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EUTELTRACS
The European Experience on Mobile Satellite Services

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ABSTRACT

EUTELTRACS is Europe's first commercially operated Mobile Satellite Service. Under the overall network operation of EUTELSAT, the European Telecommunications Satellite Organisation, EUTELTRACS provides an integrated message exchange and position reporting service.

This paper describes the EUTELTRACS system architecture, the message exchange and the position reporting services, including the result of recent analysis of message delivery time and positioning accuracy.

It also provides an overview of the commercial deployment, the regulatory situation for its operation within Europe and new applications outside its target market, the international road transportation.

SYSTEM ARCHITECTURE

The EUTELTRACS system is a mobile satellite system which provides customers in Europe with two-way data communications as well as vehicle position-fixing, such services being offered within the coverage of the EUTELSAT satellites (Figure 1).

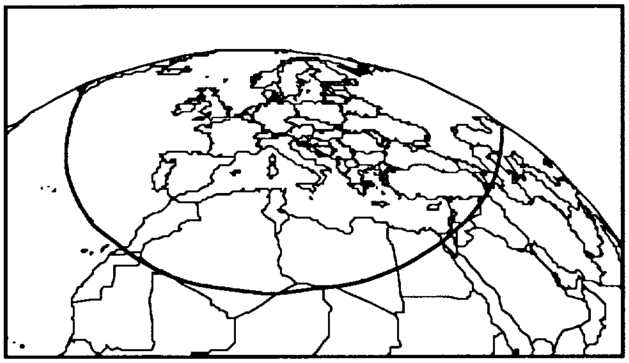

Figure 1 - EUTELTRACS Service Coverage

It is based on the same design as the OmniTRACS system [1] which has been operated by QUALCOMM on a commercial basis in the USA since November 1988.

Figure 2 highlights the components of the EUTELTRACS system. One can distinguish five basic elements in the system:

- the customer's terminal or dispatch centre, and its link to a Service Provider's Network Management Centre (SNMC), with which the customer is able to send and receive messages and also to access position information about his fleet of mobiles;
- the SNMC and its link to the Hub Station which processes and keeps a record of all transactions with the customers;

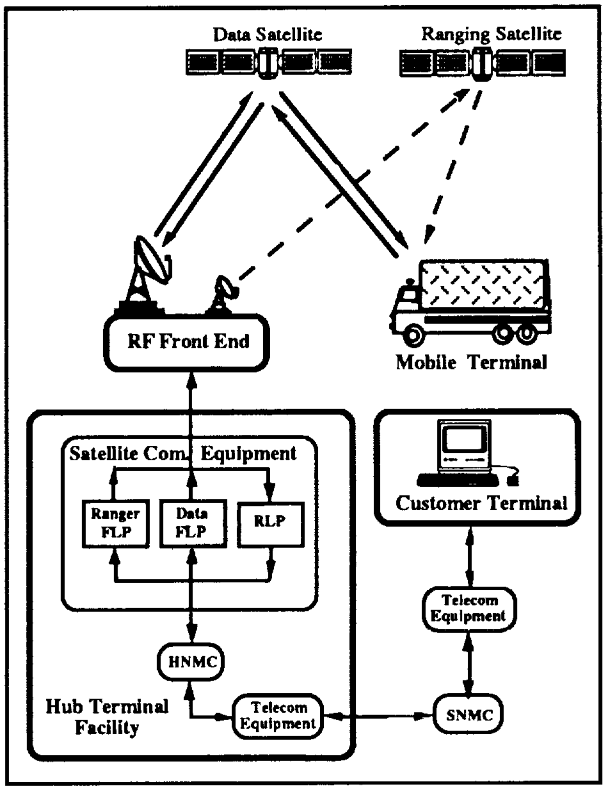

Figure 2 - EUTELTRACS Network Architecture

- the Hub Station, consisting of two antennas and associated RF frontends, and the Hub Terminal Facilities (HTF), whose main functions are to process, control and monitor the traffic flow (messages and position information) between SNMC's and the mobiles. In particular, the Hub Terminal Facilities provide all necessary functions in order to control satellite access in both directions (base to mobile and mobile to base);
- the EUTELSAT satellites, which are used to transmit the Forward Link carrier (transmitted by the primary Hub antenna to the mobiles), the Return Link carriers (transmitted by the mobiles to the Hub station) and the Ranging beacon (transmitted by the secondary Hub antenna to the mobiles).The Ranging signal is to support the localisation function (the signal is for localisation timing information only and contains no data modulation).

- the Mobile Communication Terminal (MCT), mounted on the vehicle, with which the vehicle driver can receive messages from his base and transmit messages back to it. The same Mobile Communications Terminal is used to perform the necessary measurements for the position reporting service.

MESSAGE EXCHANGE SERVICE

Satellite Transponders

The EUTELTRACS messaging system operates on the Data Satellite through two transponders on orthogonal polarisation.

The Forward Link is a "power" link, typically requiring a saturated transponder in order to maximise the power flux density on the earth's surface.

The Return Link is a bandwidth link requiring 36 MHz of bandwidth (to accommodate the messages generated by 45,000 MCT's), but little power due to the low EIRP radiated by the MCT's.

Forward Link

The Forward Link is composed by a Time Division Multiplex (TDM) stream transmitted by the Hub Station and received by the MCT's, on a single carrier communication link [2]. The Forward Link wave form is mixed with a chirp wave form to mitigate potential interference from nearby satellites and multipath fading. The Forward Link signal occupies a 2 MHz bandwidth due to the spreading wave form.

The data information is sent out at data rates of 4,960 bits/second (BPSK, rate 1/2 Golay encoded) called the 1X data rate or 14,880 bits/second (QPSK, rate 3/4 coded) called the 3X data rate. This results in a constant 9.92 ksymbol/s PSK wave form occupying 9.92 kHz of bandwidth. The choice in the actual data rate used for each individual MCT is done dynamically and depends on the reception environment of the mobile.

Return Link

The Return link (mobile to hub), is a low information data rate stream using a rate 1/3 convolutional encoder (K=9) in conjunction with Viterbi decoding. A powerful interleaving scheme reduces interference effects such as those FM/TV could create.

As shown in Figure 3, a combination of techniques [2] is involved to generate the MCT Return Link wave form. It combines a 32-ary FSK scheme, which encodes 5 coded symbols onto one FSK symbol, to a DSS (Direct Spreading Sequence) MSK modulation at 1 MHz rate. The resulting signal is then randomly frequency hopped over the whole Return link bandwidth to increase the resistance of the transmission to potential interference. The transmitting MCT and the receivers at the Hub use the same frequency hopping pseudorandom sequence, enabling the reception and demodulation of the data.

During message transmission on the Return Link, the MCT transmitter amplifier operates at half duty cycle so that antenna tracking maintains lock on the Forward Link downlink signal. Transmission is enabled 50% of the time at 15.12 millisecond intervals. During the next 15.12 ms, the amplifier is disabled to perform antenna tracking on the Forward Link down link to maintain pointing, frequency tracking and time tracking tasks.

Each transmission interval contains either one 32-ary FSK symbol at 1X data rate (55 bit/s) or three 32-ary FSK symbols at 3X data rate (165 bit/s). The choice on the actual data rate used for each individual MCT is done dynamically depending on the transmit environment of the mobile. That choice is under control of the Hub Network Management Computer (HNMC) which monitors all Return Link signal levels, thus instructing the MCT's.

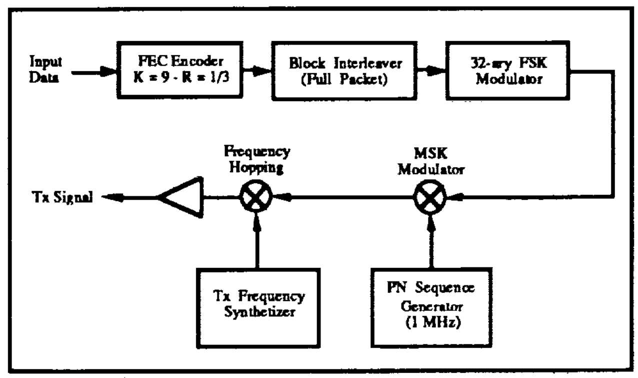

Figure 3 - Return Link Transmit Signal Generation

Acquisition of the Forward Link and set-up of the MCT through reception of special system packets is required before the MCT will attempt any transmit tasks. These packets are periodically broadcast for using the proper return frequency channel.

Data integrity

The messaging function uses a fully acknowledged store and forward protocol.

On the Forward Link, the mobile is required to acknowledge the successful reception of the packets by transmitting an acknowledgement packet on the Return Link. If no acknowledgement is received, the packet is retransmitted up to 12 times in one hour before being declared as not acknowledged. No new messages are transmitted to an MCT before completion of the previous message.

On the Return Link the packets transmitted from the MCT's are acknowledged by the HNMC. If no acknowledgement is received by the mobile the message is retransmitted for up to 50 times before aborting it.

On both links the acknowledgements are sent only if the FEC is able to reconstruct the packets without any error. This procedure ensures that the messages delivered to the mobiles or to the dispatch centre are completed and error free.

Messages Delivery Time

The performance of the system can be estimated measuring the delay time, including the queuing time before transmission, necessary to establish a full data exchange from the first transmission of a packets to the reception of the acknowledgement. The distribution of the delay time can be interpreted in terms of number of attempts to establish a full transaction.

Four categories have been defined for the purpose of the analysis:

- data exchange which only needed 1 try (delay time between 20 to 30 sec);
- data exchange which only needed 2 or 3 tries (delay time between 2 min to 3 min);
- data exchange which needed up to 8 tries (delay time between 12 min to 20 min);
- data exchange which needed up to 12 tries (delay time < 1 hour);
- packets which never go through and are not delivered.

The distribution within the above categories depends upon the mobile environment. Three kinds of different environments were defined:

- environment without any blockage (i.e. fixed site, maritime or aeronautical applications, etc.);
- environment as encountered by a land mobile in motion in flat or hilly country, suburban area, etc. refered to as the nominal environment for land mobile applications;
- marginal environment (i.e. edge of coverage, elevation angle to the satellite lower than 10°, mountainous area, large city with skyscrapers, etc.).

Table 1 presents the performance as measured during test campaigns [3] performed with mobiles in motion:

	20 to 30 sec	2 to 3 min	12 to 20 min	< 1 hour	not deliver
No block.	99.2%	0.6%	0.2%	0%	0%
Nominal	85.6%	9.9%	4.5%	0%	0%
Marginal	73.3%	14.9%	8.1%	2.9%	0.8%

Table 1 - Message delivery time distribution

These results show that for land mobile applications more than 95% of the messages are delivered within three minutes. For other applications as fixed sites, aeronautical or maritime applications, a percentage of 99% of the messages is reached within a delivery time of half a minute.

In addition they prove that the communication is still possible in extreme cases such as urban areas or edge of coverage and low elevation angle to the satellite with only less than 1% of the messages which could not get through the system with the normal procedure. In that case, the customer gets an information of no delivery of his message and can require a further try via the Hub if so desired.

MOBILE POSITIONING SYSTEM

Method

The method calls for two separate satellites in geostationary orbit in order to derive timing information from the signals transmitted through the two satellites. A precise timing measurement of the round trip delay and the time difference between the two wave forms transmitted by the Hub station as measured at the MCT provide all the necessary information for the determination of the vehicle position by multilateration [4]. This method was chosen for the positioning system because of its consistency, reliability, economy and accuracy.

Normal messaging is performed through the primary satellite with Forward and Return Links. Round trip delay is measured for all message packets as part of the demodulation process. When a Return signal is detected, time alignment must be adjusted and maintained otherwise demodulation of the message will not occur and a retransmission will ensue.

The secondary Hub station uplinks a low power signal identical to the forward message signal (though not carrying any information) through the Ranging satellite. The period of the triangular spreading signal in this copy of the message wave forms is long enough in time so that position ambiguities do not arise through the coverage when the MCT antenna acquires and tracks alternately the two forward link signals from two different pointing directions. The antenna stops tracking the Primary down link signal, acquires and tracks the Ranger signal, and then returns to the Primary.After acquisition of the ranging signal, the MCT reports the derived time difference with any return message or acknowledgements of forward messages. This Position Report packet in this system contains time difference information rather than a true position.

Satellite positioning

In order for the Position Reporting System to locate vehicles on the earth, a reliable means of supporting that function with current and accurate satellite positions is necessary. Rather than obtain ephemerides from satellite controllers, satellite position determination is obtained through the reverse process of multilaterating the satellite from fixed terminals.

The ability to pinpoint the satellite in real time provides a robust positioning system which immediately follows any stationkeeping manoeuvres and quickly adjusts to backup satellite configuration in the unlikely event of a satellite failure. There is complete identity in hardware and software used by the Fixed Units and the mobile units. The main difference between them within the system is how the Hub Terminal views them.

Fixed unit geographical locations are important for the positioning accuracy, both for the satellite location and hence the MCT location. Fixed Units must be spread as far as possible within the service coverage and yet have an antenna gain high enough to satisfy the link budget requirements.

Altitude Model Data Base

The distance values from the MCT to the two satellites derived from the time measurements must be combined with the altitude information to estimate the MCT location. This altitude model is included in a numerical database of the Earth's shape which resides in the HTF computer. The distance from the centre of the earth based on the WGS84 ellipsoid. Altitudes above this are based on the USGS (United States Geological Survey) world data base, which includes recent satellite survey data. The grid spacing currently implemented for simplicity and memory considerations is ten arc minutes, with a model height precision of 100 feet. Mobile positions within the grid spacing use linear interpolation to derive the mobile's altitude. Hence, in rough currently terrain, the altitude model will be in error by 1/2 the peak-to-peak roughness if mobiles travel typically in the valley floor.

Positioning Accuracy

The position error have been analysed in terms of two components:

- a position bias error between the measured average value given by the Position Reporting system and the real coordinates (estimated using high accuracy maps or, when not available, using a GPS receiver) mainly due to the inaccuracy of the altitude model database. This error express itself as a North / South bias in the position solution;
- a random error between the measurements for a given location, which can be described in terms of average error and maximum error with a given confidence level (usually 95%) and will depend on the angular separation between the two satellites, the timing accuracy of the different signals and the positioning accuracy of the 2 satellites used. As the angular separation along the geostationary orbital arc between two EUTELSAT satellites can at present range from 3° to 14.5°, this error express itself mainly as a East / West random error in the position solution. Figure 4 presents the random accuracy variation versus the satellites angular separation. These performances induced an operational limit of 6°.

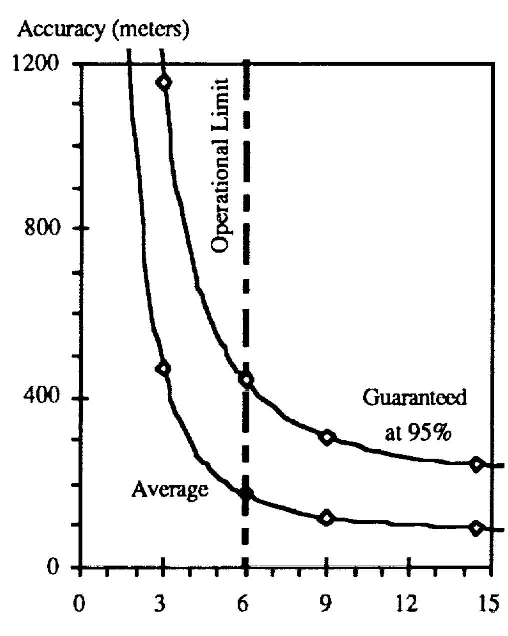

Figure 4 - Random Accuracy vs. Satellite Angular Separation

It should be noted that in the case of land mobile applications the Root Sum Square (RSS) applies with the two above errors, while in the case of maritime applications, only the random error has to be considered.

Tables 2 and 3 show the positioning performances of EUTELTRACS as recorded during recent field trials.

	Maritime	Flat	Hilly	Mount.
Aver.	n.a.	10m	40m	200m
Guar.	n.a.	20m	120m	420m

Table 2 - Bias Error versus Environment

	3°	6°	9°	14.5°
Aver.	460m	170m	120m	80m
Guar.	1150m	440m	320m	240m

Table 3 - Random Accuracy vs. Satellite angular Separation

To conclude, we can state that for instance using two satellites having 14.5° of angular separation, the positioning error of a maritime mobile is of around 80m as average value and 240m as guaranteed limit in 95% of the cases, and the position error of a land mobile travelling in hilly country is found equal to:

$\sqrt{40^2+80^2}$ = 90m as average;

$\sqrt{120^2+240^2}$ = 270m limit in 95% of the cases.

COMMERCIAL DEPLOYMENT

The Service Provision

In terms of commercial deployment, EUTELTRACS operates via national or regional Service Providers, each connected to the central Hub station operated by EUTELSAT from a base just outside Paris. The enduser therefore has the dual advantage of being able to exploit pan-European products and services while at the same time dealing directly for everyday needs with a local and immediately accessible service management.

Overall responsibility for the EUTELTRACS service is consequently divided between three key parties: as network provider, EUTELSAT makes available the space segment, the satellite capacity, and the central hub facility. It also takes responsibility for monitoring and controlling the network during EUTELTRACS operations.

All aspects concerning system hardware and software and the mobile terminals themselves are handled by ALCATEL QUALCOMM, which also takes overall responsibility for marketing.

Finally, the individual regional Service Providers deal with the endusers and act as an interface between their customers and the network provider. Service Providers operate individual Service Network Management Centres (SNMC's) in their own region, from where they channel their customers' traffic to the Hub station; consequently, it is the Service Providers who invoice the endusers for the transactions, the equipment and software, and the installation, maintenance and training.

Advantages for the Road Transportation

For the vehicle fleet operator, EUTELTRACS is a valuable tool in the drive for increased efficiency, reduced overheads, a sharper competitive edge, approved quality assurance, maximum security and tighter, Just-In-Time deliveries.

By coordinating fleet vehicle activities using the EUTELTRACS system, less time is lost on the road, there is a significant decrease in empty kilometres and forward planning becomes more effective. Fuel and maintenance overheads have been shown to be reduced, delivery dates can be guaranteed with a far higher degree of accuracy and fleet flexibility is significantly increased.

The benefits of the system for the monitoring of critical deliveries and the provision of realtime information on the status of perishable loads are considerable, as are the facilities for tracking and relaying emergency alerts on hazardous goods and valuable loads.

Finally, as the manufacturing industry continues to strive for tighter margins and streamlined productivity by using the latest Just-In-Time production methods, transportation companies can use EUTELTRACS to redirect shipments or change pickup points at a moment's notice, thereby reducing delays and increasing transport flexibility.

Specific Benefits of Euteltracs

Unlike any existing or projected competitors in the land mobile communications field, EUTELTRACS offers endusers specific benefits that are tailormade to the needs of the European transportation industry:

- Fully integrated message exchange and position reporting system: There is no additional equipment or cost burden for position reporting;
- Low entry cost system: The development of a proven communications technology that can exploit capacity on non-dedicated satellites, accurate even when in inclined orbit, has resulted in a system that offers guaranteed availability, long-term reliability and a low costtoefficiency ratio;
- A "one stop shopping" service: The enduser obtains the entire service from a single point of sale for subscription, transactions, terminals, software, installation, maintenance and financing;
- Full territorial coverage: The EUTELSAT satellites assure permanent Europeanwide access to the system even in mountain ranges and areas of low traffic density;
- It is designed for regional applications: Only a single Hub station is necessary, leading to optimised and rapid response network management;
- A proven system: The EUTELTRACS technology is well established and large numbers of terminals are already installed worldwide;
- Integrated computer communication: Messages are transmitted as computer-compatible data, enabling further processing at both ends of the data link;
- Fully harmonised system for land mobile applications: The modulation, coding and satellite access scheme, as well as all protocols used, are adapted to cope with the land mobile radioelectric and topographic environment conditions;
- Secure, closed-user-group system: There can be no "intruders" in the system.

Present Commercial Situation

At the present time nine Service Providers are offering the service to ten European countries. They will soon be joined by a Service Provider in Hungary, first country in central Europe to offer EUTELTRACS . Trials in Russia already started and a Service Provision in the course of 1993 is expected.

Nearly 2,000 EUTELTRACS terminals have been delivered to Service Providers for installation on vehicles. Present projections indicate that over 4,500 terminals will be operational by year end 1993. A similar uptake than the one of the US OnniTRACS service can be expected, where after 3 years nearly 40,000 terminals are in operation.

REGULATORY CONSIDERATIONS

Regulatory Overview

Each of the countries in Europe that comes within the EUTELTRACS service coverage area, has its own national regulations for the operation of radio equipment within its jurisdiction. In most cases, such regulations require the Mobile Service Operator to obtain an individual license for the use of the equipment concerned, on each and every occasion that he enters any country. Clearly, such a requirement is not compatible with the concept of a European wide mobile Satellite Communications Service.

CEPT Recommendation

As a first step towards resolving this situation, the CEPT, in October 1988, issued a recommendation that introduced the concept of the CEPT circulation card. This circulation card is intended to be accepted in lieu of a license for use of the designated equipment within any of the participating countries. In order to become a participant in the circulation card procedure, the Administrations of the countries concerned are required to provide a written "declaration", identifying the type of equipment involved and confirming that it may enter and/or operate within that country without the need to acquire a separate license of any kind.

To avoid the need for such a circulation card procedure in the longer term and particularly to eliminate the need for the mobile terminal operator to have to carry the associated documentation, the CEPT issued in February 1991 a further recommendation on transborder operation of EUTELTRACS terminals within Europe. This recommendation introduced a procedure that envisages unobstructed transborder operation on the basis of a European wide recognition of a properly authorised terminal carrying the appropriate logo and type approval certification number. Ultimately, this type approval will meet the European Telecommunications Standards Institute (ETSI) standard. Implementation of the requirements of this recommendation will require major changes in the regulatory regimes in most European countries and will therefore take time to achieve. In the meantime, the circulation card procedure is available as an interim solution.

EUTELSAT Regulatory Activities

In order to increase awareness of these CEPT Recommendations and to promote a speedy action in their implementation among the EUTELSAT member Administrations, the Eutelsat Executive Organ initiated a program of bilateral discussions with the respective administrations. Depending upon the circumstances of the individual administrations, these discussions were conducted by correspondence (letter / telex / facsimile), by telephone or by personal visits and meetings. Since the beginning of these efforts in April 1991, nearly 30 Administrations have signed the declaration to validate the circulation card for their countries. Some of these declarations were valid only until a specified date, while others had no time limitation. In some cases when the declarations expired they were renewed or extended; in other cases they have not been renewed.

Based on these declarations and the expiries, extensions and renewals, there are currently nearly 30 Administrations, including some in Eastern Europe, that are entitled to participate in the CEPT circulation card procedure. In all cases, the declarations authorise both the carriage and operation of the Euteltracs terminals within the countries concerned. In addition to the circulation card procedures, over 10 Administrations have so far implemented the necessary legislation, directives or instructions to permit transborder operation without the need for individual licences. In several cases this has been effected through a form of Administrative or Ministerial licence exemption under existing legislation. In other cases it has been achieved with new legislation that either grants licence exemption or establishes a General Class licence for operation of EUTELTRACS.

MOBILE SATELLITE DATA APPLICATIONS

EUTELTRACS is now also being introduced as a mobile satellite data service on a number of nonroad transport applications presented below.

Mobile Data Broadcasting

One of the main advantages of satellite communications is the ability to broadcast information to an infinite number of receivers on a large coverage zone in a very efficient manner. Thus, the EUTELTRACS network can be used to broadcast messages to a large group of vehicles. Due to its very fast forward link messaging feature, EUTELTRACS started early 1993 to broadcast every couple of seconds Differential Global Positioning System (DGPS) correction data, to achieve a positioning accuracy of approx. 3 meters. It should be noted that for this application the messages are sent through the network in priority mode, enabling the delivery to the mobiles within less than five seconds. Other messages like weather or road status information messages could be also broadcast.

Monitoring of Fishing Activities

In order to improve the control of fishing activities in European waters, the Commission of the European Communities (CEC) is in the process of discussing with the Member States the introduction of a Directive requesting that all major fishing boats be fitted with satellite communications terminals.

In the framework of this activity, the CEC is testing EUTELTRACS, a system that perfectly meets the need for position reporting of mobiles. In addition to the control function, the fishing companies could use EUTELTRACS to improve their fleet management.

Aeronautical Communications

Even if the position reporting service of EUTELTRACS cannot be used for aircraft (only mobiles on the surface of the earth can be located), the messaging service can become a valuable additional mean of communications on a frequency band different to the exhaustively used aircraft communications links. Due to the high speed of aircraft, communication means like EUTELTRACS are subject to a significant Doppler effect. This effect can be compensated by improving the stability of the local oscillator. In addition to this modification, a suitable antenna has to be mounted on aircraft.

Modified mobile units for aeronautical purposes are already being put into commercial operation.

Supervisory Control and Data Acquisition (SCADA)

EUTELTRACS solar powered terminals can be used on remote or isolated sites for monitoring and control of networks, for example pipelines. Terminals can report periodically, send alerts at special events, be interrogated by the base or used for remote control. The reliability of EUTELTRACS for SCADA applications is very high due to the fact that all terminals are fully controlled by the Hub facility (they can therefore be fully operated without attendance) and that in case of satellite failure, the terminals automatically search for the alternate satellite. Further advantages of EUTELTRACS terminals are their small size, easy installation and low cost.

REFERENCES

[1] *An overview of OmniTRACS: the First Operational TwoWay Mobile Kuband Satellite Communications System*, I. M. Jacobs (QUALCOMM, San Diego) Space Communications (Netherlands) Vol. 7, No. 1, December 1989

[2] *Modulation, Spread Spectrum and FEC Coding Techniques Used in the EUTELTRACS Land Mobile Satellite System*, L.A. Weaver, F.P. Antonio, A.J. Viterbi, I.M. Jacobs, K.S. Gilhousen (QUALCOMM Inc., San Diego) DSP 90 Politechnico di Torino 24/25 Sept. 1990

[3] *Land Mobile Communications in Kuband Result of a Test Campaign on EUTELSAT IF1*, J.N. Colcy and J. Dutronc (EUTELSAT, Paris). International Journal of Satellite Communications, Vol. 8, 4363 (1990)

[4] *The EUTELTRACS Position Reporting System Characteristics and Performance*, J.N.Colcy and J.Dutronc (EUTELSAT Paris), W. G. Ames (QUALCOMM Inc., San Diego), NAV 90 - The 1990 International Conference of The Royal Institute of Navigation, Warwick, UK