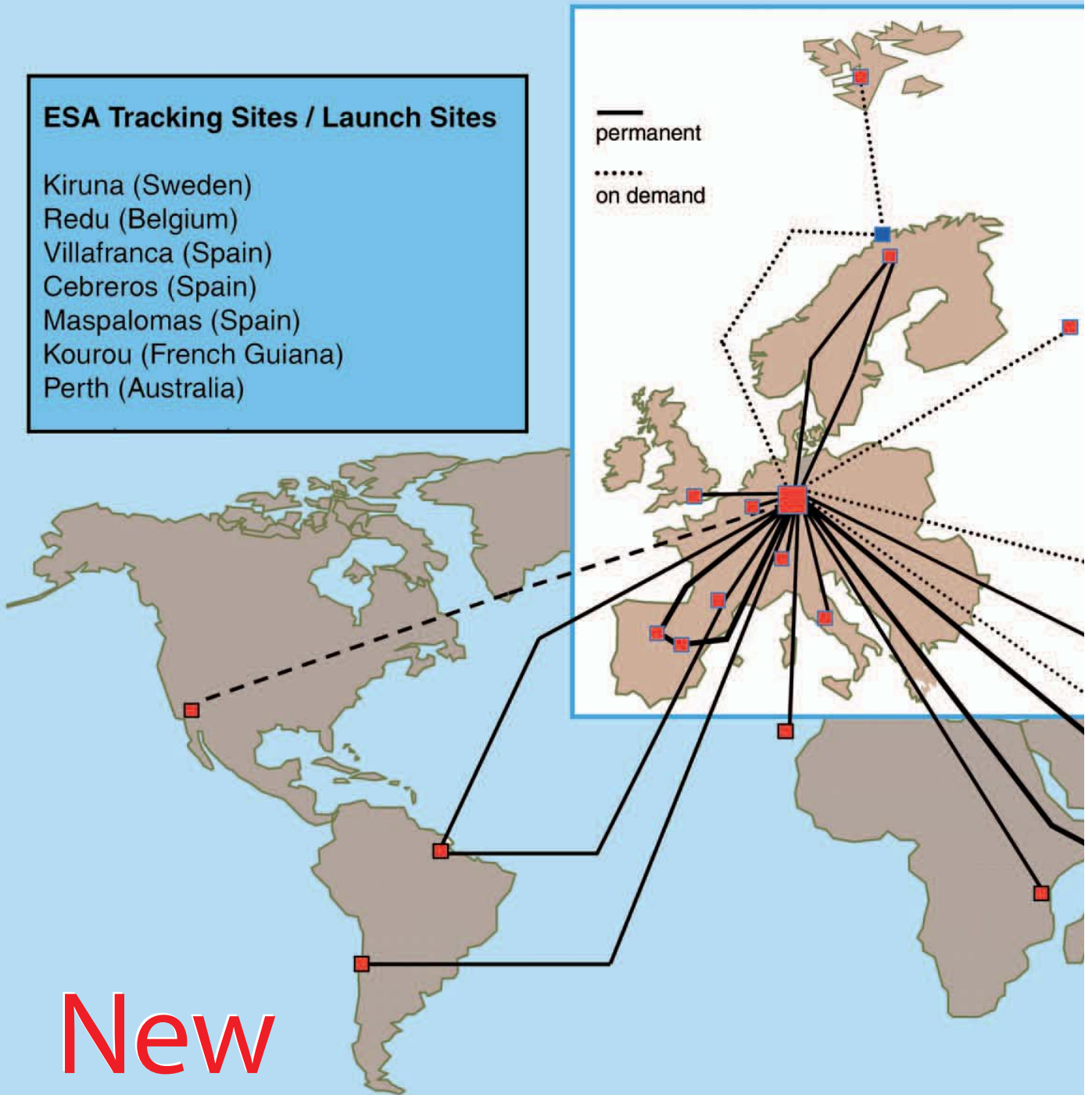


## ESA Tracking Sites / Launch Sites

Kiruna (Sweden)  
Redu (Belgium)  
Villafranca (Spain)  
Cebreros (Spain)  
Maspalomas (Spain)  
Kourou (French Guiana)  
Perth (Australia)

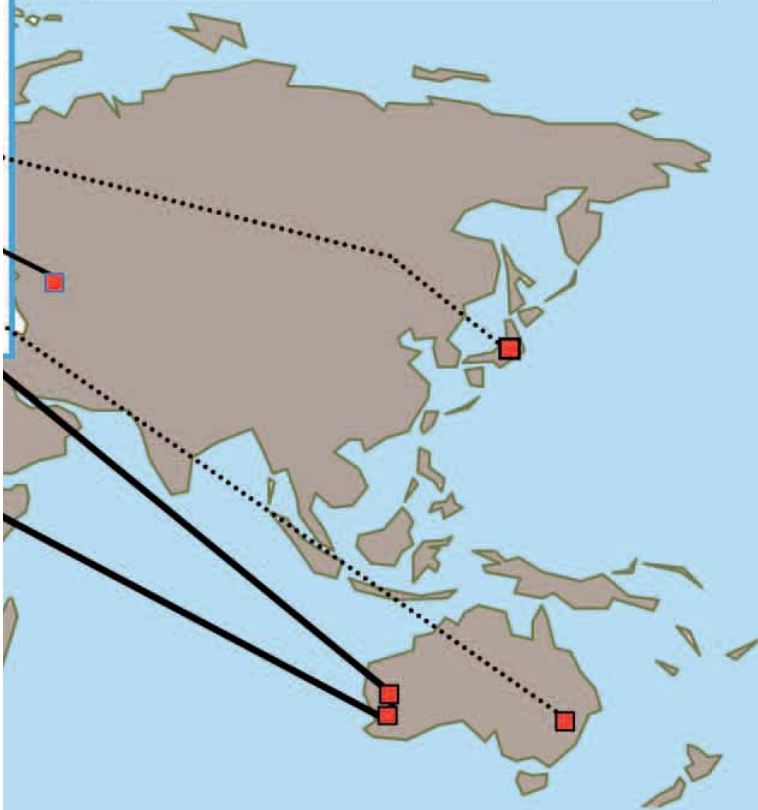


# New Communications Solutions for ESA Ground Stations

## Co-operative Tracking Sites / Launch Sites

Svalbard (Norway)  
 Plesetsk (Russia)  
 Baikonur (Kazakhstan)  
 Tsukuba (Japan)  
 Malindi (Kenya)  
 Santiago (Chile)  
 Goldstone (USA)\*  
 Canberra (Australia)

\*via JPL Pasadena, links NASA funded



## Science Centres

Cluster Joint Science Operations Centre (Didcot, UK)  
 Integral Science Data Centre (Geneva, Switzerland)  
 XMM-Newton Science Operations Centre (ESAC, Spain)

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 Directorate of Operations and Infrastructure,  
 ESOC, Darmstadt, Germany

**E**SA operates a global system of ground stations known as ESTRACK, the ESA Tracking Network. Communications services for all ESTRACK stations are provided by a network known as OPSNET. Dedicated to space mission operations, OPSNET is built as a closed private network ensuring effectively non-stop availability of control-centre facilities and ground-station services to ESA's, and also third-party, space missions. The OPSNET modernisation programme has involved all control-centre interfaces to ESTRACK and, one by one, all ESA ground stations. The hand-over of the second ESA Deep-Space Station, at Cebreros in Spain (see ESA Bulletin No. 124), for routine operations in time for the Venus Express mission marked the completion of this modernisation effort.

## Introduction

The de-facto global standard for data communications nowadays is the Internet Protocol (IP). IP had been the standard in OPSNET Local Area Networks (LANs) for several years, whereas the OPSNET Wide Area Network (WAN) was traditionally a network to which subscribers connected over the X.25 protocol, an error-correcting protocol designed to work well even over poor-quality telecommunications lines. With the ever-improving quality of international links, and the rapid growth of the Internet,

*The Communications Services of the ESA OPSNET*

- **Voice** – Permanent voice conferencing (‘Intercom’) for human coordination of OCC and ESTRACK operations
- **TT&C** – Telemetry, Tracking and Commanding data transmissions in support of spacecraft operations; real-time, near real-time, off-line
- **Payload Data** – Science data from stations to control centre; real-time, near real-time, off-line
- **M&C, Network & Service management** – Monitoring and Control data for Ground Stations systems and subsystems, in support of remote operations of Ground Stations and OPSNET
- **Special customer services** – e.g. Navigation, Delta-DOR
- **Auxiliary customer services** – e.g. building management, remote diagnostics

however, it could be predicted that the sourcing of X.25 products and support would become increasingly difficult and cost-ineffective. Since the end of the 1990s, the Internet Protocol has therefore been the de-facto data-transmission protocol for new ESA space missions. A corresponding rationale to drive towards a consolidated IP network was its ability to support international space collaboration by applying Space Link Extension (SLE) standards via IP-based interfaces with partner networks and increasingly within ESTRACK.

The Directorate of Operations and Infrastructure therefore launched a migration from X.25 to IP for the entire complex of mission operations (facilities and applications software), ground stations, and communications. The objective for OPSNET was to evolve towards IP as the single protocol, run on a globally uniform infrastructure that uses products and services sourced from a mature and highly competitive marketplace, thereby ensuring reliability and longevity.

**The Framework**

Just as the mission-control systems and ESTRACK stations play a key role in the operation of space missions, OPSNET plays a critical role as an underlying enabling infrastructure. Communications must be available effectively non-stop. A reliable, high-quality service is essential to be able to serve concurrently the 12 ESA spacecraft that are presently in their routine operational phases. Under-performances and service flaws must be

avoided, particularly during the Launch and Early-Orbit Phases (LEOPs) of space missions. Despite this rigorous need for stability, it must still be possible to reconfigure systems at almost zero notice to handle contingency situations occurring on the ground and in space, for both ESA spacecraft and those of ESA’s partners and customers. It must also be possible to react flexibly to the re-planning of project schedules, and OPSNET must continually adapt – without impacting on ongoing services – to changing technical needs, be it to serve evolutions of its user systems or ground-segment implementations for new missions.

Those demands have to be met not only by the OPSNET design and technology itself, but equally through the approach to the sourcing and change management of OPSNET facilities and services. ESA has therefore chosen to retain a maximum degree of ownership, control and agility. OPSNET equipment is fully owned by ESA (except the wide-area links, which by their very nature have to be rented from telecommunications carriers). First- and second-line maintenance and operations support (M&O) is provided by industry on site, 24 hours a day seven days a week. The lion’s share of renewals and changes are engineered by industry also on site. In each service area, there is also a close co-operation with and service management by ESA experts. Such a concept of ‘customer proximity’ – both industry to ESA communications support and ESA communications support to the mission customers – ensures smooth integration

into mission operations and a highly synergetic and effective workflow cycle from demand to introduction into service. This concept is reflected also in the modernisation of OPSNET.

A few decisions of principle that were very instrumental for the efficiency of the project as such, and for minimising service and cost impacts on the missions supported, were taken very early in the modernisation effort:

- The governance for the entire design and equipment configurations would be with ESA.
- The station communications upgrades were to be aligned with a global project for the modernisation of tracking, telemetry and telecommand (TT&C) and ranging systems in the ground stations, including their monitoring and control elements.
- The communications modernisations were always the first to be deployed at a station.
- The work was to be contracted to the same systems integration contractor, to ensure synergy and coherence of standards and documentation.
- The same active equipment was standardised upon that had been selected and deployed only some 3 years before to modernise the Local Area Networks in the Operations Control Centre (OCC) at ESOC. This minimised the need for costly and time-consuming interoperability-validation campaigns and ‘learning curves’.
- The design in principle is uniform for the OCC and each of the ground stations, with only the scale of the individual building blocks varying.
- The OCC, the stations and OPSNET were made dual-protocol-capable, but mission operations were not forced to go to IP immediately. This left it to customer missions to find reasonable and cost-effective windows of opportunity for their own migrations.
- The old packet network was ‘frozen’ as of 2001. Remaining expenditure was essentially limited to a portion of a maintenance and operations service contract and to access to the manufacturer’s software support.

## The New Communications Solutions

The top-level requirements placed on OPSNET can be summarised simply as two goals:

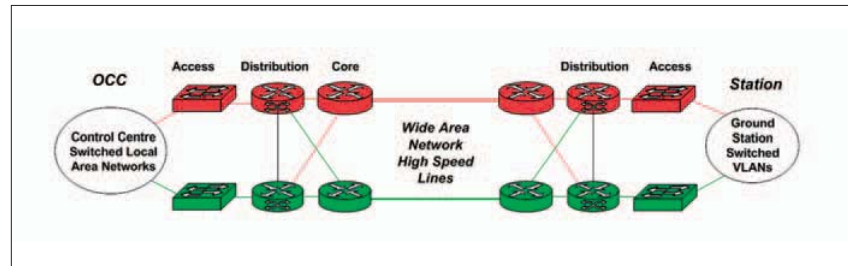
- a high-performance capability with low procurement and running costs
- high flexibility and adaptability with low maintenance and change-management costs.

Key features for achieving those goals are:

- An availability figure of not less than 99.95%, on average, per month.
- Redundancy for critical devices, with highly automated fail-overs.
- Powerful Quality of Service (QoS) and prioritisation features:
  - critical data get guaranteed capacity even under adverse conditions
  - non-critical data get capacity on best effort basis.
- Scalability/flexibility of network architecture and of station installations.
- Dedicated logical LAN segments per function/purpose (such as telemetry/telecommand, monitoring and control, intercom, office automation, telephony, video/audio conferencing, Internet access)\*.
- Centralised network management (round the clock) in the control centre, local systems management in stations available if needed in contingency scenarios.
- Longevity of installations and equipment.
- Co-existence with the X.25 network, with X.25-based mission operations.
- Low procurement cost, low running cost (devices, telecom services, maintenance & operations, and sustaining engineering services).

The modernised physical infrastructure in the ground stations is based on standards and best practices for structured hierarchical building cabling systems. One physical access point is capable of supporting all applications. The cabling towards end-user systems is Gigabit-capable and hence suitable for the foreseeable future. The LAN backbones

\* Several such 'logical' LAN segments can be configured within the same Local Area Network hardware. The technique is known as Virtual LAN (VLAN) technology.



are based on fibre optics with gigabit Ethernet interfaces. For critical services, two independent sets of devices are deployed end-to-end for redundancy (referred to as independent 'chains').

The overall network architecture is a classical hierarchical three-layer model, with:

- a core layer
- a distribution layer, and
- an access layer.

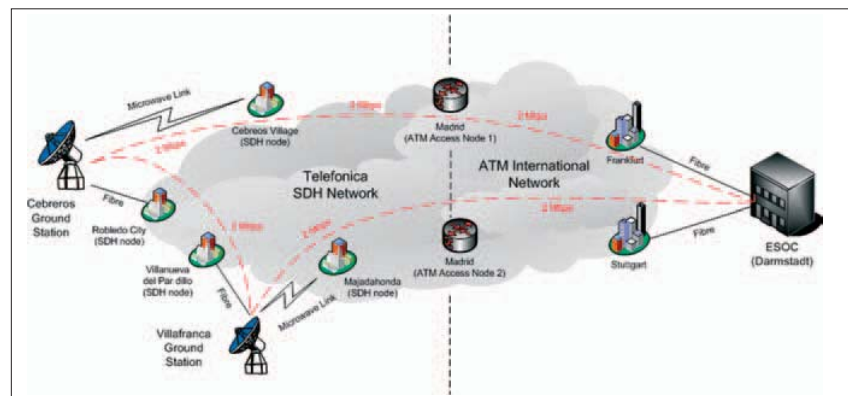
It is this architecture, and its implementation using modular equipment, that makes the network highly flexible in terms of adding sites and/or user systems.

The *access* layer provides the first point of access from a connected system to the network. The *distribution* layer handles the switching of the data streams, security, and grouping of user systems into different logical entities (the VLANs). The distribution layer also aggregates links based on the same groups, and implements the routing and security within the campus. The *core* layer of the network is designed to handle the routing between the distant sites, including re-routing in case of outages of WAN links. The core

functionality resides mainly inside the core routers at the control centre, but a few tasks are shared with the routers at the ground stations.

The accompanying figure illustrates the principle, shown here for a link between the Operations Control Centre (OCC) and one ground station. Red and green colours denote the redundancy concept of the two 'chains'. As can be seen, there always remains at least one path between user systems in the OCC and those in the station, even if a leased line or an in-between item of communications equipment would fail.

The illustration of the 'layers' and 'chains' functionality per site by one device each just shows the principle. At the Cebreros ground station, for example, a total of 18 switch/router devices are deployed, offering about 1000 ports in the access layer. With this capacity, Cebreros has the largest information and communications technology (ICT) infrastructure of any ESA ground station. The high number of ports reflects the fact that, in addition to the 'traditional' ESTRACK data and voice services, as supported in all other ground



**Snapshot of Cebreros Active and Passive Communications Installations**

- 18 LAN switches/routers yielding ca. 1000 connections
- 4 full IP address ranges (254 user system addresses each)
- 35.7 km of optical fibre lengths for data, voice, video distribution and station base-band specific links
- 2 telecom provider and 7 ESA communications equipment cabinets installed in 3 different buildings
- 6.4 km of fixed copper cabling inside and between installation cabinets
- 682 cable runs validated via ca. 1400 logical/functional tests
- 2053 patchable cables for communications and connected equipment

stations, the Cebreros ICT infrastructure supports much more. All antenna front- and back-end equipment monitoring and control, previously still based on dedicated bus structures, is now supported over IP. Furthermore, IP telephony is deployed; LAN ports provide both the channel and the electrical power for the IP phones. Audio- and video-conferencing and video-distribution are also served, and so too are building-facility-management functions. With this thorough LAN technology concept, the only links that are needed between different buildings are optical fibres. This has big benefits for electrical grounding conditions and lightning protection.

**Cebreros Active and Passive Communications Installations**

The building of ESA's two deep-space ground stations near Perth and at Cebreros has been complemented by the enhancement of the OPSNET WAN topology in both Australia and Spain. Traditionally, OPSNET was a star network with ESOC as the hub, whereby each outstation was connected to the control centre via two diversely routed international leased lines (redundant pair). With the advent of the deep-space stations, this dual-link topology could be replaced by a ring topology, for ESOC-Villafranca-Cebreros. The ESOC-Perth-New Norcia ring is similar. The physical infrastructure conditions end-to-end must of course ensure that none of these links has a potential failure element in common with another link. The three links then form a

ring in which any one site can still communicate with any other even if one link fails. The economic benefits are substantial. Instead of four international lines into the same foreign country, two can fulfil the needs. The capacity per line in the ring has to be larger than per line in a star configuration, but this is no disadvantage, as the ratio of price increase per capacity increase is strongly regressive. This redesign in fact paved the way for using 2 Mbit/s lines as standard building blocks for the rings. In recent years, this type of link has in fact become the market offering with the best price/capacity ratio for the type of trunks required for the ESA OPSNET, and is also deployed elsewhere.

**The Benefits**

The performance benefits of the modernised network are illustrated by the fact that excellent service-availability figures have been achieved both for X.25-based and IP-based missions, and that the design has been stable since the initial deployment in 2001 for New Norcia, with no need for subsequent adjustments. Key contributing factors are:

- high availability and redundancy
- enhanced IP QoS and prioritisation scheme
- capacity-management flexibility due to modularity of design and equipment
- unified physical infrastructure, with media commonality for all LAN-based station services
- uniform single-manufacturer installed base, facilitating efficient maintenance and operations support.

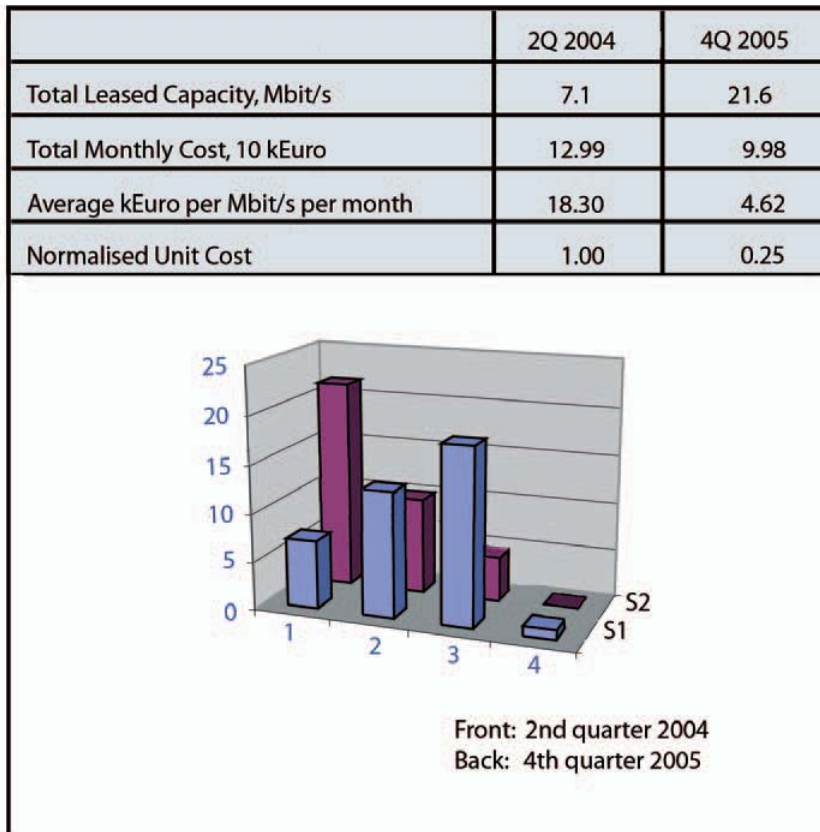
Economic benefits are already inherent in most of those factors. A particular example for flexibility is the support to 'Delta Differential One-way Ranging' (Delta-DOR) on the shared capacity available on the 2 Mbit/s rings. For Delta-DOR, the signal from an interplanetary spacecraft is recorded simultaneously at two deep-space stations, preceded and followed by calibrations using an extra-galactic radio source with a well-known position. The data volume of one Delta-DOR measurement is more than 10 Gbyte, and so if transmitted at normal telemetry transfer rates it would load the link for several days, but the Delta-DOR result must be available in far less than 24 hours. It is therefore quite a challenge to avoid the blocking of normal operations or the procurement of extra capacity at extra cost. However, in combination with a load-sharing file-transfer management scheme, the new 2 Mbit/s rings are able to support Delta-DOR transactions within a few hours with no interference with routine mission support.

OPSNET-link rationalisations have also been made for other remote sites, increasing overall capacity and driving down absolute costs (see accompanying key indicators for 2004/2005).

**Conclusion and Outlook**

The commencement of routine operations at ESA's second deep-space ground station rounded off years of effort to modernise and future-proof all of the ESA tracking stations and their backbone communications. The result is a LAN-LAN interconnecting system capable of connecting all space mission-support systems, from control centres to stations based on IP as the single data-transmission protocol.

The modernised infrastructure uses standard commercial equipment available from many vendors. This concept has brought, and will continue to bring, cost benefits in procurements, sparing, sustaining activities and in engineering, operations and maintenance services. The modularity of the implemented design gives ESA the freedom to use devices from another manufacturer should this become necessary or desirable.



OPSNET cost/performance indicators: Capacity, Total Monthly Cost, Unit Cost and Normalised Unit Cost

The unified network architecture that has been deployed provides a high degree of flexibility and scalability, fostering cost-effectiveness in capacity and service management. It also includes IP connections for systems traditionally based on other technologies. Such high exploitation of state-of-the-art LAN technology has allowed considerable economies of scale. Where possible, due to the proximity of ground stations, i.e. in Australia and Spain, the topology of the WAN has been optimised. The change from a star to a ring topology with single high-speed lines has yielded economies of several hundred thousand Euros per year.

The ESTRACK-wide and flexible IP networking, in combination with its own firewall-based security perimeter, will yield further benefits for ESA, such as inter-Agency collaboration based on Space Link Extension protocol over IP, or support to remote maintenance from industry with reduced reaction times and travel costs.

For the time after the demise of X.25, there is the potential to change the telecommunications service types and their sourcing. This will require a solid cost/benefit analysis, including also the suitability of change-management processes for the operations concept of space missions and of ESTRACK. Given a positive assessment, a future OPSNET Wide Area Network could be sourced as a managed private network. The provider could be the same as for ESA's corporate network ESACOM, or a global competitor, depending on whether an exclusive or an alternate provider sourcing strategy is adopted at Agency level.

#### Acknowledgements

The modernisation of ESTRACK communications, closely interleaved with the construction of two new deep-space ground stations and the modernisation of other ESA ground stations, has been a long and intense collaborative effort involving many entities. The authors gratefully

acknowledge the team spirit, support and contributions of colleagues in the ESOC Ground Station Systems Division, the Ground Facilities Operations Division, of NDSatCom, the Vega IT GmbH communications engineering team, the Serco GmbH operational communications facilities support, the maintenance and operations teams at each ground station, and trainees from the University of Catania. ESA is also indebted to XANTIC Australia, Telefonica Spain and T-Systems International Germany for the dedicated and coordinated support in the end-to-end optimisation of the OPSNET routings. r