Data/IP over Satellite Communications

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Objectives of today's presentation

To provide an introduction to the technology & terminology associated with computer networking via commercial satellite communications systems by:

- Giving an overview of BT's involvement
- Showing how data transmission methods have evolved over 35 years
- Describing current example services to show how network designers cope with issues facing the use of Internet Protocol (IP) over a geostationary satellite communications link.
- Near-term developments
- Common abbreviations

The T&SD Mission

The key purpose of the (Satcomms) Technology & Service Development team is:

To evaluate new and improved satcomms & related products, services, technologies & systems in a timely manner to maximise their potential for earning revenue and/or controlling costs.

The expertise gained is then applied:

(a) To carry out an **Operational Design Validation** function

(b) To conduct **investigations and resolve problems** at BT and customer communications centres to maintain revenue streams.

(c) To offer **Technical Consultancy Services** external to BT to capitalise on the expertise existing within the team (and to offset our own operational costs).

Scope of the presentation

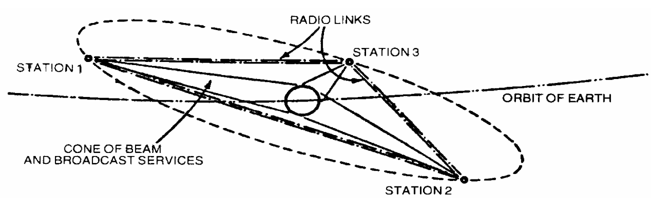
- An overview of commercial satellite communications systems
- A brief history of data communications via satellite
- Data communications terminology (ISO 7-layer model etc)
- IP via Satellite; issues for TCP/IP
- Solutions for TCP/IP via satellite
- Some example systems of Broadband via Satellite:
    - DVB-based
- New technology trends
- Terminology (throughout)

Pre-requisites for the audience

- An understanding of basic digital telecommunications terms e.g.:
  - ➔ Ones & zeroes = **bi**nary digi**ts** = bits
  - ➔ Digitized voice & video
  - ➔ Data = information = computer communication
  - ➔ Multi-media
  - ➔ Data rate = serial speed of bits from user source to destination (kbit/s, Mbit/s)
- We're assuming minimal prior knowledge of radio (or satellite) - communications terms:
  - ➔ Composite signals sent on a radio frequency (RF) carrier wave i.e. a sinusoidal waveform with centre frequency f_c
  - ➔ 11 GigaHertz (GHz) = 11 thousand million cycles per second

Brief History of Satcomms - 1945

Arthur C Clarke's bold prediction of 'extra-terrestrial relays' giving world-wide coverage:



Idea first presented in 'Wireless World'

Proposed 3 manned space stations

Over the equator at 36,000 km altitude

Each station covers 1/3 of the earth's surface

Inter-space-station radio links for global coverage

Brief History of Satcomms - 1962

1962 - The TELSTAR Experiment (low orbit)

- Goonhilly Downs in Cornwall (British Post Office)
- Plemeur-Bodou in Brittany
- Andover in Maine (USA)

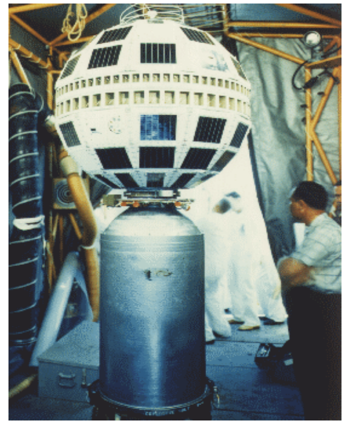
- First transatlantic television transmissions
- Orbital period 157 minutes
- 'Visible' for around 20 minutes

Diameter 0.86 m

Weight 77 kg

Power Output 2.25 W

2528 Semiconductor
devices (+ 1 TWT amplifier)

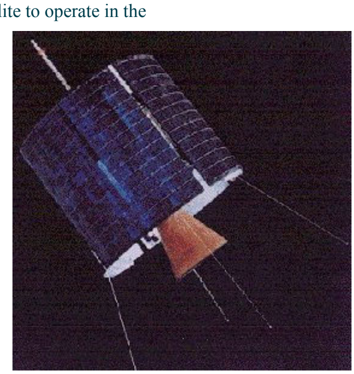


Brief History of Satcomms - 1964 to 1965

1964 - Syncom-3 (NASA) –first to reach the Geostationary Orbit
(used for Tokyo Olympics)

1964 - INTELSAT: an interim organisation for INTernational
TELecommunication SATellites

1965 - Early Bird (INTELSAT - I): the first commercial satellite to operate in the
Geostationary Orbit



Diameter 0.7 m

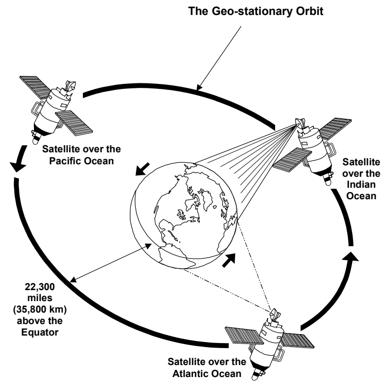
Height 0.59 m

Weight 39 kg

Solar Power Input 33 W

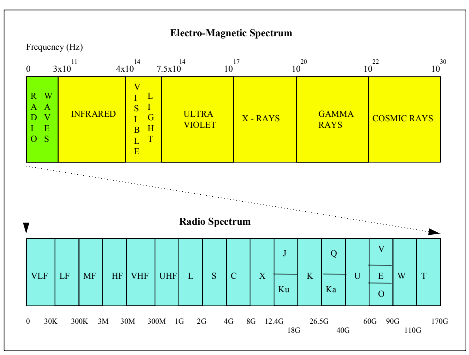
Brief History of Satcomms - 1969

1969 - Full global coverage established with satellites over the Atlantic, Indian and Pacific Oceans (within the 25 years predicted by Clarke, but NOT fully interconnected - no intersatellite links - and not manned)



Terminology - Frequency

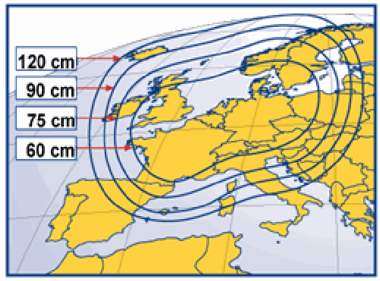
- GHz = Giga-Hertz = 1000 million cycles per second



Brief History of Satcomms - 1989 to 1995

1989 - 'Sky' Direct To Home (DTH) satellite TV via

ASTRA: TV broadcast-only @ 19.2°E

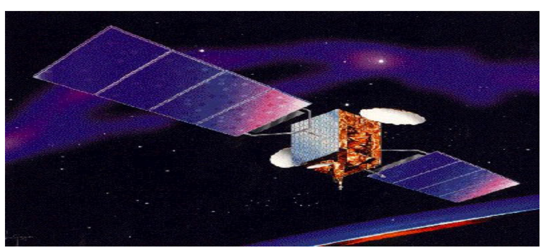


1994 - PANAMSAT: private, direct competition to INTELSAT and EUTELSAT

1995 - EUTELSAT Hot Bird 1 @ 13°E (to compete with Astra)

Brief History of Satcomms - 1997 to 2000

1997 - Feb: INTELSAT-VIII



1997 - May: 1st Iridium launch (5 x LEOs - Low Earth Orbit spacecraft)

1998 - Iridium gets 66 active LEOs working

1999 - May: EUTELSAT-W3 @ 7°E (3rd generation FSS spacecraft)

1999 - Sept.: Globalstar reaches 40 x LEOs (competition for Iridium)

March 2000 - Iridium ceases as a business…temporarily (bad press for satcomms)

Brief History of Satcomms - 2003 to 2005

2003 (Feb) – INTELSAT – 907 launched @ 332.5ºE (all 7 * IS-IX series now in orbit)

2003 (Sept) – Eutelsat EUROBIRD @ 33ºE (broadcast & broadband for Europe)

2004 (March) - Eutelsat's W3A launched @ 7ºE – Skyplex to Africa

2004 (June) - INTELSAT - X: replacement for IS-VII @ 359ºE

2005 (April) – INMARSAT – 4 "Broadband for a Mobile Planet"

Terminology - Decibel

- Decibel (dB): logarithmic measure of power gain or loss
- Power gain in dB = 10*log(Output power/input power)
- 10 dB = factor of 10
- 20 dB = factor of 100
- 30 dB = factor of 1000
- 60 dB = factor of 1000000
- 200 dB = factor of 100000000000000000000
- -10 dB = factor of 1/10 (i.e. 'loss')
- 3 dB = factor of 2
- 6 dB = factor of __??

Terminology - EIRP

- Decibel (dB): logarithmic measure of power level

- Power level relative to a given standard =
  10*log(Power/Reference)
  e.g. 100 Watts relative to 1 Watt = 20 dBW

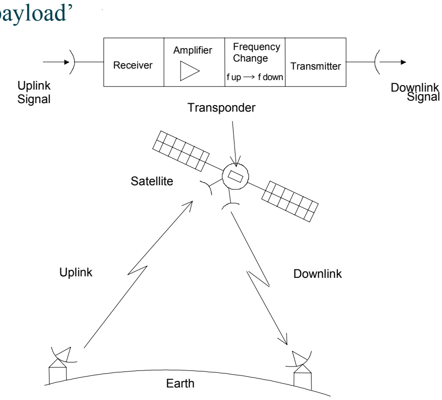
- **EIRP = Effective Isotropically Radiated Power**
  (i.e. transmitted power level, normally expressed in dBW)

Technology & Service Development

BT wholesale

Terminology - Transponder

- Transponder = channelized frequency changer + amplifier; at least 12 on a normal satellite 'payload'



Technology & Service Development

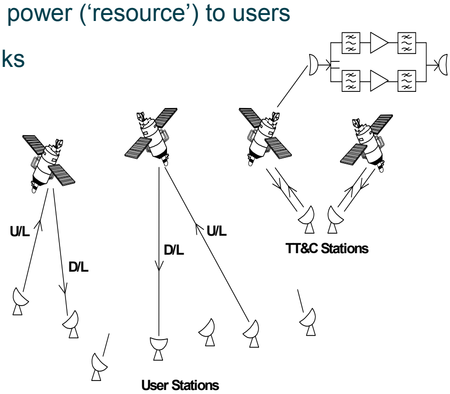
BT wholesale

Terminology - Antennas

- Antennas
- Not aerials or antennae!!

Basic Topology - Space Segment

- Space Segment
  - Spacecraft in orbit
  - Telemetry, Tracking and Control (TT&C)
  - Lease bandwidth and power ('resource') to users
  - Up-links and down-links



Basic Topology - Ground Segment

- **Ground (earth) Segment**
  - User earth stations to transmit &/or receive
  - Characterised by size of antenna
  - The bigger the (receiving) antenna, the smaller the space segment resource (power and bandwidth) needed.
  - Relationship between diameter, frequency, gain and beamwidth:
    - For a specified frequency:
      - Small antenna Low gain Wide beamwidth
      - Large antenna High gain Narrow beamwidth
    - For a specified antenna size (diameter):
      - Low frequency Low gain Wide beamwidth
      - High frequency High gain Narrow beamwidth

e.g.:

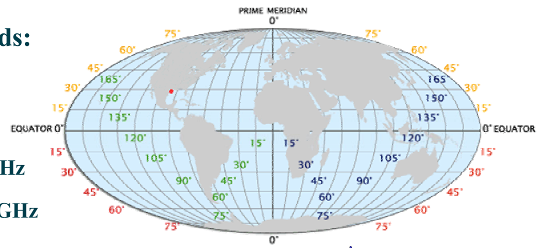
Diameter	Frequency	Gain	Beamwidth
20 m	14 GHz	65 dBi	0.1°
32 m	6 GHz	65 dBi	0.1°

Satellite Orbits

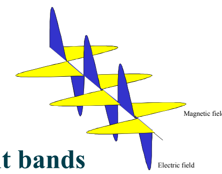
- **Satellites remain in orbit owing to a delicate balance of two forces:**
  - **the gravitational attraction of the earth**
  - **the centrifugal acceleration of the satellite's motion around the earth**
- **Types of earth-centred orbit:**
  - **Low Earth Orbit (LEO): 200 - 1000 km; moderately low inclination angle to the equatorial plane**
  - **Medium-altitude Earth Orbit (MEO): c. 10,000 km; 45 to 60° inclination**
  - **Polar Orbit (PO): as LEO but over the earth's poles**
  - **Highly Elliptical Orbit (HEO): come near to Earth at closest approach ("perigee") and very far away on opposite side ("apogee")**
  - **Molniya orbit: special type of HEO with apogee located at maximum latitude**
  - **Geostationary Earth Orbit (GEO): zero inclination; 24-hour cycle**
  - **Geostationary Transfer Orbit (GTO): eccentric orbit designed to position a satellite for efficient placement into GEO**

Today's Technology

- **Geostationary satellites (predominantly)**
  - **orbit location, normally defined as °E or °W of Greenwich**
- **Common frequency bands:**
  - **C-band: 6/4GHz**
  - **Ku-band: 14/11GHz**
  - **DBS (BSS) -band: 18/11GHz**
  - **L-band (mobile): 1.6/1.5 GHz**



- **Frequency re-use by:**
  - **Dual (orthogonal) polarisation**
  - **Multi-beam (spatial separation)**



- **Potential for interference from shared and adjacent bands**

Main Space Segment Suppliers

- INTELSAT (www.intelsat.int)
- EUTELSAT (www.eutelsat.org)
- INMARSAT (www.inmarsat.com)
- PANAMSAT (www.panamsat.com)
- SES-ASTRA (www.ses-astra.com)
- ORION (www.loralorion.com)
- NEW SKIES SATELLITES (NSS) (www.newskies.com)

Satellites in Geo-Stationary Orbit

Supplier	No of main s/c	Typical locations (°E)
INTELSAT	26	33, 60-66, 174-183, 304-310, 325-335, 342, 359
EUTELSAT	23	7, 10, 13, 16, 21.5, 25.5, 28.5, 36, 48, 70.5, 76, 345, 347.5, 349, 352, 355
INMARSAT	5	24, 63/65, 178/179, 305/306, 343/345
PANAMSAT	22	26, 68-72,166-169,227-237, 261-269,286,302,315, 317
SES/ASTRA	13	5.2, 19.2, 23.5, 24.2, 28.2
ORION	2	322.5, 345
New Skies	6	57, 95, 183, 319.5, 338, 340
Others	>200	Around the GEO

Highly congested!!
Earth station antennas can't resolve better than 2-3°

Data/IP over Satellite Communications

A Brief History of Data Communications via Satellite

Brief History of DataComms via Satellite (1)

Pre-1970: "Datel" = 2.4 kbit/s

- **'Voice-band Data' (over an analogue line)**
- **Within International Direct Dialling (IDD)**
  - **This is an example of a telecommunications PRODUCT**
  - **Which generates revenue by providing customer-dialled connections on a call-by-call basis for telephony SERVICES such as : voice, voice-band data, fax**
- **Part of multi-channel 'Frequency Division Multiplex (FDM)'**
- **Sent via satellite using 'frequency modulation (FM)'**
- **Typical FM bandwidth = 100kHz for 3.4kHz voice channel**
- **Data transmission bandwidth efficiency = 0.024 bit/s/Hz**

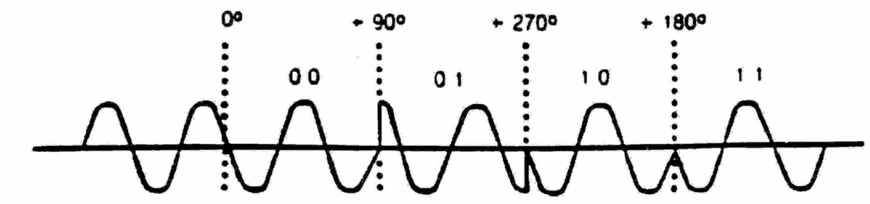
Brief History of DataComms via Satellite (2)

1972: "Single channel Per-carrier multi-Access Demand-assigned Equipment (SPADE)" = 56 kbit/s

- **1st digitized voice-channel via satellite**
- **Sampled at 8 kHz**
- **7-bit code per sample (USA standard)**
- **Serial data stream = 56 kbit/s**
- **Modulated onto a radio-frequency (RF) 'carrier' (wave)**
- **'Phase-shift-keying (PSK)' (more later)**
- **Data up to 4.8kbit/s within voice-band (over a terrestrial analogue line)**
- **Typical PSK bandwidth = 45kHz for 3.4kHz voice channel**
- **Data transmission bandwidth efficiency = 0.107 bit/s/Hz**

Phase Shift Keying (PSK)

- Phase Shift Keying (PSK) is the main modulation method for digital services. In PSK, the phase of the carrier is varied according to the value of the digital signal.
- The simplest way of doing this is Binary (B)-PSK. BPSK has 1 bit/symbol (1 or 0). A 2Mbit/s (uncoded) carrier has a theoretical bandwidth of 2MHz)
- Quadrature (or quaternary)(Q) - PSK has 2 bits/symbol (so the 2Mbit/s carrier would have a bandwidth of 1MHz). Two bits at a time are taken from the incoming bit stream and are used to change the carrier to four different phases.



- Octal, or 8 - PSK has 3 bits/symbol (2Mbit/s carrier = 666kHz b/w).

Practical bandwidths for PSK Carriers

- **Theoretical bandwidth = symbol rate (the 'Nyquist bandwidth')**
- **Practical b/w = (typically) 1.4 * symbol rate (to avoid excessive adjacent channel interference**
- **Quadrature (or quaternary)(Q) - PSK (2 bits/symbol) is still the most frequently-used for satcomms, even after >35 years, but more advanced modulation schemes are becoming popular; e.g.:**
  - **Octal, or 8 - PSK has 3 bits/symbol (2Mbit/s carrier = 666kHz b/w).**
  - 16-QAM (quadrature amplitude modulation) has 4 bits/symbol **(2Mbit/s carrier = 500kHz b/w).**
- So where is the catch?
- Unlike terrestrial radio systems, satcomm systems have to work with very low signal-to-noise ratios and the more advanced the modulation scheme, the higher the SNR required for a given transmission performance

Space Segment Resource

- Users pay satellite operators for space-segment resource on the basis of whichever is the greater of the two main parameters:
  - ➔ Allocated (frequency) bandwidth (as required by the modulation scheme)
  - ➔ Power equivalent bandwidth (PEB) – when the proportion of transponder power needed is greater than the ratio of carrier b/w to transponder total b/w
- Small receiving stations will require more transponder power for a given performance (compared to large receiving stations)

Power Efficiencies

- **However, this is not the end of the story**
- **We also need power efficiency**
- **Satcomms is usually short on power – because of the very long distances involved (36,000km – 200dB loss) and finite size of amplifiers (10 to 100W) out in space**
- **The digital format allows the introduction of 'forward error correction (FEC)' encoding: i.e. send extra bits with the 'wanted' data bits which will allow us to correct those bits which were received erroneously.**
- **This reduces the bandwidth efficiency but increases the power efficiency**

Summary of Trade-offs

- **A common FEC-rate is 'rate-3/4'; this will increase the transmission rate (after coding) by a factor of 4/3 (33% increase) so the practical bandwidth will increase by 33%**
- **However, the SNR requirement will reduce by 3 dB which, all other things being equal, or at least favourable, would lead to a 50% reduction in power**
- **Hence, this increases the power efficiency**
- **This allows us to reduce the signal gain around the transmission path and translates into getting away with smaller dish sizes (or giving higher transmission quality)**
- **This is the main driver behind the massive growth in VSAT systems in recent years**

Example Satellite Services - TV, VSAT, ISP

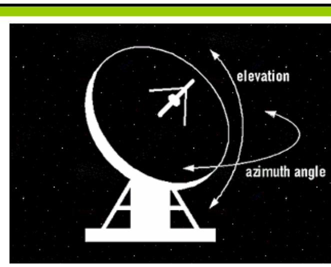
- **Television (TV) carriers (Occasional Use and Leased):**
  - **TV/FM (uses Frequency Modulation) - now replaced by digital TV**
  - **Digital TV (uses QPSK on an MPEG-2 encoded signal; often referred to as the DVB-S standard for 'digital video broadcast - satellite')**
- **VSAT carriers for Business and Corporate Networks:**
  - **Majority of terminals (e.g. at branch offices, hence also called 'remotes') use a 'Very Small Aperture Terminal (VSAT), meaning a small dish antenna (up to 2.4 m) and relatively small associated equipment.**
  - **The otherwise inefficient use of space-segment is compensated for by working to a large 'hub' terminal or station (e.g. at or close to the Corporate HQ).**
- **Internet Service Provider (ISP) carriers:**
  - **Typically using QPSK or TCM (possibly 16QAM) to provide connectivity as part of the Internet Backbone**
  - **Normally 'asymmetric' i.e. higher bit-rate on the half-circuit outgoing from the end that holds the highest proportion of information (for browsing)**

Typical Carrier Bit Rates Used in Commercial Satcomms

- **64 kbit/s to 8 Mbit/s: single-channel voice/data and multiplexed services**
- **64 kbit/s to 8 Mbit/s corporate business services via small dish VSAT systems**
- **2 to 45 Mbit/s TV broadcast and contribution services**
- **2 to 155 Mbit/s Internet Backbone Connectivity (in 72 MHz transponder)**
- **Data transmission bandwidth efficiency = 155/72 = 2.15 bit/s/Hz**
- **Recall that in 1972 the initial data transmission bandwidth efficiency = 0.107 bit/s/Hz**

- **So far, we have concerned ourselves with conveying serial bit streams.**
- **What about data format at the customer end – normally derived from a machine (usually computer)**
- **Data flow tends to have a packet structure of some type – more later.**

Terminology - Azimuth



- **Azimuth = horizontal pointing angle relative to true North**
- **Elevation = vertical pointing angle relative to horizon (normal limits are 5° at C-band, 10° at Ku-band)**
- **IDR = Intermediate Data Rate carriers (64k to 45Mbit/s)**
- **IBS/SMS = INTELSAT Business Services/(EUTELSAT) Satellite Multi-Services (64k to 8Mbit/s)**
- **TDMA = Time Division Multiple Access: individual ‘bursts’**
- **FDMA = Frequency Division Multiple Access: individual carrier frequencies.**
- **TV/FM = Television/Frequency Modulation = traditional analogue TV via satellite**
- **DVB = Digital Video Broadcast = new generation TV**
- **MPEG = Moving Pictures Experts Group: defining standards for digital TV encoding/decoding**
- **IRD = Integrated Receiver Decoder: RF input at L-band, video and audio output**
- **PSK = Phase Shift Keying (modulation)**
- **ISP = Internet Service Provider (carrier)**

Data Communications Terminology

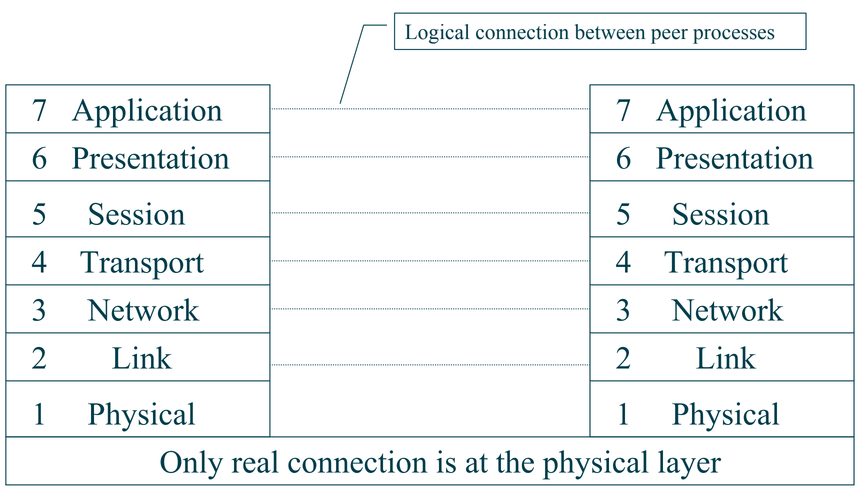
OSI 7-layer Model (1)

- OSI = Open Systems Interconnection:
  - ➔ Defined by International Standards Organisation (ISO)
- Provides:
  - ➔ Common terminology
  - ➔ Framework for networking
- Revolutionary when first introduced & is in widespread use today
- Crucial to gaining an understanding of computer networking:
  - ➔ Part of the language (e.g. 'Layer-3 protocol', 'Layer-4 switches')
  - ➔ Divides the functions needed to xfer data between machines across a network into separate independent layers, each with its own set of responsibilities.
- This separation, along with packet switching, made the Internet possible

OSI 7-layer Model (2)

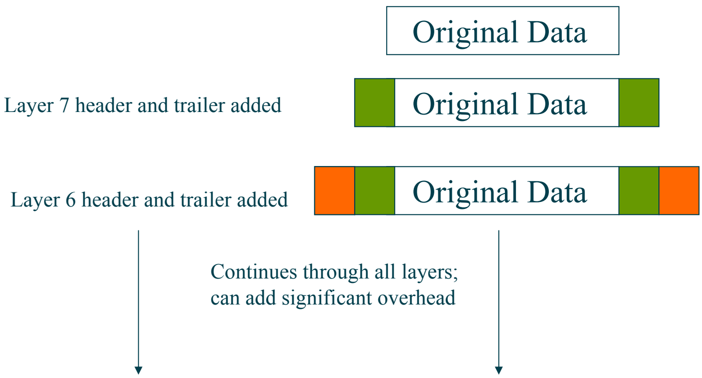
Layer Number	Layer Name	Layer Description and Services
7	Application	Network services support for email, file transfer etc
6	Presentation	Data representation - formatting, encryption and compression
5	Session	Dialog Control - set-up and management of end-to-end calls
4	Transport	End-to-end Data Integrity - message transmission
3	Network	Transmission of Packets - Internet addressing & routing
2	Link	Package of bits into frames for delivery
1	Physical	Physical transmission of data

OSI 7 Layer Model (3)



Addition of header information

Each layer in the OSI stack adds a header and/or a trailer to the original 'packet' of data



Focus on Transport & Network Layers (1)

- Important to have an awareness of Layers 4 and 3 before we address issues specific to satcomms.
- Layer 4: Transport Layer:
  - ➔ Controls e2e transmission of data between end nodes (e.g. using 'TCP')
  - ➔ Handles e2e reliability (if required) + control of txmn speed
  - ➔ Transport layer packets = 'segments'
- Layer 3: Network Layer:
  - ➔ Directs packets of data ('datagrams') through the network from a source device to a destination device (e.g. using 'IP')
  - ➔ Acts as a switching centre, taking datagrams from multiple sources & determines which direction to send each to reach destination
  - ➔ Divides an original datagram (if too large) into smaller ones ('fragmentation') and re-assembles them at the destination.

Focus on Transport & Network Layers (2)

- The Internet, by definition, is the collection of interconnected networks running the Internet Protocol (IP) as the network layer protocol
- 'Protocol' = a set of rules & formats that govern the communication between communicating peers
- Most corporate networks ('intranets') now also run IP exclusively
- Layers 4 & 3 often operate together: e.g. TCP/IP, but their responsibilities are entirely distinct:
  - ➔ network layer actions normally take place at intermediate nodes e.g. where routers located at the intersection between networks examine the destination address & simply determine which direction to send the packet
  - ➔ transport layer actions occur mainly at end-nodes; end devices don't need to know anything about network structure.

Focus on Transport & Network Layers (3)

- TCP/IP has two possible transport layer protocols:
  - ➔ Transmission Control Protocol ('TCP') for reliable communications (network level service for reliable stream delivery - nothing must be lost)
  - ➔ User Datagram Protocol (UDP) for 'best effort transmission' (network level service for unreliable stream delivery – e.g. real-time voice & video)
- TCP/IP is the 'language of the Internet':
  - ➔ The 'de-facto' standard set of protocols for computer networking
  - ➔ All other protocols are considered 'legacy protocols'
  - ➔ Available as a standard component of all operating systems
  - ➔ Comprised of: TCP, UDP, IP, routing, utilities & networking applications
  - ➔ Specified by the Internet Engineering Task Force (IETF)

OSI & Internet Models

- TCP/IP doesn't conform to the OSI 7-layer model particularly well
- It makes more sense to think of TCP/IP as separated into 4 layers:

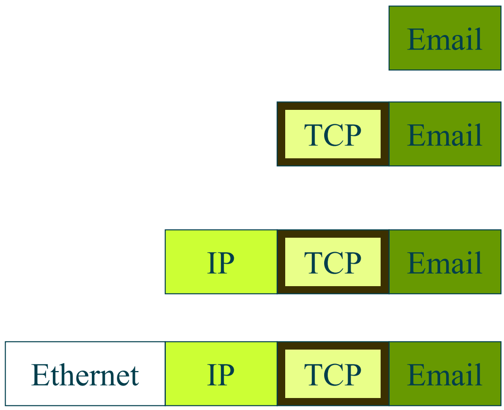
OSI Model	TCP/IP (Internet)
7 Application	Application
6 Presentation	
5 Session	
4 Transport	Transport (TCP, UDP)
3 Network	Network (IP)
2 Data Link	Network Interface
1 Physical	

TCP and IP Relationship

- IP is a Network Layer protocol responsible for link routing and addressing
- TCP is a Transport Layer protocol responsible for reliable delivery
- IP packets contain one or more TCP segments

TCP/IP Example

Consider a TCP packet that is carrying your email message



Original Email Message

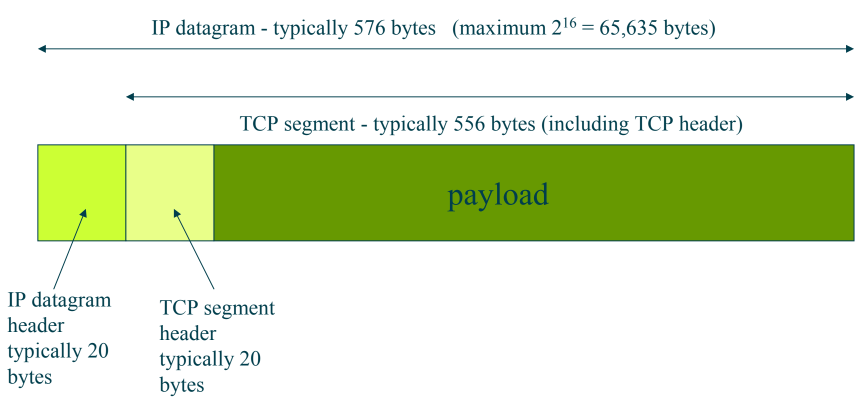
Transport Layer Protocol - TCP added to provide e2e delivery **assurance**, error free

Network Layer Protocol - IP added to provide e2e delivery addressing and routing

Link Layer Protocol - Ethernet added to provide packet and bit delivery

TCP/IP typical overhead

TCP/IP packet lengths are variable

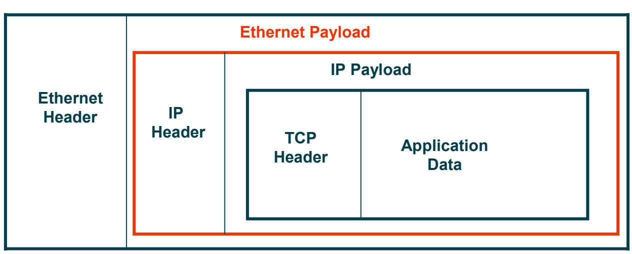


Layer Independence & Encapsulation

- Advantage of having separate protocol layers: allows each protocol to operate independently of those above or below it
- Between each layer is a standardised interface which means that, once an Ethernet network is in place, the user can run IP, IPX, NetBEUI, or any other independent Layer-3 protocol over it
- Conversely, IP can run over Token Ring, X.25, Frame Relay, PPP, HDLC, FDDI, ATM, or any other Layer-2 protocol as easily as Ethernet, and most Layer-2 protocols can run over a satellite or wireless physical network the same as over Category 5e cabling (for LANs).
- UDP and TCP run over IP, but so can XTP or SCPS – important when examining alternatives to using TCP over satellite which remain compatible with the IP network infrastructure.
- To provide this flexibility, each protocol must remain independent of all other protocols – accomplished through '*encapsulation*'.

Protocol Layer Encapsulation

- Each protocol has its own header; the rest of the packet is 'payload'
- Thus the packet of each protocol (containing header & payload) becomes the payload of the protocol for the next layer down e.g.:
  - → A TCP segment, including TCP header & data, fits into the payload of an IP datagram
  - → The IP datagram, including the IP header and payload, fits inside the Ethernet frame.



Transmission Control Protocol

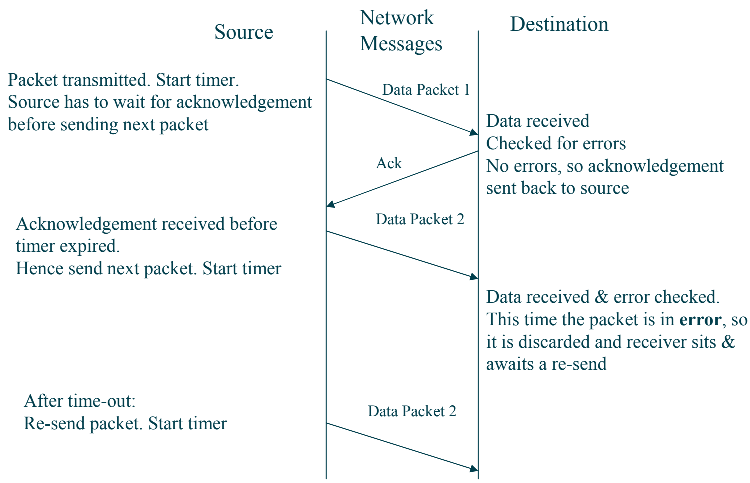
What does TCP do?

- specifies data and acknowledgement format
- error detection and correction
- looks after error recovery procedures
- stream connection and termination

TCP Establishment

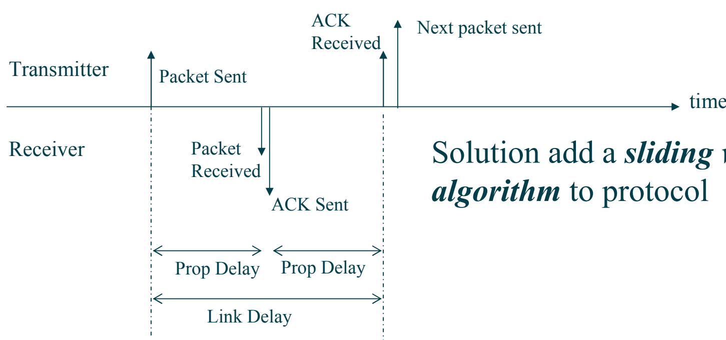
- IP Network Layer must first establish route and end-to-end connectivity
- TCP Transport Layer then permits send and receive sites to negotiate data delivery of TCP segments
- TCP protocol embodies ideas of segment acknowledgement for guaranteed delivery

A “Simple” TCP Connection



Problem with acknowledgement

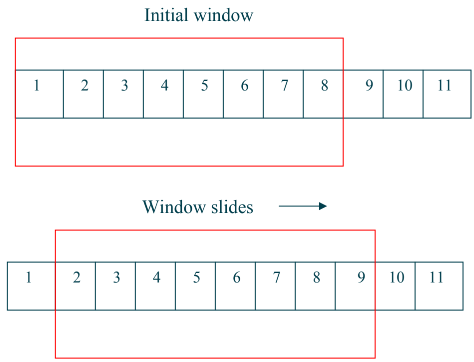
Source is idle whilst waiting for an acknowledgement.



Solution add a ***sliding window algorithm*** to protocol

TCP Sliding Window Protocol

- The source can continue to transmit packets provided that it receives an ACK for the first packet sent within a window size of W packets.

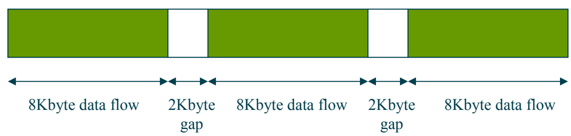


TCP Sliding Window Protocol

- Window size negotiated between send and receive terminals (advertised by receiver)
- Congestion Control important
- Window starts small, builds slowly
- Window closes rapidly if segment resends are required

TCP Sliding Window Example

- Assume a window size of 8192 bytes (8K)
- Assume a fixed data rate over the medium (e.g. satellite modem rate) = 160 kbit/s
- Assume a total round-trip delay of 520 ms (between ‘send’ and receipt of ‘Ack’)
  - equivalent to (160/8) x 520 = 10400 bytes “in transit”
- The data flow is thus in bursts of 8192 bytes with gaps of 2208 bytes
- Throughput is not the same as satellite modem data rate
  - equivalent to (8192x8)/0.52 = 126 kbit/s
- Simplistic representation
  - no window start-up, no errors, no congestion control



TCP/IP Maximum Throughput

- The TCP/IP sliding window size is set up by the end devices
- Typically 8K bytes for PCs with a Microsoft stack
- Thus, we are allowed 8192 bytes of data ‘in transit’
- Maximum throughput = window size/round trip delay
- ‘Round trip delay (RTD)’ (also known as ‘latency’) = the time between ‘send’ and receipt of ‘Ack’ – includes the physical propagation delay over the transmission medium + processing time
- Example: for a geostationary satellite link with typical RTD = 520ms:

  Maximum data throughput per session (bits/s)

  = 8192 x 8 / 0.52

  = 126 kbit/s
- Throughput is less during session start-up and following any errors

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User Datagram Protocol

- Best effort, non-guaranteed thin protocol
  - No error detection/correction
  - No handshaking processes
  - Simple communication
  - Defines format of UDP Datagram

Network Layer

7	Application	File Transfer Telnet
6	Presentation	
5	Session	
4	Transport	TCP, UDP
3	Network	IP
2	Link	X25, ATM, LAN
1	Physical	Coax, Fibre, etc

Network Layer

- Transmission of packets across network
- Internet Protocol (IP)
- Unreliable connectionless delivery mechanism
- Routing functions
- Addressing functions

IP Address Structure (1)

- IP address field is a part of the IP header
- An IP address comprises 32 bits (4 bytes)
- Dotted Quad Notation divides the 32-bit Internet address into four 8-bit byte fields, e.g. 192.146.219.88

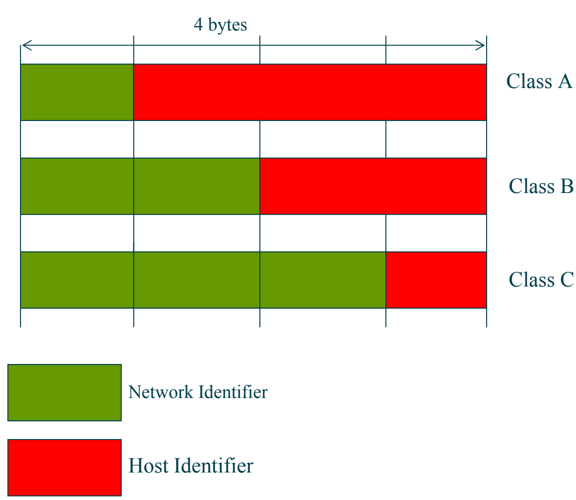
Dotted decimal 192	Dotted decimal 146	Dotted decimal 219	Dotted decimal 88
Binary 11000000	Binary 10100010	Binary 11011011	Binary 01011000

4 byte IP address

IP Address Structure (2)

- In principle, a 32 bit address can support over 4,000 million hosts (e.g. PCs).
- In practice, first part of address defines the network and the second part the host
- This enables easier routing, but is less efficient and cannot support so many hosts
- We therefore need Subnetting

IP Address Structure (3)



Data/IP over Satellite Communications

IP via Satellite

Issues & Solutions for TCP/IP

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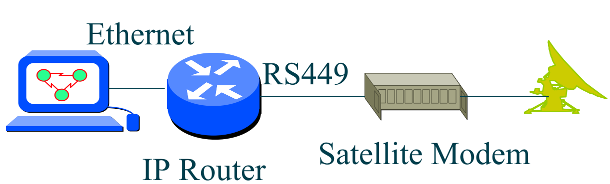
IP via Satellite

- Achieved by interfacing satellite modems directly to IP routers
  - via clear channel serial router interfaces
    - G703: 2Mbit/s
    - RS449/422 up to 8Mbit/s and HSSI up to 52Mbit/s
  - using serial encapsulation link layer protocols (e.g. Frame Relay)
- Maximises satellite broadcast capabilities



TCP and Satellite Networks

- Unfortunately, the TCP protocol is not well suited to satellite networks because of the conditions which are typical of those networks:
  - ➔ Long delay (round trip 'latency' on geostationary satellite systems)
  - ➔ Bursts of bit errors
  - ➔ Asymmetric bandwidths

- Satellite network architects therefore need to understand the cause of these limitations and how to overcome them in order to create an efficient, responsive network that does not suffer from performance constraints and can compete with terrestrial alternatives.

TCP/IP via Satellite: Issues (1)

- Propagation delay
  - 520ms round trip to acknowledge TCP segment
  - Typical window size 8192 bytes (8K)
  - maximum data throughput per session

    = window size/round trip delay

    = 8192 x 8 / 0.52

    = 126 kbit/s
  - Throughput is less during session start-up and following any errors
  - Increasing window size by 8 to 64K would take the maximum throughput to about 1 Mbit/s **per session**

TCP/IP via Satellite: Issues (2)

- It is the *per-session*, not overall, throughput that counts
- Data throughput limit of around 100 kbit/s for window size of 8Kbyte
- Data throughput limit of around 1 Mbit/s for window size of 64Kbyte
- Not noticeable for short duration HTTP/Web transactions
- But noticeable with high bandwidth applications e.g. large file transfers
- Made worse by slow start nature of traditional TCP/IP Stacks
- Made worse by error bursts over the physical link (e.g. due to rain-fade)
- [Does this all mean that there is no point in having satellite carrier data rates above 128 kbit/s? Yes...if only one session is being carried. However...the satellite data link may be carrying hundreds of sessions simultaneously in a 'multiplex' e.g. in a 45 Mbit/s point-to-point carrier between ISPs ('Internet backbone connection')].

TCP/IP via Satellite: Issues (3)

- Solution if high data throughputs are required.
  - Use highest window size possible.
  - Enhanced satellite-specific TCP/IP stacks (e.g. 'spoofing').
- UDP applications do not require acknowledgements.
  - video streaming therefore can operate at high data rates.
- The throughput is only as high as the weakest link on the Internet. Often, it is not the satellite which is the bottleneck
  - slow servers
  - terrestrial lines with data rates less than 100 kbit/s
  - terrestrial congestion

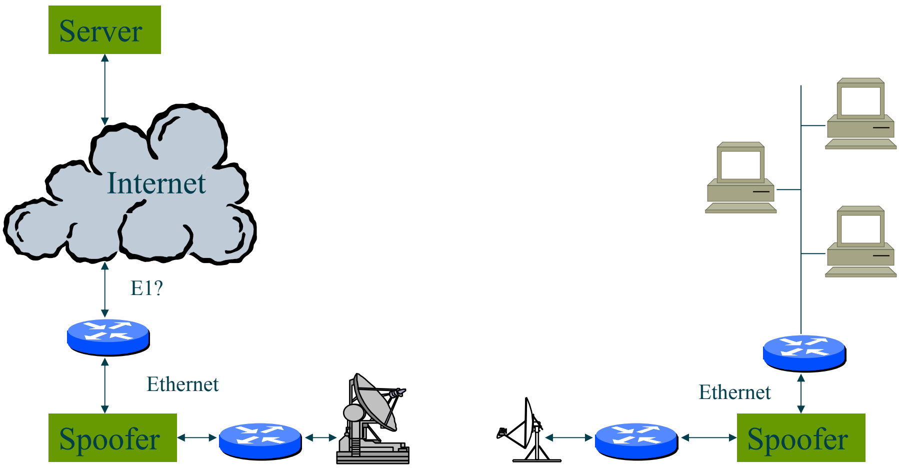
Window issues

- It is possible to change the default window size within a PC
  - default is 8Kbytes
  - user can change, but some PC expertise is required
- Increasing the window size over a combined terrestrial and satellite link can introduce pitfalls
  - any errors tend to have a detrimental effect on throughput with a large window size.
  - Although the satellite link may have a low error rate, the same might not be true for the terrestrial tails.

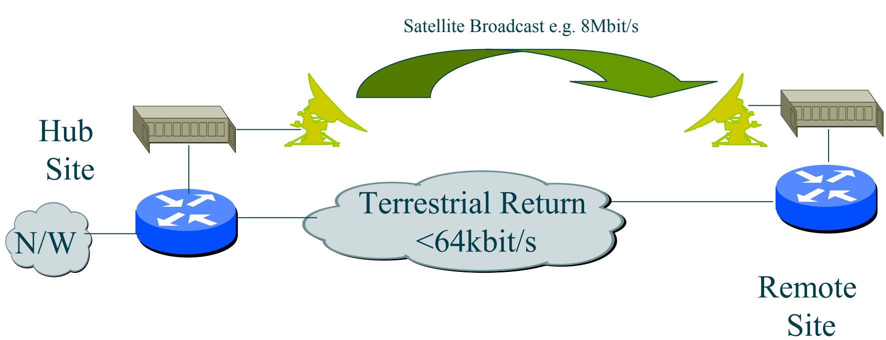
Spoofing

- ‘Spoofing’ is a protocol translation system:
  - accepts TCP/IP data and converts to a proprietary, satellite-friendly, protocol (e.g.: see http://www.mentat.com)
  - designed to fool the clients & servers on the net that the satellite link does not exist
- Allows accelerated performance of TCP/IP over satellite
- Best spoofing devices are transparent to the network and operate only over the satellite part of the network
  - satellite link appears as a low delay connection
  - used only for the transfer of data between the spoofing devices on either side of the satellite link
  - clients and servers continue to use standard TCP/IP for communications

Spoofing example



Asymmetric Services



Some Examples of Broadband Systems via Satellite

IP Access Using RO-VSAT

- Hughes DirecPC
  - Offers users satellite delivery from ISP with terrestrial dial-up
  - Uses proprietary data link layer protocol
- Many RO-VSAT Internet offerings now sit on a DVB platform
  - cheap receiver
  - multi-media capabilities
  - worth DVB overhead penalty
- DVB = Digital Video Broadcast (as used for digital TV)

DVB

DVB is based on MPEG-2 generic coding for audio and video-compression.

DVB adds the necessary elements to bring digital broadcast services to the home through cable, satellite and terrestrial broadcast systems.

DVB specifies the type of medium (e.g. satellite or cable), the type of modulation (e.g. QPSK or QAM), the FEC coding, etc.

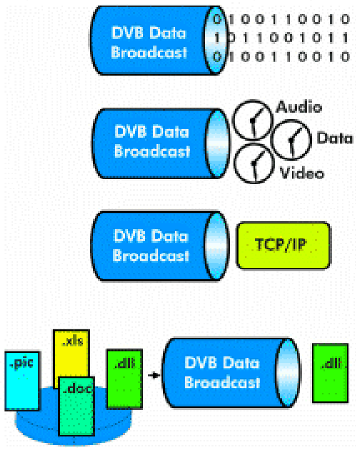
DVB also specifies how IP packets can be encapsulated and transmitted over DVB systems

DVB Standards for Data Broadcasting

The DVB standards specify four different data encapsulation profiles:

- Data piping
- Data streaming
- **Multiprotocol encapsulation (MPE)**
- Data carousel.

Profiles



1. **Data Piping** - transport of anonymous non-synchronised bit-streams
2. **Data Streaming** - transport of synchronous or synchronised bitstreams
3. **Multiprotocol Encapsulation** - Use of the DVB transport mechanism for different communication services
4. **Data Carousel** - periodic transmission of comprehensive files of data. This application area resembles teletext if teletext pages are replaced by data files.

IP Data Encapsulation (MPE)

IP/DVB Gateway receives incoming IP Traffic

Gateway encapsulates IP Datagrams

Routes it to appropriate PID as defined by the service provider

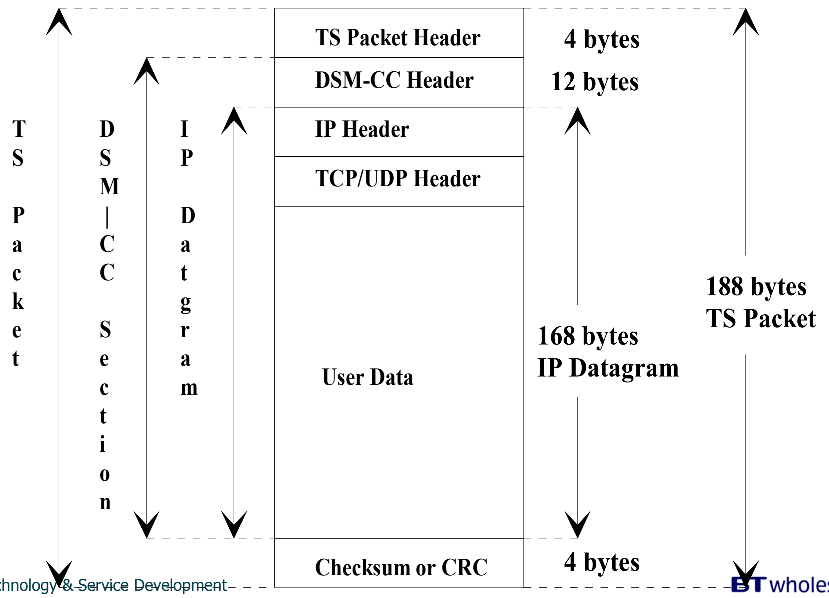
- usually statically defined, user must be informed which PID to use by some means

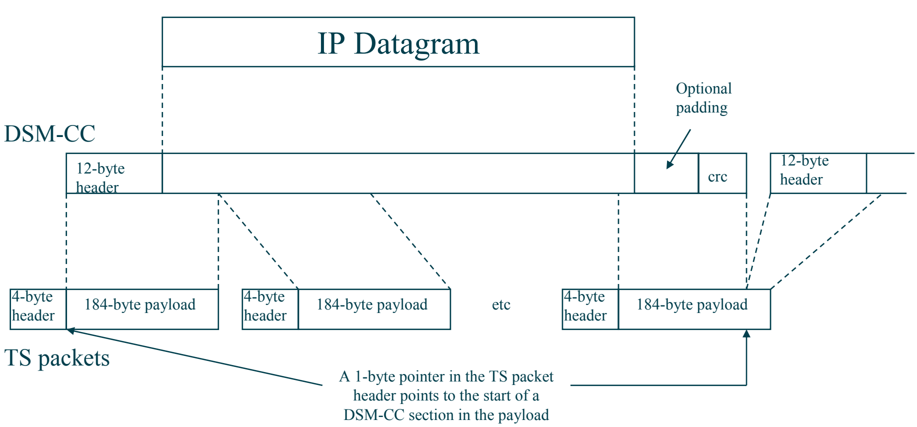
In future, PID selection may be table driven, depending on service required

- user looks into electronic programme guide and tunes to service automatically

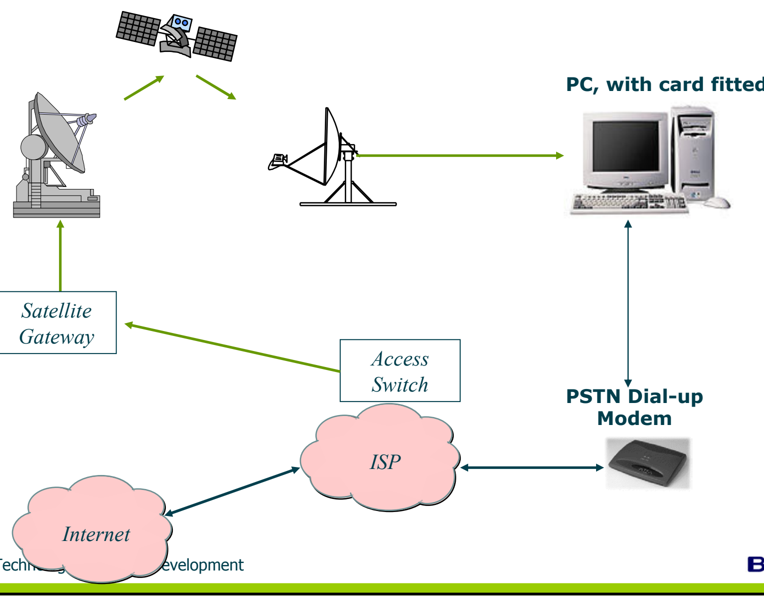
Remote receiver configured to receive desired services

IP Datagram Encapsulation (MPE, DSM-CC)

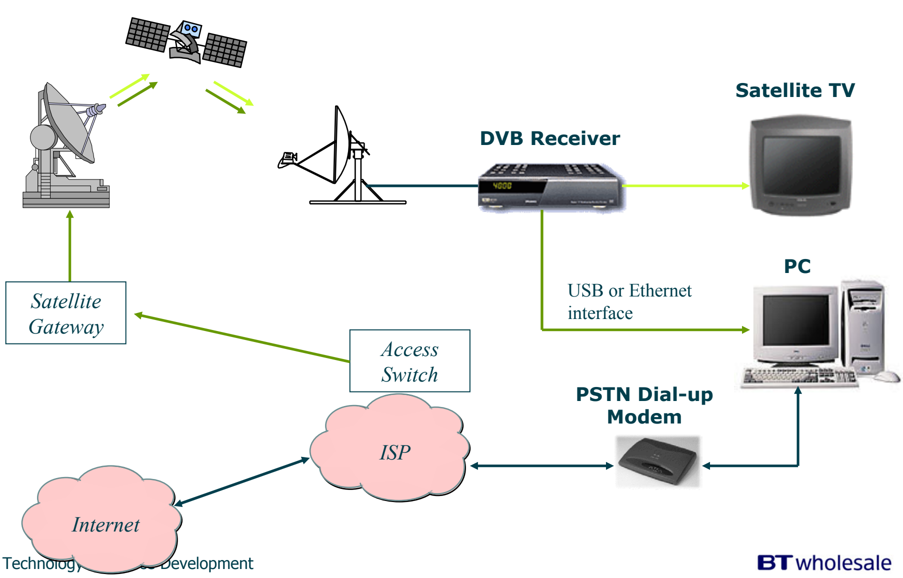




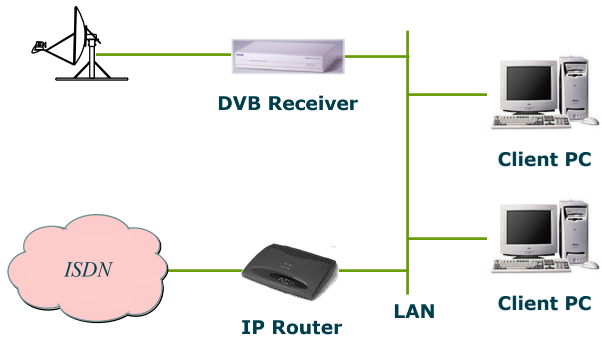
Remote site with PC Card



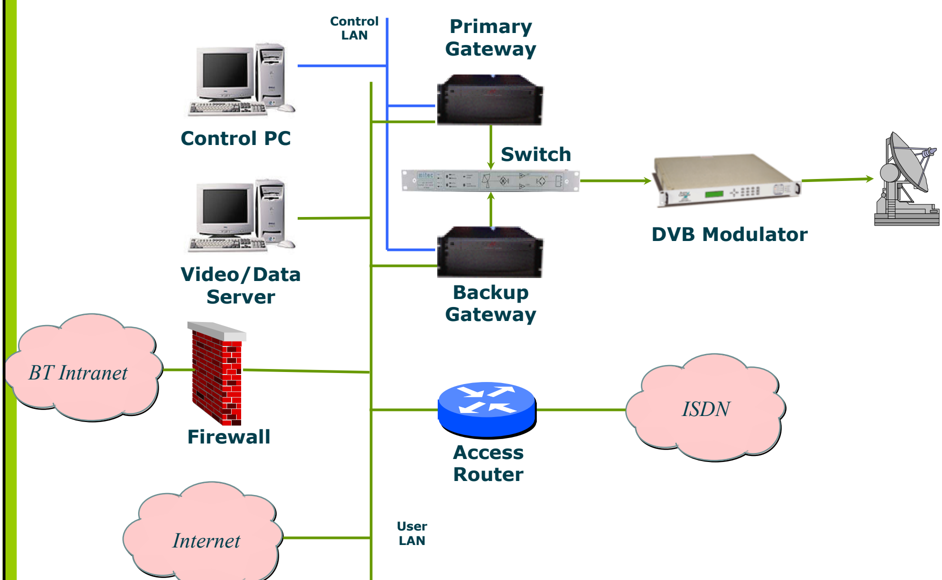
Remote site with DVB Receiver for Residential



Remote Site with LAN, e.g. for SOHO



Typical Hub Site



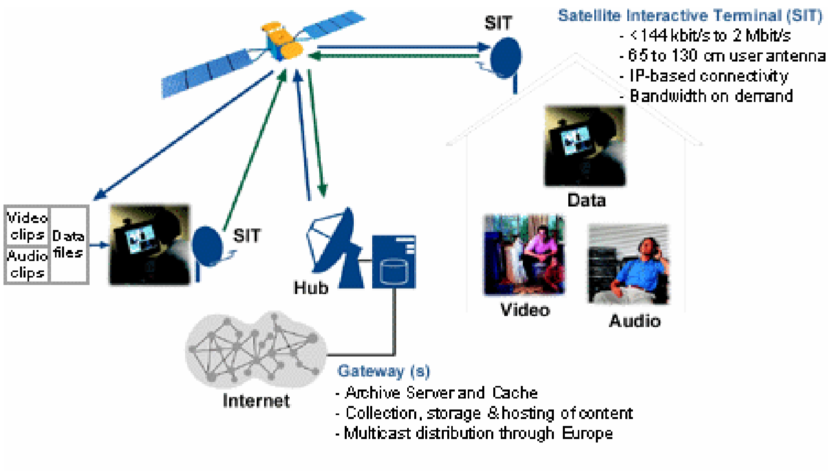
Current Trends

- Ka-band 20/30GHz micro-terminals
  - small, greater bandwidth, but propagation issues
- DVB-RCS open standard for return link via satellite
  - ETSI EN 301 70
  - intended for use in a domestic environment
  - satellite return channel offers greater upstream rates than PSTN
  - Independent of terrestrial network
  - useful in areas of poor terrestrial infrastructure
- Bandwidth on Demand
  - fast access
  - flexible

Astra-Broadband Interactive

- Two-way domestic satellite terminal
  - Satellite Interactive Terminal (SIT) transmits at **Ka band**
    - DVB-RCS using MC-TDMA on up-link
    - remote site up-link rates 144kbps to 2Mbps
  - SIT receives at Ku-band
    - DVB multiplex at 38Mbps
- Bandwidth on demand
- Active now on Astra 1H at 19.2°E

Astra Broadband Interactive (BBI) System



DVB-RCS

20/30Ghz DVB-RSC going to market now

- Astra Broadband Interactive
- Eutelsat Multimedia

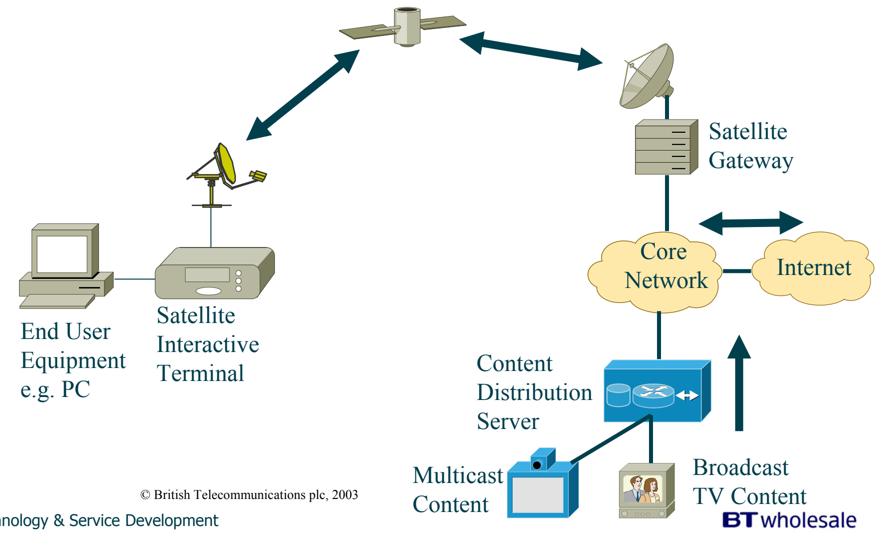
What is the market?

- Use in areas of poor terrestrial infrastructure
- flexible : the user pays for the bandwith used
  - no need to pay for a 2Mbps terrestrial private circuit if, for 90% of the time, the user requires only 30kbps

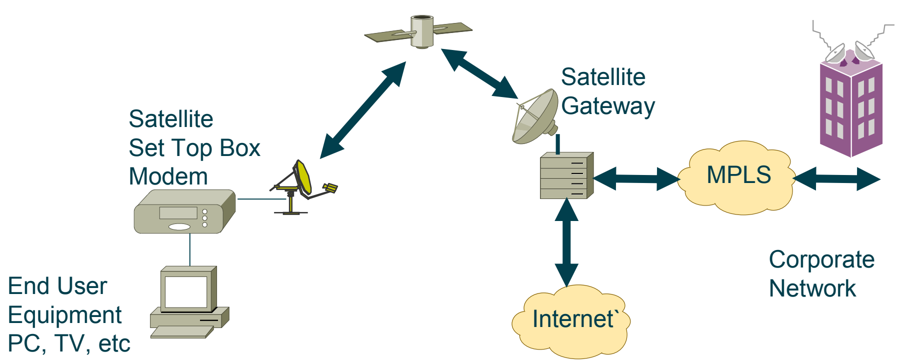
Cost of SIT will fall with mass usage

Propagation problems at Ka-band may be an issue

Two-way Satellite Solution



i-Direct



iDirect

- Same broad architecture as DVB-RCS - a 2-way system
- A proprietary system
- Successful sales to Barclays and VISA. Bollore next?
- Terminal size 0.95m to 2.4m (3.7m + also available)
- 5Watt 2.4m antenna C-Band with Netmodem 250 Cost = $9000
- Download up to 9Mb/s contended
- Uploads typically 380kb/s contended (Max 4.5 Mb/s dependent on antenna and BUC size)
- Typically better than 20:1 contention

Service Trends for Satellites

- **Broadband for Corporate Businesses:**
  - **Virtual Private Networks (VPNs):**
    - **Rapid Service Solution (RSS) e.g. for construction industry**
  - **Disaster recovery**
- **Voice-over-Internet (VoIP):**
  - **Attractive for closed network (corporate PBXs)**
  - **Competition for carrier-class international phone calls.**

- **Digital Video Broadcast – DVB-S2: increased range of modulation & coding formats; adaptable to link conditions (e.g. to combat rain-fades)**
- **High Definition Television (HDTV)**

Data/IP over Satellite Communications

Conclusions (1)

- Delay is the key issue for satcoms
  - Avoid "chatty" protocols that reduce throughput, e.g. X.25
- Allow TCP to take care of guaranteed delivery (if required)
  - use streamlined protocols at the data link layer
- No significant problems for satellite transmissions using ATM, Frame Relay or DVB

Data/IP over Satellite Communications

Conclusions (2)

- Satellite delay limits throughput with TCP
  - 100kbit/s to 1Mbit/s per session according to window size for two-way satellite links (up to 2Mbit/s for one-way satellite asymmetric links)
  - Satellite friendly TCP stacks and proprietary spoofing over the satellite improve throughput
- No delay issue for UDP
  - high speed video streaming possible

Data/IP over Satellite Communications

Conclusions (3)

- In practice, satellite delay not too much of a problem:
  - web browsing appears unaffected, even when compared to high speed LANs
  - throughputs superior to PSTN, and to ISDN in many cases
- Satellite in the access network suited to:
  - broadcast / multicast, long reach to areas of poor fibre penetration, quick installation, coupling with broadcast TV in DVB mux, etc.
- New satellite initiatives:
  - Powerful GEOs
  - LEOs & MEOs
  - On-board switching, inter-satellite links, network integration.......

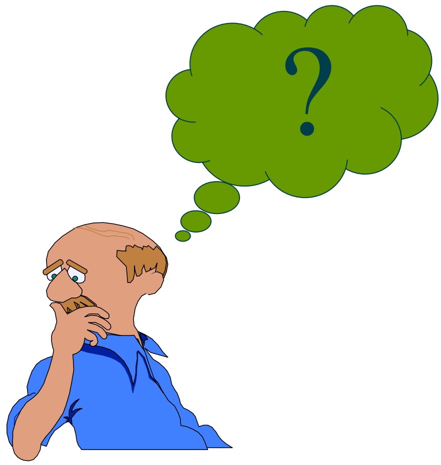
.....but that's a whole new subject for a future presentation!!

Data/IP over Satellite Communications

Review of the presentation

- An overview of commercial satellite communications systems
- A brief history of data communications via satellite
- Data communications terminology (ISO 7-layer model etc)
- IP via Satellite; issues for TCP/IP
- Solutions for TCP/IP via satellite
- Some example systems of Broadband via Satellite:
  - DVB-based
- New technology trends
- Terminology (throughout)

Any Questions?



Earth Station Layout - Goonhilly

List of Abbreviations

ACSE	Access, Control & Signalling Equipment	HEO	Highly Elliptical Orbit	PID	Packet Identifier
AM	Amplitude Modulation	HPA	High Power Amplifier	PSK	Phase Shift Keying
ASI	Asynchronous Serial Interface	IBS	INTELSAT Business Services	QAM	Quadrature Amplitude Modulation
ATM	Asynchronous Transfer Mode	IDD	International Direct Dialling	QPSK	Quadrature PSK
BPSK	Binary PSK	IDR	Intermediate Data Rate (carrier)	RAS	Registration Admission Status
BSS	Broadcast Satellite Service	IETF	Internet Engineering Task Force	RCS	Return Channel (via) Satellite
BUC	Block Up Converter	IF	Intermediate Frequency	RC&M	Remote Control & Monitoring
CRD	Client's Requirements Definition	IOT	In Orbit Test	RF	Radio Frequency
C/N	Carrier-to-Noise (power) ratio	IP	Internet Protocol	RFI	RF Interference
DAMA	Demand Assigned Multiple Access	IPC	International Private Circuit	RoF	Radio-over-Fibre
dBm	10xLog (base10) power relative to 1mW	IRD	Integrated Receiver Decoder	RTD	Round Trip Delay
dBW	10xLog (base10) power relative to 1W	ISDN	Integrated Services Digital Network	SCPC	Single Channel Per Carrier
DBS	Direct Broadcast Satellite	ISO	International Standardisation Organisation	SHF	Super High Frequency
DTH	Direct to Home	ISP	Internet Service Provider (carrier)	SMS	Satellite Multi-Services
DVB	Digital Video Broadcast	KPA	Klystron Power Amplifier	SOR	Statement of Requirements
E2e	End-to-end	LAN	Local Area Network	SSOG	Satellite System Operations Guide
EIRP	Effective Isotropic Radiated Power	LEO	Low Earth Orbit	SSPA	Solid State Power Amplifier
ESVA	Earth station Verification & Assistance	LNA	Low Noise Amplifier	TCM	Trellis Coded Modulation
FDM	Frequency Division Multiplex	LNB	Low Noise Block	TCP	Transmission Control Protocol
FDMA	Frequency Division Multiple Access	LNC	Low Noise Converter	TDMA	Time Division Multiple Access
FEC	Forward Error Correction	MEO	Medium Earth Orbit	TES	Transportable Earth Station
FM	Frequency Modulation	MF	Multi-frequency	TT&C	Telecommand, Tracking & Control
FMT	Fade Mitigation Techniques	MPEG	Moving Pictures Experts Group	TVOB	TV Outside Broadcast
FSS	Fixed Satellite Service	MPE	Multi Protocol Encapsulation	TVRO	TV Receive-only
FTP	File Transfer Protocol	MPLS	Multi Protocol Label Switching	TWTA	Travelling Wave Tube Amplifier
GEO	Geostationary Earth Orbit	NGSO	Non-Geo-Stationary Orbit	UDP	User Datagram Protocol
GHz	Giga-Hertz (1 billion cycles/sec)	NSS	NewSkies Satellites	U(P)PC	Uplink (or Up-Path) Power Control
GSO	GeoStationary Orbit	NTSC	USA colour TV system	UPS	Uninterruptible Power Supply
GTO	Geostationary Transfer Orbit	OSI	Open Systems Interconnection	VSAT	Very Small Aperture Terminal
G/T	Gain-over-Temperature	PAL	UK colour TV system	WAN	Wide Area Network
HDLC	High level Data Link Control	Pol	Polarisation		

End of Presentation

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