Satellite Data Networks

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This paper provides a brief overview to Satellite Data Network Communications. It discusses the latest trends in satellite communication technology and protocols for data networks on satellite channels.

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1. List of Acronyms

ATM	Asynchronous Transfer Mode
ALE	ATM Link Enhancer
BER	Bit Error Rate
BS	Base Station
CDMA	Code Division Multiple Access
DAMA	Demand Assignment Multiple Access
DLC	Data Link Control
DTH	Direct To Home
ES	Earth Station
GEO	Geostationary Earth Orbit

ISP	Internet Service Provider
LEO	Low Earth Orbit
LOS	Line Of Sight
LNA	Low Noise Amplifier
LLC	Logical Link Control
MAC	Media Access Control
MAN	Metropolitan Area Network
MEO	Medium Earth Orbit
MSS	Mobile Satellite Services
PHY	PHYsical layer of a network model
PRMA	Packet Reservation Multiple Access
QoS	Quality of Service
UPT	Universal Personal Telecommunications
VSAT	Very Small Aperture Terminal
VCI	Virtual Circuit Identifier
WAN	Wide Area Network

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2. Satellite Communications-An overview

A communication satellite functions as an overhead wireless repeater station that provides a microwave communication link between two geographically remote sites. Due to its high altitude, satellite transmissions can cover a wide area over the surface of the earth. Each satellite is equipped with various "transponders" consisting of a transceiver and an antenna tuned to a certain part of the allocated spectrum. The incoming signal is amplified and then rebroadcast on a different frequency. Most satellites simply broadcast whatever they receive, and are often referred to as "bent pipes". These were traditionally used to support applications such as TV broadcasts and voice telephony. In recent times, the use of satellites in packet data transmission has been on the rise. They are typically used in WAN networks where they provide backbone links to geographically dispersed LAN's and MAN's [Elbert] .

Satellite communication channels are characterized by ;

- Wide Area coverage of the earth's surface.
- Long transmission delays.
- Broadcast transmission.
- Large Channel Bandwidth.
- Transmission costs independent of Distance.

The received microwave power involved in satellite links is typically very small (of the order of a few 100 picowatts). This means that specially designed earth stations that keep C/N (carrier to noise ratio) to a minimum are used to transmit/receive satellite communications. The front end receiver is the most crucial part of the tranceiver and is a major factor in the overall cost of the satellite ES. It typically employs a large antenna (Gain of a parabolic antenna is propotional to the square of its diameter) and a highly linear, low noise microwave amplifier (LNA)[Berkeley] .

Satellite links can operate in different frequency bands and use separate carrier frequencies for the up-link and down-link. Table 1 shows the most common frequency bands. The use of C bands was most common in 1st generation Satellite systems. However this band is already crowded as terrestrial microwave links also use these frequencies. The current trend is towards the higher frequencies of Ku and Ka bands. Attenuation due to rain is a major problem in both of these bands. Also due to the higher frequencies, microwave equipment is still very expensive, especially in the Ka band.

BAND	UP-LINK (GHz)	DOWN-LINK(GHz)	ISSUES
C	4 (3.7-4.2)	6 (5.925-6.425)	Interference with ground links
Ku	11 (11.7-12.2)	14 (14.0-14.5)	Attenuation due to rain
Ka	20 (17.7-21.7)	30 (27.5-30.5)	High Equipment cost
L/S	1.6 (1.610-1.625)	2.4 (2.483-2.500)	Interference with ISM band

Table 1: Frequency spectrum allocation for some common bands

Modern Satellites are often equipped with multiple transponders. The area of the earth's surface covered by a satellite's transmission beam is referred to as the "footprint" of the satellite transponders. The up-link is a highly directional, point to point link using a high gain dish antenna at the ground station. The down-link can have a large footprint providing coverage for a substantial area or a "spot beam" can be used to focus high power on a small region thus requiring cheaper and smaller ground stations. Moreover, some satellites can dynamically redirect their beams and thus change their coverage area [Tenanbaum].

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3. Satellite Constellations

Satellites can be positioned in orbits with different heights and shapes (circular or elliptical). Based on the orbital radius, all satellites fall into one of the following three categories;

1. LEO: Low Earth Orbit.
2. MEO: Medium Earth Orbit.
3. GEO: Geostationary Eart Orbit.

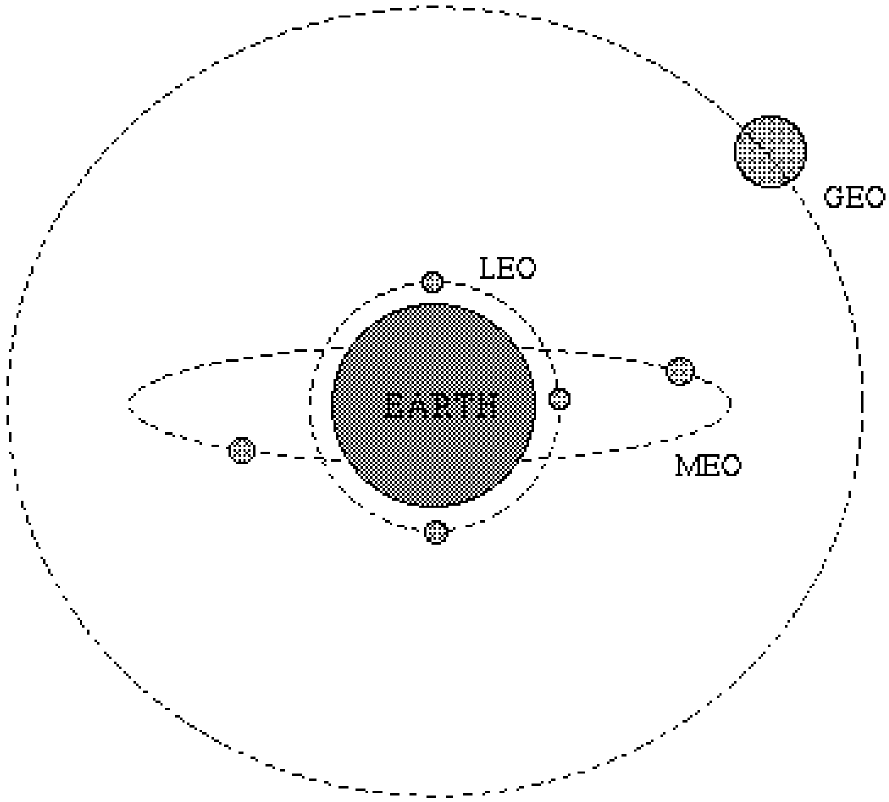

Fig 1. Different satellite constellations

These satellite constellations are shown in figure 1. The orbital radius of the satellite greatly effects its capabilities and design. Table 2 summarizes the design issues related to different type of satellite constellations.

Type	**LEO**	**MEO**	**GEO**
Description	Low Earth Orbit	Medium Earth Orbit	Geostationary Eart Orbit
Height	100-300 miles	6000-12000 miles	22,282 miles
Time in LOS	15 min	2-4 hrs	24 hrs
Merits	1. Lower launch costs 2. Very short round trip delays 3. Small path loss	1. Moderate launch cost 2. Small roundtrip delays	1. Covers 42.2% of the earth's surface 2. Constant view 3. No problems due to doppler
Demerits	1. Very short life 1-3 month 2. Encounterts radiation belts	1. Larger delays 2. Greater path loss	1. Very large round trip delays 2. Expensive ES due to weak signal

Table 2: Salient features of different satellite constellations

Satellites are also classified in terms of their payload. Satellites that weigh in the range of 800-1000 kg fall in the "Small" class, whereas the heavier class is named as "Big" satellites. GEO satellites are typically "Big" satellites, whereas LEO satellites can fall in either class [Elbert] .

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4. MAC protocols for satellite links

Satellite channels have some unique characteristics that require special considerations at the DLC (Data Link Control) layer of the OSI model. The satellite links are often referred to as Long Fat Pipes; they represent paths with high bandwidth-delay product. Moreover, since they typically provide a broadcast channel, media sharing methods are needed at the MAC (Media Access Control) sublayer of the DLC. The traditional CSMA/CD (Carrier Sense Multiple Access/Collision Detection) schemes typically used in LAN's cannot be used with satellite channels since it is not possible for earth stations to do carrier sense on the up-link due to the point to point nature of the link. A carrier sense at the down-link informs the earth stations about potential collisions that may have occoured 270ms ago (for GEO). Such delays are not practical for implementing CSMA/CD protocols.

Most satellite MAC schemes usually assign dedicated channels in time and/ or frequency for each user. This is because the delay associated in detecting and resolving multiple collisions on a satellite link is usually unacceptable for most applications. Typical MAC schemes are briefly discussed below [Berkeley] ;

ALOHA : Pure Aloha allows every competing stations to transmit anytime. It has a very low efficiency of 18%. S-ALOHA (Slotted ALOHA) using the satellite broadcasts to synchronize the ground station transmissions to the start of a slot time, can improve the efficiency to around 36%. If the number of ground stations is fixed and small, it may be considered as an option.

FDMA : (Frequency Division Multiple Access) It is the oldest and still one of the most common method for channel allocation. In this scheme the available satellite channel bandwidth is broken into frequency bands for different earth stations. This means that guard bands are needed to provide separation between the bands. Also the earth stations must be carefully power controlled to prevent the microwave power spilling into the bands for the other channels.

TDMA : (Time Division Multiple Access) In this method, channels are time multiplexed in a sequential fashion. Each earth station gets to transmit in a fixed time slot only. More than one time slot can be assigned to stations with more bandwidth requirements. This method requires time synchronization between the (ES) Earth Stations which is generated by one of the ES and broadcast via satellite.

CDMA : (Code Division Multiple Access) This scheme uses a hybrid of time/frequency multiplexing and is a form of spread spectrum modulation. It provides a decentralized way of providing separate channels without timing synchronization. It is a relatively new scheme but is expected to be more common in future satellites.

The ability to use on board processing and multiple spot beams will enable future satellite to reuse the frequencies many time more than today's system. In general, channel allocation may be static or dynamic, with the latter becoming increasingly popular. DAMA (Demand Assignment Multiple Access) systems allow the number of channels at any time be less than the number of potential users. Satellite connections are established and dropped only when traffic demands them .

Long round trip delays and high bandwidth-delay product are the dominating issues that effect the design of DLC layers in satellite data networks. In order to isolate the effect of these undesirable features from higher layers and provide transparent interface with other terrestrial networks, research is continuing for efficient MAC and LLC protocols. Most schemes use a combination of different protocols to achieve higher channel efficiency and make channel allocation highly dynamic. Some of the latest protocols are discussed in the following sections.

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4.1 PRMA

The Packet Reservation Multiple Access (PRMA) method is an improved form of TDMA that combines TDMA with the techniques of S-ALOHA. It is intended to be used for mobile satellite links comprising of a BS and a number of MS [PRMA] .

A TDMA satellite channel consists of multiple time slots in a framed structure. Each time slot can carry data packets belonging to one of the N users. The assignment of time slots to a channel is not fixed but is handled in real time dynamically. Each data packet carries a VCI (Virtual Circuit Identifier) field that indicates its receiving earth station. Different earth stations can recognize their packets on the down-link broadcast by checking the VCI field in the packet.

At any instant a TDMA frame consists of fixed numbers of reserved and empty slots. This information is broadcast to all ES via satellite broadcasts. When an ES has reserved a slot, the packets are termed as "safe" packets. Whenever a new ES tries to establish a channel, it sends an "unsafe" data packet in one of the available slots. If the packet reaches the destination without collision, the slot is reserved and the ES can transmit "safe" packets. If a collision occours, collision avoidence schemes (for example binary exponential backoff alogarith) are used to resolve the conflicts between the contenders. A user that has no data to send in a reserved time slot, loses its resrvation for that slot. A user may reserve more than one time slots, if required. Figure 2 shows an instance of channel allocation for two simultaneous requests.

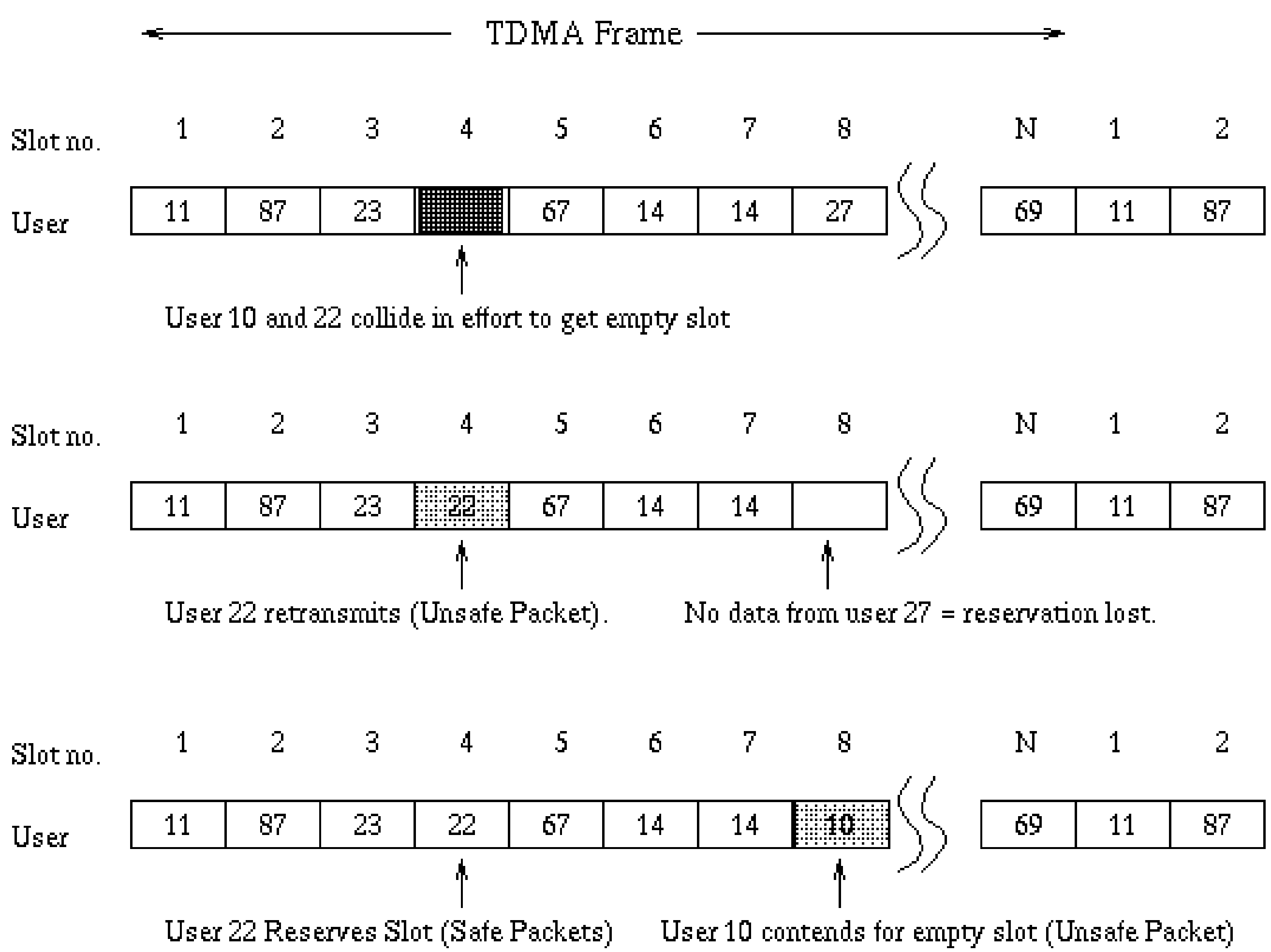

Fig 2. Sequence of steps in a PRMA process

The application of PRMA to a satellite environment depends on;

1. Round trip delay (270ms for GEO before an ES can transmit safe packets.)
2. The application and its required QoS (Quality of Service).
3. BER rate of the link.

For instance, a LEO satellite environment has small delays and low BER and is therefore "PRMA-compatible" for packetized voice applications. On the other hand, for the same application, a GEO satellite link is "PRMA-uncompatible", due to longer delays and higher BER. A PRMA-uncompatible link would require traditional TDMA to explicitly request time slots for virtual channel setup. Moreover, a ES can interleave a PRMA compatible service within the empty slots of a non-PRMA compatible service. For example non-time critical paging data can use the empty slots of a voice call. This results in improving the channel efficiency of the PRMA technique.

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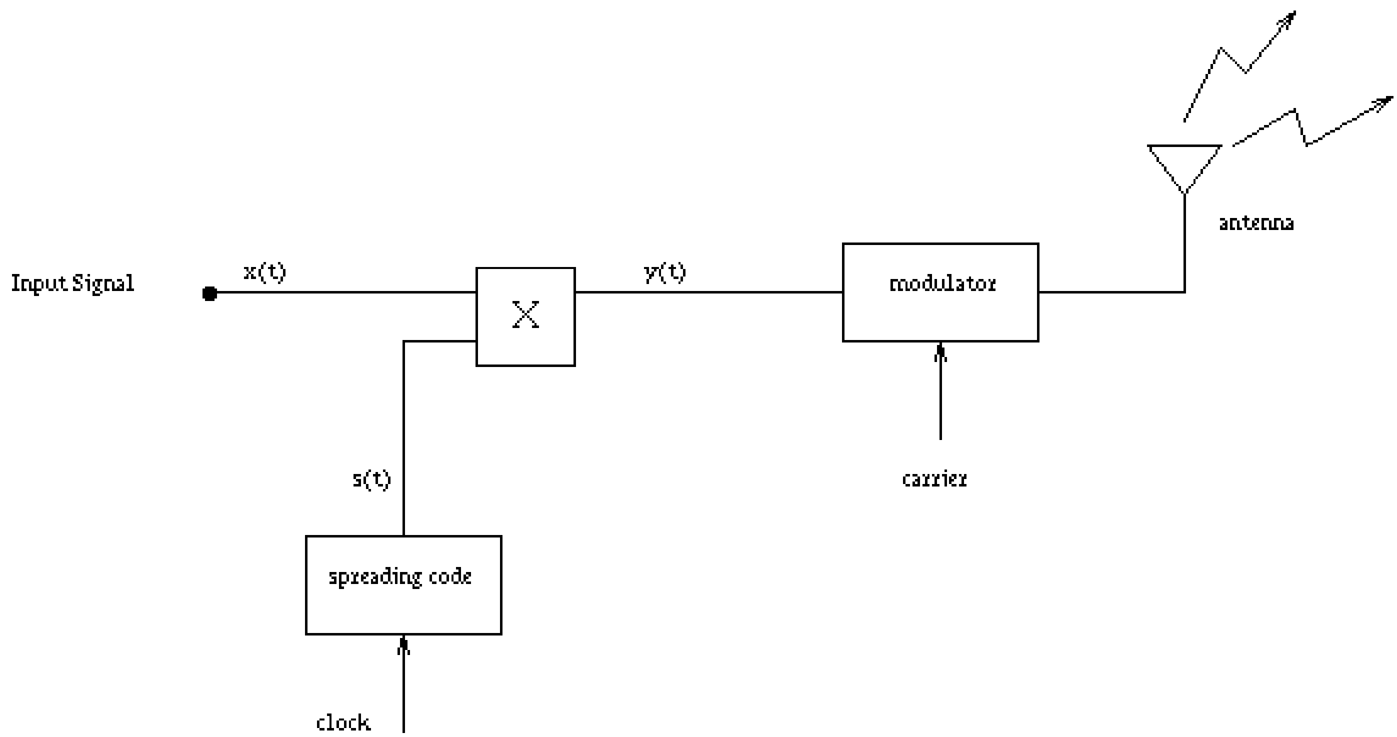
4.2 CDMA

Code Division Multiple Access is a type of spread spectrum commmunication. It was initially used only in military satellites to overcome jamming and provide security to the user [Tenanbaum] .

The basic principle of operation is shown in figure 3. Each binary transmission symbol is represented by a spreading code consisting of a zero one sequence. The bit rate of the code is typically much higher than the symbol bit rate and is referred to as the "chip rate". Each user has a unique code that is orthogonal to all the other codes. The resulting signal is obtained by the product of the input data stream and the spreading code. At the receiver, the incoming bit stream is correlated with the receivers's spreading code and user data is retreived. If the data is not meant for that user (i.e. different spreading code), it appears as noise.



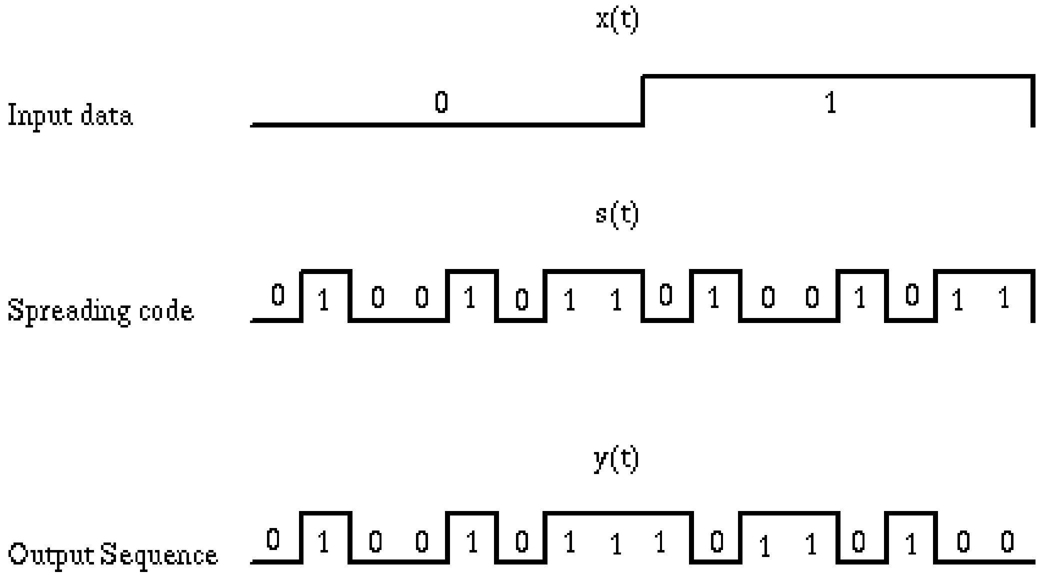


Fig 3. A Simple CDMA process

This method of modulation has the following advantages;

1. It solves the problem of multiple access without any coordination among the users. Each user can transmit its data at anytime without interference from the other user.
2. The chip or spreading code provides a method to identify and authenticate the source transmitter ES without explicit information in the packet.
3. This method gives high security against eavesdropping in satellite broadcast channels, since it is difficult to detect a user's pseudo-random spreading code.
4. Allows the reuse of same frequencies in adjacent beams in a multiple spot beam satellite by assigning different spreading codes to each user.

The main limitation of this method is that the spread spectrum signal of N users increases the noise level. Therefore as the number of users increases, the BER degrades. It is extremely difficult to accurately determine the degradation in system performance with increasing simultaneous users. Still, due to its apparent advantages, most modern satellite systems are employing CDMA as the channel access method.

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5. VSAT Networks

As mentioned earlier, due to high performance requirements, design of earth station is quite complicated. This increases the costs and the need for maintainence. Very Small Aperture Terminals (VSAT) provides a solution to this problem. The key point in VSAT networks is that either the transmitter or the receiver antenna on a satellite link must be larger. In order to simplify VSAT design, a lower performance microwave transceiver and lower gain dish antenna (smaller size) is used. They act as bidirectional earths stations that are small, simple and cheap enough to be installed in the end user's premesis [Elbert] .

5.1 Operation of VSAT Networks

VSAT networks are typically arranged in a star based topology, where each remote user is supported by a VSAT. The Earth hub station acts as the central node and employs a large size dish antenna with a high quality transceiver. The satellite provides a broadcast medium acting as a common connection point for all the remote VSAT earth stations. VSAT networks are ideal for centralized networks with a central host and a number of geographically dispersed terminals. Typical examples are small and medium buisnesses with a central office, Banking institutions with branches all over the country, backbone links for an ISP and Airline ticketing system.

The weaker signal from the remote ES is amplified at the satellite acting as a bent pipe and received by the hub ES. Thus the lower gain at the uplink is compensated at the downlink by the high performance Hub ES. The down side of this arrangement is that in case two VSATs need to communicate, two satellite hops are required, since all connections must pass through the hub ES node. The data link supported from the hub to the VSAT is typically slower (19.2 kbps) than that in the reverse direction (512kbps). Figure 4 shows how two VSAT terminals can communicate in a simple VSAT network.

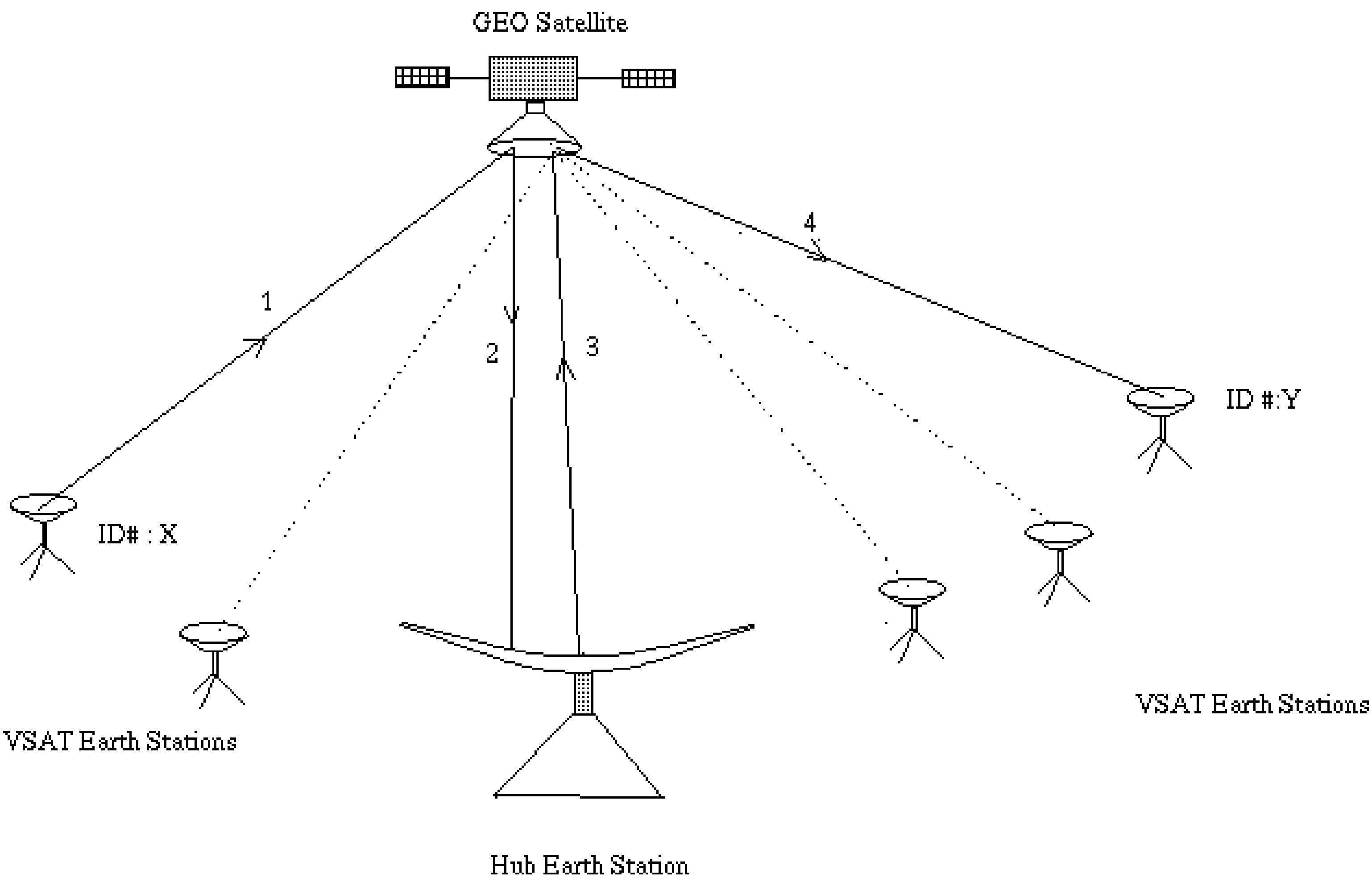

Fig 4. Communication between two VSAT terminals

The most common MAC schemes used on VSAT's are S-ALOHA and TDMA. At the LLC sublayer, a "look back N" protocol with selective reject ARQ (Automatic Repeat reQuest) retransmission strategy is used. The most common implementation uses a transmission window with N=128 packets and the receiver responds with retransmission requests for only erroneous or missing packets. This protocol combined with FEC (Forward Error Correction) produces reliable data transfers while providing low average delays on satellite links. TCP/IP does not fit well in the VSAT scenario, though it can be supported. The most commonly used network protocol on VSAT links is X.25.

Recent advances in satellite technology have enhanced the functionality of the satellites above the bent pipe operation. Modern satellites now employ on-board processing with switching functions. This means that the satellite repeater is capable of demodulation, amplifying in baseband and retransmitting at full power. Thus the basic function of the Hub ES can be eliminated and the satellite can provide full point-point mesh connectivity between VSAT ES with larger bandwidth in both directions. The trend towards multiple high power spot beams in the Ku band would further reduce the VSAT cost and size (60 cm dia antenna dishes). All of the above, combined with the improved hardware and communication schemes will make it possible to provide end user's with several Mbps links.

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5.2 DirecPC services

It is one of the most useful applications of VSAT networks, developed by Hughes Network Systems (HNS) a pioneer in VSAT technology. This service comes with an ISA computer card, a RF dish antenna (2 ft dia) equipped with an LNA, and supporting software. All that is required is an IBM compatible with 486 or higher processor and Windows OS. The VSAT terminal is installed at an open location. A cable runs from the dish antenna and connects to the ISA card inside the PC. The receiver processes of demodulation, decoding and demultiplexing are carried out inside the card. The satellite dish can be aimed at the right angle using a software utility.[DirecPC]

DirecPC supports two kinds of services.

Digital Package Delivery:

This service allows the end user to download files at speeds 100 times faster than that supported by public telephone network. Large files can be broadcast and received by multiple DirecPC end points. The download requests are made using the standard analog modem over telephone lines. The access speed of the satellite link is typically 12 Mbps. Large multimedia files incorporating sound, photos and video can, therefore, be transferred to any user on demand.

Turbo Internet:

With the increasing popularity of the World Wide Web, the demand for speedy downloads is increasing. The main bottleneck is the analog telephone line, which is incapable of supporting higher data rates. Network congestion on the Internet is another factor contributing to the problem. Using DirecPC, an end user overcomes the telephone line barrier and is capable of receiving data at 400 kbps. This is much faster than typical analog modems (28.8 kbps), ISDN or T1 leased service (384 kbps). Figure 5 shows a simple functional diagram for this system. The operation of the network is as follows;

1. A connection is setup with the local ISP using the analog telephone line modem.
2. All mouse and keyboard actions in the web browser are communicated to the web server on the other end using this link.
3. Instead of directing the data to the requesting node, data is directed to the DirecPC Network Operations Centre (NOC).
4. The data is transferred from the NOC to the end user via a satellite link operating at 400 kbps.

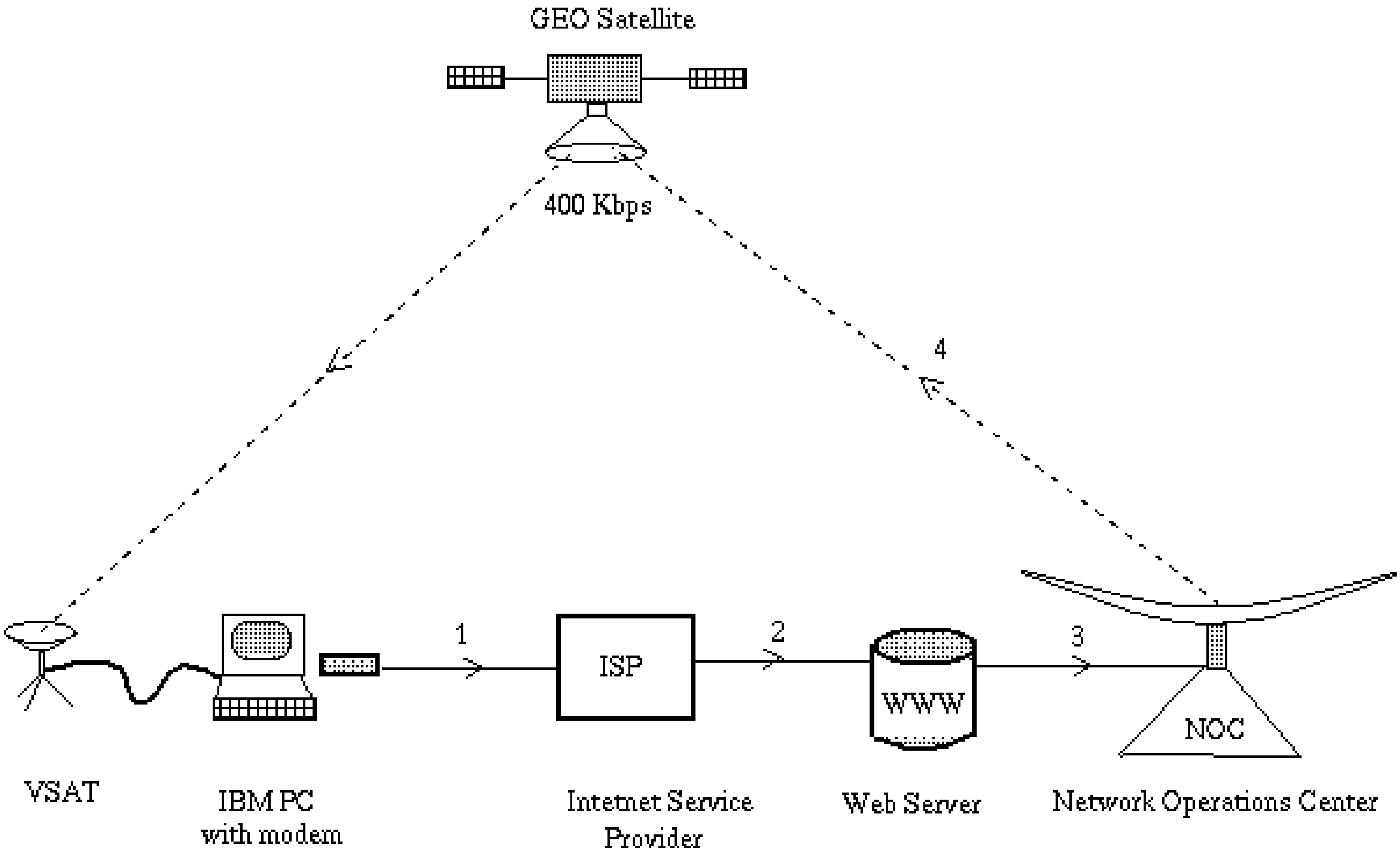

Fig 5. DirecPC service; Sequence of operations

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6. ATM on satellite channels

ATM (Asynchronous Transfer Mode) is one of the most promising technology for the information super-highway. Future networks are required to provide broadband integrated services for voice, video and data. ATM is capable of providing the requested QoS (Quality of Service) guarantees typically required by these multimedia services. It is worthwhile to investigate the performance of ATM on Satellite channels.

The basic transfer unit in ATM is a 53 byte unit referred to as a cell. 5 bytes are reserved for the header and the remaining 48 bytes are for the payload. The header field containing the routing, payload type and other network information. It is protected by a single HEC (Header Error Control) byte. This byte allows error detection and corrects all single bit errors in the header.

One of the ATM performance factors is the Cell Loss Ratio (CLR). It depends on the BER of the underlying PHY layer. ATM was designed typically for channels with low BER like fiber, whereas on a satellite channel, the BER is orders of magnitude higher. Moreover, modems used in a satellite channel employ convolutional block coding at the PHY layer for optimum performance. This results in burst error characteristics instead of isolated errors. This means that the self correcting advantage of the HEC in an ATM cell header is lost. The cells with a bad header are discarded which results in significant increase in the CLR.

Research efforts are continuing to find a solution to the problem of bursty noise on satellite channels. One solution is developed by COMSAT [ALE] and is known as the ALE (ATM Link Enhancer). The ALE module is inserted in the transmitting\receiving paths before\after the satellite modems. The ALE performs selective interleaving of the cells before sending them on a satellite channel. This helps in isolating the ATM cells from burst errors. The advantage of the HEC is restored resulting in improved overall performance. COMSAT reports that the CLR improves by several orders of magnitude as a result of using the ALE.

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7. Modern Satellite Networks

Future satellites will no longer act as "bent pipes"; they would incorporate Inter-Satelite Links, on board switching, data buffering and signal processing. The 1990's have been characterized by the trend of reaching the end user with DTH satellite services. Moreover communication satellites are expected to play a crucial role in providing global PCS (Personal Communication Services). With improving performance in satellite receivers and decreasing cost, satellite receivers equipped with dish antennas are now becoming a household commodity.

Satellites are the obvious choice for universal access for data services as they solve the main hindrance towards this goal, namely distance [Telesat]. Design of modern satellite networks (the so called 3rd generation satellites) is highly influenced by the global trend of user instead of network oriented services. Due to the rapid growth in the cellular market, the telecommunication industry is making large investments in Mobile Satellite Services (MSS) [PCS] . This type of service requires;

- Low power and simple user terminals.
- Interconnectivity with the ground cellular network and PSTN (Public Switched Telephone Network).
- Satellite constellations that provide global coverage with possibly some allowance for diversity.
- Onboard signal processing, baseband amplification and switching.
- Intersatellite links and handoffs for LEO.
- Data security and authentication.
- Dynamic channel access schemes to support a variety of applications and higher layer protocols.

Quite a few of the above performance requirements go in favor of "Small" and "Big" LEO satellites. The lower altitude of LEO satellites allows simpler receivers due to smaller attenuation, lesser propagation delays and also allows easy launch (a high altitude aircraft can accomplish the launch). Due to these reasons, LEO satellites are becoming a candidate (though some systems use MEO satellites) choice for providing network services. On the downside, the spot beam property results in constellations that need a large number of LEO satellites (and accompanying ES) for global coverage. Managing and coordinating this large number of earth stations as well as complex handover schemes between satellites is a major drawback for LEO systems. On the other hand GEO satellites can provide both large and narrow footprints with multiple transponders. This combined with the ability to switch data between spot beams are the major factors that go in favour of GEO system [Elbert] .

The following list presents some salient features of some of the modern satellite networks that use LEO, MEO as well as GEO satellite constellations

.

IRRIDIUM

Owner	Motorola
Satellites	66, 11/orbit

Orbits	900km, 6 polar orbits
Type	Big LEO
MAC method	FDMA\TDMA
Round trip delay	10 ms approx.
Start of Service	1998
Services	Voice, Data (2.4 Kbps), FAX, GPS
Remarks	Supports Intersatellite links and handoffs during calls
On-line Reference	http://www.sat-net.com/L.Wood/constellations/iridium.html

INMARSAT M

Owner	Comsat etc.
Satellites	6-20
Orbits	36000 km
Type	GEO
MAC method	FDMA
Round trip delay	500 ms
Start of Service	1993
Services	Voice, Data (2.4 Kbps), FAX, Telex
Remarks	Allows a 6.4Kbps voice channel, suitcase terminal

GLOBALSTAR

Owner	Loaral, Qualcomm
Satellites	48 (8 spares)
Orbits	1400 km, inclined
Type	Big LEO
MAC method	CDMA
Round trip delay	10 ms approx.
Start of Service	1997
Services	Voice, Data (9.6 Kbps), FAX Location services
Remarks	No Satellite handovers, elliptical spot beams
On-line Reference	http://www.globalstar.com/

TELEDESIC

Owner	Bill Gates, Craig McCaw
Satellites	840
Orbits	700 km
Type	small LEO
MAC method	ATDMA, FDMA, SDMA

Round trip delay	8 ms approx.
Start of Service	2002
Services	Voice, Data upto 2Mbps
Remarks	Phased array antennas, installation costs - US $9,000 !!
On-line Reference	http://www.sat-net.com/L.Wood/constellations/teledesic.html

ODYSSEY

Owner	TRW
Satellites	12
Orbits	10370 km
Type	MEO
MAC method	CDMA
Round trip delay	120 ms approx.
Start of Service	1999
Services	Voice, Data (9.6Kbps), FAX, GPS
Remarks	No handover, steering antenna eliminates spot beam handover
On-line Reference	http://leonardo.jpl.nasa.gov/msl/QuickLooks/odysseyQL.html

ICO

Owner	INMARSAT, Hughes
Satellites	10, 2 spares
Orbits	8-10000km
Type	MEO
MAC method	TDMA
Round trip delay	200 ms approx.
Start of Service	2000
Services	Voice, Data (2.4Kbps), FAX, GPS
Remarks	4500 telephone channels per satellite

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8. Conclusions

The role of satellites is changing from the traditional telephony and TV broadcast services to user oriented data services. This trend is expected to continue in the future. Due to this reason, 3rd generation MSS will use smart satellites that will incorporate functions such as switching, buffering and beam switching in addition to signal reproduction. Satellite data services on existing GEO satellite systems, like VSAT, will continue to compete with the terestrial options such as Telephone line and Fiber links. Small and large LEO constellations are expected to become a candidate in the cellular market. At the same time the popularity of GEO systems is not expected to diminish. In order to meet the increasing demand for real time traffic, channel access and link layer protocols will have to be optimized to ensure smooth operation over the satellite channel. TDMA and CDMA appear to be two of the stongest candidates for the MAC protocol. The evolution of satellite technology alongwith the fixed and mobile terrestrial communications is expected to merge into Universal Personal Telecommunications (UPT).

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