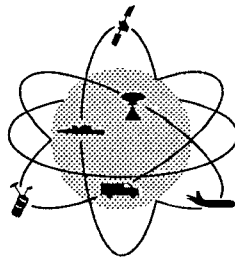


TECHNICAL RESEARCH REPORT

LAN Interconnection by Satellite --- A Literature Review

By S. Ramseier

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LAN Interconnection by Satellite —

A Literature Review

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Abstract

In this report we give an overview on experiments interconnecting LANs by satellite, which are reported in the technical literature. Most reported scientific experiments have been performed in Europe and Japan, whereas in the USA a more application oriented, commercial approach seems to have been taken. In this report, we briefly describe several projects, such as the French NADIR, the European STELLA, UNIVERSE and SATINE-2, some experiments performed by the European Space Agency ESA, such as PRODAT and CODE as well as a special internetworking experiment. We also mention some Japanese and a Canadian project.

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Chapter 1

Introduction

Local Area Networks (LANs) are a popular means to interconnect computers located at a single site. LANs are characterized by their high data rates, the high number of connected terminals or computers, and the limited coverage. A few years ago, LANs were being operated independently, serving users within separate islands. In the last couple of years, the need for interconnecting LANs arose, and special interconnection techniques and protocols have been developed. Today, the most typical interconnection media are wire and fiber, where, however, radio and especially satellite links are becoming more popular.

Satellite communication links have been existing for about thirty years now. Depending on the size of the earth station and on the frequency band, data rates of several Mbps are now available for point-to-point links. In the mid-1980's, Very Small Aperture Terminals (VSATs) were introduced, which made it possible and cost-efficient to interconnect thousands of remote sites (garages, grocery stores, etc.) to a central location (e.g. the headquarters). Typical VSAT applications are the interconnection of remote computer terminals to a central host computer.

As an alternative to terrestrial links, it seems natural to investigate the interconnection of remote LANs via satellite links, using standard high data rate satellite terminals or VSATs. To do so, the characteristics of LANs and satellite links have to be taken into account, however. Compared to terrestrial links, satellite links introduce a longer propagation delay, and data rates (for VSATs) are typically lower than for wired links, and bit error probabilities and availability may also differ. Hence, special channel access methods and network protocols have to be investigated for LAN interconnection by satellite. Of considerable interest are aspects such as flow and congestion control, and their impact on throughput and delays.

In this report, we try to summarize some of the experiments to interconnect LANs by satellite that have been performed in Europe, Japan and North America in the last few years. In Chapter 2, which is largely based on [Ram91], we describe European projects. They include the French NADIR project, the European STELLA, UNIVERSE and SATINE (SATellite INternetworking Experiment), experiments performed by the European Space Agency ESA: CODE (Cooperative Olympus Data Experiment) and PRODAT, as well as CHEOPS and the on-going European COST226 research project. In Chapter 3

we describe experiments performed by Japanese research institutes, and in Chapter 4 we describe the effort for LAN-interconnection by satellite that is undertaken in North America. This report closes with a summary (Chapter 5), some conclusions (Chapter 6) and a extensive bibliography.

Chapter 2

European Projects and Experiments

This chapter contains a description of several European experiments and projects performed to interconnect LANs by satellite.

The first of a series of projects found in the literature is NADIR, a French pilot project started in the early eighties that used the TELECOM1 satellite to interconnect LANs (see Section 2.1).

About at the same time the project STELLA used a leased point-to-point satellite link to interchange data between two sites. The second phase of STELLA, called SATINE, and the parallel UK UNIVERSE experiment, were designed for quasi-simultaneous transmission between several sets of users on local area networks, using a rather primitive satellite access controller. The SATINE project demonstrated transmission of tapes between several European research laboratories. The results were sufficiently promising to set up a much improved version. This experiment, SATINE-2 (cf. Section 2.2), was developed for sharing a 5 MHz channel between users in a number of sites, for traffic covering interactive access, file transfer, as well as packet voice or slow scan video. It used specially developed hardware and software for time division multiple access to the satellite (project FODA, see Section 2.3). Contrary to previous satellite services based on small terminals, the SATINE-2 system was not restricted to fixed point-to-point links, but supported the special requirements of distributed computing and information dissemination.

Some ESA projects to interconnect LANs by satellite are reported, such as PRODAT and CODE and a high-speed computer networking experiment. PRODAT is a demonstration system for satellite communication between small mobile terminals and stationary (fixed) stations, see Section 2.4. An ESA computer networking experiment with a high-speed satellite link is described in Section 2.5. Another ESA project, CODE, is an experimental very-small-aperture terminal (VSAT) system utilizing the 20/30 GHz payload of the Olympus satellite, see Section 2.6. CHEOPS, a collaboration between several European research institutes intends to distribute massive quantities of scientific data for remote analysis, also using the OLYMPUS satellite, see Section 2.7.

SATINE-2, FODA, PRODAT and CODE were the basis for an on-going European research project, COST226, which was started in 1990. It is described in Sec. 2.8.

2.1 NADIR – A French Pilot Project to Interconnect LANs by Satellite

The NADIR pilot project was launched by the end of 1980 by the French PTT and the Ministry of Industry [Hui82, Dua84, Dua86]. It aimed at investigating new types of computer applications made feasible by taking advantage of new satellite communications systems. Among these applications, interconnection of LANs through satellite links were studied.

Within the French TELECOM1 satellite, five transponders were shared for business communications. The TDMA system provided digital links either on a call per call basis, or in a semi-permanent fashion. Multipoint and point-to-point links were used at data rates from 2400 bps to 2 Mbps. Point to point links were either simplex or duplex.

In a first phase, a satellite simulator was developed to emulate TELECOM1 links [Hui82]. It allowed to establish various link configurations between computers with various data rates, bit error rates and propagation delays. The parameters of the TELECOM1 satellite were about 300ms propagation delay, an uncoded bit error rate of less than $1E-6$ in 99% of the cases, and a coded bit error rate of about $1E-10$ using a rate 4/5 forward error correction code.

In a second phase, experiments using the TELECOM1 satellite were performed [Dua86]. One of the five 25 Mbps transponders were used. These 20 W transponders were working in the 14/12 GHz frequency band, allowing the use of small antennas (3.5 m).

Access to the satellite was made by means of a Time Division Multiple Access (TDMA) with demand assignment. This mechanism allows to share the total channel capacity among the terrestrial transmitting stations. A major drawback of the demand assignment mechanism is that it is not possible for a transmitting application to have a fast acknowledgement. If an acknowledgement is necessary, it can be built from a sequence of partial acknowledgements as follows:

- applications asking for a transfer set up a connection with the local gateway and transmit to it all the data associated with the transfer acknowledgement request
- the sending LAN gateway sets up a point-to-multipoint satellite link with the receiving LAN gateways and transmits both data and transfer acknowledgement request
- the receiving stations provide the receiving LAN gateways with acknowledgements
- the receiving LAN gateways take advantage of the next satellite link to send acknowledgement responses
- the transmitter receives the acknowledgements.

The time between the data transfer and its acknowledgement depends on the time between two successive satellite link set-ups, which may not satisfy the requirements of some applications.

No publication was found about the results of the project NADIR.

2.2 SATINE-2 – Satellite Internetworking Experiment

SATINE-2 [Hin88, Kou88, Ada89] was an experiment to use Mbps satellite links to interconnect users in research laboratories with performance comparable to that of local facilities. It was designed to test a complete system for sharing a 5 MHz channel between users in a number of sites, for traffic covering interactive access, file transfer, as well as packet voice or slow scan video. It used specially developed hardware for time division multiple access to the satellite. The project involved CERN, Geneva, Rutherford University, U.K., CNUCE, Pisa and Graz University of Technology.

Contrary to previous satellite services based on small terminals, the SATINE-2 system was not restricted to fixed point-to-point links, but supported the special requirements of distributed computing and information dissemination. It took into account the bursty nature of the traffic and made short interactions possible.

A group of users in different places shared a satellite channel in Time Division Multiple Access (TDMA) mode on a demand basis; that means that only in case of traffic from a particular station time slots were actually allocated to a station (Fig. 2.1).

The access to the satellite channel was provided by a so-called satellite bridge, a device specially developed for SATINE-2. It received packets from individual users via a LAN (Cambridge Ring) and transferred them over the satellite channel to the addressed user or host (Fig. 2.2). The earth-station used was the Marconi small dish terminal, which has a fixed 3-meter antenna, a maximum transmission power of 140 watts and a receive G/T of 22.5 dB/K. The station was driven by a 2 Mbps BPSK burst modem.

The SATINE system not only provided computer data transmission facilities as in the previous STELLA system, but also voice and slow scan or compressed video communications. These services have their own *quality of service* parameters: required bit rate, maximum tolerable bit error rate, priority of the service and burstiness of the data.

To satisfy all these parameters in an efficient way, a new TDMA access scheme was developed by CNUCE (see Section 2.3). It supports stream traffic (e.g. voice) and datagram (interactive or bulk computer traffic) dynamically and according to the traffic requirements.

To provide an essentially error-free service, adaptive methods were used (variable transmission and code rates on a block by block basis) to cope with a time-varying channel quality. These methods will be very important for satellite channels in the 20/30 GHz bands, where rain attenuation can cause serious transmission losses.

The key features of SATINE-2 may be summarized as follows:

- Up to 64 stations each linked to a LAN can be interconnected by satellite to constitute a wide area network which is able to handle many calls in parallel
- The system supports mixed-media traffic (voice, video and computer data)
- Separation of stream (e.g. voice) and datagram traffic (e.g. computer data) provides low and constant delay for the critical stream traffic

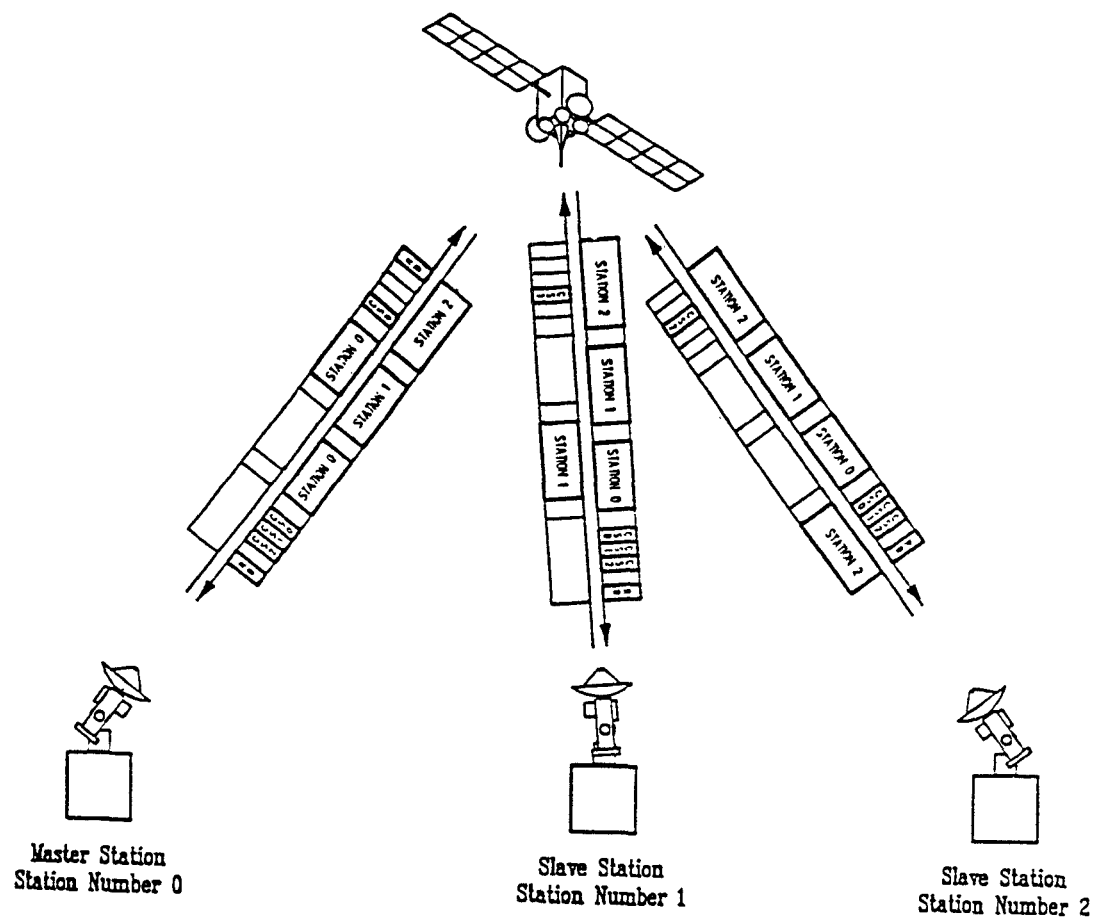


Figure 2.1: Interconnection of sites in the SATINE-2 system [Kou88]

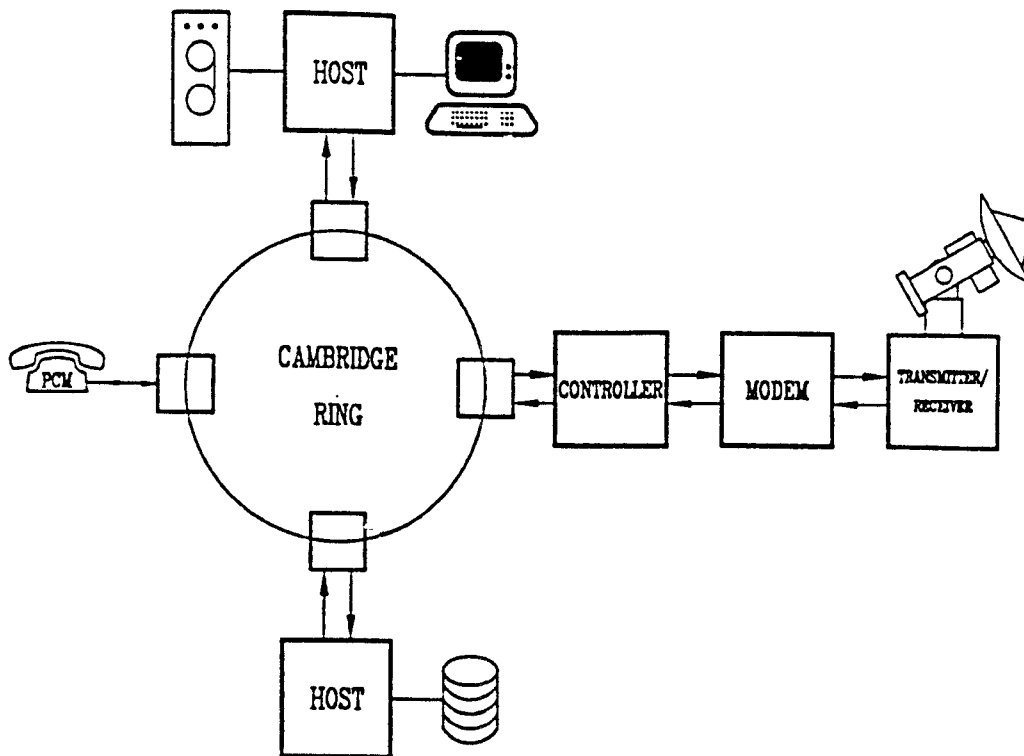


Figure 2.2: SATINE-2: LAN/Earth station environment [Kou88]

- The channel capacity is dynamically allocated taking into account the type and priority of the traffic to make optimum use of the channel capacity.
- High-quality services even under degraded channel conditions are achieved by adaptive communication methods: variable transmission rate and variable coding.

Advances in digital modem and codec design allowed a change of transmission and/or code rate on a burst-by-burst basis. This gives individual users having, for instance, different channel qualities, exactly the desired low-error performance.

The digital modem specially developed for the experiment ran at 4 Mbps, with speed variable from block to block.

The underlying architecture of the system is that of a high-speed local switch, in this case a LAN, connecting the local users, and a remote switch, here the satellite, which transfers the data between local switches as streams of packets of all users intermingled. This is different from a network with private branch exchanges (PABXs) at each site interconnected by ISDN, where fixed capacity circuits are allocated between every pair of active users.

Tests with the EUTELSAT satellite ECS-2 showed that bit error rates of better than $1\text{E-}7$ at the maximum power (65 dBW effective radiated power) could be verified, even at the edge of coverage of the satellite [Hin88]. This figure applies to uncoded mode. In coded mode, the bit error rate was better by about two orders of magnitude.

2.3 FODA – FIFO Ordered Demand Assignment

For the SATINE-2 project (cf. Section 2.2), a special access scheme for the satellite channel was developed by CNUCE, the research institute of the University of Pisa [Cel88, Hin88, Cel89, Cel90, Cel90a, Fer90, Cel91]. The FIFO Ordered Demand Assignment (FODA) is the realization of a reliable transmission system suitable for optimizing the use of a Mbps satellite channel for handling mixed digital traffic (stream and datagram) coming from a heterogeneous network environment. The system is not restricted to fixed point-to-point links, but supports the special requirements of distributed computing and information dissemination.

A group of users (up to 64 active stations in a range of 255 addressable ones) shares a satellite channel in a time division multiple access (TDMA) mode on a demand basis: only when packets are to be sent are transmission time slots actually allocated to a station. The access to the satellite channel is given by the satellite TDMA controller running the FODA software. It receives packets from individual users via a LAN and transfers them over the satellite channel to the addressed user or host (see Fig. 2.3). The system not only provides computer data transmission facilities, but also voice or slow scan or compressed video communications. These different services have their own quality-of-service parameters, as already described in Sec. 2.2.

The FODA access scheme is essentially based on reservation of bandwidth. The time is divided into slots in which the various stations alternate in their use of the entire capacity of the channel. The assignment of the time slots is made dynamically upon demand of the users (earth stations). Requests for datagram and for stream slots are managed by the system in different ways. One of the active stations plays the role of master (channel dispatcher) as well as its normal slave role. Techniques to replace the master station, in case of fault, are provided, in order to create the minimum trouble to the users.

The design is based on the following assumptions:

- the satellite network attempts to satisfy the quality of service needed by higher level protocols to match the requirements of the different applications;
- operations such as opening/closing of virtual circuits, and retransmission of corrupted packets for application requiring error free delivery, must be performed by higher level protocols; the data packets must be organized at the stations in different FIFO queues, according to the quality of service (priority). There are a stream queue and two different queues for datagram traffic, since higher priority is given by the station to sending interactive as opposed to bulk traffic;
- in order to make the time-slot length independent of the packet length, fragmentation/reassembly techniques are used. Channel saturation control techniques are also implemented.

The transmission time is divided into frames 31.25 ms long, in order to synchronize events like the stream slot repetition and the datagram slot assignments. The master station sends a reference burst at the beginning of each frame for synchronization purposes

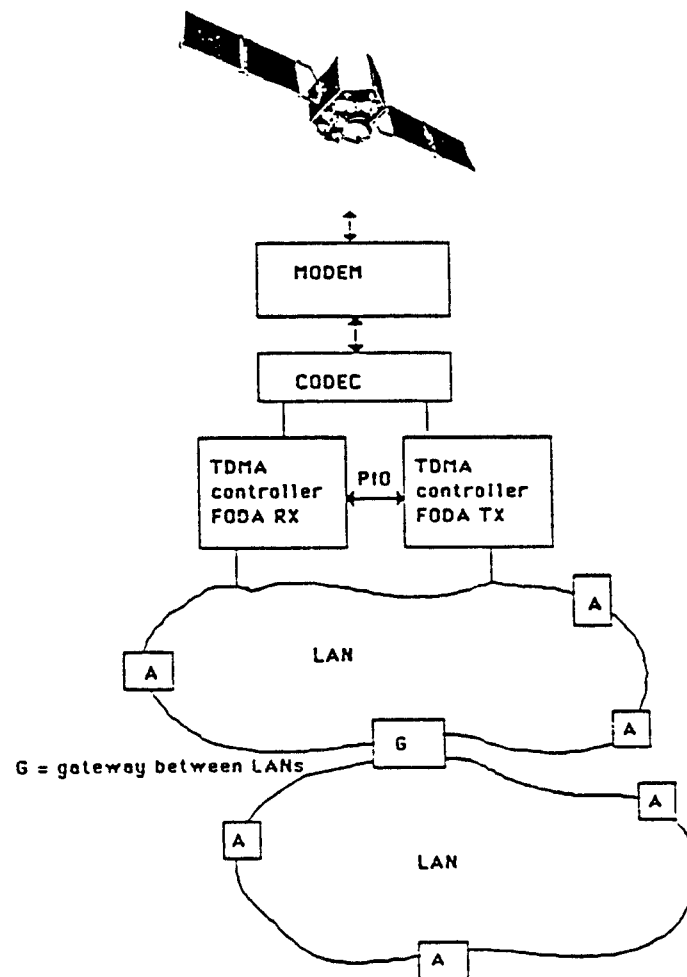


Figure 2.3: Network Configuration supported by the FODA access scheme [Cel91]

and for distributing control information to all the stations. A bigger period of 2 seconds is chosen to schedule events varying with lower frequency, e.g. stream channel set-up. This super-frame is made of 64 frames.

The request for the stream channels is made only once and, if accepted, it will be considered valid until the station sends a relinquish indication or it is declared dead. The request is made on the basis of a multiple of the stream channel, whose throughput is 16 kbps, corresponding to the allocation of one slot every fourth frame. The datagram assignment slots are assigned in the remaining space of the time frame, after the stream locations. A datagram request contains the number of elementary slots needed by the station at the moment. Each request is put in a FIFO queue by the master station.

Experiments showed that in general the satellite delay of some 0.27 s does not increase by more than 0.1 s even with heavy loading and with many stations active. For an overall loading of 70%, all stations are being delayed by about the same amount by the system load, and none are being badly treated by the scheduling algorithm.

The effect of the longer delay on receiving the allocations due to the adoption of centralized control in contrast to a distributed one is counterbalanced in the FODA system by putting in the user request a term proportional to the incoming traffic, as a sort of backlog prediction [Cel91]. The result is quite good at least for a quasi-stationary type of traffic, i.e., a variable traffic with periods of many seconds in which it practically remains constant. In this case the datagram queuing delay is in theory zero and in practice very small.

While supporting the most common type of network traffic, the FODA system offers performances comparable to distributed systems, without presenting the relative drawbacks [Cel91]. Moreover, the adoption of features like the possibility to send datagrams in the stream channels when no stream packets are available, contribute sensibly to increase the efficiency of the channel utilization.

2.4 PRODAT

PRODAT [Rog87, Kri91] is an ESA demonstration system for satellite communication between small mobile terminals installed on trucks, aircraft and small ships, and stationary (fixed) stations connected to the system by means of various public terrestrial networks. PRODAT operates in the L-band (1.5-1.6 GHz) frequency range for the link between the satellite and the mobile terminal. The feeder link between the earth station and the satellite is in the C-band (6 GHz). The use of C-band and the power constraints of available satellites necessitate the use of a rather large antenna and a powerful transmitter at the hub station. Therefore, a single hub station is used, and the fixed terminals are connected to it by means of public communication networks.

The system is organised around a PRODAT Network Management System (NMS), co-located with the hub station. The primary functions of the NMS are:

- control the communication-link protocol used on the satellite link with the mobile stations

- control the protocols used for the fixed terminals via the various terrestrial networks
- perform the message switching function between mobile stations and fixed terminals.

PRODAT provides the following services:

- transmission of messages from fixed- to mobile-terminal users, from mobile- to fixed-terminal users, and from mobile- to mobile-terminal users
- transmission of requests from fixed-terminal users to a mobile terminal, followed automatically by a reply supplying information, such as the position of the mobile, from the mobile equipment
- broadcasting of messages to a fleet of mobile-terminal users
- automatic periodic polling of mobile-terminal positions. This function currently being only available for aircraft within the framework of an air-traffic-control experiment.

Until December 1990, PRODAT was operated using the Marecs-B2 satellite. Because this satellite has been moved in the meantime, PRODAT later accessed an Inmarsat-2 satellite over the Atlantic Ocean. The NMS has therefore been moved to Fucino, Italy.

PRODAT users based at fixed locations are able to access the system via various terrestrial networks:

- the public telex network, using a telex machine or a PC-based telex system
- the public Packet-Switched Data Network (PSDN) based on the X.25 protocol (the user must have a computer and suitable software)
- the Public Telephone Network (PSTN) using a modem and a PC with suitable software
- the international airlines network SITA (only for airlines participating in the experiment).

Furthermore, PRODAT has been demonstrated, together with a Very Small Aperture Terminal (VSAT) satellite communication system, at a number of exhibitions. One of the experiments in the demonstration program associated with ESA's Olympus telecommunications satellite connects computers by means of a high-speed satellite link, using a hub station and a VSAT station operating at 20/30 GHz. This project is described in some detail in Section 2.5.

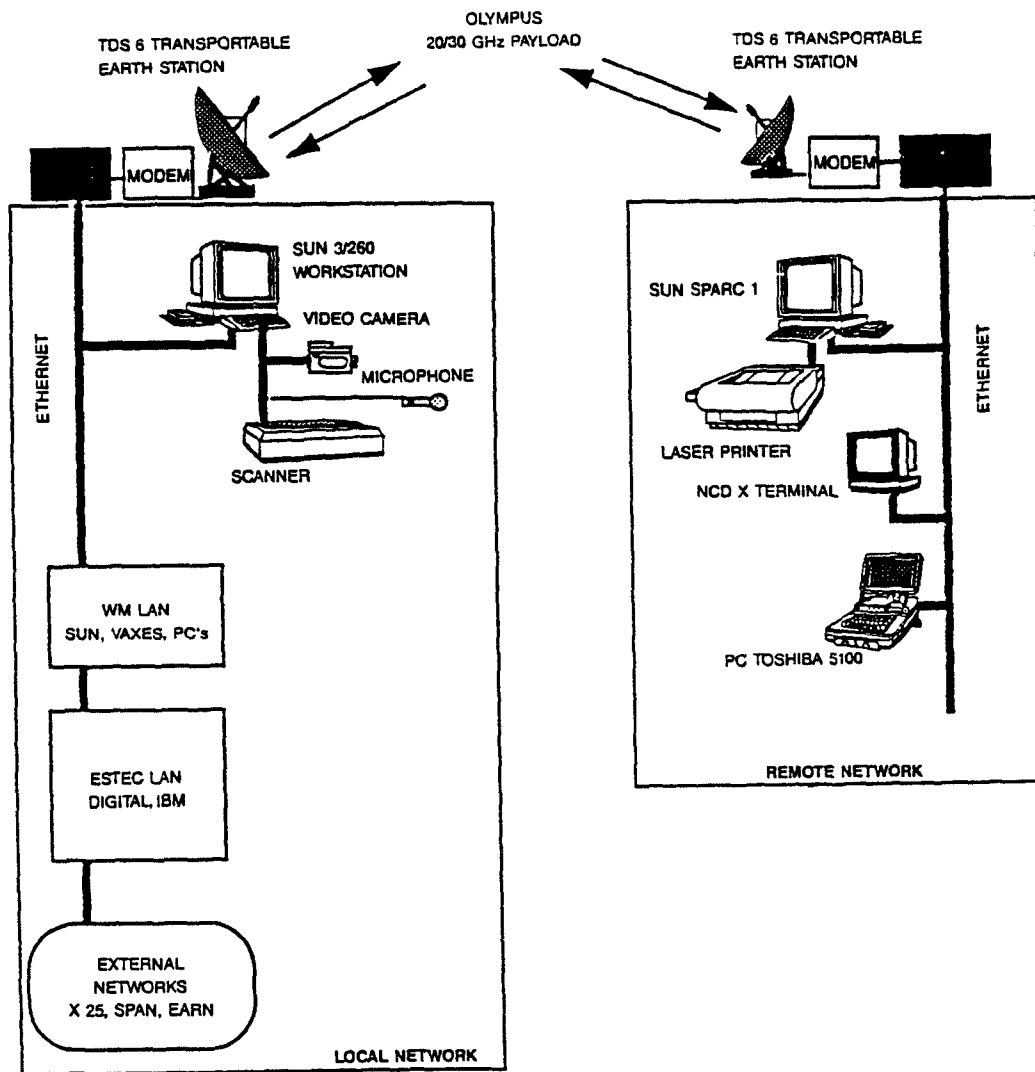


Figure 2.4: Hardware configuration for the computer-networking experiment [Gar90]

2.5 The ESA Computer Networking Experiment

A computer networking demonstration was begun at ESTEC in April 1990 using the 20/30 GHz payload of ESA's Olympus satellite [Gar90, Kri91]. In setting up this experiment, special attention was paid to minimizing the need for specialized hardware or software development by employing off-the-shelf hardware, software and protocols where possible. The Olympus satellite channel was treated as a straightforward point-to-point link. The goal of this experiment is to gain knowledge concerning the interconnection of Local-Area Networks (LAN) using high-speed links to and from satellites, and in particular in coping efficiently with both the high transmission rates (megabits per second) and the substantial round-trip signal delays (of the order of 0.5 s).

The experiment was conducted using two physically separated networks, called the

local and the *remote* network, see Fig 2.4. They are both based on Ethernet, using the Unix TCP/IP protocol suite. The two networks were connected to the satellite modem via a network router, providing a hardware interface between the Ethernet network and the V11 modem. The function of a router is to link two or more LANs by means of a long-distance line, normally operating at a lower data rate than the LAN itself. In this case, the long-distance line is the satellite link. The router is able to determine which computers are on the same LAN as the router, and which are on a remote LAN. Only the traffic to the remote computers is transmitted over the satellite link, at the data rate supported by this link. The speed of the local traffic is not reduced by the router.

The two modems, operating from 32 kbps to 4 Mbps, were each connected to one transmit and receive chain of one TDS-6 transportable Earth station at ESTEC, transmitting and receiving at two different frequencies via the 20/30 GHz Olympus payload.

The configuration of Fig. 2.4 had been realized completely with commercially available equipment. It was, in fact, not very different from conventional wide-area networks established by connecting LANs by means of land lines. The main difference is in the speed of the satellite link, namely 2 Mbps, which is considerably greater than the rate normally available on long-distance lines. At this data rate, the propagation delay of approximately 270 ms becomes significant and may limit the throughput of some applications.

The routers, in conjunction with the satellite link, effectively establish a transparent bridge between the two LANs, and almost any application that can run between two computers on a single LAN can run across the satellite link, though in most cases at a reduced speed.

Using this architecture, a variety of software applications such as file transfer, electronic mail, remote login with terminal emulation, remote database access and document processing have been successfully demonstrated.

For the future, a point-to-multipoint setup, a so-called *star configuration*, in which a central station or hub can undertake simultaneous transfers with several remote stations will be tested. A static, pre-defined Frequency-Division Multiple Access (FDMA) scheme will be used to communicate with the satellite. Next, a dynamic TDMA scheme will be used, such as that designed for ESA's CODE experiment (cf. Section 2.6).

The work conducted so far has shown that [Gar90]:

- It is possible to interconnect two LANs quickly and easily via satellite, provided a point-to-point satellite link is available, and the correct combination of computer hardware, software and communications protocols is selected.
- A wide variety of software applications can be installed and used with practically no modification via such a network.
- Once implemented and properly tuned, the presence of a satellite link in the network is almost invisible from the user and application point of view.
- A throughput of about half a megabit per second has been achieved with crude tuning, on a single end-to-end circuit. Several such circuits can be operated simul-

taneously via the satellite in a manner transparent to the user in order to use the channel's bandwidth efficiently.

2.6 CODE – Co-Operative Olympus Data Experiment

The Cooperative Olympus Data Experiment (CODE) is an experimental very-small-aperture terminal (VSAT) system utilizing the 20/30 GHz payload of ESA's Olympus satellite [Hug89, Mwa89, Nes89, Hug90, Kou91]. It is being used by universities, research organizations and industry for a variety of applications, such as database access, message transmission, image and document dissemination and data broadcasting, as well as for interactive communications.

CODE was initiated by ESA primarily as a stimulus for the development of the technological skills and infrastructure needed within Europe to develop inexpensive K_a -band equipment, complete stations and networking techniques. These objectives have now been achieved.

VSAT systems have become very popular both in the United States and in Europe. One consequence of the opening up of Eastern-European countries is that the telecommunications industry is now confronted by a strong demand for satellite-based communications facilities to provide basic communications, particularly in those countries where the existing infrastructure is poor.

Commercial VSAT systems use the C- and Ku-bands. Although there is currently no shortage of Ku-band capacity, it is predicted that there is likely to be an interference problem in the future. This implies that a move to higher frequency bands is inevitable in the long run. The aim of CODE is to test and demonstrate the use and reliability of a K_a -band system together with the network software needed to meet known user needs.

The CODE experiment is organized by the ESA with the support of European universities, research organizations and industry.

The present system consists of a central hub station, with an antenna diameter of 2.5 m, and a large number of user terminals with antenna diameters down to 80 cm, which together form a 'star network'. Although the primary mode of operation is via the hub station, direct communications between user terminals is also possible, using the hub for network control only. This mesh-configured feature achieves a fast response time between VSATs, whilst retaining the organizational power of the hub station. The system concept allows several independent CODE systems to co-exist using the same transponder.

All links are protected by 1/2-rate convolutional coding / Viterbi decoding, providing a bit error rate of $1E-8$, with an availability of 99%. Sufficient link margin is provided to cope with propagation effects. Availability is determined almost entirely by the system parameters of the user terminal.

The outbound link from the hub station is normally a single 2.048 Mbps Quadrature Phase-Shift Keyed (QPSK) modulated carrier. The in-bound links from user to hub, and between user stations, are Binary Phase-Shift Keyed (BPSK) modulated carriers,

providing each with a user rate of 64 kbps. The access scheme is Frequency-Division Multiple Access (FDMA), with frequency assignment using an ALOHA access channel to the hub.

CODE is designed to operate initially with the 20/30 GHz payload of ESA's Olympus communications satellite. However, the technology is applicable to any 20/30 GHz satellite capacity, or indeed other frequency bands, with appropriate changes in front-end equipment. When used with Olympus, the coverage provided is equivalent to an area roughly the size of Central Europe. The normal mode of operation is with identical up-link and down-link coverages, and consequently with the hub and all the VSATs simultaneously accessible. In the configuration, which is usually established during the European day-time, all the major European population centers are covered.

Moreover, because of the steerable antenna system on the Olympus satellite, a vast additional area equal to about one third of the Earth's surface can be covered on a store-and-forward basis. Hence, the CODE experiment has participants in, for example, Canada and the United States who are able to access information resident at the hub station or data emanating from, or destined for, European VSATs. Beam coverage of this type is organised such that one beam remains over the hub station and the other sequentially covers remote user communities. Such a configuration is conveniently adopted during the European night-time.

In the early days of the CODE experiment, it was thought that each VSAT would be associated with a small personal computer which would communicate with other VSAT sites with similar simple low-cost installations. It soon became apparent, however, that the size and complexity of the computing facilities available at the various establishments varied considerably, from simple and cheap computers to, in some cases, very advanced Local Area Network (LAN) systems. It was therefore decided that an Ethernet interface would be provided at the VSAT to enable almost any configuration of computers and peripherals to be employed with CODE at any site.

This approach has enabled standard applications such as electronic mail, databases, voice mail, file transfer, etc. to be run on the satellite system. It has therefore been unnecessary to develop special applications software.

In the first CODE deployment, key elements such as hub station, hub computers and the satellite capacity were provided by ESA. Users could build their own station according to the specifications and minimum system requirements established in system-specification documents regularly published and updated by the CODE design group.

The major factor governing the design of a digital satellite communications link is the data capacity required. The requirement for the CODE system is 64 kbps duplex links between the VSAT terminals and a 2.048 Mbps simplex link from the hub station to the VSAT terminals.

Another major consideration is the G/T performance of the VSAT terminals, because it is important that the available EIRP of the Olympus 20/30 GHz payload be used efficiently. The G/T of a VSAT terminal with an 80 cm-diameter antenna and a low-noise amplifier with a noise temperature of 150 K is 18 dB [1/K], and consequently the maximum capacity of the 20/30 GHz payload is in excess of 20 Mbps. It is therefore

considered sensible to use VSAT terminals of this size.

A further important consideration regarding digital links is the choice of modulation and coding method. In view of the 40 MHz transponder bandwidth and the limited satellite transponder power available, power efficiency clearly has a higher priority than bandwidth efficiency. The industry standard for power-efficient digital satellite links is the use of QPSK modulation and rate constraint length 7 convolutional coding with soft-decision Viterbi decoding. An E_b/N_0 of 6.5 dB provides a bit error rate of $1E-8$, which was selected as the minimum design rate for the CODE system. It should be noted that BPSK modulation may also be used without penalty as an alternative to QPSK modulation, since both QPSK and BPSK have the same level of performance. In fact, there are some practical and theoretical advantages in using BPSK and it has therefore been selected for the 64 kbps links.

Operational experience to date has been very positive [Kou91]. In particular, the effects of atmospheric attenuation due to the use of the 20/30 GHz frequency band has not been as problematic as expected. Sufficient data is not yet available, however, to quantify these effects in detail, but the VSATs used at Conferences and Exhibitions during 1990 were certainly able to operate without noticeable errors under a wide variety of weather conditions. At the Luxembourg VSAT Conference in November 1990 in particular, images and messages were transferred over a period of four days without need for repeat transmissions, despite periods of continuous heavy rain.

An extension to the CODE system is envisaged that will use an even smaller antenna of less than 35 cm diameter and less than 50 mW RF power. A form of spread spectrum with low-rate forward error correction may be used at 16 kbps and below. A suitable code for this application would be a (256,12) BCH, in which 256 bits are transmitted for every 12 information bits. The code rate is (12/256) and the received signal-to-noise ratio would be typically -7 dB with the signal below the noise level. Hence the system is itself insensitive to interference, and does not cause any significant interference. Many users may occupy overlapping frequency bands on a CDMA basis. This system is presently under investigation because it offers great potential to exploit the satellite transponders more efficiently.

2.7 CHEOPS – A Distribution of Massive Quantities of Data by Satellite

CHEOPS is a collaboration between several European research institutes [Alt91]. Its objective is an experiment in the use of ESA's OLYMPUS satellite to demonstrate that the properties of satellite transmission can be used to distribute massive quantities of scientific data for remote analysis. CHEOPS is concentrating on efficiency, access to geographically remote regions, and on integration of the application of the satellite into the general computing environment. At each site, there will be a UNIX-based server, integrated in a suitable way into the LAN and computing environment. Initially, standard TCP/IP protocols will be used, with multiple parallel transactions to improve efficiency.

Later, optimized protocols will be used in an attempt to maximize throughput.

Four Nokia earth stations will be used at the beginning, each having a 3 meter antenna, an 8 W radio-frequency amplifier, and a G.703 modem capable of bit rates up to 8.442 Mbps with a bit error rate of better than 10^{-9} in the K_u band (12/14 GHz). Experiments will take place in 1992.

2.8 COST226 – A European Research Project on Integrated Space/Terrestrial Networks

The COST226 project (Integrated Space/Terrestrial Networks) was defined by the working group on satellite communications of the Technical Committee "Telecommunications" of the Commission of European Communities [Cos91, Har91, Kou91a]. It started in May 1990 and aims to carry out research in the area of integration of terrestrial closed and public networks by transparent and future intelligent satellites (with on-board switching and processing). The relevant earth segment is also taken into account. Problems of internetworking and gateways between heterogeneous networks, network management and control, traffic management techniques and strategies for network evolution are studied and concepts elaborated. Transmission signal interfaces, signal and routing interfaces are defined, particularly with respect to the interconnection of LAN and ISDN networks by satellite. Efficient satellite access schemes shall be developed, taking into account the properties of existing and future satellite systems as well as different ground station environments (small user stations, e.g. VSATs, as well as medium and large terminals). It is the aim of the project to elaborate a pilot system for integrating terrestrial and satellite networks supporting mixed-media traffic (data, voice, video). In this respect the harmonization with future terrestrial networks and the relevant techniques (e.g. ATM switching) is important. The purpose is to demonstrate the advantages of satellites, particularly in areas with poor telecommunications infrastructure. In order to create a system which could be adopted as a future service, the close coordination with standardization bodies and operators is of vital importance.

Participants in COST 226 include representatives of user groups, network operators, research organizations, universities and industry, from Austria, Belgium, Denmark, Germany, Hungary, Italy, Portugal, Spain, Sweden and Switzerland, as well as the European Space Agency ESA.

So far, the LAN interconnection activities of COST226 concentrated on satellite systems available in Europe which are suitable for closed user groups. They have been investigated in terms of their characteristics (EIRP, G/T, coverage). Existing facilities such as off-the-shelf satellite terminals and earth station components, standard TDMA equipment, LAN bridges and routers have been evaluated for their applicability in a LAN interconnection system. Suitable equipment for supporting voice and video in addition to computer data traffic has been identified. A scenario for an efficient transmission system using multi-frequency TDMA techniques has been proposed, as well as a design for a flexible transputer-based TDMA controller architecture.

Recently, the specifications of the future COST226 system have been drafted [CTD92]. Key topics include *Users and Their Requirements, Satellite Subnetwork, Networks and Protocols* and *Network Management and Security*.

Chapter 3

Japanese Projects and Experiments

Little publication in English is available about early Japanese projects to interconnect LANs by satellite. Some information could be obtained by the INSPEC data base for technical publications, however, where the abstracts of Japanese papers are available in English.

Japan's first domestic satellite communication systems were put into commercial service in June, 1983 by the successful launches of Communication Satellite-2s (CS-2a and CS-2b), in February and August, 1983 [Kak82, Mor88]. They were the world's first commercial satellite communication systems using the K_a frequency bands (30/20 GHz).

First experiments with the CS-2 satellite were intended for a small to medium scale (data rate of 50-500 kbps) private data network typically in use in a company, institute, etc. Physical layer and data link layer have been implemented [Kaj89, Ito85]. The system used a satellite single channel per carrier (SCPC) channel, and exchanged data in a form of a packet. A channel was multiple-accessed by the slot reservation method with a distributed access control. The logical link was controlled by HDLC. The experimental system consists of three earth stations in Radio Research Laboratories and one earth station in Tohoku University.

It was seen, however, that unless a high-quality link is provided, the throughput efficiency with the existing HDLC error recovery methods tends to decrease. Therefore, a new error control scheme named Multi-Numbered Selective Reject (MN-SREJ) method was developed, an improved version of SREJ and HDLC, which permits high speed and reliable communication even under long propagation delay and poor transmission quality [Mat85].

As a next step, the design concept of a multiservice satellite communication system based on network integration and ISDN protocols was investigated [Iis85]. An integrated circuit/packet switching system based on demand assignment control (ISSDA) was designed, and several problems in applying the No.7 signaling system with ISDN user part to demand assignment control and their solutions were considered. The key feature of this system is that the modified No.7 signaling system with ISDN user part is adopted as a satellite signaling system for demand assignment control. This ISSDA can be applied to a multiservice satellite communication system, and the integrated communication system can be applied toward the ISDN.

The explosive growth of computer terminals and other non-telephone terminals has created a huge demand for data communication links. To meet these demands, NTT has been constructing the Information Network System (INS) which is composed of digital transmission lines and digital exchanges. Along with this target, NTT started a new broad band digital satellite service, which is called Satellite Digital Communication Service (SDCS) in 1984 and a new video satellite service, which is called Satellite Video Communication Service (SVCS) in 1986. These two services offer dedicated networks to customers by small earth stations.

Three Japanese experiments, for which a detailed description in English has been found, are described in the next sections. These are MASPnet, Satellite Digital Communication Service (SDCS), and an experiment performed by NEC.

3.1 MASPnet

An interesting approach utilizing the broadcast nature of a satellite channel resulted in the development of a LAN type global network called MASPnet (multiple access-type satellite packet network) [Ito86a, Ito87, Kak87, Ito91]. This is a wide area packet network using a satellite channel with a multiple-access technique. MASPnet has been designed to include the following features:

- Multiple access type network: MASPnet user stations communicate with each other via a single common channel.
- Dynamic channel assignment: The channel is dynamically assigned according to the instantaneous requests of the stations.
- Fully distributed control: Each station is made logically equal, and access control is completely distributed among the stations.
- Flexibility in the network configuration: The configuration of the network can be freely and easily changed independent of other stations.

Furthermore, MASPnet was designed to offer the following services:

- Point-to-point and point-to-multipoint communication services with exchanges of acknowledgement packets.
- Complete recovery of line errors in the MASPnet data link layer.
- Packet transmission delay of less than 0.5 sec under normal traffic or 1 sec under heavy traffic.

MASPnet directly spans the communication paths among the widely dispersed earth stations. It uses a K -band (30/20 GHz) transponder of a geostationary communication satellite with SCPC (single channel per carrier) technique, and it offers transparent paths of both point to point and point to multipoint communications. This system is of small

type facility and its function contains the protocol up to transport-layer in OSI (Open Systems Interconnection).

On the physical layer, the bandwidth is 38kHz, with which 64 kbps QPSK signals can be transmitted. A rate 2/3 convolutional code is used, such that the real data rate is 48 kbps. Relatively small (such as 1...2 m diameter antenna, 2W HPA) earth stations are employed to access the satellite. MASPnet adopts a slot reservation method as a multiple access technique, and a new link control procedure specially designed for controlling the satellite channels. For the multiple access sublayer, a slot reservation technique with distributed access control was chosen. For the logical link control sublayer, HDLC was not considered to be attractive, because of the poor efficiency of reject-type error recovery, and the lack of multi-destination addressing capability.

Therefore, a different data link control procedure, named DLSC (data link control procedure for the satellite channels) [Ito91, Kat89, Ito86], was developed. DLSC has the following features:

- DLSC recovers nearly all errors by only retransmitting the packets with errors, thus reducing the overhead in the error recovery phase.
- The DLSC frame has both the source and the destination address, which makes a direct link between any stations possible.
- The link control for one direction is made logically independent of the control for the other direction, which significantly simplifies the protocol. Still, the acknowledgement information of opposite direction packets can be sent using the control header of a data packet.
- The same frame format and the same control procedure is used for both point-to-point and broadcast communications.

The performance evaluation experiments were carried out using two earth stations located at Koganei (near Tokyo) and one at Kashima (100 km east of Koganei). Experiments were conducted for two types of communication mode, i.e. a point-to-point mode communication and a broadcast mode communication. Throughput, delay and other parameters were measured through the transport layer to evaluate the gross performance of the MASPnet protocol. For both point-to-point and point-to-multipoint communications, it was shown that a delay of 0.5 sec (light traffic) and 1 sec (heavy traffic) could be attained with good channel conditions, i.e. low packet error rates.

Another experiment was performed by bridging a UNIX network. A modified version of the UUCP protocol was used, and a bit rate of about 1 kbps could be obtained.

3.2 Satellite Digital Communication Service (SDCS)

NTT's Satellite Digital Communication Service (SDCS) was used for another Japanese project to interconnect LANs. It comprises a Multi Access Closed Network (MAC-Net),

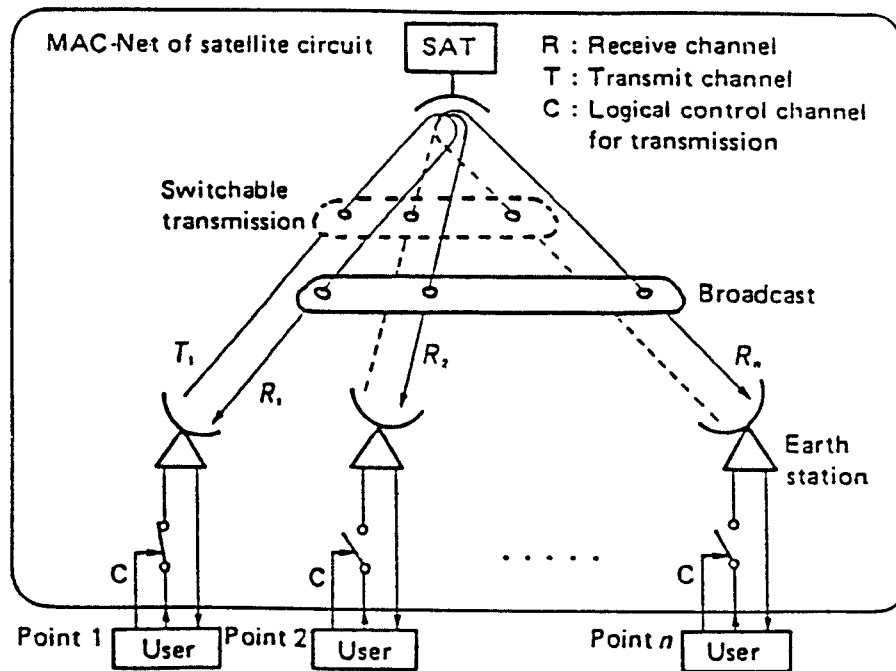


Figure 3.1: MAC-Net system configuration [Mor88]

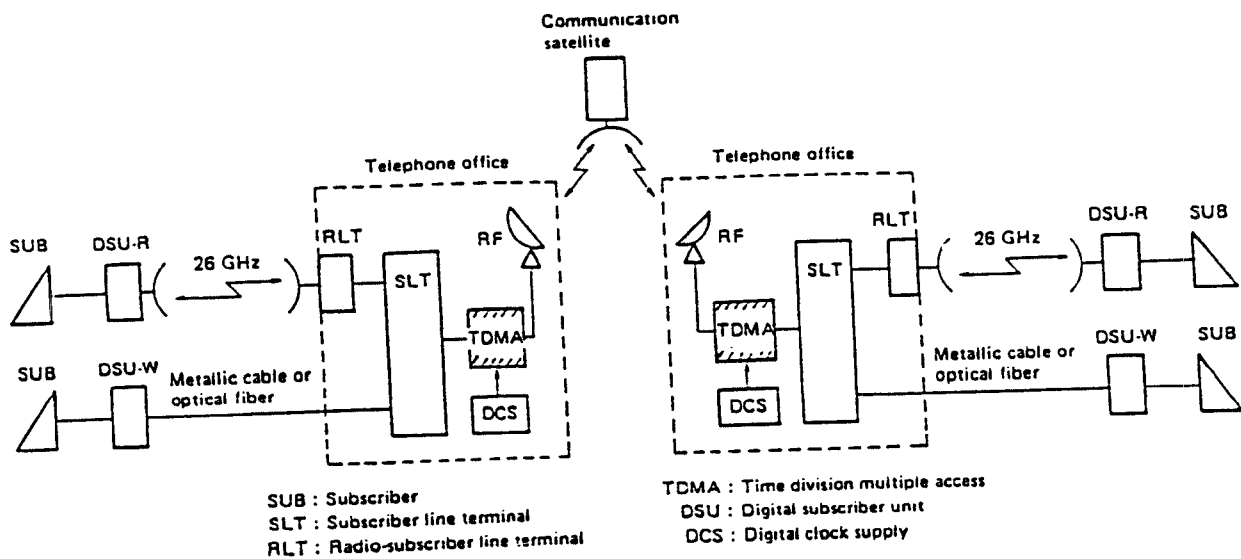


Figure 3.2: SDCS system configuration [Mor88]

very close to a Local Area Network (LAN), making use of full advantages of satellite communication networks such as flexibility in setting up circuits, broadcast capability and multi-access capability [Mor88]. It is described with some detail below.

In the MAC-net, a satellite channel is allocated to each user group based on a pre-assignment mode. However, differing from conventional TDMA channel assignment, in the MAC-net, a user group controls on/off of pre-assigned burst(s) by using signaling (S) bits. Therefore, there will be no bursts transmission to a satellite as far as the “S” bit is “0”. On the other hand, all users who belong to the same user group can always receive the transmitted signals to the dedicated channels. The logical channel configuration of the MAC-Net is shown in Fig. 3.1. As seen from this figure, by using the MAC-Net, it is easily possible to communicate in modes of (a) point to multi-point, (b) Multi-point to point and (c) Half-duplex (changing transmitting points alternately) and so on. In addition to these pre-assignment services, the MAC-Net offers circuit switched services for higher speed than 192 kbps. This system requires as many demand assignment equipment (DA) as the number of user stations and one demand assignment controller (DAC).

A configuration of the SDCS is shown in Fig. 3.2. The SDCS is composed of TDMA (Time Division Multiple Access) earth stations located in telephone offices with user interface bit rates varying from 64 kbps to 6144 kbps. This system employs 30/20 GHz frequency bands to avoid interference from/to terrestrial radio communication systems and QPSK (Quadrature phase shift keying) modulation and coherent detection. Moreover, convolutional encoding - Viterbi decoding as an FEC scheme is employed. This system has a transmission capacity of 160 channels (in 64 kbps both way). Subscriber data by radio- subscriber lines, optical fibers or metallic cables and are then multiplexed into 2.048 or 8.192 Mbps signals by the SLT and interface to TDMA equipment. The major parameters of the SDCS are shown in Table 3.1.

Frequency	30/20 GHz
Multiple access	TDMA
Earth stations	Reference stations: 2 Traffic terminals: 50
Burst synchronization	Reference stations: closed loop Traffic terminals: feed-back loop
Modem	QPSK-coherent demodulation
FEC	Rate 1/2, constraint length 4 convolutional code
Clock rate	24.528 MHz
Transmission capacity	160 channels / transponder
Service bit rate	64, 192, 384, 768, 1536, 6144 kbps
TDMA-SLT interface	2.048, 8.192 Mbps

Table 3.1: Major SDCS system parameters [Mor88]

With the SDCS project it could be shown that by using flexible and rapid network construction capability and other superior performances of satellite communications, more

and more services will be offered.

3.3 A Satellite LAN Interconnection System by NEC

A recent experiment to interconnect LANs by satellite was reported by NEC in 1990 [Kob90]. It uses a connection-oriented satellite protocol which can establish multiple logical links between two nodes. Based on this architecture, a satellite LAN interconnecting system has been developed, which includes a specially developed Satellite Node Processor. The system can support high-speed transmission rates of up to 768 kbps and superior network management as well.

A system has been implemented between the NEC Central Research Laboratories in Kawasaki and the Tsukuba Research Laboratories in Tsukuba. The satellite channel with a 768 kbps transmission rate has been provided by a C&C VAN leased 14/12 GHz transponder in the commercial JC-SAT satellite. Each site includes a 3.6 meter antenna and a transceiver with 2W power output. The modem operates with QPSK modulation, a rate 3/4 convolutional coder and a Viterbi decoder.

The satellite protocol stack is managed by a specially developed Satellite Node Processor, which also accomplishes protocol conversion between LAN protocols and satellite communication protocols. The satellite medium access control (MAC) layer performs framing and CRC checking, but because of point-to-point topology, it has no access control function. The satellite logical link control (LLC) layer is based on the IEEE802.2 LLC control, with selective repeat ARQ to counteract satellite propagation delay. In addition, to maintain high performances for satellite bit errors, multiple logical links can be established between any two nodes.

On the LAN-side, a conventional TCP/IP and CSMA/CD protocol stack is used. A router-type interconnection between the LAN and the satellite is implemented. The IP process accepts a packet from the LAN, requests the LLC process to create a new logical link if necessary, and sends the packet to the LLC process. When an established logical link is not used during a predetermined time interval, that logical link is terminated.

The system, which has been installed between the NEC Central Research Laboratories in Kawasaki and the Tsukuba Research Laboratories, has been operating since Oct. 1989, and has been used by computer users.

Chapter 4

North American Projects

During the literature search on LAN interconnection by satellite very little information was found in the scientific literature about North American studies or experiments on the subject, especially in the U.S.A. In spite of this, it was observed that there is a large population of VSATs, which might be used to interconnect LANs by satellite. A possible explanation of this fact may be that LANs are indeed interconnected by VSATs, by using a straight-forward, market-driven approach, which does not reflect in the scientific literature, and which may be sub-optimum from the scientific point-of-view. This assumption may be verified by a report found in [Cac91]: “In the VSAT environment, LANs have traditionally been supported by gateways ... which typically are PCs that convert LAN protocols to WAN protocols (such as SDLC), for interfacing with VSATs at rates of 9.6 to 56 kbps. These external solutions do not provide access to the full transmission potential of the VSAT, and thereby limit the ability of the VSAT network to support higher rate LAN traffic.” In 1991, however, integrated commercial LAN-VSAT interfaces have become available, which provide better access to the transmission potential of the VSAT.

In Sec. 4.1, we give a brief overview on the VSAT scene in North America, and in Sec. 4.2, we describe the concept of a Satellite Wide Area Network (SWAN), which was proposed by Telsat Canada.

4.1 LAN Interconnection by VSATs

Satellite technology has traditionally been used to provide broadcast-type services or long distance trunk lines. However, as business applications for satellite have grown, technology issues such as multiple access, handling of wide dynamic traffic range, complex networking, data integrity, and security have become important to the satellite communications industry. The history of Very Small Aperture Terminal (VSAT) networking is a story of technology evolution to address these issues.

VSAT networks typically have a star topology, in which a central hub, with an antenna of 6 to 9 meters in diameter, communicates with a large number of geographically dispersed VSATs, with antennas of 0.75 to 2.4 meters in diameter. Data rate on the outbound route, i.e., from the hub to the VSATs is typically between 64 kbps and 512

kbps, and between 9.6 kbps and 128 kbps on the inbound route. Geostationary satellites with transponders in the C and the K_u band are used. Data protocols supported include SDLC, Bisync and X.25, which are well suited to for terminal-to-host communications.

Most applications require a central host computer, typically located at the hub, communicating with a large number of remote terminals connected to the various VSATs. Such applications include automobile dealerships, banks, brokerage firms, pipelines, hotel and airline reservations, retail stores/franchises, high speed facsimile, electronic mail and point-to-multipoint corporate communications [Pol91, Hol91, Cha88, Chi88, Str88]. In 1991, about 30000 VSAT terminals were installed in the U.S.

Most often, a terminal or a PC is directly connected to the VSAT terminal. Traditionally, if LANs have been connected to a VSAT network, this was done by gateways which convert LAN protocols to a WAN protocol (such as SDLC) [Cac91]. However, these external solutions do not provide access to the full transmission potential of the VSAT, and thereby limit the ability of the VSAT network to support higher rate LAN traffic. One of the reasons why these sub-optimum solutions have existed for a fairly long time is the different structure of VSAT and LAN protocols [Hol91].

During the year of 1991, new integrated commercial LAN interfaces have become available, which provide direct access to the full inroute and outroute capacities of the VSAT and, as an integrated part of the VSAT network, are managed from the VSAT network management system [Cac91, Pol91].

Although VSATs do not provide the megabit-per-second data rates associated with LANs, they are an ideal solution for interLAN traffic. Traffic between LANs typically represents only 5% to 15% of the total traffic on the LAN. The data rate required on the WAN is therefore far below that required for intraLAN traffic.

Very little is known about what protocols that are used in commercially available VSAT systems. Most of these protocols seem to be proprietary, and the only reference that was found is that Hughes may have implemented a frame relay type protocol [Cac91]. Because of the good link quality and the minimum overhead in the VSAT and the Hub station, this seems to be a reasonable choice.

4.2 Satellite Wide Area Network SWAN

The satellite wide area network (SWAN) architecture was proposed by Telsat Canada in [Mur87a, Mur87b, Mur89a]. A SWAN can be viewed as a high-speed wide area backbone network capable of providing variable bandwidth facility access to interconnect remote LANs and MANs. However, SWAN is not just a backbone Wide Area Network (WAN). It is a network with very flexible architecture realized by combining unique features of satellites in general and VSAT technology in particular. Some high-speed VSATs have the ability to dynamically allocate bandwidth to users based on the type of incoming traffic. Further, the user could have the flexibility of choosing network topology (e.g., point-to-point, star, full mesh) for their WAN with either little or no cost penalty.

The SWAN with its different options should be able to support the following topologies:

- Point-to-Point Configuration
 - LAN to LAN interconnection
 - LAN to MAN access
 - LAN to remote Mainframe access
- Star Configuration
 - LAN to Information Database Center (IDC)
 - LAN to (Super) Computer Center (SCC)
 - LAN to MAN
- Mesh Configuration
 - LAN to LAN
 - LAN to MAN

Specific interconnection solution is achieved by choosing appropriate technology to meet topology, speed, etc., requirements. However, users or service providers requiring complex interconnection network topologies need to develop a very flexible architecture for SWAN. A possible SWAN architecture overlaid on a currently existing star-configured VSAT network is shown in Fig 4.1. In many cases the remote-to-remote connections in a star network can be established through a switch in the Hub.

Point-to-point interconnection between similar LANs can be established via satellite, using existing bridge products and a low BER satellite link. However, more flexible bridges and LAN to Satellite Gateways (LSGs) may be required to meet most of the interconnection network requirements. It is also necessary that the bridges and gateways used in conjunction with SWAN are designed to optimize the performance and protocol requirements of both LANs as well as satellite (VSAT) networks. Efficient and versatile LSGs are fundamental to SWAN.

Applications

SWAN can be seen as a separate architecture, perhaps overlaying the VSAT network, adding flexibility to it and value to its services. With such a flexible architecture, a fully developed SWAN could serve as a wide area backbone network for a LAN interconnection and will offer a wide range of information, communication, and computing services to LAN-based users. These include:

- Wide area communication services
 - E-mail, Text, Data, Fax., etc.
- Remote area computing services
 - Remote time sharing, job entry

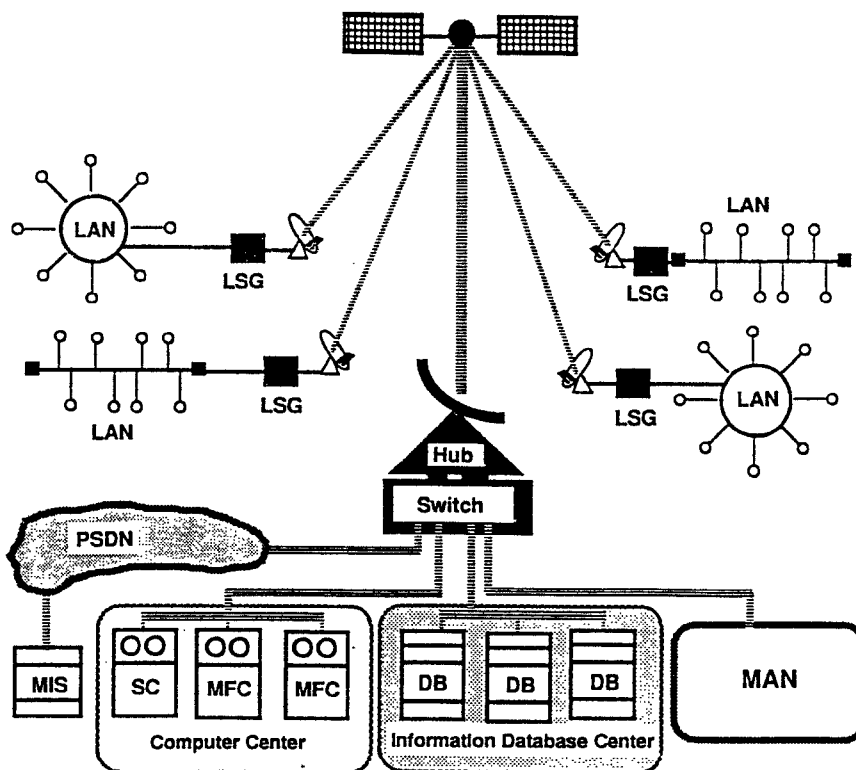


Figure 4.1: The Satellite Wide Area Network (SWAN) architecture [Mur89a]

- Remote area information services
 - Corporate database access, public/private information database access, MAN access
 - Remote area manufacturing services
 - CAD/CAM, chemical process control, etc.
 - Telehealth and other services

It may be noted that most of the above applications are currently supported on existing LANs. These applications currently use standard or proprietary softwares, and it is necessary that SWANs protocols should be transparent to these applications.

Performance Analysis

In a recent paper [Yan92], file transfer was modeled in a SWAN network, and performance was analyzed. It was shown that it is necessary to jointly optimize a number of dependent and independent parameters including window sizes, transfer delays, frame sizes, link protocols, buffer management, the traffic (number of workstations and activity) and transmission speeds. The authors obtained tight upper and lower bounds for the throughput, which were verified by computer simulation.

Chapter 5

Summary

In this section, we try to summarize and compare the research projects to interconnect LANs by satellite, which were described in this report. Let us first have a look at Table 5.1, which gives an overview of the key features and parameters of the various projects.

Note that all of the research projects listed in Table 5.1 were either performed in Europe or Japan, but not in North America. This is due to the fact that very little information was found in the scientific literature about North American studies or experiments to interconnect LANs by satellite. A reason for this may be that in North America LANs were interconnected with commercial VSATs by a gateway which performed a (sub-optimum) protocol conversion, which was not reflected in the technical literature. In the meantime, integrated commercial LAN-VSAT interfaces have become available in North America, which provide access to the full transmission potential of the VSAT.

Activities for LAN interconnection by satellite started in the early 1980's, and currently there is still a considerable research effort being undertaken. In the beginning, non-standard LANs were interconnected, but most of the recent experiments used Ethernet LANs with the TCP/IP protocol stack. Both commercial and experimental satellites were used, with frequencies in the L (1.5 GHz), C (6 GHz), K_u (12/14 GHz) and K_a (20/30 GHz) bands. A wide earth station power range of 2...200W and antenna diameters between 0.8m and 3.6m were employed. Radio signals were mostly QPSK modulated, and the by far most popular access scheme was TDMA, but also FDMA and CDMA were reported. Most experiments relied on some sort of forward error correction scheme, with coding rates between 1/2 and 4/5. This resulted in a bit error rate between 10^{-4} and 10^{-9} , depending on a variety of factors. The experiments involved data rates between 300 bps and 8.442 Mbps.

Common to almost all experiments that are reported was the fact that in a first phase, emphasis was put on point-to-point links. In more recent projects point-to-multipoint links were also investigated. The latter configuration is very promising, as it takes the broadcast nature inherent to the satellite channel into account. All projects allowed the transmission of computer data, and some also support voice and video.

The propagation conditions on the satellite channel seem to be favorable, even for the 20/30 GHz channel, where rain attenuation proved to cause less severe problems than expected. With a forward error correction code, bit error rates of less than $1E-8$ seem to

Project	NADIR	SATINE-2	PRODAT	ESA Exp.	CODE	CHEOPS	MASPnet	SDCS	NEC
Country	France	A, GB, I, CERN	ESA	ESA	ESA	various	Japan	Japan	Japan
Date	1980-?	1986-89	1987-?	1990-	1989-	1991-	1983-	1986-	1989-
LAN-type	DANUBE	Cambridge Ring	Inmarsat-2	Ethernet	Ethernet	Ethernet	?	?	Ethernet
Satellite	TELECOM1	Olympus	1.5 / 6 GHz	Olympus	Olympus	Olympus	CS-2	CS-2	JC-SAT
Frequency	14/12 GHz	20/30 GHz	?	20/30 GHz	20/30 GHz	14/12 GHz	30/20 GHz	30/20 GHz	14/12 GHz
Bandwidth	?	5 MHz	?	?	40 MHz	?	38kHz	?	?
HPA / EIRP	20 W	140 W/65 dBW	24 dBW	?	77 dBW	8 W	2 W	200 W	2 W
Antenna Ø	3.5 m	3m	?	?	2.5/0.8 m	3 m	1...2m	4.2m	3.6m
G/T	?	22.5 dB/K	?	?	18dB/K	?	?	?	?
Modulation	?	QPSK	?	?	QPSK/BPSK	?	QPSK	QPSK	QPSK
Access scheme	TDMA	FODA-TDMA	TDM/CDMA	FDMA	FDMA	SS-TDMA	TDMA	TDMA	-
Error correction	rate 4/5,1	rate 1/2 .. 1	RS 16,12	?	rate 1/2	?	rate 2/3	rate 1/2	rate 3/4
Bit error rate	1E-9	1E-7	?	?	1E-8	<1E-9	<1E-4	?	?
Data rate (bps)	2.4k...2M	1M...8M	1.5k / 0.3k	32k...4M	2M / 64k	8.442M	48k	64k...6M	768k
DAMA Control	Centralized	Centralized	Centralized	-	Centralized	?	Centralized	Distributed	-
point-point	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
point-multipoint	Yes	Yes	Yes	Future	Yes	?	Yes	Yes	No
Computer data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
voice	No	Yes	No	No	Yes	No	No	No	No
video	No	Yes	No	Yes	Yes	No	No	No	No

Table 5.1: System parameters of some projects

be feasible.

Special attention was given to the access of the satellite channel. Here, the major problem is the long round trip delay of about half a second, which makes an efficient allocation scheme difficult to realize. Some early or simple experiments used a fixed allocation scheme, whereas more sophisticated solutions implemented a demand assignment control scheme. In the context of the European SATINE-2 project, a special protocol hardware and software was developed (the so-called FODA-TDMA access scheme). It is intended to handle mixed digital traffic (stream and datagram) coming from a heterogeneous network environment by means of a centralized control. In Japanese projects, the access problem was also investigated. In the MASPnet experiment, for example, a distributed control scheme was developed. Low packet delay and efficient channel utilization were reported.

While it is obvious that for random traffic a demand assignment control scheme is more efficient than a scheme that uses a preassigned channel allocation, no conclusion can be drawn so far whether centralized or distributed control should be preferred. Only one distributed control approach was reported, however; all other projects used centralized control.

Chapter 6

Conclusions

In this chapter, we analyze the key achievements of the LAN-interconnection experiments reported in the literature to date, and we attempt to identify the technical challenges to be overcome to improve cost and performance factors of LAN interconnection by satellite.

The experiments described in this report have shown that LAN interconnection by satellite is feasible even with commercial off-the-shelf hardware and software. Some adjustments to the protocol software, such as increase of the window size of some flow control algorithms, are necessary however to accommodate the long round trip delay of the satellite link. Although the resulting systems worked successfully, the implementations are not considered scientifically optimal. For instance, one approach to improve performance might be to terminate the LAN protocols at the satellite ground stations, and to run a special network protocol on the satellite link. In such a system, a considerable increase of the throughput may be achieved with flow and congestion control algorithms which are specially tailored to the satellite link.

The following major research topics in the field of interconnecting LANs by satellite were identified:

1. **Satellite Access Schemes:** A considerable amount of work has already been done in the area of satellite access schemes. A promising approach seems to be to use a contention-type access scheme (such as a variant of ALOHA) for the transmission of small data packets, and to use a demand-assignment scheme for bulk traffic. Despite the good results that have already been presented, further improvements seem still to be achievable. This holds especially for the reservation mechanism of the demand-assignment multiple access schemes, which involves a multitude of satellite hops and, hence, a long delay.
2. **Hybrid Networks:** Another research topic which will become more important in the future is the integration of hybrid terrestrial and satellite networks which support mixed-media traffic (data, voice, video). For mixed-media traffic, constant delay applications, such as voice and video, and variable delay applications, such as data transfer, have to be treated separately, as has been successfully demonstrated in the FODA project. For the use of hybrid satellite and terrestrial networks, the

harmonization with future terrestrial networks and the relevant techniques (e.g. ATM switching) is important.

3. **On-Board Processing:** Another significant research area covers intelligent on-board processing and switching satellites and their application in hybrid terrestrial/satellite communication networks. Here, new algorithms will have to be developed to efficiently use the capabilities of these future satellites, such as the on-demand bandwidth assignment and the ‘switch in the sky’.

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