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SATELLITE INTEROPERABILITY WITH TERRESTRIAL NETWORKS

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1. Executive Summary

Satellites have continually expanded their role in integrated networks for telephony and data over the past decade, despite the widespread introduction of terrestrial links. Nevertheless there is scope to expand much further the use of satellites in new and future networks with advantages to both end-users and network operators.

This guideline reviews the evolving role of satellite links in core and access telecommunications networks, paying particular attention to the interworking and interoperability issues that must be addressed to achieve integration of the satellite and ground based infrastructure. The QoS implications of satellite links are discussed, as are the implications for different types of services.

It starts by considering regulatory constraints on the more widespread use of satellites for delivering communications services and recommends actions for overcoming these problems.

Architectures for integrating satellite solutions into both the access and core segments of networks are then presented, followed by a detailed discussion of the interworking issues at the bearer, transport and network layers.

The guideline concludes by reviewing ways in which satellites could support future Internet, multimedia, mobile and broadcast applications and highlighting the management implications of integrating satellite systems into the network and service infrastructure.

2. Rationale

Satellites have continually expanded their role in integrated networks for telephony and data over the past decade, despite the widespread introduction of terrestrial links. Nevertheless there is scope to expand much further the use of satellites in new and future networks with advantages to both end-users and network operators. This depends on wider recognition of the advantages of satellites, such as

- rapid global deployment for new services
- wide and continuous geographical access, independent of cost
- flexibility and adaptability to rapidly changing markets
- support for global mobility
- high quality of service.

This guideline therefore provides recommendations on the role of satellites in overall networks and the interoperability issues which they raise.

To end-users, the use of satellites in telecoms is perhaps most familiar for TV broadcasting, and to a lesser extent for VSAT data services, since these provide direct-to-user access. Other examples of integrated satellite access networks include mobile telephony/data services from Inmarsat and Direct Internet services from several operators.

It is not so obvious to end-users that satellites are also extensively employed as trunk links in global networks since they are transparent to traffic. Examples include Intelsat and Eutelsat for international links, and many operators also employ satellites to extend the boundaries of their national telephony networks.

2.1. Regulatory Issues
Satellite Interoperability with Terrestrial Networks

Satellites have been prevented from further expansion into international access networks for bi-directional traffic by national regulations on transmitting stations, and by the lack of international operators to mediate for such services.

With telecoms deregulation encouraging competition between network operators and with the agreement of simpler procedures for installation of ground stations, service providers and users (e.g. corporate) are increasingly able to choose their preferred means of transmission. This has seen the emergence of new international service providers and growth in application of satellites, and in new global satellite systems which is likely to continue. Nevertheless further steps are needed. These can be classified in two major types of actions:

1. Further de-nationalisation of satellite service regulations is needed (e.g. in Europe) to allow effective competition with terrestrial networks.
2. Competition between national operators needs to be further stimulated and barriers to market entry removed.

2.2. Technical Issues

Interoperability depends not only on complementary features offered by alternative networks but also on use of common standards. Satellites are essentially an alternative network physical layer which is independent of higher layer protocols where common standards can be used. Nevertheless standardisation remains an issue for greater harmonisation.

The most familiar "transparent" satellite systems behave as a "bent-wires" and are implemented with network interfaces in the ground stations which form part of the complete satellite system.

New technology such as on-board processing (OBP) enables satellites to increase capacity and use resources efficiently by implementing routing (or switching) in order to route traffic in multi-beam systems. In this case internetworking functions may be required in the satellite as well as in the ground stations. Nevertheless the satellite system should still be a self-contained sub-network with any interworking included.

There are many technological issues involved in the development of future broadband satellite multimedia systems. These cover areas from TCP/IP and Internet over satellite, ATM over satellite, cheap terminal technology, advanced space and antenna technology, spot-beams, network and networking issues, operator issues, service provider issues, billing mechanisms, network and satellite management and much more.

Standardisation can benefit technology development, as it can focus work on consistent targets for different communities. Therefore, broadly speaking, many of the areas that are currently in focus for R&D may also be interesting to standardise.

The European ACTS programme has on-going research in several fields of satellites. This includes work on multimedia communications systems such as:

- the future Universal Mobile Telecommunications System (UMTS) of ETSI and the IMT-2000 equivalent of the ITU
- Multicast MPEG services using DVB transport.

3. Interoperability of Satellites across Network Architectures
In terms of physical network architecture, satellites are suitable for any part of the infrastructure including core and access network segments. Often satellites can fulfil both of these roles simultaneously through shared capacity between ground stations of different network segments.

3.1. Satellite Solutions for the Access Segment

Probably the most important role of satellites is in the access network since the wide coverage enables easy and low cost access directly to users. Mobility is most easily provided at lower data rates where antennas are compact.

Provision of satellite gateway station as the interface for the access network should provide all interworking functions. This station can provide access to users within a wide coverage region, from almost half the globe with geostationary (GEO) satellites to regional coverage with low earth-orbit (LEO) satellites.

The broadcast property of satellites should favour point-to-multipoint connectivity, depending on suitable network protocols.

3.2. Satellite Solutions for the Core Network

The long-distance capability of satellite links covering up to half the globe is a valuable way of avoiding complex terrestrial links especially to areas where access is difficult. The widespread installation of fibre-optic trunk links has not diminished the increasing need for satellite capacity in this segment (e.g. Intelsat). The capacity of trunk links generally needs to be high, which implies large ground stations.
In this architecture satellites provide links to the core network or between access and core network nodes.

4. Interworking at Protocol Levels

From an interoperability standpoint, satellites can be considered essentially as an alternative network physical layer which can be applied to any transport section within a network. They should therefore be mainly transparent to higher layer protocols, except in those cases where physical layer characteristics have an impact.

This section describes interoperability features and recommendations at each of the main network protocol layers.

Note: An Ad Hoc group, consisting of representatives from Eutelsat, Hispasat, Intelsat, SES-ASTRA, Telenor, Telesat, Teracom and ESA, met between September 1997 and August 1998 to initiate development of an open standard for a satellite interactive terminal, which would allow operators of different satellite systems offering a DVB forward channel and an interactive return channel to implement different service provisions with the same SIT hardware. The Ad Hoc Group is preparing a definition of the SIT characteristics including RF, modulation, coding, framing, multiple access protocol and signalling parameters.

4.1. Bearer Service Features

4.1.1. Multiple Access

A number of multiple access schemes are in use:

- Code Division Multiple Access
- Frequency Division Multiple Access
- Time Division Multiple Access

Perhaps the most common access format for broadband satellite systems is TDMA on the uplink, and a TDM structure on the downlink.

CDMA is being introduced for narrowband services (e.g. Globalstar) and may well become suitable for higher bit rates as processing technology advances.

FDMA offers advantages for lowering the cost of uplinks from small terminals. It is used for Inmarsat services as well as some other data networks.

4.1.2. Data Rate

Data rates range from narrowband to broadband. The main factors which determine data rate are size and cost of the ground station. These are also influenced by the operating frequency band of the satellite, which determines antenna gain for a given diameter and total bandwidth available:

- L: - mobile narrowband
- C: - medium data rate fixed services
- Ku: - high data rate fixed services (up to 155Mb/s)
- Ka: - experimental very high data rates (up to 622Mb/s)

Different solutions are proposed, of which a number of examples are given below.

For example, broadband satellite multimedia services, with speeds up to 34 Mbps, can be offered by Ku-band on antennas as small as 60 cm

At Ka band a 3.5 m antenna is capable of transmitting data at 622 Mbps.
4.1.3. QoS

Satellite links are capable of providing any desired QoS, depending only on the size and cost of the ground stations. Therefore a cost/QoS trade-off is usually applied to the required service.

The ultimate means of providing QoS appears to be the use of ATM. This does not seem to be seriously challenged by other transfer modes, and even when they have internal QoS control mechanisms, such as in IP, there is always an underlying assumption that ATM QoS control will be available if needed at some (lower) level of the network architecture, in particular in the neighbourhood of the end user, where no advantage can be taken of very high capacities for statistically levelling out traffic peaks.

ATM layer QoS, in terms of cell loss and cell errors, is therefore an important criterion. Whilst ATM cells can correct a single bit error in a header, it is important to avoid a high incidence of multiple errors causing cell loss. Satellite links are capable of the highest QoS, depending only on ground station cost. To maintain QoS whilst reducing system cost, suitable coding methods are available. A minimum cell loss rate target of $10^{-6}$ is proposed for a satellite link to maintain compatibility with ATM networks, which will not achieve lower values under typical traffic loads.

4.1.4. Connectivity (point-to-point or multipoint etc.)

One of the key advantages of satellite systems is their ability to provide connectivity, both point-to-point and multipoint over extended regions, and even to provide global connectivity when constellations of satellites are used in combination with inter satellite links. In practice, however, some limitations have to be taken into account. The system capacity is one of these limitations, which will encourage the use of the terrestrial infrastructure for connectivity when appropriate.

In existing and proposed systems, various arrangements have been used.

4.1.5. Coverage (geographical dependence on orbit etc.)

There are a number of issues affecting the economics of using of satellites for broadband communications. These include licensing, coverage, orbits, number of satellites, network architecture, latency, competitive technologies and enabling and complementary technologies.

While easy coverage of extended regions is an inherent feature of satellite communication, the economic benefits of such an approach very much depend on local circumstances. The markets will vary depending on geographic location, e.g. whether they are urban, suburban or rural areas. Several systems highlight their ability to provide global coverage with the same service for an African farmer as a businessman in New York, but it is dubious whether this sort of market will provide any strong financial benefit for any global data-transport provider.

Constant benefits of satellite access will only exist for special users such as travelling (nomadic) users, like TV-crews and news gathering applications as a cheaper alternative to the super VSAT systems of today.

Issues to be considered are:
- coverage of sparsely populated areas;
- Coverage: Global and regional. Land mass or oceans as well. Polar regions.

A number of these are related to the characteristics of the orbit. Future broadband satellite multimedia systems can be categorized as being either Global or Regional in their coverage domain.

There is a difference in coverage between GEO and non-GEO systems: Whilst GEO systems can adapt their beam coverage to market regions, and thus not cover oceans or other regions that are not...
economically worth covering, this is not as easy for LEO and MEO systems. Here the satellites will have footprints that cover most of the earth and will come closer to providing "real" global coverage. However, even LEO and MEO systems may choose not to cover some regions, for instance to save power.

GEO systems can cover approximately 1/3 of the Earth; so 3 satellites would be sufficient for a global system. The polar regions; above 70 to 80 degrees, are not covered but close to 100% of the potential market is.

Non-GEO satellites have different coverage capabilities depending on the inclination of the orbits. Polar orbits can cover the whole Earth and are thus useful for imagery missions and the like, but a large amount of orbit time is spent over polar regions where little traffic is expected. In practice, therefore, non-GEO systems will usually provide coverage somewhere between +/- 60 to 70 degrees north and south.

The satellite track in orbit, traced on the surface of the Earth is termed the satellite footprint or coverage circle.

There are proposals for multimedia satellites in GEO, MEO and LEO orbits, and in the S, Ku, Ka and V frequency bands.

MEOs are circular orbits at an altitude of around 10 000 km, with an orbit period of around 6 hours. The time during which a MEO satellite is in view to an observer on the earth is in the order of a few hours. A global communications system, using this type of orbit, requires a modest number of satellites (around 10-20) in 2 to 3 orbital planes to achieve global coverage. Compared to a LEO system, hand-over is less frequent, but propagation delay and free space loss are greater.

A polar orbit covers both poles, and is inclined at about 90 degrees to the equatorial plane. The orbit is fixed in space, and the Earth rotates underneath, therefore a single satellite can in principle provide coverage to the entire globe (but not at the same time). There would be long periods when such a satellite is out of view of a particular ground station, but it may still be acceptable for a store-and-forward type of communication system (messaging).

Broadband terrestrial radio access is another means of rapidly connecting users on a point to point (or point to multi-point) basis. 155 Mbps radio access networks are available today. However, such systems do not provide the (global) coverage that a satellite system can provide.

Some examples of coverage by planned systems are given later.

4.1.6. Mobility

In October 1996, ETSI published the report "Global Multimedia Mobility, A Standardisation Framework for Multimedia Mobility in the Information Society". The report recognises the, then new, allocations by WRC 1995 of Ka-band spectrum to non-geostationary satellite networks, as well as existing allocations for geostationary satellites, as permitting the development of new systems offering multimedia services. It states "The major attraction of such systems is that they could provide a global, high quality set of services in a mobile environment".

The report defines a generalised standardisation framework for GMM by identifying four "domains" for standardisation:
- The terminal equipment domain;
- The access network domain;
- The core transport network domain;
- The application services domain (including content provision).
Any ETSI standardisation developed for Broadband Satellite Multimedia will fit within this domain structure.

A GMM Companion Document is currently in preparation in ETSI. Like the original GMM report, the proposed companion document is intended to provide the ETSI view on a broad range of aspects of critical importance for the future telecommunications business (e.g. fixed-mobile convergence, virtual home environment).

**UMTS and S-UMTS**

The ITU's work on the IMT 2000 (previously the Future Public Land Mobile Telecommunication System, FPLMTS) is aimed at the establishment of advanced global mobile communication services within the frequency bands identified by the World Administrative Radio Convention (WARC 92) at 1885-2025 and 2110-2200 MHz.

ETSI is defining UMTS as the European third generation system within the IMT 2000 framework. UMTS standards and ITU recommendations for FPLMTS will be available before the turn of the century, the system will be introduced around the year 2000, and some services or features may be implemented earlier in GSM.

- Mobility will dominate personal communications in year 2000;
- Broadband services will dominate computer communications;
- UMTS will have a satellite component.

UMTS aims to provide a comprehensive set of services, features and tools, which enable services to have the "same look and feel" wherever they are used. UMTS will support multimedia services. All calls will have the potential of becoming multimedia calls and there will be no requirement to signal in advance any requirement for any number of media components.

**4.2. Transport Service Solutions**

Satellite links are generally interoperable with all transport services, but care has to be taken with ensuring QoS is compatible with the network. Link coding methods may need to be adapted to each solution.

**4.2.1. DVB/MPEG-2**

DVB has created standards (ref. [2]) specifically for high quality transmission by satellite guaranteeing BER of $10^{-10}$. These are designed for transport of MPEG-2 streams for a range of digital video audio and data services. DVB has defined an architecture for DVB interactive services.

**4.2.2. ATM**

Standardisation of ATM over satellite is progressing with several organisations working in parallel:

- the ATM forum, in its Wireless-ATM (WATM) group.
- Telecommunications Industries of America (TIA, www.tiaonline.org) via TR-34.1 has specific working groups on Wireless Asynchronous Transfer Mode (ATM), Internet over Satellite, ATM Speech, ATM Traffic Management and Congestion Control, ATM Quality of Service and Hybrid Reference Models. TIA is also working on a standard air interface for satellites, both for mobile and broadband communications.
- ESA.

ATM supports a choice of various transfer capabilities:
Constant Bit Rate (CBR) is defined by a committed Peak Cell Rate (PCR) for the duration of the connection;

Variable Bit Rate (VBR), where the connection is defined by a Sustainable Cell Rate and the Maximum Burst Size. Real time (RT) considerations adds a constraint on the cell transfer delay and the cell delay variation, while non-Real Time (nRT) does not.

Unspecified Bit Rate (UBR) is a «best effort» scheme. There is no commitment on errors, delays or throughput.

Available Bit Rate (ABR) is a network protocol, which is rate based, allowing the overall bandwidth of the network to be optimised. A flow control mechanism is provided (through resource management cells), enabling modification during a connection of a guaranteed Minimum Cell Rate (MCR)

Guaranteed Frame Rate (GFR) is a frame based ATC, suitable for IP traffic, and also for Frame Relay / ATM inter-networking. It is defined by a source traffic descriptor including Peak Cell Rate (PCR), Minimum Cell Rate (MCR), Maximum Frame Size (MFS), Maximum Burst Size (MBS).

ATM can guarantee a user a set of service parameters, which is one of the biggest advantages of ATM over competing technologies such as Frame Relay and Fast Ethernet, which do not support different QoS levels.

However, transition to ATM will require some time and meanwhile, intermediate solutions are proposed.

An example is the Skybridge system. Gateways are made up of local exchanges, routers and RANs with IP QoS control and of ATM switches for dispatching the traffic between the access network and the terrestrial WAN. This provides the means for integrated services and network management.

The system supports ISDN, IP over PPP, Frame-Relay and ATM (PVC trunking and MPOA or MPLS). Asynchronous Transfer Mode (ATM) is used on the radio interface and may not be visible externally. Quality of Service (QoS) is guaranteed by classical ATM processes.

4.2.3. UMTS

Satellites are considered to be necessary as an integral part of the UMTS access network. The lower technology-dependent layers are intended to be interchangeable for multimode terminals. ACTS projects are working on satellite air interfaces which are largely protocol-compatible with terrestrial W-CDMA proposals.

4.2.4. OBP

A new feature for many forthcoming satellite systems is on-board signal processing, OBP, providing recovery of baseband signals via channelisation, demodulation, decoding/encoding and possibly resource control, in contrast to the bent-pipe approach of most current systems. OBP allows smaller antennas and/or higher system capacity. It also opens the door to greater flexibility of routing and switching such as on-board ATM switching or IP routing. OBP is also useful to complement adaptive antennas.

Systems which have implemented this technology include Italsat and Iridium. The latter also has intersatellite links and on-board switching, so that few gateways are needed.

4.3. Network Layer Solution

Most systems claim to be able to support all major protocols (like TCP/IP and UNI, User Network Interface), but this can be supported by different underlying satellite transmission (air interface) formats.
The broadband satellite multimedia systems coming in the near future often are seen as belonging to what can be divided into two different classes:

- DVB systems, adding inter-activity and generally asymmetric data services to a broadcasting system. These generally also take advantage of existing Ku-band DBS systems, and an to some degree an existing consumer customer base.
- ATM systems, typically found fully at the Ka-band.

### 4.3.1. Effects of Delay

One factor, which may have a significant bearing on network layer performance, is transmission delay. Satellite path delay is approximately 270 milliseconds for GEO systems. Adding system delay caused by processing and buffering brings the total well above 300 ms. The impact is different for voice and data communications.

In voice communications, the most noticeable effect of path delay has been echo, and challenges have related to echo cancellers.

Where data transfer is concerned, delays are generally more tolerable than errors. The requirement for low error rates for computer-data, therefore results in requirements for high power transponders to obtain a sufficient low carrier to noise ration at the receiver. File transfer and data distribution is not very sensitive to a few hundred ms delay. However, current versions of TCP/IP, for instance, can have a limited upper-bound capacity for delay through the channel. These issues will be resolved, and the Internet over satellites can be as for terrestrial connections.

Client/server applications often rely on "transaction-oriented" application-layer protocols that consist of large numbers of low bandwidth requests and responses. Delay influences the set-up of such connections. The main issues regarding latency in Internet protocols relate to:

- The default buffer-size in many TCP/IP protocol implementations acts as a bottleneck on communications over high-latency links.
- TCP includes congestion control mechanisms which mean that Internet connections (such as viewing web pages and sending e-mail) start out at low speed and then advance up to higher speed if no congestion is encountered. The problem is that each cycle of speed increase requires a full round-trip communication between sender and receiver, and dozens of such round-trips can be necessary to reach the full potential of a link. With a sufficiently long delay, as encountered in some GEO systems, the communication can end before the connection can ever reach the full bandwidth of the link.

### 4.3.2. Network Layer Protocols

Network layer protocols are also critical for interoperation of satellite and terrestrial networks at gateways. Seamless interfacing with terrestrial protocol should be guaranteed through the use of networking standards, including ATM and TCP/IP. Standardisation plays a key role here. For instance, the ETSI project BRAN intends to develop interworking specifications that allow broadband systems to interface to existing wired networks, notably those based on the ATM and TCP/IP protocol suites.

A number of mechanisms have been introduced into the IP protocol to allow management of QoS. These mechanisms can be used to advantage in satellite communications.

Reliable IP Multicast protocols are an emerging standards area, and new protocols have been developed to support real-time multimedia delivery and Quality-of-Service (QoS) for multicast and unicast network services. These include the

- Real-time Transport Protocol (RTP);
- Control protocol (RTCP) that works in conjunction with RTP;
- Resource reservation protocol (RSVP);
- Real-time streaming protocol (RTSP).
NASA and IETF are also active in this field.

4.4. **New Applications Services**

4.4.1. **Internet/Multimedia**

Today there appears to be no Internet over satellite service provider or system that offers customers an integrated satellite solution. The systems rely on broadband delivery over satellite, and a receive-only antenna at the customer premises. The return link, which is not usually broadband, is often via terrestrial modems to some central hub, or gateway, which transmits to the satellite.

4.4.2. **Narrowband/Mobile**

Mobile communications is one of the potentially very attractive applications of satellite systems. A very good complementarity could be achieved between current cellular terrestrial systems, which are cost effective in populated areas with a good existing terrestrial infrastructure, and satellite systems which permit continuity of service in areas which are not yet covered by terrestrial systems or cannot be covered by such systems because of geographical factors (mountains, deserts, oceans etc.). The objective is to have a seamless operation between the different systems.

Several organisations have shown interest in such solutions. In particular, a MoU (ref. [5]) has been signed by several participants, including Skybridge, CyberStar and EUTELSAT who want to see its principles applied to fixed satellite service as well as mobile.

4.4.3. **TV Broadcast**

The European ACTS programme has ongoing research in several fields, including an Interactive Digital Multimedia Services Domain. This includes work on, for example, MPEG, defining a range of state of the art image and sound coding and multiplexing techniques. This standard has been accepted by bodies like the DVB (the Digital Video Broadcasting project), ETSI as the basis for new television broadcasting services and by DAVIC (Digital Audio-Visual Council) as the basis for multimedia services via Telecom, CATV and satellite networks.

Digital television and Digital Video Broadcasting are technologies that provide a need for (personal) broadband satellite communication systems. In 1997, DVB delivered its Data Broadcasting specification to ETSI. Already Data Broadcast Networks (DBNs) making use of DVB return channels and DVB-S satellite delivery are up and running in Europe. DVB DBN operators include ASTRA, Hispasat and Eutelsat. Services include the Internet.

The DVB approach provides great flexibility in terms of transmitted digital information, owing to its MPEG-2 data "container" concept. DVB delivers to the receiver "containers" with compressed image, sound or data. The DVB Service Information acts like a header to the MPEG-container, ensuring that the receiver knows what it needs to decode.

Items for further investigation include:
- Portable terminals, multimedia and Ka band Direct TV Broadcasting (DTVB) terminals;
- Direct-to-home TV broadcasting at 11/14 GHz (reception with 0.3 - 1 m antenna dishes);
- Protocols supported / used. DVB versus ATM.
5. **Network Management and Control Requirements**

One of the most difficult parts of network management is to agree on stable standards which are of practical use insofar as they cover a substantial part of the system specifications. Many generations of standards have been produced, but they often coexist without real integration.

ETSI is active in this field. Network management aspects are standardised by TC TMN (Transmission Management Networks).

The SkyBridge system is one of the satellite networks which has paid special attention to network management. The approach taken is to locate these functions in Gateways made up of classical ISDN local exchanges, routers and RANs with IP QoS control and of ATM switches for dispatching the traffic between the access network and the terrestrial WAN.

6. **Conclusions**

Satellites have played an expanding role in communications over the last decade. This role could be expanded further, if better harmonisation of regulations covering satellite services made it easier for new services to be introduced on an international basis.

New technology, such as on-board processing, makes it possible to use satellite systems much more flexibly. This guideline has presented architectures for integrating satellite solutions into both the access and core segments of networks and has explored the interworking issues at the bearer, transport and network layers.

It has also explored ways in which satellites could support future Internet, multimedia, mobile and broadcast applications and reviewed initiatives and has highlighted the management implications of integrating satellite systems into the network and service infrastructure.

7. **References**

[2] DVB satellite transmission standard: ETS 300 421