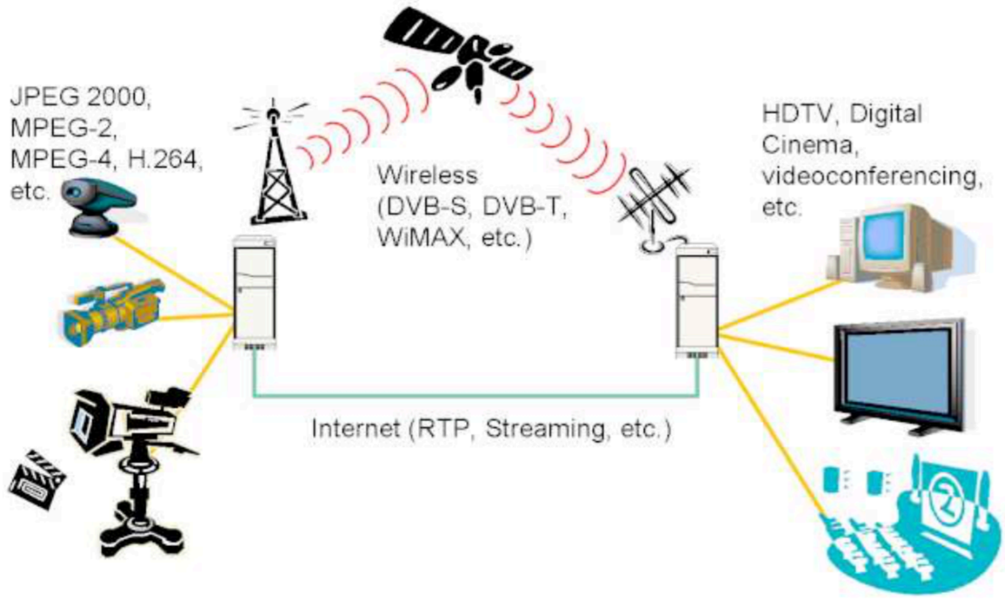


Figure 22: Multi-Media over Satellite

When satellite network becomes a part of this whole scheme, certain aspects have to be considered. High bandwidth and reliability along with lower cost per customer is still feasible option when considering terrestrial network. But when available bandwidth is limited due to nature of architecture of satellite links, that bandwidth becomes an expensive commodity to be shared amongst many users. Multimedia over satellite has to take in account of the cost incurred as it increases the overhead passed on to the customers. Multiple hops over the satellite are avoided and satellite network or part of satellite network is used as the final hop between the Internet and the end users.

7.2 DVB, DVB-RCS, SDVB

- ### DVB - Digital Video Broadcasting

Past decade or so transmission of digital images was considered not only undoable but also economically unfeasible, as it required 105 - 270 Mbps bandwidth. Instead time and resource was spent on developing high definition television. However around the 90’s technological developments in network infrastructure, efficient compression algorithms, invention of MPEG made it possible to transmit digital moving images as it now required only a fraction of bandwidth around 30 Mbps depending on the resolution and the quality of image. The standard for transmitting these images was established by a group consisting of all fraction of the broadcasting industry from across nation and thus DVB was born. DVB defines the protocol for transmission of signals using interworking between satellite network and terrestrial networks.

Based on channel of transmission, MPEG data transmitted can be classified as DVB-Satellite, DVB-Cable and DVB-Terrestrial.

DVB was established to achieve the following:

- High performance multimedia transmission integrating voice, video and data
- Adopt to different requirements of subscriber and provider regarding the quality and quantity of content
- Allow use of secondary service such as file sharing, text
- Secure, reliable, high availability and high data rate.

DVB-IP system consists of two types:

- DVB IP for unidirectional services
- DVB-RCS (DVB-Return Channel System) for bidirectional service.

- **DVP - Satellite:** Terrestrial PSTN or ISDN is used as a return channel. DVB-IP technology is well researched and tested. It is widely used, as there are many manufacturers off the DVB transmitter and receivers and is economical. DVB-S is very convenient for communication over longer distance and enjoy the advantages of wide area coverage, avoid terrestrial traffic, faster handovers and high scalability. IP over DVB is fully equipped for high data transmission over satellite. The DVB equipment can be easily integrated with the consumer equipment for receiving media. DVB technology relies on the fact that DVB-IP is responsible for transmission of data through encapsulation of IP packets with the DVB protocol stack. Multi-Protocol Encapsulation or MPE is a standard established by ETSI and its primary function is to make different hardware protocol inter-operational. The transmission packet in TDM with each packet 188 bytes. 4 bytes are allocated for header and rest for variable small data packets called Packet Stream element (PES). Each PES consists of header and variable body of data. Header along with start of prefix has identifier flow, number bytes, and optional header.

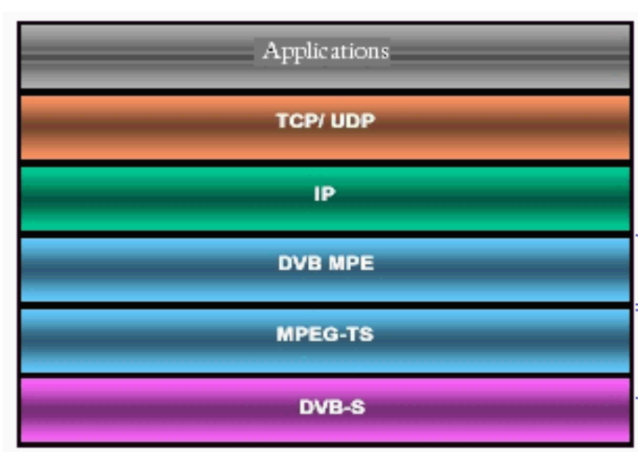


Figure 23: DVB-IP Protocol stack

- **DVB-RCS:** This technology is born out of need of peripheral stations to communicate with the master station. It is a bi-directional communication unlike the DVB-S. The return channel has variable bit rate and operate in MF-TDMA. It can dynamically allocate frequency from a pool of available frequencies to the station requesting it in that time slot. Applications that require DVB-RCS are WWW, file transfer and content media. Multicasting of data such as multicast file transfer streaming via satellite also supported by DVB-RCS. Used for application such Voice over IP, it allows steady and good control of flow rate.

- **DVB-SH:** This is a hybrid integrated service combining the benefits if both DVB-S and DVB-H. It is designed to let subscriber take advantage of services provided to terrestrial mobile devices and fixed terminal via satellite. The advantage of this system is that along with stream of video/audio to fixed device, the user can take the same services on mobile device.

- **Satellite Digital Multimedia Broadcasting (SDMB) system**

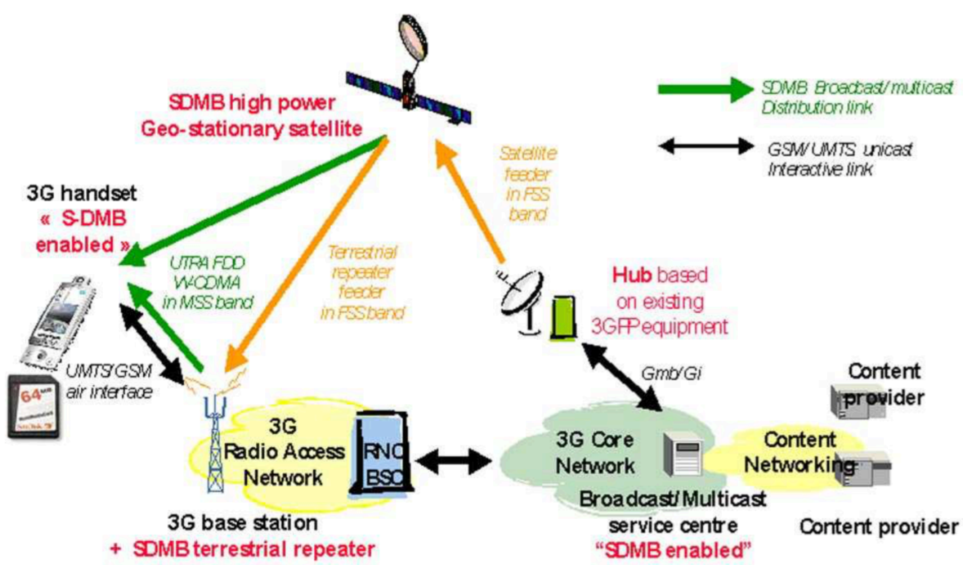


Figure 24: SDMB Architecture

SDMB consist of interaction between satellite network and terrestrial network containing Universal Telecommunication network (UTMS) to provide multimedia services to mobile devices.
This can be done by using low power ground stations and geostationary satellites. Communication between satellite network and terrestrial network is through synchronized signals through repeaters and the subscriber can use signal for improved reception and can support multimedia service for 3G cellular systems.

Chapter 8: Conclusion

As technology develops and new user services keep on coming on market, new levels of integration between satellite and terrestrial network is required. Few years ago nobody would have even imagined we would be using mobile phones for services other than basic telephony medium. Now mobile devices provide us with services nobody thought was even possible coupled with availability anywhere anytime. Satellite communications are going to be constantly evolving by providing new services in Digital Broadcast Service, Fixed Satellite Service and Mobile Satellite Service.

However it is difficult to predict future developments for certainty, but going by the developments in the past it is not difficult to predict that we need to integrate satellite network into global network infrastructure to provide access with QoS to areas that were unreachable in the past, create new applications to host variety of services to meet the needs of user's diverse requirements. Despite the merits of satellite network, Internet is not were we would like it to be today. Even though satellite can cover wide area network, as discussed before there will always be less coverage over the poles, but then other research stations very few people live there.

Latency is one of its major drawbacks. Despite its ability to provide high bandwidth, the time it takes for communication to travel from earth station to satellite and back is much longer than what it takes for it to travel through terrestrial networks. Round Trip Time is lesser for satellites closer to earth but we would need more satellites to cover wider area increasing the number of hops from end-to-end, so does not reduce latency. More the hops weaker the signals get. Latency also impedes real time applications. User can live with inferior quality but cannot handle delay in video/audio services worst even lose connection due to environment interference.

But satellite is most viable options in case of emergencies or natural disasters when terrestrial network can fail and communication can happen only through satellites.

In this paper we reviewed the basis of satellite network architecture and how we can use satellite network to transmit multimedia data over wide areas. Satellites have become more sophisticated with improved battery life, much more lighter and therefore less expensive to launch. Improved life span of satellite has made it a more reliable and a driving force behind expansion and development Internet. With all the technological innovations happening, multimedia over satellite is new buzz and a nice niche business. It's all about finding the right compromise between quality and cost.

Acronyms

1. LEO Low Earth Orbit
2. GEO Geosynchronous Equatorial Orbit
3. MEO Medium Earth Orbit
4. VoIP Voice over IP
5. VSAT Very Small Aperture Terminal
6. ISL Inter Satellite Link
7. ISDN Integrated Service Digital Network
8. B-ISDN Broadband - Integrated Service Digital Network
9. NCC Network Control Center
10. STM Synchronous Transport Module
11. SONET Synchronous Optical Network
12. SDH Synchronous Digital Hierarchy
13. PDH Plesiochronous Digital Hierarchy
14. PLCP Physical Layer Convergence Protocol
15. DAMA Demand Assignment Multiple Access
16. FDMA Frequency Division Multiple Access
17. TDMA Time Division Multiple Access
18. CDMA Code Division Multiple Access
19. ASIU ATM Satellite Interworking Unit
20. AIU ATM interface unit
21. EIU Ethernet interface unit
22. TIU token ring interface unit
23. FIU FDDI interface unit
24. MIU IEEE 802.6 MAN interface unit
25. LMAPC LAN/MAN-to-ATM protocol converter
26. ACMU ATM cell multiplexer unit

27. ACDU ATM cell de-multiplexer unit
28. SIU Satellite Interface Unit
29. DVB Digital Video Broadcasting
30. DVB-S Digital Video Broadcasting - Satellite
31. SDMB Satellite Digital Media Broadcasting
32. QoS Quality of Service

References

1. *Satellite Networking - Principles and Protocols By Zhili Sun, ISBN-13 978-0-470 87027-3 (HB) ISBN-10 0-470-87027-3 (HB). Published by John Wiley and Sons, Ltd

The author of this paper has taken extensive guidance from the reading material presented in this book. The author of this paper is grateful for the detailed information provided in this book.

2. Cross-Layer Designs Architecture for LEO Satellite Ad Hoc Network Zhijiang Chang and Georgi Gaydadjiev Computer Engineering Laboratory Delft University of Technology Mekelweg 4, 2628 CD Delft, the Netherlands

3. http://www.radio-electronics.com/info/satellite/satellite-orbits/elliptical-satellite-orbit.php

4. http://csbapp.uncw.edu/mis213/08/8-1.html

5. Analysis of Satellite-Based Telecommunications and Broadband Services, November 2013

6. http://www.vsat-systems.com/satellite-internet-explained/latency.html

7. http://www.mpoweruk.com/satellites.htm

8. https://en.wikipedia.org/wiki/Transponder_(satellite_communications)

9. https://www.cse.wustl.edu/~jain/cis788-97/ftp/satellite_nets/#BE , David Hart, dhart@cse.wustl.edu

10. Satellite communications systems move into the twenty-first century Leonard S.Golding *Hughes Network Systems, Inc., Germantown, MD 20876, USA*

11. Multimedia Traffic over Wireless and Satellite Networks - Floriano De Rango, Mauro Tropea and Peppino Fazio DEIS Dept., University of Calabria, Italy

12. A Practical Introductory Guide on Using Satellite Technology for Communications, by intelsat - http://www.intelsat.com/wp-content/uploads/2013/01/5941-SatellitePrimer-2010.pdf

13. Architecture and Protocols for Satellite SDH Networks by Yanlang Hu, Quan Zhou, Jun Li, Yi Zhang, Jingling Li, and Tao Cui, International Journal of Future Computer and Communication, Vol. 5, No. 5, October 2016

14. Satellite ATM Networks: A Survey by Ian F. Akyildiz and Seong-Ho Jeong, Georgia Institute of Technology, IEEE Communications Magazine - July 1997