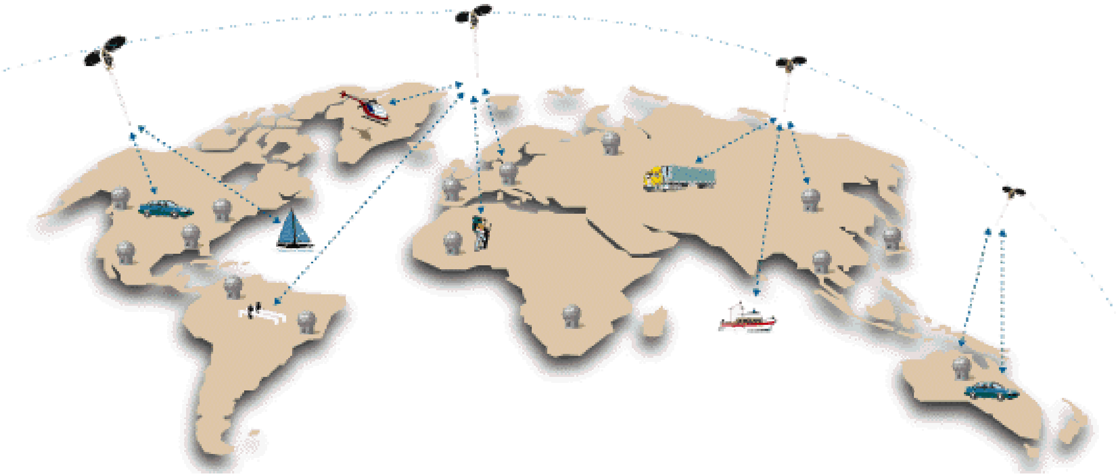
Satellite data communications as a complement to GSM



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Abstract

The use of mobile Internet has reached the transport industry. Internet will be used to transport important and security-critical information from and to vehicles. Using Internet in this context raises a severe problem. Only 6% of the world is covered by GSM, the primary Internet bearer for mobile usage. The subject of this thesis is to explore suitable backups in order to provide the user with global coverage for important information exchange.

The messages to send and receive are small in size, often less than 100 bytes. The time factor of the transmission is important, an alert message often has to be passed within minutes to be of any use. These factors together with the global coverage leave us with only one suitable solution, a satellite data communication system.

The first part of this thesis contains an investigation of the satellite communication market. Two different systems, Inmarsat-C and ORBCOMM, are chosen for further study and evaluation. One Inmarsat-C unit and two ORBCOMM units are found suitable for the application. The last part of the thesis contains the evaluation, testing and system integration of these units.

The conclusion is that ORBCOMM, although not yet fully developed, has the capabilities and performance necessary for use in a mobile environment such as a truck. The two different ORBCOMM units tested, Panasonic and Stellar, were found to have comparable qualities.

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1 Introduction

This Master's project was performed at Scania Infotronics AB, during the fall and winter of 1999/2000. The author is a Master of Science student at KTH Stockholm with specialization towards telecommunication from Technische Universität Wien, Austria. The academic supervisor and examiner of the project is Professor Gerald Q. Maguire Jr. at the Department of Teleinformatics, KTH. The industrial supervisor at Scania Infotronics AB is Mathias Björkman.

The goal of the project was to examine the satellite communication market in order to gain knowledge about satellite systems and hardware manufacturers suitable for Scania's SVIP project (see section 3 for details). Interesting units were to be evaluated and if possible integrated in a SVIP prototype for further evaluation.

2 Abbreviations

AMPS	Advanced Mobile Phone Service
API	Application Programming Interface
ARQ	Acknowledge Request
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
ETSI	European Telecommunication Standards Institute
GCC	Gateway Control Center
GEO	Geostationary Earth Orbit
GES	Global Earth Station
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HEO	Highly inclined Elliptical Orbit
ISDN	Integrated Services Digital Network
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
MIS	Management Information System
OEM	Original Equipment Manufacturer
RF	Radio Frequency
SAE	Society of Automotive Engineers
SC	Subscriber Communicator
SVIP	Scania Vehicle Informatics Platform
UTC	Universal Time, Coordinated
VHF	Very High Frequency

3 Scania Vehicle Informatics Platform

The ground transport industry has progressed a long way since the first trucks turned up a hundred years ago. Today's trucks are loaded with much more than cargo: They are full of electronics and computer controlled devices, communicating via the truck's internal computer network. A natural continuation of this development is to place a personal computer in this network. This computer can communicate with the truck as well as with the global environment through a mobile Internet connection. The driver can then retrieve information from any Internet connected host in the world as well as receive and send E-mail.

An Internet connected computer opens the door to a whole world of information, limited only by the imagination. The truck driver can download traffic information, weather forecasts or restaurant tips at will. New transport-related services will arise as soon as the drivers start to ask for them.

Problems and maintenance of the truck can often be solved remotely by a central assistance center. The service engineer simply connects to the truck and reads diagnostics or upgrades software. The driver will have continuously updated instructions from the back office about loading places, cargo and other logistical details. The back office will have information about truck status and position, cargo status and data like for example trailer interior temperature or engine oil pressure within reach.

Scania Vehicle Informatics Platform (SVIP) is a PC-based computer platform that will be integrated in Scania trucks and buses. The SVIP has a GSM/GPRS interface for Internet connection, sophisticated software for navigation together with GPS, voice control and a number of other components. One of the main features of the SVIP will be to report different types of alarms to the home base or an assistance center. The most important are distress and theft alarms, together with an accident alarm, which might be trigged by the vehicle's airbag. A limitation for this system today is the limited coverage of GSM. Only 6% of the world is covered by GSM. That is perhaps acceptable for Internet access, but not for alarm purposes. An alarm has to go through even when the vehicle is positioned in rural areas. It should also be possible to send a short message to and from the vehicle at all times. The only possible solution with global coverage is a satellite system.

My main objective was to find a suitable satellite system and integrate it in SVIP. The main parameters of such a satellite system can be defined as follows:

- **Security** – The system has to have global coverage and short access times.
- **Price** – Both hardware and access costs have to be low in order to attract customers to the SVIP system.
- **Hardware** – The terminal equipment must be ruggedized (designed to survive the arduous environment of a truck cabin), small in size and easy to handle. Antennas should preferably be possible to build into the vehicle in order to prevent an attacker

from disarming the system. The control interface of the terminal has to be extensive and well designed in order to simplify integration with the SVIP software.

The communication needs of such a system is relatively low in terms of data rate. The system is intended to work as a backup to the primary Internet bearer; for example GSM/GPRS or short-range radio, not as the main communication system. This means that heavy-duty data communication such as World Wide Web applications will be handled by GSM, and GSM only – the use of such services are not security critical and can be shut off when GSM connections are impossible. This leaves us with only short text-based messages to pass over the satellite link. Such messages can consist of position data, alarm data and logistical information from/to the home office or assistance center.

4 Introduction to satellite communications

In 1945, the technical magazine “Wireless World” published an article by the famous science fiction author Arthur C. Clarke, at the time president of the British Interplanetary Society. He sketched an idea about using radar technology for communication purposes. This was to be implemented through reflection of radar beams against reflectors placed in earth orbit. The idea was considered extremely futuristic and advanced at that time. Only twelve years later, 1957, the Soviet Union placed their and the world’s first artificial satellite, SPUTNIK, in orbit. The “space war” between the great powers has driven the technology forward ever since. The first satellites to provide transceiving capabilities were TELSTAR and RELAY in 1962. All these satellites were placed in elliptical orbits. The first television transmission over satellite took place in 1964 during the Tokyo Olympics. The relay station used was the very first geostationary satellite (see section 4.1 below), SYNCOM.

Almost every communications satellite in use today has a circular orbit. The tasks range from communications, scientific research and remote sensing to surveillance, meteorology and navigation. The satellite systems can be classified as GEO, MEO or LEO systems as described in the following sections.

Figure 4.1 – Satellite communication principal sketch – the modern version of Arthur C. Clarke’s vision. [20]

4.1 GEO (Geostationary Earth Orbit) systems

GEO satellites are launched into an equatorial orbit. The round-trip time of the satellite is exactly 24 hours, following the earth’s rotation. This makes the satellite appear at a fixed position over the earth surface. These conditions lead to a satellite altitude of about 36,000 km. The advantage of a geostationary satellite is that the stationary dish antenna on the ground can be directed towards the satellite once and for all. A GEO satellite is an expensive construction, both to build and to launch. At such a great distance, signal strength is a problem. Both the satellite and the terminal equipment on the ground have to have powerful and therefore expensive amplifiers and sensitive receivers. GEO technology is the most explored of the satellite types. GEO satellites are mainly used for Television broadcast, but there exists two-way communication systems in this category as well.

4.2 LEO (Low Earth Orbit) systems

LEO satellites orbit the Earth at much lower altitudes, between 300 and 1,500 km. This gives them an orbit time of about 90 minutes to two hours. The satellite paths are usually inclined to the equator in order to let the satellites pass over Europe and North America. The satellites are not geostationary; they appear to move constantly over the sky. The combination of orbit and Earth rotation makes them perform a sinus-shaped track over the ground. Many LEO satellites are required to cover the world continuously. Interesting however is that every point on Earth, except for the Polar Regions, will have a satellite pass sooner or later. For geostationary satellites, the satellite is either visible or not, there is no need to ask “when”. The big advantage of LEO satellites is that they are smaller and cheaper, both to build and to launch. Their lower altitude makes the access much simpler; it is even possible to use mobile or cellular sized handsets.

The term LEO is often extended to contain both LEO and MEO (see below) satellites. “Little LEO” refers to systems operating below 1 GHz, while “Big LEO” refers to those over 1 GHz. LEO systems have been in use mainly for non-communication applications such as remote sensing, satellite imaging, meteorology and military surveillance. The market is however soaring; pushing the technology forward towards more communication oriented solutions. LEO systems are mainly used for telephony, data communications and surveillance.

4.3 MEO (Medium Earth Orbit) systems

MEO systems have a greater altitude than LEO systems, usually between 5,000 and 15,000 km. The purpose of a MEO system is to combine the flexibility of a LEO satellite with the better coverage of a satellite with higher altitude. MEO satellites are used for meteorological applications as well as communications.

Section 4 sources: [1], [2], [3], [4] and [5]

5 Satellite systems

In my search for suitable satellite networks, I encountered a great number of different systems. The one thing almost all of them have in common is that many are not yet in service. It can however be of interest for the future to know the possibilities existing in the satellite market. I will therefore make a short presentation of some of the major satellite projects. A couple of systems look indeed very interesting for the requirements Scania has for the SVIP project (see section 3). I have picked Inmarsat-C and ORBCOMM mainly because they are in operation today, which gives me the opportunity to test these systems practically as an integrated part of SVIP. The notes for the expected time of operation start are very rough for most of the systems; many of them have already been delayed several times.

5.1 Broadband systems

There are a number of systems planned for broadband data services. The intention is to provide worldwide multimedia access with high data rates. These systems might be of interest, but only if the pricing and the size of antennas and terminals are suitable. The systems are mainly circuit switched, which means expensive short messages, due to the connection cost caused when sending messages separated in time.

5.1.1 Astrolink

Astrolink [9], [10] is a $4 billion project financed by Lockheed Martin Telecommunications, which is intended to come into service by 2000. It consists of nine geostationary (GEO) satellites and will be able to transmit data with rates ranging from 16 kbps to 9.6 Mbps.

5.1.2 Expressway

Expressway [10] is a $3.9 billion project financed by GM Hughes. The application was filed in 1997 and has not yet been approved. The system will consist of 14 GEO satellites.

5.1.3 Spaceway

Spaceway [15], [10] is intended to come into service during 2002. It is a $3.2 billion project from Hughes Network Systems consisting of 9 GEO satellites and will provide data rates from 16 kbps to 6 Mbps.

5.1.4 Teledesic

Teledesic [29], [10] is a joint venture formed by Microsoft Corporation and AT&T Wireless Services. It will be a huge system with 288 LEO satellites in 12 planes. The service is planned to begin in 2004, and the system will provide data rates up to 64 Mbps on the downlink and 2 Mbps on the uplink. It is intended to support broadband data services including real-time applications.

5.2 Voice Systems with data support

Many of the existing and planned satellite systems mainly focus on voice transmission. The growing need and market for data communications has made it interesting for these system providers to extend their systems to also provide data services. However, voice systems are circuit switched rather than packet switched. This results in an inefficient and expensive support of short data transmissions. Another problem with voice systems is that they are very expensive to develop. This means that the customer base has to be much more extensive than for more inexpensive low-rate data systems. This leads to higher service prices, at least during the introduction phase. It can also lead to financial trouble for the providers; Iridium and ICO are examples of this.

5.2.1 Ellipso

Ellipso [11], [10] is a $1.5 billion project, intended to begin service in 2002. The financiers are Boeing, Harris Corporation, IAI, Spar, L-3 Com and Lockheed Martin. It consists of 14 HEO (Highly inclined Elliptical Orbit) satellites. The reason for elliptical orbits is that the populated landmasses not are spread evenly over the Earth, they are concentrated to the north. With elliptical orbits, it is possible to concentrate the coverage on these parts. The data rates supported will range from 300 to 9600 bps.

5.2.2 Globalstar

Globalstar [14], [10] intended to start service in 1998, but problems with lost satellites and governmental disagreements have delayed the initiation to early 2000. It will consist of 48 LEO satellites and cost about $3.5 billion. The data rate supported will be 9600 bps. Globalstar partners include Loral Qualcomm, AirTouch Communications, DACOM/Hyundai, France Telecom/Alcatel, Daimler Benz, Vodafone, Alenia Spazio, Elsag Bailey,Finmeccania and Space System/Loral

5.2.3 ICO

ICO [16], [10] was created and later spun off by Inmarsat as an answer to the Globalstar and Iridium projects. Consisting of 10 Medium Earth Orbit (MEO) satellites, ICO plans to be operational by 2000. ICO is known to have financial troubles.

5.2.4 Inmarsat

Inmarsat [18] is one of the oldest providers; they were established in 1979. The system is wide spread for voice communications, but it also supports data services; mainly for message based services at sea. Inmarsat has about 140,000 subscribers worldwide (1998). It consists of 9 GEO satellites: 4 Inmarsat-2 (second generation) and 5 Inmarsat-3 (third generation). A data service with by the byte charging instead of the current connection time based charges will be introduced in early 2000. The transmission rate will be 64 kbps and follow standard ISDN procedures. Inmarsat is well established, with a great number of national providers and terminal equipment manufacturers. The messaging capabilities and E-mail support of Inmarsat suit the communication needs of Scania in the SVIP project (see section 3). I have therefore chosen this system together with ORBCOMM (see below) to look at more closely.

5.2.5 Iridium

Iridium [19], [10] is an operational $5 billion project formed by Motorola. It consists of 66 LEO satellites. The data service supported today is one-way paging/messaging, but plain data transmissions will also be supported in the future. The main disadvantages with Iridium today are their prices and their financial problems. The expensive system and the low customer interest have brought Iridium to the brink of bankruptcy. Iridium does not reveal anything about the number of subscriptions sold so far; they only describe subscriber levels and revenues as “significantly below its prior estimates”.

5.3 Packet oriented data systems

The need for inexpensive global data communications has caught the interest of a number of satellite providers. The systems in this group are much simpler and therefore more inexpensive than those of the other categories. The satellites are “dumb” in terms of computer power; their only mission is to relay the data packets from a subscriber’s terminal to the nearest Earth station. The only intelligence needed is a memory to store the message until an Earth station is within reach. This makes the satellites small and inexpensive, both in terms of construction and launch. Their packet orientation means that no circuit switching capabilities have to be included in the network, only inexpensive data routers. The low cost (10 to 20 times lower than the other system types) and simple architecture of these systems make the service rather inexpensive. In some cases small amounts of data are even less expensive than cellular networks like GSM, AMPS and Mobitex.

5.3.1 FAISAT

FAISAT [13], [10] is a promising system planned for 2002. It consists of 32 LEO satellites and costs about $250 million, financed by Final Analysis and Polyot Enterprises. The service provided is messaging and paging through E-mail. This makes it excellent for tasks like asset tracking and monitoring, distant hardware control and so on. The data rate can be adjusted between 300 bps and 300 kbps according to demands.

5.3.2 GEMnet

GEMnet [10] consists of 38 LEO satellites and intends to enter service by 2000. Total cost of the system is estimated to $160 million, founded by Orbital Sciences. Services provided will be tracking, monitoring, paging and E-mail.

5.3.3 LEO One

LEO One [20], [10] intends to start service by 2000. The system is based on 48 LEO satellites at a total cost of $250 million, financed by dBX Corporation. Market segments targeted are messaging, tracking and monitoring. Communication bitrate is 24 kbps (downlink) and 2.4 to 9.6 kbps (uplink).

5.3.4 ORBCOMM

ORBCOMM [22], [24], [10] came into full service during 1998. It consists of 48 LEO satellites where of 35 are already in orbit. Communication bitrate supported is 2400 bps. ORBCOMM is a joint venture of Orbital Sciences Corporation, Teleglobe Inc, Technology Resources Industries and Teleglobe Inc. The system has more than 200,000 subscribers today, and expects to reach the break-even point of 350,000 during 2000. The interest is huge, and the number of national providers is soaring, as is the number of terminal equipment manufacturers. ORBCOMM looks very interesting for the type of services Scania needs for the SVIP project (see section 3) and is, together with Inmarsat (see above), the second of the systems I have chosen to study farther.

5.3.5 QUALCOMM OmniTRACS

QUALCOMM [26] introduced their OmniTRACS system in 1998. The system is designed exclusively for trucks and provides tracking capabilities and text message services through QUALCOMM terminals and software. OmniTRACS uses dedicated transponders on commercial GEO satellites on the C and Ku radar frequency bands. The system has 230,000 subscribers (as of late 1999) and is operational in 33 countries.

OmniTRACS is not suitable for the SVIP project (see section 3 for details). The coverage is not global and the system is not flexible enough as only QUALCOMM terminals and software can be used.

6 Inmarsat

Inmarsat [18] was established in 1979 to serve the maritime industry by developing satellite communications, both for voice and data applications. The main objective was to provide a system with global coverage for distress and safety applications. Inmarsat entered service in 1982 and has continuously upgraded their system to meet the needs of a growing subscriber base. The third generation of Inmarsat satellites is currently in orbit, and the definition of the next generation is in progress. Inmarsat is a geostationary (GEO) system (see section 4.1) with 9 satellites in total, 4 Inmarsat-2 (second generation) and 5 Inmarsat-3 (third generation). The Earth coverage is divided into four regions: Atlantic Ocean Region East (AORE), Indian Ocean Region (IOR), Pacific Ocean Region (POR) and Atlantic Ocean Region West (AORW). One Inmarsat-3 satellite serves each region with one Inmarsat-2 or Inmarsat-3 satellite (two over the Atlantic Ocean regions) as backup. Some of the primary satellites also serve as backup in another region.

6.1 Inmarsat services

Inmarsat provides services for voice, data, fax, telex, e-mail, high quality audio, compressed video, still video pictures, telephoto, slow-scan television, videoconferencing and telemedicine to a total of 140,000 subscribers (1998) all over the world. The interesting services for Scania's purposes are above all data and e-mail. The data flow between the truck and the home office consists of short text messages, excellently suited for e-mail distribution. Inmarsat provides these services through the Inmarsat-C system.

6.2 Inmarsat-C

The Inmarsat system is divided into a number of different services; Inmarsat-A is for example analogue telephony, Inmarsat-B digital telephony and Inmarsat-E naval distress alarm services. The Inmarsat-C system provides two-way, packet oriented data communications globally. The communications can be either data or message based. The transfer rate to and from an Inmarsat-C terminal is 1200 bps. Reasonably low packet error probability is achieved through interleaving together with ½ convolutional encoding (see section 10 for encoding details). The transfer is also secured with an ARQ protocol based on a 16-bit cyclic redundancy check sum. Security is a critical factor in many Inmarsat-C applications; hence the system communication structure was constructed to support for example distress alarms and delivery acknowledgements.

The terminals are relatively compact and lightweight, a great number of them also support serial communication through an RS-232 port. The mobile antennas are big compared to the small VHF antennas of a "Little LEO" system (see section 4.2). They have to be placed with a clear view of the sky to establish a good connection with the distant satellites. This raises a security problem; a thief should not be able to break the satellite connection by destruction or covering of the antenna.

6.3 Inmarsat-C services

- **Two-way messaging** – The text messages in Inmarsat-C messaging can consist of a maximum of 32 Kbytes (1024 data packets).
- **Data reporting and polling** – Inmarsat-C provides the possibility to send data packets with a maximum length of 32 bytes. Polling allows the home office to interrogate the truck terminal at any time and thereby trigger automatic transmission of required data, for instance position data or oil pressure.
- **Position reporting** – Inmarsat-C is designed to be integrated with a position-reporting system such as GPS or dead-reckoning equipment.
- **Enhanced group calls** – Inmarsat-C enables the home office to send messages to a whole fleet of vehicles simultaneously. This could be used for example for road/traffic information.
- **E-mail support** – most of the providers of Inmarsat-C offer the capability to send and receive E-mail over the Internet. This service exists in all the four ocean regions.

6.4 Availability

Inmarsat-C is available globally through the main Inmarsat satellite constellation and Inmarsat Earth stations all over the world. Local providers of Inmarsat-C access exist in a great number of countries and there are over 100 different terminal models from almost 40 manufacturers available on the market.

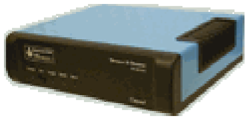
6.5 Inmarsat-C terminal equipment

A great number of manufacturers provide terminal equipment for use with the Inmarsat-C system. I have investigated the market in order to find a suitable unit to integrate with the Scania Vehicle Informatics Platform, SVIP (see section 3). The following is a presentation of the most interesting terminals I have found.

6.5.1 Thrane & Thrane TT-3022C

The Danish manufacturer Thrane & Thrane A/S [31], [33], [36] has developed a compact, ruggedized data communicator for land-mobile applications. The unit supports all Inmarsat-C communication modes. Features of the communicator are:

- 8 channel integrated GPS (12 channel GPS as option)
- 2-way data, fax and e-mail transfer to world-wide destinations
- Programmable sleep mode for power conservation
- RS-232 serial port for PC connection



- Operable in -25°C to +55°C

This communicator looks promising for Scania's SVIP project (see section 3). I have managed to get hold of a unit from an earlier investigation of satellite communications at Scania. For a more thorough evaluation of the unit, see section 8.2

The price of a complete system including transceiver, software, antenna and cables is SEK 22,000. This is the price for one unit and gives only a hint of the actual price if the unit is to be factory installed in Scania trucks. However it is useful when comparing with other units.

6.5.2 Trimble Galaxy TNL7002

The Galaxy transceiver [32], [17] is (according to Trimble) the best-selling Inmarsat-C product in the world. The unit supports all kinds of Inmarsat-C services. Other features are:

- 8 channel integrated GPS
- Supports message mode, polling and data reporting services together with e-mail.
- Password protected access control
- RS-232 serial port for PC connection
- Operable in -25°C to +55°C

The price of a complete Galaxy system including antenna and software is about SEK 35,000. This is way too expensive, probably even by large volumes, to be of interest for SVIP. The unit is bigger, heavier and performs worse than the Thrane & Thrane unit, at least according to specifications.

6.6 Mobile antennas

A mobile antenna has to be lightweight and compact. This, however, leads to two major disadvantages in electrical characteristics, namely low gain and wide beam coverage. The low gain, in turn, means that the satellite has to have a large antenna and a high-power amplifier to compensate for the low performance mobile unit. It also sets the limits for transfer rates of the air interface. The wide beam coverage is both positive and negative: the antenna is transmitting and receiving in all directions, meaning that it possibly interferes with other radio equipment in the area. The positive part with this is that the antenna can be pointed in any direction, regardless of satellite position. This is a huge advantage when the antenna shall be mounted on a truck. The antennas used in some voice applications have antennas with higher gain (flat phased array antennas). The problem with such antennas is that they have to be directed towards the satellite. That is done electronically by changing the characteristics of the antenna and thereby “point” towards the satellite. This demands the satellite position to be measured and the array to be steered accordingly, which is expensive and power consuming.

The antennas used for low-rate data applications such as Inmarsat-C are of the type mentioned above. The antennas are omnidirectional, meaning that it is unnecessary to direct them towards the satellite, they only need a clear view of it. Antenna gain is typically 0 dBi for satellite elevations over 5°. The most common design is the quadrifilar helix, which has a well-controlled radiation pattern with acceptable circularity. A typical quadrifilar helix antenna is about 100 mm tall. The antenna usually has integrated RF electronics to minimize feeder losses. The power to operate the electronics is usually provided through the antenna cable.

The GPS antenna, in the case of an integrated GPS, is usually integrated in the Inmarsat antenna base. The antennas usually share one coaxial antenna cable.

Section 6 sources: [18], [3], [6], [17], [12] and [30]

7 ORBCOMM

ORBCOMM [23], [24] was the first commercial system for global data communications. It consists of a number of Low Earth Orbit (LEO) satellites, 35 today – 48 in the near future. This means an effective coverage of the whole earth except for the extreme arctic regions. The system is designed exclusively for packet oriented data communications and it supports TCP/IP for Internet access. Its primary objectives are to provide messaging for control and surveillance of, or communication with, distant places and assets not reachable with conventional communication systems.

7.1 Messages

The communication in ORBCOMM is done through data packets. Here is an example of a typical ORBCOMM communication sequence (see Figure 7.1):

1 A mobile ORBCOMM subscriber creates a message intended for the home office on his laptop PC. Using a common E-mail application, he sends the message to the Subscriber Communicator (SC).

2 The SC transmits the message to an ORBCOMM satellite that receives, reformats and relays the message to a Gateway Earth Station (GES).

3 The GES transmits the message to a Gateway Control Center (GCC). The GCC sends the message to the recipient’s Internet Provider.

4 The receiver connects to his Internet Provider and receives the message.

Messages from the home base to the mobile will, naturally, follow the same path in the opposite direction.

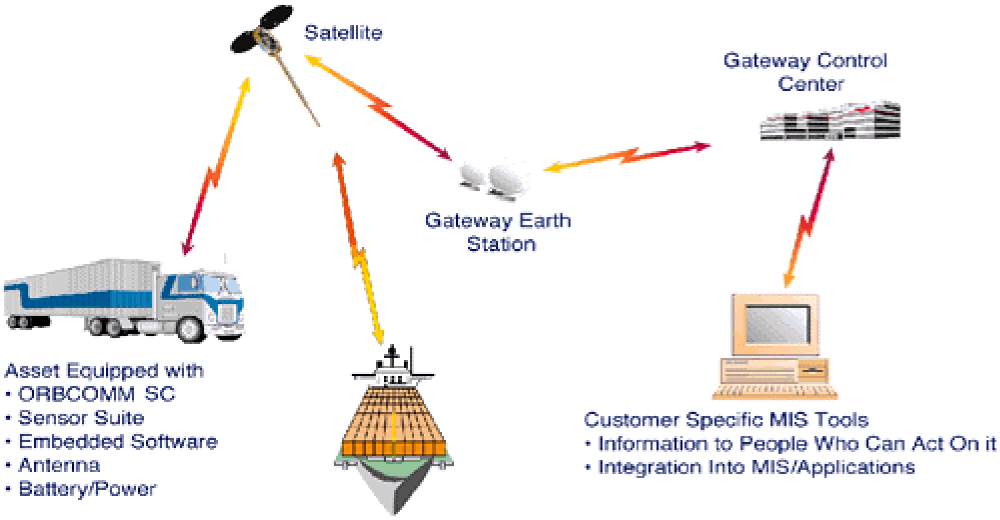


Figure 7.1 – The ORBCOMM Communication Network [22]

7.2 Satellites

The ORBCOMM Satellite constellation will consist of 48 LEO satellites in 6 circular orbital planes as seen in Figure 7.2. The altitudes of the satellites range from 780 to 825 km. Each satellite has a coverage spot with a diameter of approximately 5150 km that moves over the earth as the satellite orbits. The orbit time is about 104 minutes.

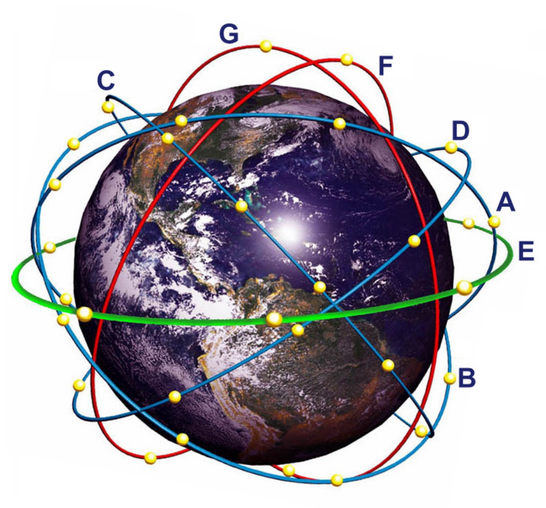


Figure 7.2 – The ORBCOMM satellite constellation [24]

The times between satellite passes will be small as soon as the full constellation is deployed during year 2000. Today's constellation of 35 satellites (only 34 are functional) means that some areas have a low passage rate, sometimes not more often than every 15 minutes. This is the case for example in some parts of northern Scandinavia.

The satellite functions as a relay station between the SC and the GES. Due to the small number of Earth Stations, the satellite will not have a constant earth connection. This is solved by a store and forward mechanism, which stores the messages in an internal memory until a GES can be reached. This is however another source of communication delay.

Satellite Data
Weight: 42 kg Dimensions (deployed): 420 cm × 218 cm Power source: 2 solar arrays, totally 160 W, 14 V Launch system: Orbital Science Taurus, Pegasus XL
Orbits (see Figure 7.2): Planes A, B and C Eight satellites in each plane

Plane D Seven satellites Plane E Planned equatorial launch, late 2000 Planes F and G Two satellites in each plane
Data Rate: 2400 bps subscriber uplink, 4800 bps subscriber downlink

7.3 *Hardware*

One of the advantages with a LEO system is the possibility to use relatively low frequencies in the VHF band for the communications. This means simple and rather inexpensive terminal hardware, as well as small antennas.

7.4 *Terminal equipment*

ORBCOMM has not been on the market for very long, but the huge interest in the system has attracted a great number of different terminal manufacturers. Most terminals on the market have the capability to work as stand-alone units. They are programmable and equipped with a number of digital and analogue inputs to measure various input parameters and can therefore be used in many different applications. One of these units can for example be set up to handle the alarm system in a distant oilrig or the oil pressure in a waterpump engine – only imagination sets the limits. The key issue for a terminal integrated in a PC environment such as SVIP (see section 3) is however the serial interfaces. The terminal has to work as a satellite modem, simply distributing data from the PC to the home office.

I have investigated the market of terminal equipment in order to find a suitable unit for the SVIP project. The following is a presentation of the most interesting terminals I have found. The most interesting units are the Stellar and Panasonic communicators; I have chosen these two for further investigation.

7.4.1 Magellan Satellite Modem

Magellan Corporation has developed an OEM board for use with the ORBCOMM network [21]. Some features of this card are:

- 10 channel GPS
- Serial interface – the board supports the standard ORBCOMM serial protocol
- Byte/Protocol mode – The user can choose whether to let the

board arrange data into ORBCOMM packets or do so before the data is passed to the unit.

- Flow control
- Power control – The board has a power-saving sleep mode.
- Built-in functions – The board has 8 programmable digital I/O ports, the possibility to react to different GPS conditions, for example if the position diverges from the planned route of the vehicle (geofencing), and wake on schedule.
- Development Kit – There is a development kit available with all necessary peripheral equipment included, including development software and antennas.
- Temperature range – operable in -40°C to +85°C

Magellan has an encapsulated version of the Satellite Modem under development. This version will have a rugged housing with power supply. Magellan has not yet applied for ETSI approval of the Satellite Modem. The price is about SEK 5200, less for quantities over 500 pieces. The Development Kit costs SEK 8600.

The Magellan board is an interesting product, but the low flexibility of an OEM board makes it less usable for Scania's purposes. An OEM board has to be encapsulated, either in the SVIP computer or in a separate box. The SVIP computer is intended to be a standardized unit with as few variations as possible to keep down costs. The idea of an optional card to be installed in some units does not comprehend well in this context. The encapsulated version looks promising, but is not yet available. It might be interesting in the future if Magellan gets ETSI approval.

7.4.2 Panasonic KX-G7101 ORBCOMM Data Communicator

Panasonic Industrial Company manufactures a flexible ORBCOMM communicator [25], [35]. The unit has a variety of functions such as:

- 8 channel GPS
- Serial interface – RS-232C compatible serial port
- 128K programmable flash memory
- I/O ports – 2 digital and 2 analog inputs, 2 digital outputs
- Geofencing reports (divergence from planned route)
- Temperature range – Operable in -40°C to +75°C
- Metal housing
- ETSI approved

The price of the Panasonic Communicator is about SEK 7200; a VHF antenna is not included (costs about SEK 500). I have borrowed one of these units from the Swedish

Space Corporation (SSC) for evaluation. For more detailed information about this unit and the evaluation of it, see section 8.5.

7.4.3 Stellar ST2500 ORBCOMM Data Communicator

Stellar Satellite Communications manufactures an encapsulated ORBCOMM communicator designed for flexible use for everything from remote monitoring to trailer tracking [28], [34]. Interesting features are:

- 8 channel GPS
- Serial Interface – 2 RS-232 Ports, 1 RS-485 Port
- 8K programmable flash memory – Optionally 128K
- I/O ports – 6 digital and 5 analog inputs, 6 digital outputs
- Power saving
- Over-the-air configuration programming
- Integrated backup batteries
- Available as OEM board
- Temperature range – Operable in -40°C to +70°C
- Metal housing
- ETSI approved

The price of an ST2500 with everything except the VHF antenna included is SEK 5800 (17-Dec-99).

One ST2500 was purchased for evaluation from Geographia AB. For more detailed information about this unit and the evaluation of it, see section 8.6.

7.5 Mobile antennas

ORBCOMM antennas are very simple in comparison with the antennas used by Inmarsat-C. This is due to the fact that Inmarsat-C satellites have an altitude of 36,000 km, while ORBCOMM satellites circulate only 825 km above the Earth surface. The frequencies used by ORBCOMM are also much lower, located in the VHF band. These facts together give ORBCOMM the possibility to use inexpensive whip/rod antennas for their communications. The antenna height is about 500 mm ($\lambda/4$) for this kind of antenna. Other more complex antenna types exists, an evaluation of them is however yet to be done.

Section 7 sources: [24], [22], [35] and [34].

8 Evaluation

My investigation of the satellite market has led me to three interesting units, two of them using the ORBCOMM system and the third Inmarsat-C. The evaluation I will make includes a comparison between the two satellite systems as well as between the different hardware manufacturers. The characteristics of the satellite systems are quite different, but I have tried to test the hardware as fairly as possible. The main issues to test, evaluate and compare are these:

- **Security** – How certain can you be that your message is passed to the recipient? Is it possible to destroy or obstruct the satellite communication before you steal the truck? The security in means of eavesdropping of the communication is not considered in this evaluation. This potentially important matter must be handled through for example encryption at a later state.
- **Delay** – How long is the transmission time, from issued transmission to reception?
- **Transmission price** – What is the cost to transmit and receive over the satellite system?
- **Hardware price** – How much is the terminal equipment?
- **Hardware size** – A truck might look large from the outside, but the interior volume is very limited.
- **Hardware characteristics** – What does the equipment demand from the truck? This includes for example the power consumption and the temperature range.
- **Hardware durability** – The terminal must survive in the rough environment of a truck cabin for many years.
- **EMC** – The unit may not disturb or be disturbed by any other electronic equipment in or near the truck.

8.1 Inmarsat-C versus ORBCOMM – a competitive analysis

Two of the three communicators (Panasonic and Stellar) uses ORBCOMM, while the third (Thrane & Thrane) uses Inmarsat-C. What are the biggest differences between the two systems? What are the benefits and drawbacks of each system?

To start with, the most important difference is that ORBCOMM uses LEO satellites (see section 4.2) while Inmarsat-C uses GEO satellites (see section 4.1). So how does this affect the mobile terminals and the performance of the system?

A GEO system has, as the name says, satellites that stay stationary in the sky from a terrestrial user’s point of view. The coverage pattern is constant, as is the shadowed areas without a line-of sight contact with the satellite. This means that an immobile truck without a satellite connection will have to move before it can establish such a connection.

If the driver has had an accident and wants to send an SOS alert, this may be impossible. The satellites of a LEO system are moving over the earth and thereby passing the immobile truck sooner or later. The more satellites in orbit, the better is the coverage, or passage rate if you prefer to see it that way.

The GEO satellites are bound to equatorial orbits, while the LEO orbits can be placed anywhere around the earth. This means that the polar regions always have bad coverage in a GEO system, while a LEO system can be extended to true global coverage. However this is however seldom the primary objective of the LEO providers. The subscriber basis is concentrated to Northern America and Europe, and that is where the systems primarily are designed to have their best coverage. ORBCOMM has only planned four satellites in high inclined orbits (the planes F and G in Figure 7.2). That is way too few to provide a continuous coverage of the Polar Regions.

Inmarsat uses frequencies in C-band for Earth Station communications, about 5 GHz. This means a wavelength of about 6 mm. This wavelength is not the optimal when it comes to penetration of constellations of particles such as raindrops. Attenuation due to unfavourable weather conditions is a problem in these high-frequency systems, particularly in the tropical regions. This problem does not exist in ORBCOMM as the VHF frequencies used (about 145 MHz) have a wavelength of approximately 2 m.

The antennas of Inmarsat-C look quite different to those used by ORBCOMM. The ORBCOMM whip antenna can quite easily be integrated in the truck, for example into the wind deflector on the cabin roof. An Inmarsat-C radome on the other hand has to be placed with a free view of the sky. There exists flat alternatives to the cone-shaped radomes; the problem is that they require a more inclined elevation angle to the satellite, about 20° compared to the cone-shaped antenna's -15° (the antenna may be tilted and thereby form a negative angle to the horizontal plane). This is fully acceptable in Continental Europe, but not in the middle and northern parts of Scandinavia.

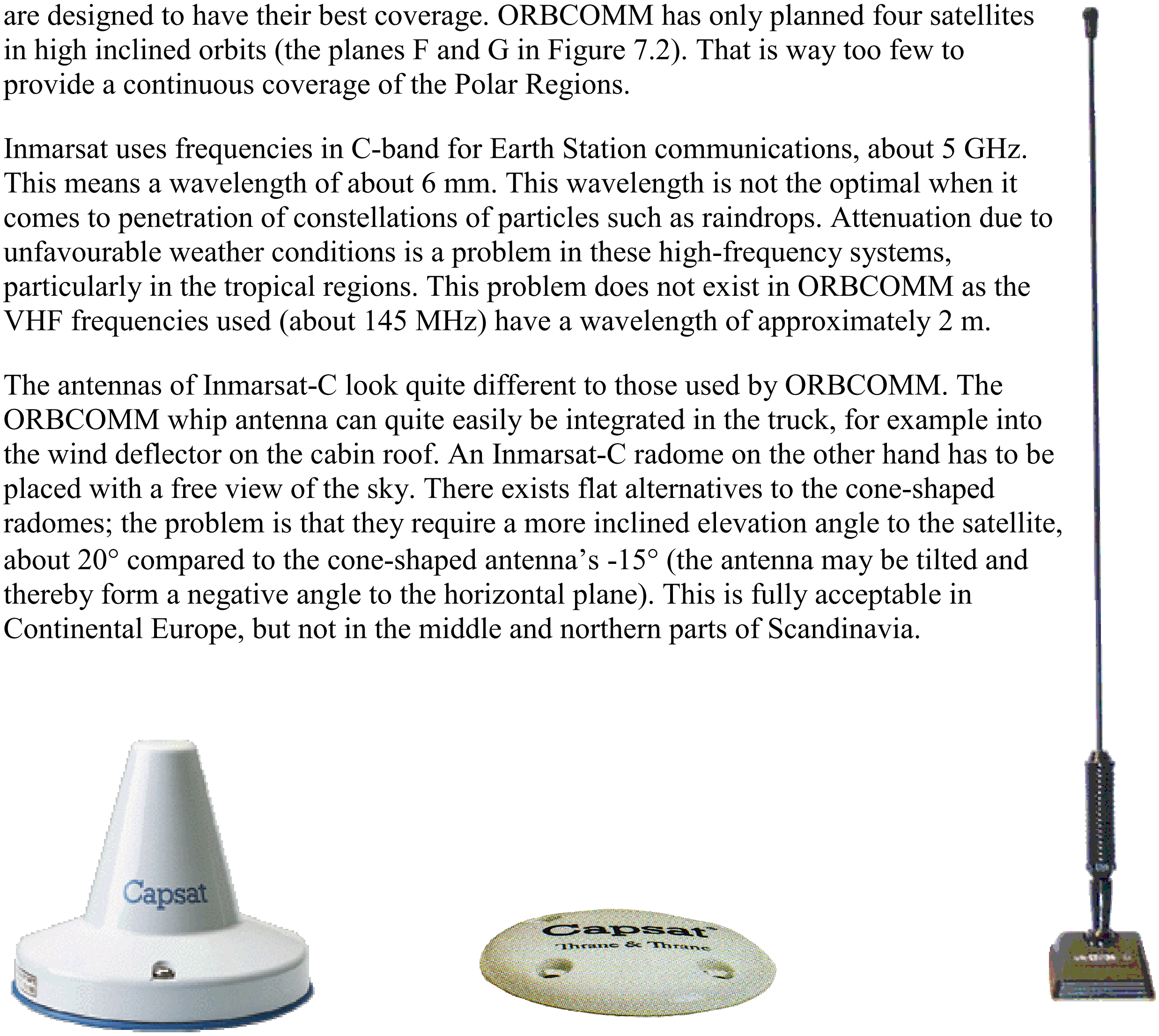


Figure 8.1 – Satellite Antennas. The two antennas on the left are Inmarsat-C antennas with a base diameter of 122 mm. The Cone height is 125 mm. The ORBCOMM antenna on the right has a height of 480 mm.

The traffic pricing in both ORBCOMM and Inmarsat-C is of by-the-byte type, which means that you pay for the data you actually transmit rather than the time you are connected. The costs however differ between the two systems. Inmarsat-C has no connection fee and no monthly costs. You pay only for the data transmitted, or more correctly the frames transmitted. A frame is 32 bytes of data and costs $0.18 (0.5625 cent per byte). You have to pay for every frame you send – a 33-byte message is for example two frames. A message can at the most consist of 1024 frames, both in send and receive direction, for cost security reasons – a large message can raise huge costs. The service providers also allow a user-specific message size limit for the same reason. A data report, for example GPS position, can be fitted in the unused 6 bytes of the initial signaling frame, and is thereby much cheaper.

ORBCOMM has not yet started their customer charging. The prices are to be about 0.4 cent per byte in the future. In addition to this there is a one-time connection fee of $25 and a monthly fee of $15-$20. However the monthly fee is prepaid traffic charges – you may use this amount for communication without extra charge. Notable is that you only pay for the bytes actually transmitted; you are not bound to a frame size as in Inmarsat-C. It will also be possible to pre-pay your traffic charges and thereby get a better price.

8.2 Inmarsat-C

I have found one Inmarsat-C communicator that looks promising for the SVIP project (see section 3). The unit, TT3022C, is manufactured by the Danish company Thrane & Thrane A/S. Thrane & Thrane has more than 200 employees and their products range from satellite base stations to mobile satellite transceivers for land, sea and air applications. Thrane & Thrane has manufactured 50,000 of the 140,000 Inmarsat mobile terminals in operation. The company is also one of the two leading suppliers of access equipment for Global Earth Stations.

TT3022C has the ability to send text messages, reports and data over the Inmarsat-C satellite system. The communication sequence with an Inmarsat-C terminal looks as follows:

1. The user writes a message on his terminal, in this case on the SVIP computer, and passes it to the communicator over the serial interface. The communicator could also be set to automatically generate position or other data reports.
2. The communicator formats the message in 32-byte frames and queues it for transmission. A data/position report fits into the unused 6 bytes of the initial signaling frame.
3. The communicator sets up a connection with the appropriate satellite and transmits the message.
4. The satellite relays the message to the chosen Earth Station; in this case EIK located in Bergen, Norway.

5 The Earth Station sends the message to the desired E-mail recipient. In case of a data/position report it is formatted and sent to a preset destination. The messages can also be passed over telex, fax or X.25 if these methods are preferred.

6 The message passes the desired network, in this case the Internet, and reaches its destination.

8.2.1 Security

If we define security as the necessity for certain messages to reach their destination, Inmarsat-C has a main limitation. As mentioned, the stationary satellites have a stationary coverage pattern. This fact makes the communication from an immobile truck impossible if it is located in a non-covered area.

Another aspect in this context is the best-effort service of E-mail. The providers of E-mail routers and services take no responsibility what so ever for the messages passed through their routers. A message can be delayed, distorted or even deleted. This is however very seldom the case, and can be solved through an appropriate acknowledge procedure. Another way is to use some other type of transmission, for example X.25 for this type of messages.

There exists a third security drawback of the Inmarsat-C system: the antennas. The rather big, characteristically shaped radome of Inmarsat-C has to be placed with a clear view of the sky. The antenna is easy to recognize, easy to destroy and impossible to integrate in for example a wind deflector.

8.2.2 Satellite coverage

Inmarsat has almost global satellite coverage. That is, every point on earth between 78° South and 78° North has an Inmarsat satellite visible above the horizon. This means that a ship between Iceland and Greenland has an elevation angle of 0 degrees to the Atlantic-East satellite. However land-mobile users will seldom have free views of the sky on a 0-degree elevation angle. That makes the coverage map in Figure 8.2 rather optimistic. In the outer parts of the satellite footprint the coverage is usually limited by obstructions.

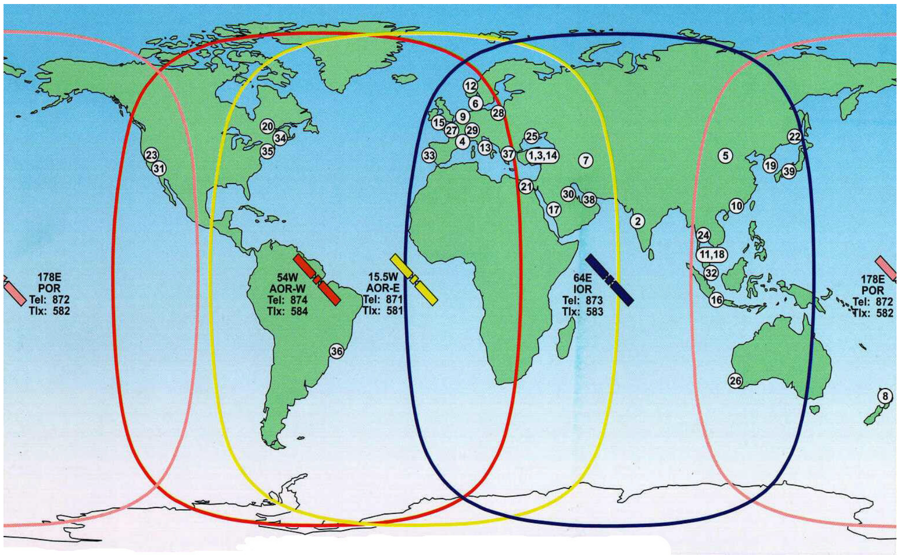


Figure 8.2 – Inmarsat coverage map, 0° elevation mask [36]

8.2.3 Spectral usage

Inmarsat uses frequencies in the C and L bands. These frequencies have been reserved for Inmarsat. The system was introduced already in 1979, before the frequency bands were completely explored by different kinds of radio equipment. The only source of disturbance is military radar transmitters.

Inmarsat satellites of the third generation have the ability to concentrate their radio power on areas with high traffic within its main beam, the footprint. This is done through spotbeams. There can be as many as seven spotbeams within the footprint. Non-adjacent spotbeams can reuse the same portions of the L-band for communications.

8.3 Thrane & Thrane TT3022C

The equipment used for the evaluation is this:

Equipment	**Unit**	**Provider**
Communicator	TT3022C	Thrane & Thrane A/S
Antenna	TT-3005B, integrated GPS	Thrane & Thrane A/S

8.3.1 Technical specification

Interface	Serial Input Port Input/Output Port Printer Port ArcNet Interface GPS Port	RS-232, 38 400 bps 2 bit (TTL) 4 bit (TTL, open collector) Centronics ATA/ANSI 878.1 NMEA 0183
Up-link (Transmit)	RF TX Power Frequency Modulation Data rate	5 W 1626.5 to 1660.5 MHz BPSK 1200 symbols/sec 600 bps
Down-link (Receive)	Frequency Modulation	1525 to 1559 MHz BPSK 1200 symbols/sec 600 bps
Position Determination (GPS)	Method Accuracy	8/12 ch parallel <100m 2D rms
Temperature	Operation Storage	-25 to +55°C -40 to +80°C
Mechanical Vibration Enclosure	Vibration Shock Dimensions Weight	Random 5-20 Hz 0.005g^2/Hz, 20-150 Hz -3dB/Oct. (0.5g rms) Half sine, 20g/11 ms 180×165×50 mm 1300 g (+antenna 750 g)

Source: [33], [31], [36]

8.3.2 Transmission delay

The Inmarsat-C transceiver has to have an unobstructed view of the satellite to be able to send messages. This proves to be the key issue when communicating in the Inmarsat-C network. The measurements made on the Thrane & Thrane transceiver therefore focused on the signal strength of the satellite beacon signal. The transceiver measures this signal strength every two seconds and grades it in six steps where 0 means no signal and 5 means direct, unobstructed contact with the satellite. This value can easily be read out with terminal commands on the serial interface. I wrote a simple program in Visual Basic that logs this value to a Microsoft Access database and plots the readings in a graph as well as calculates characteristic parameters. The example in Figure 8.3 was logged during a 40-minute trip between Södertälje and Kista in Sweden. The route is mainly South-

North along E4, which means a rather good environment for the communication without the problem of obstructing buildings or trees.

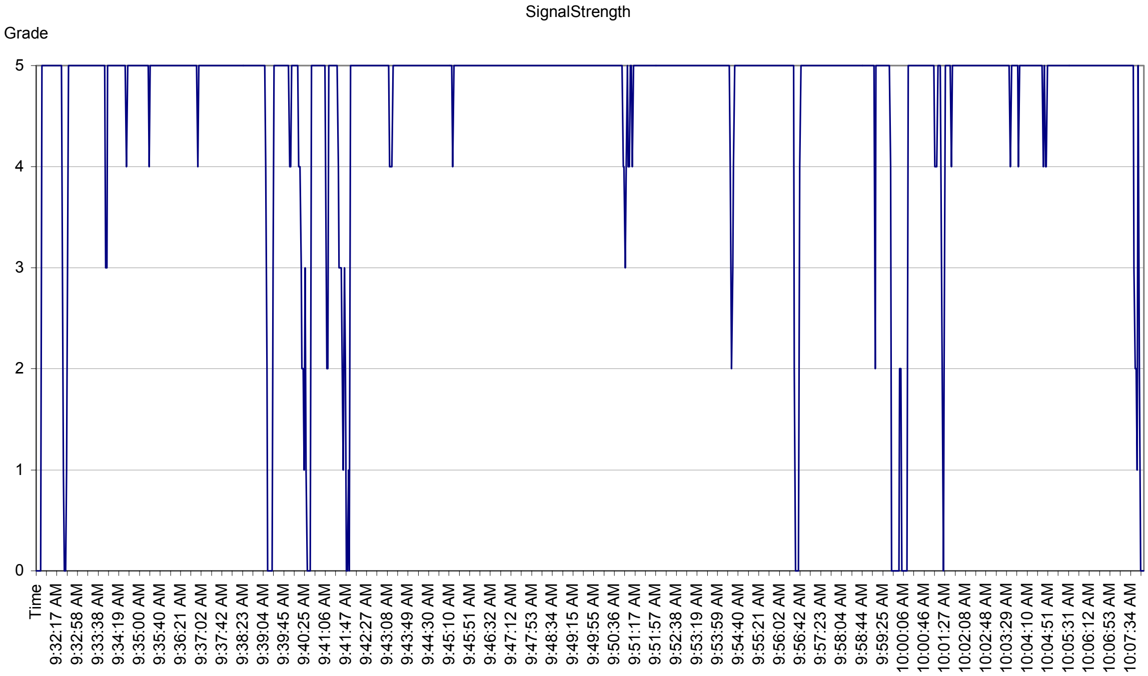


Figure 8.3 – Signal strength characteristics, Södertälje – Kista

As seen the signal strength and therefore satellite contact is mostly sufficient for communications. If we assume that a reasonably good satellite connection has a grade of 3 or above, some interesting parameters can be calculated from the data visualized above. The total measurement time is 2146 seconds. 132 of those seconds have signal strength below 3; this means 6.1% of the time. The longest duration of such a signal strength loss was 32 seconds. This result might look extremely good, and in fact it is. As mentioned above, the test environment is very suitable for this system. A test in a more demanding environment gives a bit more extensive results. Figure 8.4 shows the signal strength variation during a trip in Roslagen northeast of Stockholm. The road types are evenly mixed, from large highway to small forest road. Total duration of the measurement was 6560 seconds. 622 of those (9.4%) had signal strength below 3. The longest duration of a signal loss was 64 seconds.

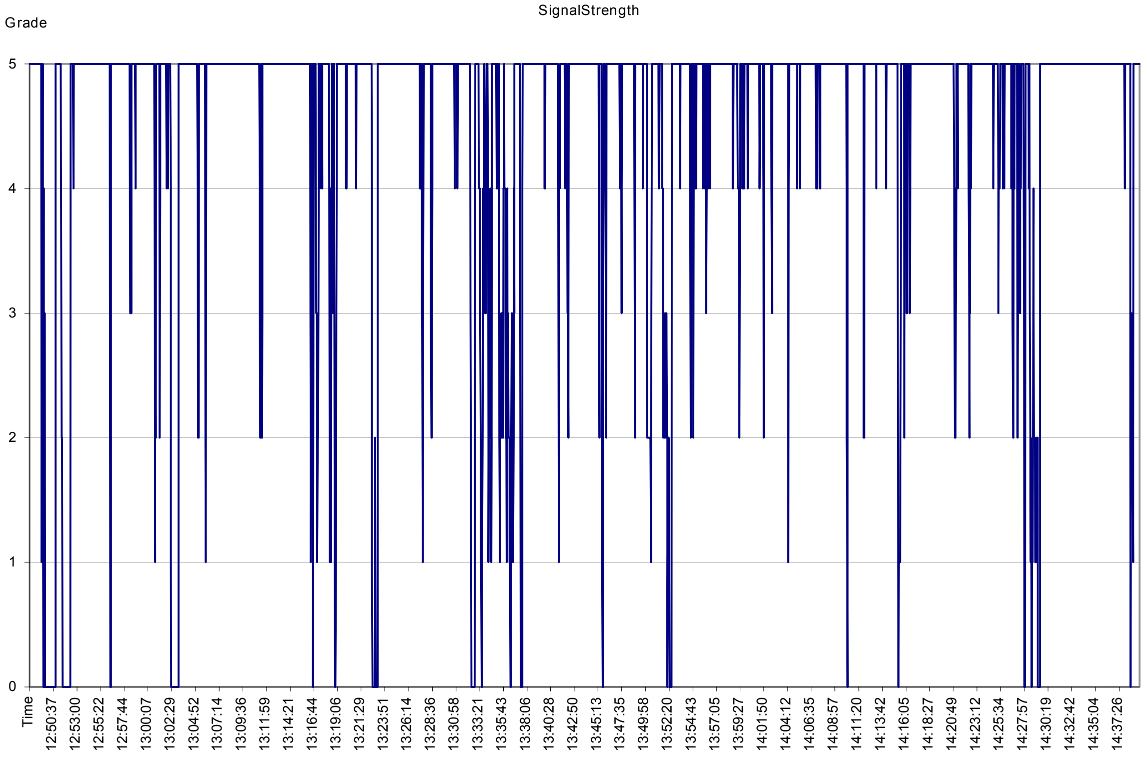


Figure 8.4 – Signal strength characteristics, Roslagen

The most demanding environment was of course the narrow forest road. Figure 8.5 shows the signal strength variation during this part of the trip. The diagram is cut from the logger application and shows the signal strength average since the last diagram point, the logger actually measures every two seconds. This is the reason for the decimal values. The effect of obstructing trees is obvious, what however is interesting is that the signal strength peaks are sufficient for communication and that they occure with relatively short intervals.

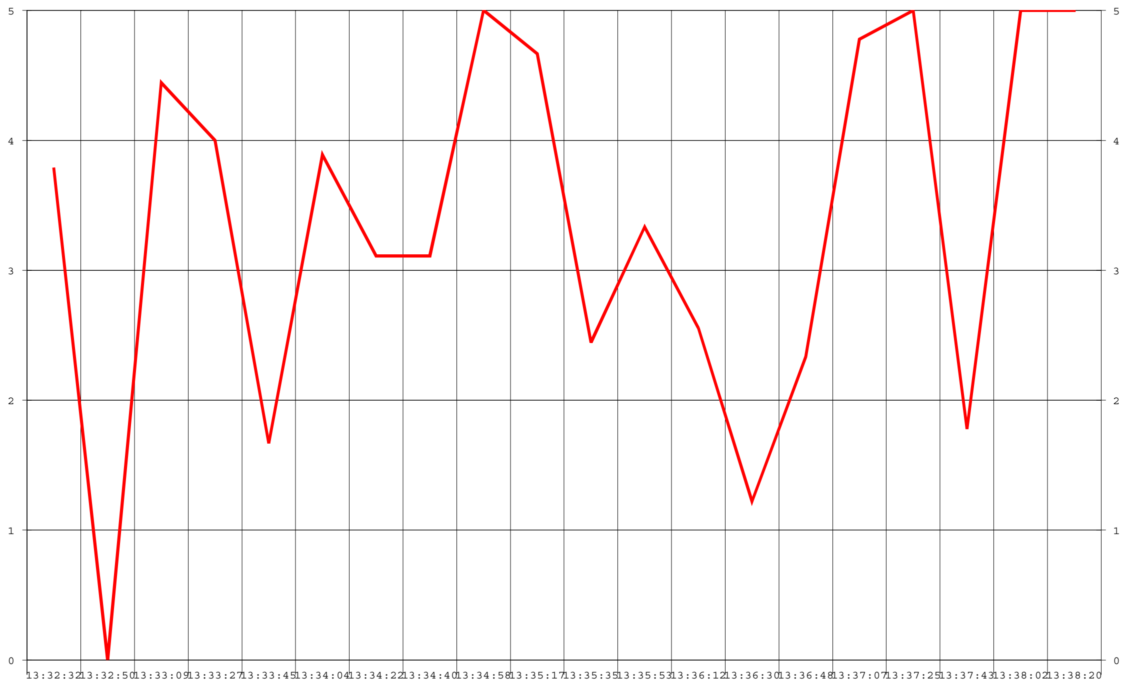


Figure 8.5 – Typical forest road signal strength characteristics

The last measurement scenario is a round trip in the inner city of Stockholm. This environment is very unsuitable for the Inmarsat-C system, with tall obstructing buildings and narrow streets. SVIP (see section 3) is designed to use GSM/GPRS for the data traffic in these areas. However the customer has the possibility to choose satellite communication only. Figure 8.6 shows the signal strength variations during this trip. The total measurement time was 3204 seconds, whereof 2800 (87.3%) had a signal strength grade below 3. The longest duration of a beacon signal loss was 14 minutes and 30 seconds. This grade of service is not sufficient for the SVIP communication needs, but the system is intended to use GSM in this environment in any case as mentioned above.

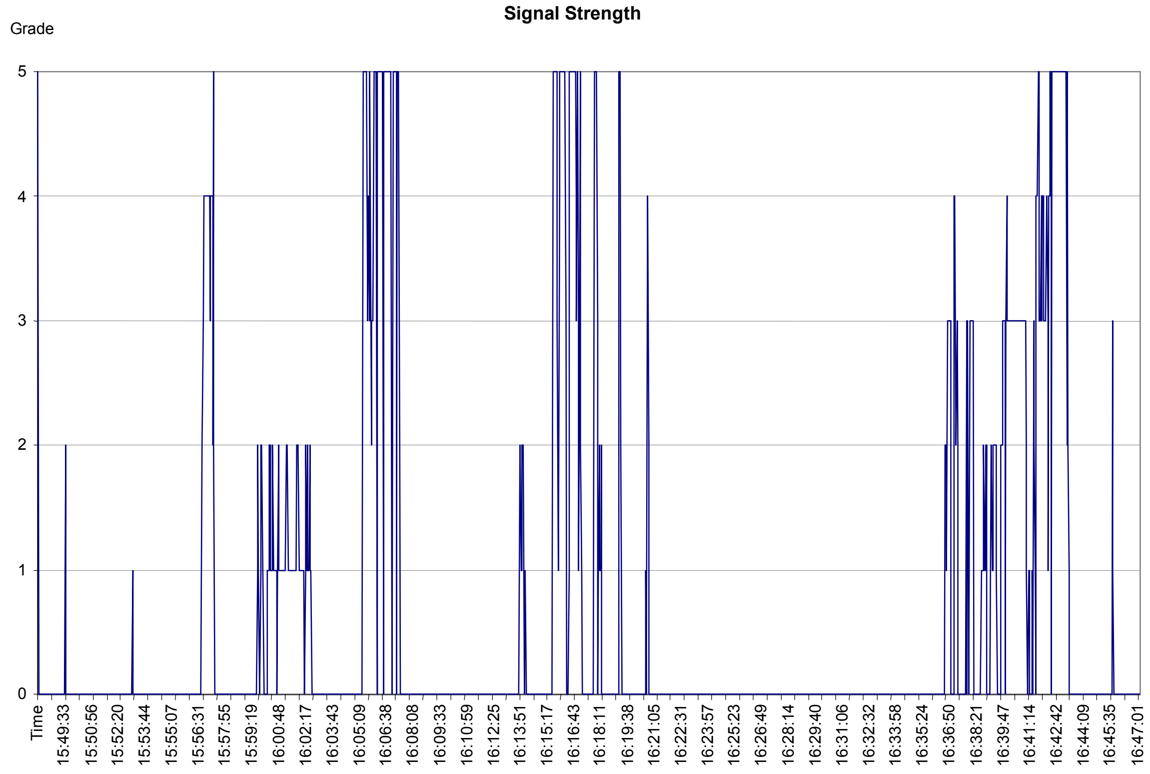


Figure 8.6 – Signal strength characteristics, Stockholm City

These signal strength measurements give us a good picture of the coverage of Inmarsat-C. Then how long are the actual transmission times? The Thrane & Thrane communicator was set up to send a position report every ten minutes and the time from position report queuing to reception was measured. The test route was the one in Roslagen.

The measurement shows that the transmission delay is overall low, rarely over ten minutes. The average delay is less than 4 minutes. See Figure 8.7 for a histogram of the measurement results. The rest legend shows the percentage of measurements with the same or longer delay.

The conclusion from these measurements must be that the Inmarsat-C system and the Thrane & Thrane communicator meets the communication requirements of SVIP. In rural areas where no GSM connection can be established the coverage is good and transmission delay is low enough.

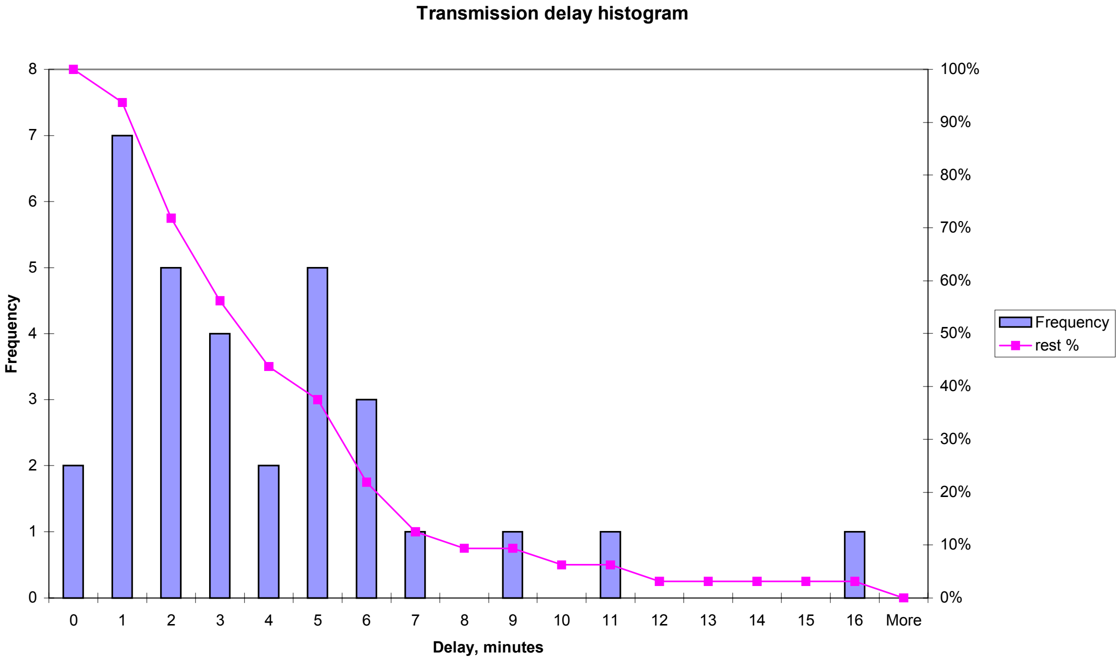


Figure 8.7 – Thrane & Thrane TT3022C transmission delay histogram

8.3.3 Hardware characteristics

The TT3022C can be powered with 10 to 32 VDC, and it does not require constant powering. Inbound messages will be stored at the Earth Station and transferred when the unit is powered. However one should be careful with outbound messages, as they are lost if the power is broken before the messages are sent to the satellite. The unit also has a sleep mode, both timer and event programmable. The power consumption is then lowered. How much depends on the settings of the timers. If the unit is set to wake up every 10 hours to look for an incoming message, the power consumption is only 30 mW on average. This means about 1.25 mA at 24 V, not very much in comparison with SVIP's total sleep mode current which is specified to be 40 mA.

8.3.4 Durability and EMC

The T&T communicator is fitted in a robust metal housing in ISO case (car radio) size. The unit was EMC tested by Scania and found to comply with their demands. The only reservation is that the antenna should be placed as far away from other communication devices and antennas as possible due to the strong emissions in send mode. Remainig are tests for Scania's high demands for vibration, environmental stress (temperature, humidity, dust) and ESD survival.

8.4 ORBCOMM

I have decided to evaluate two different ORBCOMM Subscriber Communicators (SCs): the Panasonic KX-G7101 from the Panasonic Corporation and the Stellar ST2500 from Stellar Satellite Communications in Israel. ORBCOMM uses LEO satellites, which means that the coverage pattern is fluctuating. One important aspect is that every point on earth is passed sooner or later, but the question is how often it is passed. ORBCOMM lets the subscriber choose between several possible solutions for the communications between the Global Earth Station and the final destination, including for example satellite link, leased line, X.25 and e-mail. I have chosen to use the cheapest and easiest solution, e-mail over the Internet.

So, let us start with the communication sequence:

1. The user sends a message via the serial interface to the SC or the SC is set to automatically generate a report, this could be for example GPS position or I/O port status.
2. The SC formats the message in ORBCOMM packets and queues it for transmission.
3. A satellite passes and the SC receives the beacon signal.
4. The SC transmits the message to the satellite.
5. The satellite transmits the message to the Gateway Earth Station (GES). In the case of European traffic the GES is located in Matera, Italy. If no GES is in sight, the satellite stores the message until the connection is established.
6. The GES transmits the message to the Gateway Control Center (GCC).
7. The GCC relays the message to the end recipient.
8. In the case of e-mail, the message passes over Internet and reaches its destination.

8.4.1 Security

The problem with e-mail is that the transmission is not guaranteed, neither in terms of delivery nor delay. The first part of the problem can be solved through acknowledgements, but the second remains. The whole problem could however be handled by letting the GCC take care of security-critical messages. The GCC has 24-hour service personnel for exactly this purpose. The delay because of bad satellite coverage is another security aspect, see heading 8.4.3 below for details.

8.4.2 Spectral usage

The ORBCOMM system uses VHF frequencies in the 137.00-138.00 MHz band (downlink) and the 148.00-150.05 MHz band (uplink). This together with the relative short distances between SC and satellite means that the antennas can be made small and that they are well suited for integration. The frequencies used are insensitive to weather conditions. A problem is however the use of these frequencies for different national radio services and meteorological applications. ORBCOMM has measured the disturbance from other transceivers in these spectrums and found that the problem is smaller than first expected. The ORBCOMM satellites measure the disturbance level and tries to predict which channels are currently unused. The disturbance prediction algorithm has shown 95 percent accuracy in practical tests. Known disturbance sources such as the meteorological applications mentioned above can be avoided in different ways, for example by lowering the data rate and thereby the band usage when a weather satellite is close.

8.4.3 Transmission delay

The transmission delay consists of two parts:

- Delay because of bad satellite coverage
- Internet delay

In Europe, more specifically at latitudes between 20° and 60° north and south of the equator, the coverage is almost continuous. The theoretical delay between SC and GCC is in this case about 30 seconds. North of the 60°N latitude and south of the 60°S latitude the coverage is more sporadic. ORBCOMM specifies the gaps between satellite passes to be a few minutes, more the further north/south you go. See section 12 for detailed pass prediction examples. However coverage does not automatically mean that you see the satellite. The problem of obstructing objects such as buildings and trees encountered in the Inmarsat-C evaluation exists here too.

Another limitation is the lack of GESs in the polar areas. The fact that a satellite is in sight does not mean that the satellite can transfer the message to the Earth Station at once. If the message is destined for example to the GES in Italy, a polar satellite passing northern Sweden on its way north around the globe will store the message for as long as an hour until Italy is passed. Registering the Subscriber Communicator in more than one GES could shorten this delay. The satellite can then transmit the message to any of the registered GESs.

The gaps in satellite coverage on and around the equator are of another type. The problem is that the simple VHF antennas used has no lobe in the vertical direction. This means that the contact is lost when the satellite passes directly above the antenna. Using another type of antenna could of course prevent this.

The Internet delay is the time it takes for the mailed message to travel from the GCC to its final destination. This delay is very unpredictable and can only be expressed through statistical models. The typical value is a few seconds to a few minutes.

8.5 Panasonic KX-G7101

The Swedish Space Corporation, who also is the Swedish ORBCOMM provider, distributes the Panasonic SC in Sweden [25], [35]. I have borrowed one unit from them in order to evaluate its capabilities. The antenna used is a mobile VHF antenna with magnetic mount from Carant AB.

This is the equipment used for the evaluation:

Equipment	Unit	Provider
Communicator	Panasonic KX-G7101, revision F	Swedish Space Corporation
VHF Antenna	Whip antenna with magnetic mount, cut to 146 MHz	Carant AB
GPS Antenna	Panasonic KX-GNA04-G	Swedish Space Corporation

8.5.1 Technical Specification

Interface	Serial Input Port Output Port Analog Input Power Control Status Monitor	RS-232 2 ch (TTL) 2 ch (TTL) 2 ch, 8 bit (0 to 3.3 V) 1 ch (SW) 2 ch (TTL)
Up-link (Transmit)	RF TX Power Frequency Modulation	5 W 148 to 150.05 MHz, 819 ch SDPSK 2400 bps
Down-link (Receive)	Sensitivity Frequency Modulation	-118 dBm at BER 1E-5 137 to 138 MHz, 399 ch SDPSK 4800 bps
Position Determination (GPS)	Method Accuracy	8 ch parallell <100m 2D rms
UTC time pulse (GPS time)	Pulse period timing accuracy	1ms pulse every second 1 µs
Temperature	Operation	-30 to +75°C

	Storage	-40 to +85°C
Mechanical Vibration **Enclosure**	Standard Shock Dimensions Weight	SAE J1455 4.9G 220×90×33mm 660g

Source: [25], [35]

8.5.2 Transmission delay

The transmission delay is, exactly as in the Inmarsat case, dependant on the satellite coverage as well as other factors such as Internet delay. The signal strength is however not as easy to measure as with the Inmarsat-C equipment. I have decided to measure only the total transmission delay, this is after all the most interesting parameter.

The delay was measured by setting up the Panasonic Communicator for position reports every 15 minutes. The time was measured from queued reports (the report completion takes about a minute in the SC due to GPS position calculation) to message reception in the destination mailbox. For a graphical presentation of the measurement result, see

Figure ***8.8***. The rest legend shows the percentage of measurements with delay longer than or equal to the current value. The measurement was performed on a test route in Roslagen northeast of Stockholm, Sweden. The road types vary from a large interstate highway to narrow local road. The obstruction density is varied and the weather conditions reach from clear sky to heavy snow. The route is the same as for the Thrane & Thrane unit and the units were tested simultaneously.

The transmission delay average is less than 6 minutes, with only a few peaks above 10 minutes. On many occasions the transmission times are even below 1 minute, close to the theoretical minimum of 30 seconds.

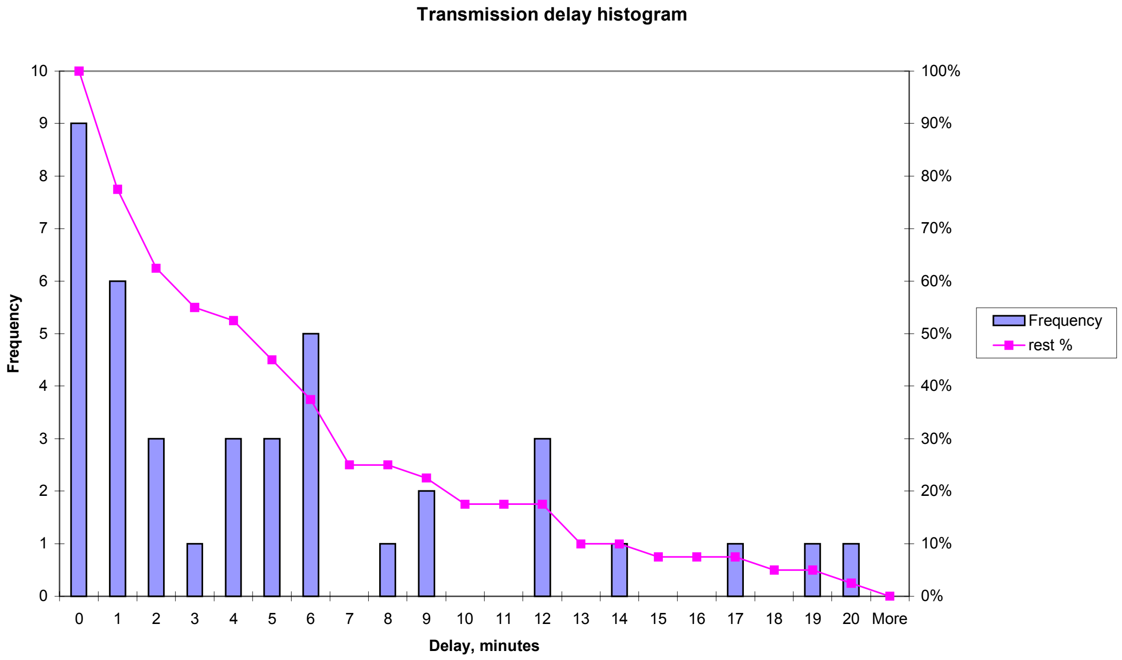


Figure 8.8 – Panasonic KX-G7101 transmission delay histogram

8.5.3 Hardware characteristics

Panasonic's equipment does not have to be powered when the truck is shut off and no messages are to be sent. Incoming messages will be stored at the GCC and transferred when the communicator is powered on again. Outgoing messages are stored in the unit's non-volatile memory and are not lost when the unit is disconnected. Panasonic has also equipped their unit with an intelligent sleep mode for power conservation. The Communicator powers down automatically and stays asleep until wake-up is raised. This is done when the timed report mode or a timed message poll is activated. If a message is due to be sent, the unit stays asleep until a satellite pass is predicted, then it wakes up and performs the send operation or message poll before it goes to sleep again. In order to predict satellite passes, the Communicator downloads orbital elements from the satellites. The Communicator downloads a new element when the old one is obsolete, normally every 672 hours. However the power consumption is low at all times. Table 8.1 shows the power source current at 24 V for different modes of operation.

Sleep Mode	1.2 mA
Idle	115 mA
Receive	120 mA
Transmit	0.7 A

Table 8.1 – Panasonic KX-G7101 power consumption [25]

The other control units in a Scania truck have a sleep mode current maximum of 1 mA. This means that the communicator can be left in sleep mode for weeks without the need for battery recharge. The whole sleep mode current of SVIP (see section 3) is specified to be 40 mA.

8.5.4 Durability and EMC

The Panasonic Communicator is fitted into a robust metal housing and follows the SAE J1455 environmental standard for heavy-duty trucks [7]. This industrial standard sets high demands for vibration, shock and other environmental influence as well as Electromagnetic Compatibility (EMC). The unit has an ETSI approval for sales in Europe. The unit still has to be approved in Scania's own tests for vibration, environmental disturbance (heat/cold, damp and dust), ESD and EMC before it can be factory mounted in a Scania vehicle.

8.6 Stellar ST2500

Stellar Satellite Communications Ltd. is located in Bene Beraq, Israel. The ST2500 is a brand new ORBCOMM communicator with a very flexible construction. The base of the unit is the ST2500 OEM board. The board can be extended with optional equipment such as GPS card, backup batteries, extra flash memory and metal case. The configuration interesting for SVIP (see section 3) is in the first stages a fully equipped unit in a metal housing.

This is the equipment used for the evaluation:

Equipment	**Unit**	**Provider**
Communicator	Stellar ST2500	Geographia AB
VHF Antenna	Whip antenna with magnetic mount, cut to 146 MHz	Carant AB
GPS Antenna	Trimble	Geographia AB

8.6.1 Technical Specification

Interface	Serial	2 RS-232 optional RS-485
	Digital Input Port	6 ch (TTL/optocoupler)
	Digital Output Port	6 ch (TTL/optocoupler)
	Analog Input	5 ch, 8 bit

	Power Control LED indicators	1 ch, 3A 2
Up-link (Transmit)	RF TX Power Frequency Modulation	5 W 148 to 150.05 MHz, 819 ch SDPSK 2400 bps
Down-link (Receive)	Sensitivity Frequency Modulation	-116 dBm (BER 10^{-5}) 137 to 138 MHz, 399 ch SDPSK 4800 bps
Position Determination (GPS)	Method Accuracy	8 ch parallell <100m 2D rms
I/O Processor Application development environment	Program memory Data memory Programming language	8K (128K optional) flash 512B (4K optional) RAM and EEPROM C
Environmental specifications	Operational temperature Humidity Corrosion and vibration	-40 to +70°C (85°C optional) 95%, 40°C SAE-J1455
Internal battery (optional)	Type Capacity Operating temperature Charging temperature	Lead Acid 8V, 2.5 Ah (12V optional) -60 to +60°C -40 to +60°C

Source: [28], [34]

8.6.2 Transmission delay

The Stellar and the Panasonic units are very similar in this regard. This is maybe not so very surprising as they use the same satellite system and transmitters/receivers with about the same characteristics.

The measurement was made in the same way as with the Panasonic unit. The Stellar communicator was set up to send a position report to the home office every 15 minutes. The total transmission time, from report queuing to e-mail reception was measured. The results are shown in Figure 8.9 as a histogram. The rest legend shows the percentage of measurements with a value equal to or greater than the current one.

The measurement was made during several trips in various environments in the southern and middle parts of Sweden.

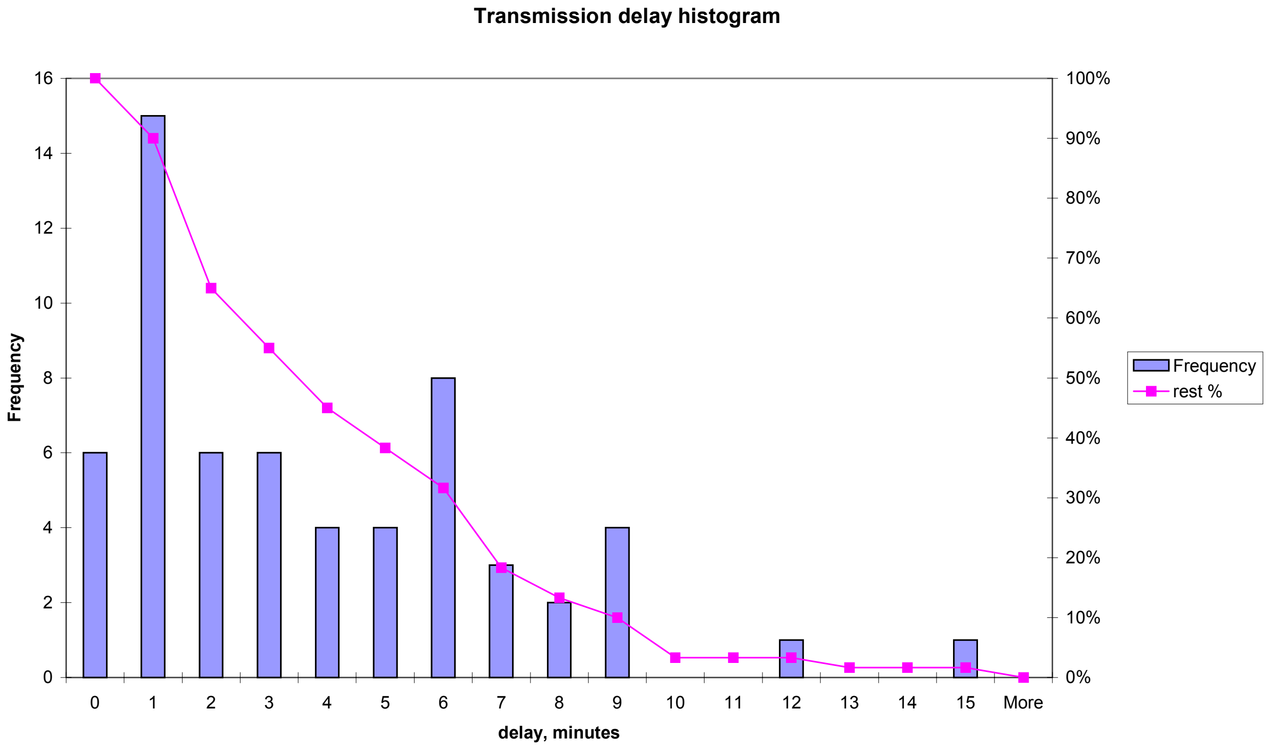


Figure 8.9 – Stellar ST2500 transmission delay histogram

8.6.3 Hardware characteristics

The Panasonic communicator stores the contents of the in- and outbound queues in non-volatile memory to avoid data loss when the unit loses power. Stellar has another solution to this problem: an external backup battery. The unit can be set to function normally on this battery or enter sleep mode as external power is shut off. The sleep mode current is very modest, 100-150 µA (from the 8V battery) depending on if the digital inputs are to be monitored or not. Table 8.2 shows the power consumption for different operation modes of the ST2500. The battery capacity of 2.5 Ah is enough to run the unit in monitoring mode for more than a year.

The battery is charged by an internal charger circuit as soon as the unit is connected to an external power source of 10 to 30 VDC.

Sleep Mode	100 µA
Monitoring	150 µA
Standby	90 mA
Transmit	2.5 A

Table 8.2 – Stellar ST2500 power consumption (8V battery)

The monitoring mode power consumption is very modest in comparison to the overall SVIP sleep mode consumption of 40 mA. The combination with a backup battery also gives the possibility to let the unit stay in standby mode until the battery is empty and then enter monitoring or sleep mode. In this way messages can be received even during a shorter stop, for a maximum of about 24 hours. If the unit has to send for example a distress alarm, the unit leaves monitoring mode and transmits using the truck's batteries as power source.

8.6.4 Durability and EMC

The Stellar ST2500 OEM board is fitted in a sturdy metal case. The unit is not hermetically sealed, but it should withstand the environment in a truck cabin. The unit has an ETSI approval for RF emissions and EMC. It is tested according to SAE J1455 for corrosion, shock and vibration.

The unit has still to pass Scania's own tests including vibration, shock, extreme temperature fluctuations, damp, dust, EMC and ESD before it can be factory mounted in any Scania vehicles.

9 System integration

The three units evaluated in the previous section of this thesis are all qualified candidates for serving as backup communication system of SVIP. The next question is if it is easy, or at least possible, to integrate the satellite communication units in SVIP. As we shall see, it is both possible and rather easy. I have implemented an application that takes care of the SVIP E-mail handling. Let us start with a brief description of a part of the SVIP before the integration.

9.1 Fleet Management System client

One of the more important applications of SVIP is FMS, the Fleet Management System. This client-server application handles the exchange of logistical information between the home office (server) and the truck (client). Such data consists of transport orders, acknowledgement of orders, status messages, positions and so on. This system makes it possible for the home office to manage a large fleet of trucks as efficiently as possible, avoiding stops and empty trailers.

The FMS system is today implemented to use the GSM Short Message Service (SMS) for communications. A communication sequence from the client to the server takes place as follows:

1. The FMS client constructs a message and puts it as a text file in the outbox, a folder on the hard disc of the client computer.
2. An external SMS application detects the file in the outbox and picks it up.
3. The SMS application reformats the message and sends it to the servers GSM modem in an SMS message.
4. An SMS application on the server receives the SMS message, reformats it to its prior format and saves it as a text file in the server's inbox folder.
5. The FMS server detects the new message in the inbox and picks it up.

The communication sequence in the opposite direction follows exactly the same steps. The interesting part in this sequence is the steps 2 to 4. The SMS application is an external program that easily can be replaced. The problem is then reduced to an application that picks up a text file from the outbox folder and transmits it. The question is then only how the transmission is to take place.

9.2 Transmission agent

It is desirable that the transmission agent chooses the most effective and least costly way to transmit the message. Which method to use depends of the communication state of SVIP which can be one of the following:

1. SVIP has an Internet connection, either through a GSM dial-up connection, through GPRS or through short-range radio, for example Bluetooth. The message should be sent through E-mail
2. SVIP has no direct connection to Internet. GSM coverage is sufficient. The message should be sent through SMS.
3. SVIP has no direct connection to Internet and no GSM coverage. The message should be sent through the satellite communicator.

The states can be identified as follows:

1 The mail server is pinged. This method works for both dial-up and GPRS connections. It also handles the case of an inaccessible mail server.

2, 3 The GSM signal strength is read with Hayes AT commands sent directly to the GSM modem. A threshold value gives appropriate state.

The problem is now reduced to three communication modules. The code is implemented in Microsoft Visual Basic. The application is intended to run in the background, controlled through an icon in the Windows System Tray. This agent is of interest for its flexibility. Every file put in the outbox folder will be detected and transferred to the destined recipient. This can easily be used for other applications in addition to FMS

9.2.1 E-mail module

The E-mail module uses Microsoft Windows MAPI commands to send the message to a chosen E-mail recipient. The MAPI commands simply pass the message to the existing mail handling application, in the SVIP case that is Microsoft Outlook. The mails are identified through their subject, “E-mail FMS”.

9.2.2 SMS module

The SMS module uses Hayes AT commands to control the GSM modem and send the SMS message. A problem is that different hardware manufacturers have implemented the AT commands differently. The module is constructed to support Nokia’s CardPhone and Ericsson’s GC25. The messages are sent to an SMS-to-E-mail converting server, which sends it to the same recipient as the E-mail module. The messages can be identified at the receiving end through their subject, “SMS message”.

9.2.3 Satellite module

The satellite communicators can be controlled through their serial interfaces. There is no standardized command set; the implementation of the module is completely different for the three units. The module is implemented to support both Thrane & Thrane TT3022C and Panasonic KX-G7101. The implementation for Stellar is a bit more complicated, although possible, as you have to use the ORBCOMM serial protocol. This is however a more effective way to do it, as this protocol is an industrial standard for ORBCOMM communicators and can be understood by both the Stellar and the Panasonic unit.

In the TT3022C case the messages are sent from the Earth Stations as E-mail to the same destination as the E-mail module. The messages are recognized at the receiver through their subject, “Sat FMS”. Panasonic uses another method. The message is sent by E-mail to the units default recipient. With this method is it possible to send messages without having to include the complete recipient address every time. The subject can not be set when using this method; the messages are instead recognized through their originating address.

9.3 Reception agent

The messages are now transmitted to the FMS server through E-mail. What we need now is a reception agent, which receives the messages and puts them as text files in the inbox folder on the server’s hard disc. This agent was written in Microsoft Visual Basic, using MAPI commands for E-mail handling. The different messages are recognized through their subject or originating address as mentioned above.

10 Summary

The idea of turning the truck into a mobile informatics platform with access to different communication possibilities and all the potential applications that can be run on such a platform is certainly an interesting step forward. The platform is intended to be modular; components can be added or removed at will. The satellite component is intended to increase the availability of the platform by providing global access to a communication network. This component is not at all necessary for basic operation, but it can enhance the important messaging services such as alarms or logistical information within the Fleet Management System (FMS).

10.1 Conclusions

The satellite market is soaring. New manufacturers turn up all the time, promising more and more extensive solutions. More thorough research, however, shows that very few of these systems are in service today. The problems of the Iridium system show the difficulty to launch multi-billion projects before the market is actually ready to use the system.

The three different satellite communicators evaluated in this report all have their advantages and disadvantages. The choice of which communicator to use depends only on which parameters you consider most important.

All weighted together, the Stellar and Panasonic ORBCOMM units end up as the most usable units. They are cheaper in price, smaller in size and better designed for the use in a truck cabin. The main drawback with the Thrane & Thrane Inmarsat-C unit is the use of GEO satellites, which prevents the truck from getting a satellite connection in non-covered areas by simply waiting for a satellite to pass. The main drawback with the ORBCOMM communicators is the rather bad passage rate of the satellites. This is however steadily growing better; the ORBCOMM network is still under construction. Hopefully the satellite system will be fully developed in a year or two.

10.2 Future work

The ORBCOMM units have to be integrated in the Scania Vehicle Informatics Platform. Making an API that implements the ORBCOMM serial interface will be the best solution. That way all ORBCOMM communicators can be used without the need to change software.

The chosen unit must be approved and tested by Scania for use in a Scania-developed system such as SVIP. These tests include EMC, vibration, humidity, dust, corrosion and temperature.

The unit shall be tested in a “live” environment together with SVIP hard- and software. The transmission agent described above is useful in one direction: from the truck to the home office. The opposite direction is not as simple, at least not if the unit has a dial-up or SMS connection. How do you know if the truck is reachable through the GSM network? GPRS will solve this problem, as it will be possible to ping the unit to try the connection. This is harder to do with the dynamically allocated IP address of a dial-up connection.

11 Appendix A – Encoding basics

Data transmitted on an air interface, for example over the link between the satellite and the Subscriber Communicator or the Global Earth Station, has to be encoded. This is done to avoid and correct transmission errors. The encoding is performed in several steps where each step has its own purpose. So, let us start from the beginning:

11.1 Interleaving

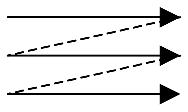
Interleaving does not actually mean encoding. The real encoding is made later, and the purpose is to recover transmission errors. What is then interleaving? The coding has the peculiarity that it can correct one single error, or maybe two or three errors in a row. The problem with channel disturbances and the errors they produce is that they often give birth to a whole burst of erroneous bits. In order to correct such bursts, we have to prevent them from occurring in the actual data, only in the transmitted stream. This is achieved by shuffling the data before it is transmitted and then sort it again as the stream arrives. Let us look at a simple example:

Principle: Erroneous data bursts are spread to different data words
Example: Blocks of 12 information symbols are saved in a two-dimensional matrix. They are written horizontally and read vertically

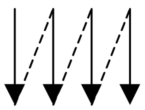
Original data: S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}

The data is written into the matrix horizontally:

S_1	S_2	S_3	S_4
S_5	S_6	S_7	S_8
S_9	S_{10}	S_{11}	S_{12}



Write sequence



Read Sequence

The data is then read vertically and transmitted:

Transmitted data: S_1, S_5, S_9, S_2, S_6, S_{10}, $\boxed{S_3, S_7, S_{11}}$, S_4, S_8, S_{12}

Introduced error burst ↑

The data is then written to the matrix again, this time vertically. The final step is to read the data horizontally to restore the original order:

Sorted data: S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}

Correctable single errors ↑

This small example shows the purpose and the method of interleaving. The small 12-element matrix above can spread error bursts with up to three elements into single errors.

A four-element error burst will however give a two-element error burst by the receiver. A bigger matrix can spread longer error bursts that thereby can be corrected. There is however a drawback with a big matrix (you never get anything for free in this business): A delay is introduced, as the matrix has to be filled before it can be read. This is mainly a problem during real-time applications such as voice traffic in a mobile telephony system. The transmission matrix can only be written as fast as the data arrives. If the application is of non-real-time type, the matrix can usually be written and read very fast and the delay is therefore much less noticeable.

11.2 Systematic encoding

Encoding means that you add information to the data sequence in order to make error recovery or detection possible. The simplest form of encoding is the parity check. Parity means that you add information about the number of "High" bits in a block of data, let us look at a simple example:

Data: 1011011

The parity bit is then calculated as $P_1=B_1 \oplus B_2 \oplus \ldots \oplus B_7$ ($\oplus$ = XOR). This means that an odd number of 1s will give $P_1=1$, an even $P_1=0$. If you merge P_1 with the data word, it means that the total number of 1s always is even (even parity).

Encoded data: 10110111
Parity bit ↑

A word with a single error will thereby have an odd number of 1s and can be detected (but not corrected). A word with two errors will however be undetected with this very simple encoding. If more encoding bits are added, the possibility to correct errors arises. This is the principle of the systematic (non-manipulative) encoding; for example the *Reed-Solomon* codes. These codes do not change the information bits; they only add additional information.

11.3 Convolutional encoding

The convolutional codes are non-systematic, which means that the data bits are changed during the encoding. A usual data stream consists of a number of independent data bits. If one bit is lost, the others have no information about it. The idea of convolutional encoding is to add such information. This is achieved by letting the data pass a transversal filter:

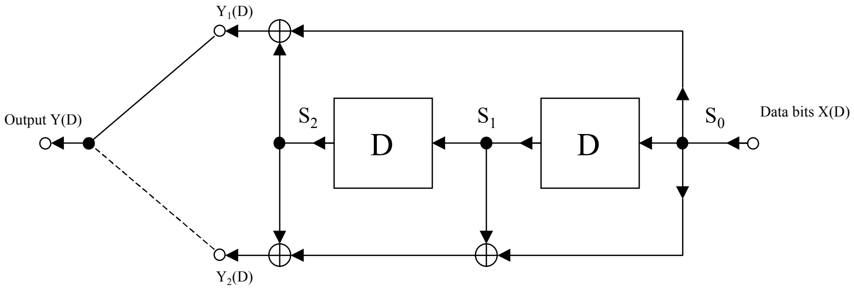


Figure 11.1 – Convolutional encoding transversal filter

Every bit inserted gives birth to two new bits at the other end. This is called ½ convolutional encoding. Another important parameter is the length of the delay chain; this parameter has the value two in the filter above. The output bits are dependent on earlier bits – they carry information about the other bits transmitted. The following state diagram shows the principle of the encoding:

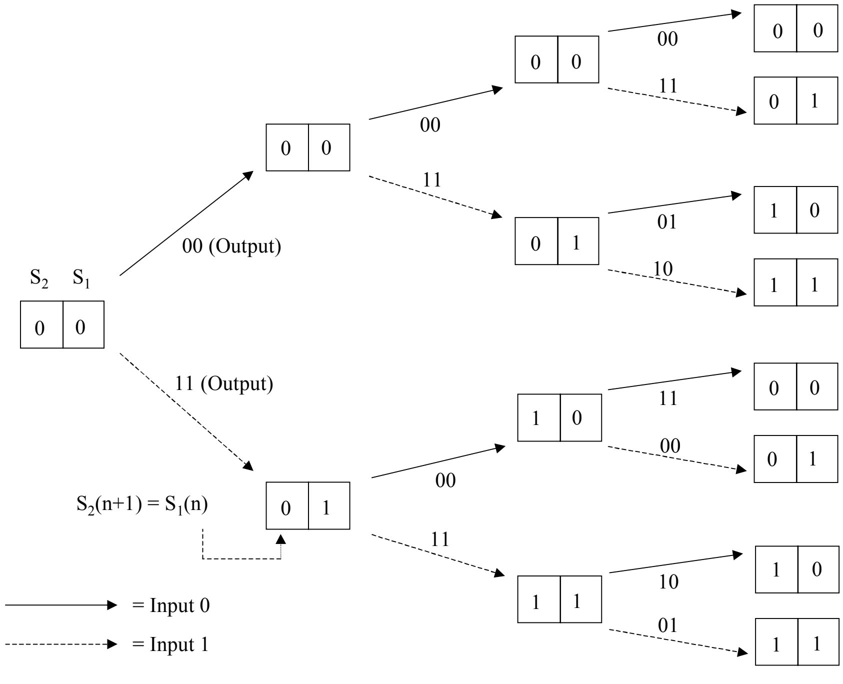


Figure 11.2 – Convolutional encoding state diagram

This diagram can be transformed into the so-called *Trellis Diagram* if the equal states on the right-hand side in Figure 11.2 are put together:

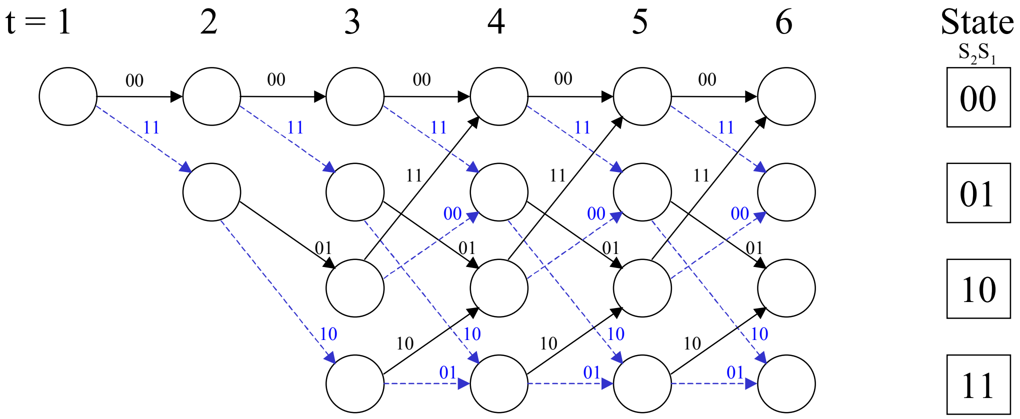


Figure 11.3 – The Trellis diagram

This gives us the bits to send. The question is then: How do we decode the received bitstream? How do we correct encountered errors? The answer to this lies in the Trellis diagram. The receiver simply tracks the path in the diagram and thereby decodes the message. But what if an error occurs? The answer is that the receiver has to track **every** path in the Trellis diagram to see which one that is the most probable. Another way of doing it is the *Vitterbi algorithm*. Every path is then tracked as above, but if two paths lead to the same state, only the "best" in means of bit error or probability will survive, the other one is discarded. After a while, only one path has "survived", hopefully the correct one. Let us look at an example of this, Figure 11.4. The numbers in the circles tell how many bits that differ from the data actually received along the path. If one path leading to a circle implies a higher value than the second does, it is discarded. In the case that they imply the same value, the least probable is discarded. "Least probable" could for example mean the path with the greater total sum of accumulated errors along it.

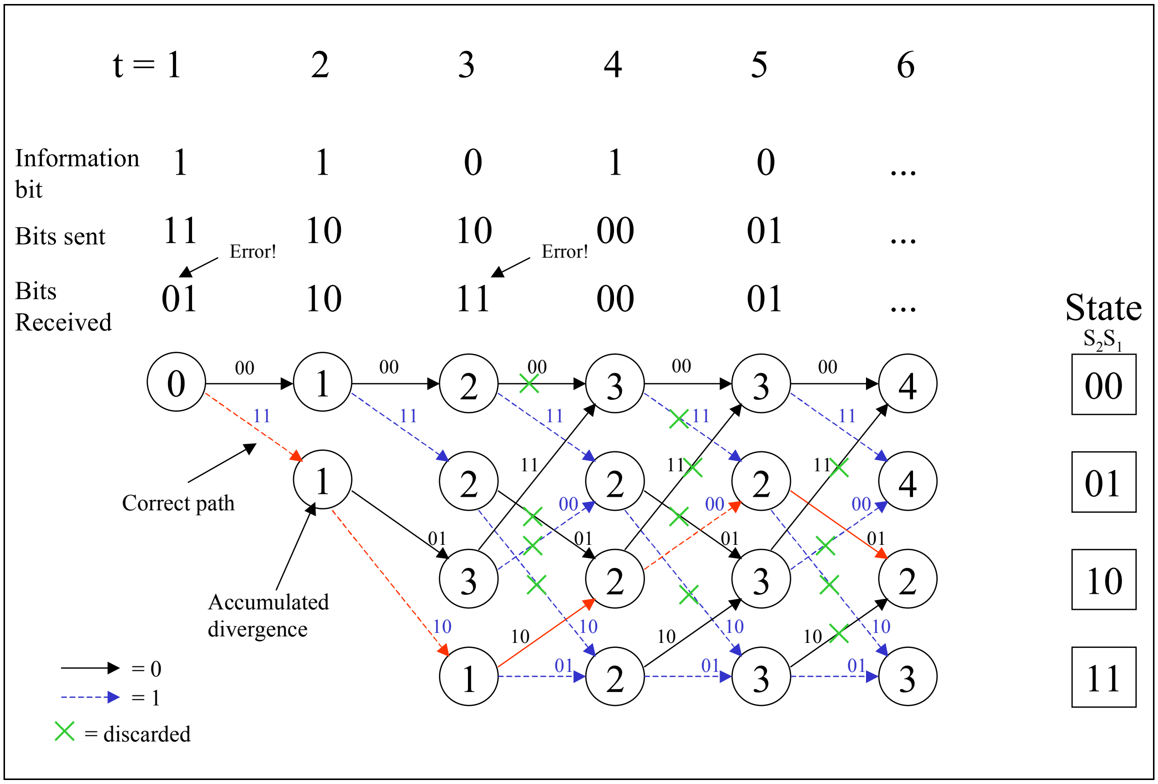


Figure 11.4 – The Vitterbi algorithm

If we track the four paths backward after a while, we will see that they all origin in the same state; this one is the most likely to be correct. As only one path leads to every state, the whole sequence can be unambiguously read up to this point. Let us visualize this by continuing the graph above and remove all the discarded paths:

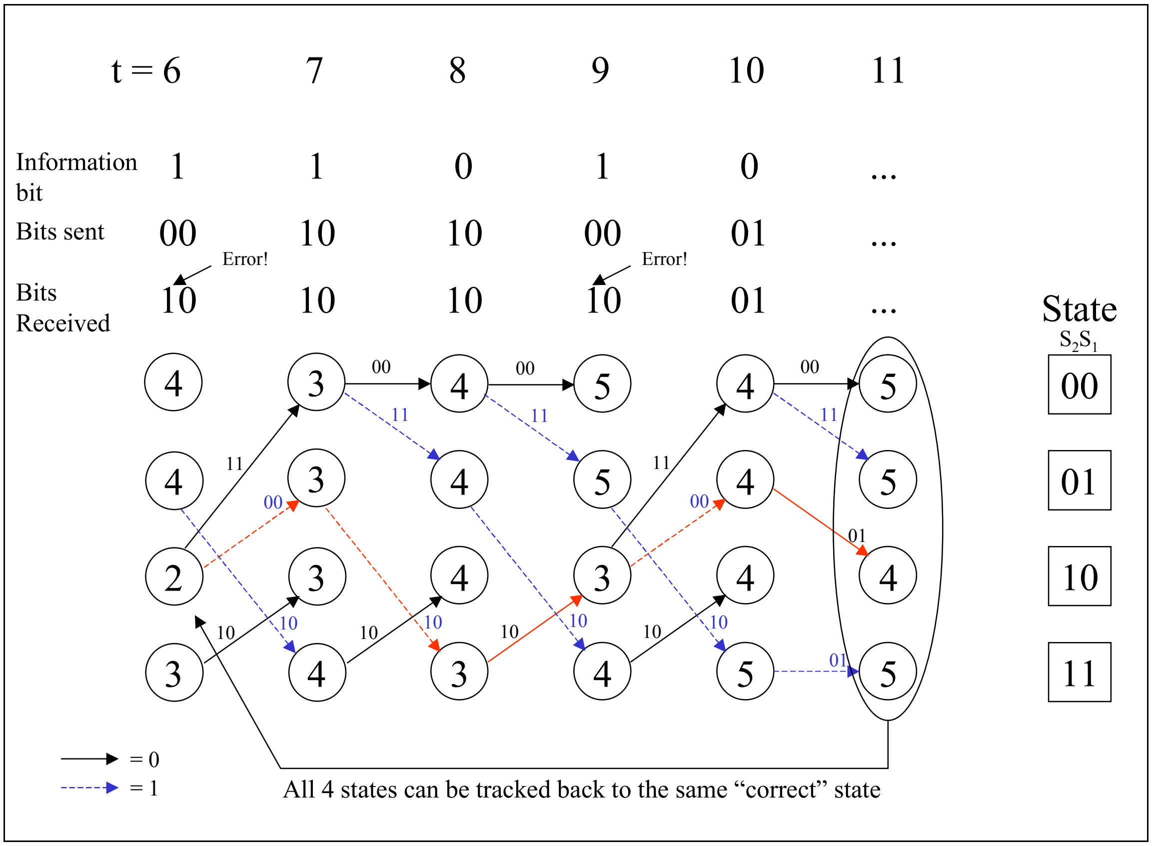


Figure 11.5 – A Completed example of the Vitterbi alghoritm

So, how good are these codes actually? Is it really worth the trouble to encode the data? Let us look a little closer at the actual gain. The codes are as mentioned above characterized through three parameters, (<bits out>,<bits in>,<delay steps>). The code in the above example is a very simple one with the values (2,1,2). The more redundancy that is added, either through longer delay chain or through raised number of output bits, the better is the performance of the code. The bit error probability after the transmission can be approximately calculated as $P_b = 2^{d} \cdot P^{d/2}$, where P is the channel’s bit error probability. The *Hamming distance* d can be read from the following table:

Delay chain length	Hamming distance	Delay Chain Length	Hamming distance
2	5	10	14
3	6	11	15
4	7	12	16
5	8	13	16
6	10	14	18
7	10	15	19

8	12	16	20
9	12		

Table 11.1 – Hamming distance for ½ convolutional codes

If the channel bit error probability is for example 10^{-3}, the coded data will have a bit error probability P_b of approximately 10^{-6} with the very simple code above. If we use a delay chain length of 16 instead, a channel bit error probability of 10^{-3} can be lowered to approximately 10^{-24}.

Source: [8]

12 Appendix B – ORBCOMM satellite pass predictions

The satellites in the ORBCOMM system are of LEO type, which means that they are moving over the earth. The orbits can be mathematically modeled in order to calculate the satellite passes for any location on earth. Here follows a few examples of pass predictions for different earth locations. Active satellites at the calculation time were A1, A2, A4, A5, A6, A8, F2, G1, G2, B1-B8, and C2-C8, a total of 24 satellites. The table headers are defined as follows:

Sat	Satellite code. The initial letter refers to the orbital plane, see Figure 7.2.
Az	Azimuth. The compass azimuth at which the satellite can be seen.
Elev	The elevation angle at which the satellite can be seen.
Dist	The distance to the satellite in kilometers.
Dur	Duration of the pass in minutes.
Next	Time to next pass. 00:00 means no gap between the passes.

Larger coverage gaps are marked.

	Pass Begins at		Peaks at				Ends at			Next
Sat	Local Date/Time	Az	Time	Elev	Az	Dist	Time	Az	Dur.	In
G1	07-Dec-99 09:56	108	10:02	43	36	1138	10:08	322	12	00:00
F1	07-Dec-99 09:57	317	10:03	46	34	991	10:09	112	12	00:00
A4	07-Dec-99 10:06	243	10:11	16	195	1988	10:17	146	10	00:11
A5	07-Dec-99 10:28	245	10:33	15	199	2067	10:38	152	9	00:01
A7	07-Dec-99 10:39	245	10:44	14	200	2113	10:48	155	9	00:00
G2	07-Dec-99 10:46	129	10:53	70	46	874	10:59	323	12	00:00
A6	07-Dec-99 10:48	245	10:52	14	202	2154	10:57	158	9	00:00
F2	07-Dec-99 10:51	318	10:57	76	45	764	11:03	133	12	00:00
A2	07-Dec-99 11:00	246	11:04	13	204	2215	11:09	163	8	00:01
A1	07-Dec-99 11:11	246	11:15	12	206	2274	11:19	167	8	00:01
A3	07-Dec-99 11:21	245	11:25	11	208	2335	11:29	171	8	00:03
A8	07-Dec-99 11:33	244	11:36	10	210	2428	11:40	177	7	00:00

G1	07-Dec-99 11:35	151	11:41	68	237	884	11:48	322	12	00:00
F1	07-Dec-99 11:39	317	11:45	58	238	856	11:51	158	12	00:01
A4	07-Dec-99 11:53	241	11:56	8	214	2570	11:59	188	5	00:16
A5	07-Dec-99 12:16	234	12:18	6	218	2738	12:19	202	3	00:06
G2	07-Dec-99 12:26	175	12:32	36	247	1288	12:38	318	12	00:00
F2	07-Dec-99 12:33	313	12:38	30	248	1308	12:44	183	11	00:32
G1	07-Dec-99 13:16	202	13:21	19	257	1891	13:27	311	10	00:00
B7	07-Dec-99 13:21	146	13:22	5	141	2822	13:23	135	1	00:01

Table 12.1 – Satellite pass prediction, 5° elevation mask; Latitude 59.403°N, Longitude 17.953°E (Kista, Stockholm, Sweden).

The satellite coverage in Scandinavia has large gaps as seen above. The coverage gets worse as you move further north, but the northern parts of Scandinavia also have another problem. The communicator and the Global Earth Station in Italy are not visible from the satellite at the same time. The satellite therefore has to store the message until the GES is passed next time, which could take up to an hour.

	Pass Begins at		Peaks at				Ends at			Next
Sat	Local Date/Time	Az	Time	Elev	Az	Dist	Time	Az	Dur.	In
A2	16-Dec-99 09:01	270	09:07	24	212	1650	09:13	152	11	00:00
G1	16-Dec-99 09:02	24	09:04	6	6	2692	09:06	347	3	00:00
A1	16-Dec-99 09:12	269	09:18	21	213	1737	09:23	157	11	00:00
A3	16-Dec-99 09:23	269	09:28	19	214	1830	09:34	161	10	00:02
F1	16-Dec-99 09:36	335	09:42	39	49	1102	09:48	122	11	00:00
B7	16-Dec-99 09:38	152	09:40	6	133	2705	09:42	113	4	00:08
G2	16-Dec-99 09:50	47	09:53	9	17	2519	09:56	348	6	00:00
B8	16-Dec-99 09:52	165	09:55	9	135	2523	09:58	105	6	00:00
A4	16-Dec-99 09:55	263	09:59	13	220	2169	10:04	177	9	00:00
A8	16-Dec-99 09:57	263	10:02	13	221	2203	10:06	179	9	00:00

B4	16-Dec-99 10:05	174	10:09	11	137	2359	10:13	100	8	00:03
A5	16-Dec-99 10:17	258	10:21	10	224	2406	10:24	189	7	00:00
B3	16-Dec-99 10:21	183	10:26	13	139	2180	10:30	96	9	00:00
A7	16-Dec-99 10:29	254	10:32	8	225	2538	10:35	197	6	00:00
F2	16-Dec-99 10:29	329	10:35	84	57	741	10:41	149	12	00:00
B2	16-Dec-99 10:35	190	10:40	16	142	2032	10:45	94	10	00:00
G1	16-Dec-99 10:37	71	10:41	13	28	2183	10:45	346	8	00:00
A6	16-Dec-99 10:37	249	10:40	7	227	2638	10:43	204	5	00:00
B1	16-Dec-99 10:43	194	10:48	17	143	1954	10:53	93	10	00:00
B5	16-Dec-99 10:49	198	10:54	19	145	1857	11:00	92	10	00:09

Table 12.2 – Satellite pass prediction, 5° elevation mask; Latitude 50.100°N, Longitude 8.670°E (Frankfurt am Main, Germany)

Only 5% of Scania's trucks are sold in Sweden, which means that Table 12.1 might be quite uninteresting. Continental Europe is a far bigger market and also has a great deal better ORBCOMM coverage than Scandinavia, as can be seen in Table 12.2. The gaps between satellite passes are seldom longer than a few minutes.

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