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Architecture of Orbcomm Space Segment for Global Mobile Satellite Communications (MSC) Networks

Dimov Stojce Ilcev[1,*]

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ABSTRACT

This paper introduces the Orbcomm space segment as a wide area packet switched and global two-way data transfer network providing satellite communication, tracking, monitoring and logistics services between mobile, remote, semi fixed or fixed Subscriber Communication Units (SCU) in Mobile Satellite Communication (MSC) and Gateway Earth Stations (GES) or Gateway Control Centres (GCC) accomplished via LEO satellites and Network Control Centres (NCC). Orbcomm Global, L.P., from placeCityDulles, StateVirginia, country-regionUSA equally owned by Teleglobe and the Orbital Sciences Corporation, provides global services via the world's first LEO satellite data and messaging communications system. The US Federal Communications Commission (FCC) granted Orbcomm system a commercial license in October 1994 and the Commercial service began in 1998. Orbital Sciences was the prime contractor for the design project of Orbcomm satellites. The Company owns and operates a network consisting in 36 Little LEO satellites and several GES deployed around the world, connecting small, low-power and commercially proven SCU terminals to private and public networks, including the Internet. Orbcomm delivers information to and from virtually anywhere in the world on a nearly real-time basis to the Terrestrial Telecommunication Network (TTN). The Orbcomm space segment has subscriber transmitters (Tx) that provide a continuous 4.8 Kb/s to 9.6 Kb/s stream of downlink packet data to the receivers (Rx), and vice versa.

1. Introduction.

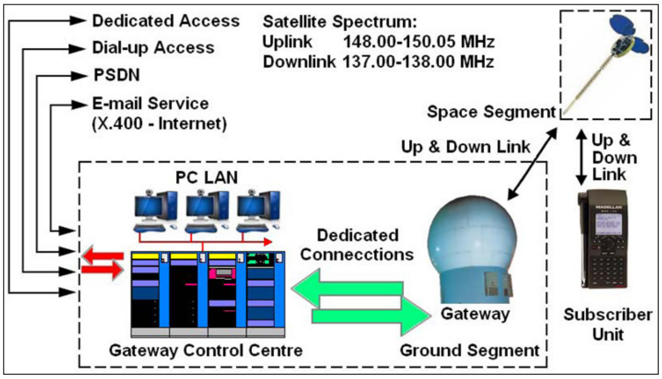
The Orbcomm communication network consists in 36 operational satellites in little LEO orbit at about metricconverterProductID825 km825 km above the Earth's surface. Vital messages generated by a variety of space applications are collected and transmitted by an appropriate mobile or fixed SCU to the Orbcomm satellite. The satellite receives and relays these messages down to one of several GES. The GES then relays the message via certain satellite link or dedicated terrestrial line to the NCC. The NCC routes the message to the final addressee via Internet via E-mail to a personal computer, through terrestrial networks to a mobile subscriber unit or pager and to dedicated telephone or facsimile, see **Figure 1**. Messages originating outside the placecountry-regionUSA are routed through international GCC in the same way to its final destination. In reverse mode, messages and data sent to a remote SCU can be initiated from any PC onboard using common E-mail, Internet and X.400. The GCC or NCC then transmits the information via Orbcomm ground network.

Orbcomm serves customers with fixed and mobile units through distributors and so-called Value Added Resellers (VAR), which provides whole product solutions and customer support to the end-users. Thus, customers from around the world currently rely on Orbcomm for a wide range of mobile and fixed site data applications including:

1. Monitoring and controlling assets at remote or rural sites for oil and gas platforms, extraction and pipeline operations, meteorological centres, water stations, construction and agriculture, satellite SCADA (M2M) control, storage, custody trans-

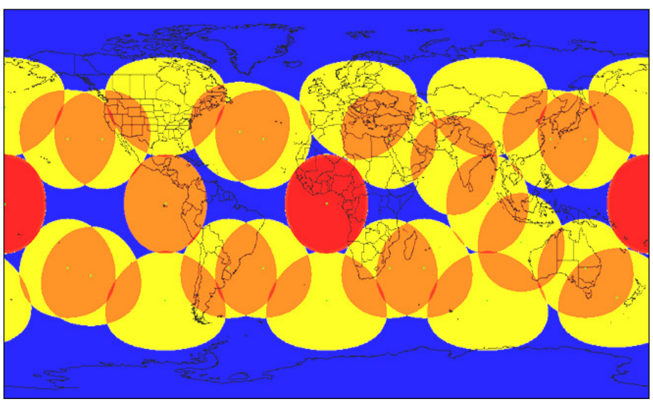
[1]University of Johannesburg, Johannesburg, South Africa.
*Corresponding author: Dimov Stojce Ilcev. E-mail Address: ilcev@uj.ac.za.

Figure 1: Orbcomm System Overview.



Source: Author.

Figure 2: Orbcomm Satellites Coverage.



Source: Author.

fer and electric power generation and distribution;

2. Messaging for truck and bus fleets anywhere, owner operators and remote workers;

3. Tracking and managing construction devices, locomotives, rail cars, trucks, trailers, containers, vessels, aircraft and locating and recovering stolen vehicles and cargo and

4. Weather data reports for general aviation and especially for small aircraft.

The Orbcomm system allows users to track, monitor and manage remote assets via satellite network, which almost global coverage is shown in **Figure 2.** Through a network of LEO satellites and regional GES, users can communicate with their mobile or fixed assets anywhere in the world. Orbcomm is in a position to offer low-cost and high-quality service, which staff is dedicated to fulfilling the specific needs of all potential users.

2. Orbcomm System Redundancy and Operational Frequencies.

The Orbcomm MSC operator has received a license to launch up to 47 satellites. The constellation consists of four planes of eight satellites each inclined at 45 degrees, two highly inclined planes of four satellites each, and one equatorial plane of seven satellites. The amount of time available each day on the Orbcomm satellite network depends on the number of satellites and gateways in operation and the user's location. As the satellites move with the Earth, so does the approximately 5100-km (3200-mile) diameter geometric footprint of each satellite.

Satellite Radio Frequency (RF) downlinks to SCU and GES terminals are within the 137 - 138 MHz band. Downlink channels include 12 channels for transmitting to SCU and one Gateway channel, which is reserved for transmitting to the GES terminals. Each satellite transmits to SCU terminal on one of the 12 subscriber downlink channels through a frequency-sharing scheme that provides four-fold channel reuse. Each Orbcomm Gateway shares the single satellite/gateway downlink channel using a TDMA scheme.

The RF links that connect an Orbcomm Gateway or GES terminal to an Orbcomm satellite are designed to use a single 57.6 Kb/s uplink and downlink channel via the TDMA protocol. This protocol permits simultaneous RF links between a single satellite and several GES installations within the satellite footprint. It also provides a virtually seamless hand-over of a satellite from GES to GES under the centralized control of the GMSS.

In selecting specific channel frequencies, a number of factors have been considered, including the current and future usage of the frequency bands of interest, and the effect on existing and planned systems. The USC RF uplink transmissions to the satellites occur within the 148-149.9-MHz band, thus it transmits at frequencies that are assigned to them dynamically by the satellite.

The Orbcomm satellite receiver complement includes six uplink subscriber receivers, one Dynamic Channel Activity Assignment System (DCAAS) receiver, and one Orbcomm Gateway (GES) receiver. Furthermore, the satellites also transmit a beacon signal at 400.1 MHz. The transmission frequencies for these channels are listed in **Table 1.**

Table 1: Orbcomm Transmission Frequencies.

	No. of Channels	Spectrum	Data Rate
Satellite/Subscriber Downlink Channels	12 available, 1 assigned to each satellite	137-138 MHz	4.8/9.6 Kb/s
Satellite/Gateway Downlink Channel	1 available	137-138 MHz	57.6 Kb/s
Subscriber/Satellite Uplink Channels	6 available, DCAAS assigns the frequency	148-150.05 MHz	2.4 Kb/s
UHF Beacon	1 available	400.1 MHz	-

Source: Author.

3. Orbcomm Space Segment.

Orbcomm communication network consists in 36 first generation operational satellites in Little LEO orbit at about 825 km above the Earth's surface. Orbcomm is also developing second new generation (OG2) satellites, which will also provide new service known as Satellite - Automatic Identification System (S-AIS).

Thus, the main function of Orbcomm satellites is to complete the link between the SCU and the switching capability at the NCC in the USA, or a licensee's GCC in other countries, shown in **Figure 3 (Left).** The Orbcomm LEO satellites are "orbiting packet routers" ideally suited to "grab" small data packets from mobile or fixed sensors and relay them through a tracking Earth station and then to a GCC.

The Orbcomm satellites constantly move, so large obstructions do not prohibit available coverage is in remote rural areas. In comparison, the GSM (cellular) coverage depends on tower location, usually centered on major highways and cities and cannot reach remote areas. Moreover, the GEO satellite system requires large space constructions, costly and power-intensive hardware. Except slow data transfer, large data files (such as graphics) or emergency response latencies are, however, not appropriate applications for Orbcomm.

As mentioned, the last Orbcomm satellite constellation consisted in 36 Little LEO satellites in the following orbits:

1. Planes A, B and C are inclined at 45° to the equator and each contains eight satellites in a circular orbit at an altitude of approximately 815 km.

2. Plane D is also at 45° containing seven birds in a circular orbit at an altitude of 815 km.

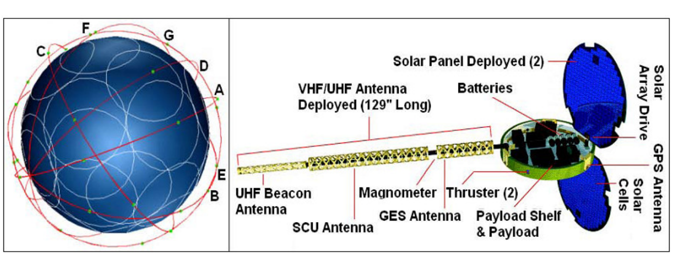
3. Plane F is inclined at 70° and contains two birds in a near-PEO at an altitude of 740 km.

4. Plane G is inclined at 108° and contains two satellites in a near-polar elliptical orbit at an altitude varying between 785 km and 875 km.

5. Plane E is in circular equatorial orbit.

The Orbcomm network depends on the number of satellites and Gateways in operation and the users location. As the satellites move with the Earth, so does the approximately 5100 km diameter geometric footprint of each satellite. This system provides redundancy at the system level, due to the number of satellites in the constellation. Therefore,, in the event of a lost satellite, Orbcomm system will optimize the remaining constellation to minimize the time gaps in satellite coverage. Consequently, the Orbcomm constellation is tolerant of degradations in the performance of individual satellites.

Figure 3: Orbcomm Little LEO Satellite Constellation and Components of Deployed Satellite .



Source: Author.

To date, 36 Orbcomm satellites have been launched, using Pegasus XL and Taurus launch vehicles. Each of the satellites is based on the Orbital Microstar satellite bus. Undeployed, the Orbcomm satellite resembles a circular disk and the spacecraft weighs circa 43 kg, measuring approximately 1 m in diameter and 16 cm in depth. Circular panels hinge from each side after launch to expose solar cells. These panels articulate on the 1-axis to track the Sun and provide 160 W.

The satellites electrical power system is designed to deliver circa 100 W on an orbit-average basis, near its expected EOL in a worst-case orbit. The satellite solar panels and antennas fold up into the disk (also called the "payload shelf") with the remainder of the payload during launch and deployment. Once fully deployed, the spacecraft length measures about 3.6 m from end to end with 2.3 m span across the solar panels disks. The spacecraft long boom is a 2.6 m VHF/UHF gateway antenna. **Figure 3 (Right)** shows the main parts of a fully deployed satellite.

Each spacecraft carries 17 data processors and seven antennas, designed to handle 50,000 messages per hour. Its satellite transponder receives by 2400 b/s at 148 to 149,9 MHz and transmits by 4800 b/s at 137 to 138 MHz and 400.05 to 400.15 MHz. The system uses X.400 (CCITT 1988) addressing and message size is typically 6 to 250 bytes (no maximum). The most important orbital parameters of the Orbcomm constellation are presented in **Table 2.**

Table 2: Orbital Parameters of Orbcomm Spacecraft .

Background	Prime contractors: Orbital Science Corporation
Owner/Operator: Orbcomm Global LP, USA	Type of satellite: Microstar (Little LEO Project)
Present status: Operational	Stabilization: Magnetic with gravity gradient assist
Altitude: 775/739 km	Design lifetime: 4 years
Type of orbit: LEO	Mass in orbit: 43 kg
Inclination angle: 45°/70°	Dimensions stowed: 1.83 x 12.50 m circular
Number of orbital planes: 4/2	Electric/ SSPA power: 135 W (EOL)/ 10 W
Number of satellites/planes: 8/2	**Communications Payload**
Number of satellites: 32/4 Little LEO	Frequency bands:
Coverage: Worldwide	Service/Feeder uplink 148.0-150.05
Additional information: system offers data and asset tracking messaging with 14 GES all over the world	Service/Feeder downlink 137.0-138.0 MHz
	Multiple access: FDMA/TDMA
	Number of transponders: 6 Uplink Rx; 2 Downlink Tx; Ka-band operation
Spacecraft	
Name of satellite: Orbcomm	Channel capacity: 15 Gb/s total data rate
Launch date: Started in November 1998	Channel polarization: Circular
Launch vehicle: Pegasus XL & Taurus	EIRP: Varies over coverage area
Typical users: Global Mobile Messaging Service	G/T: Varies over coverage area
Cost/Lease information: Approximately 900M $	Saturation flux density: High

Source: Author.

The Orbcomm communication subsystem is the principal payload flown on the satellite, consisting in five major parts:

1. Subscriber Communications Section as the main payload part consists in one subscriber Tx, seven identical receivers and the associated receives and transmits filters and antennas. Six of the receivers are used as subscriber receivers and the seventh is used as the DCAAS Rx. The subscriber Tx is designed to transmit an operational output power of up to circa 40 W, although the output is less during normal operations. So, the power of each Tx can vary over a 5 dB range, in 1 dB steps, to compensate for aging and other lifetime degradations. The SDPSK modulation is used on the subscriber downlink at a data rate of 4800 b/s. (It is capable of transmitting at 9600 b/s.). The satellite uplink modulation is SDPSK; with a data rate of 2400 b/s. Raised cosine filtering is used to limit spectral occupancy.

2. The Orbcomm Gateway Communication Section (GES) contains both the Gateway satellite Tx and Rx. Separate RHCP antennas are used for transmits and receives functions. In fact, the Orbcomm Gateway Tx is designed to transmit 5 W of RF power. The 57.6 Kb/s downlink signal to the GES is transmitted using an OQPSK modulation in a TDMA format. The Gateway Rx is designed to demodulate a 57.6 Kb/s TDMA signal with an OQPSK modulation. The received packets are routed to the onboard satellite network computer.

3. The Satellite Network Computer receives the unlinked data packets from the subscriber and the Orbcomm Gateway receivers and distributes them to the appropriate Tx. The computer also identifies clear uplink channels via the DCAAS Rx and algorithm and interfaces with the GPS receiver to extract information pertinent to the communications system. Several microprocessors in a distributed computer system aboard the satellite perform the satellite network computer functions.

4. The UHF TX is a specially constructed 1 W Tx to emit a highly stable signal at 400.1 MHz. The Tx is coupled to a UHF antenna designed to have a peak gain of circa 2 dB.

5. The Satellite Subscriber Antenna Subsystem consists in a deployable boom containing three separate circularly polarized quadrifilar antenna elements.

The Attitude Control System (ACS) is designed to maintain both nadir and solar pointing. The satellite must maintain nadir pointing to keep the antenna subsystem oriented toward the Earth. Solar pointing maximizes the amount of power collected by the solar cells. This satellite employs a three-axis magnetic control system that operates with a combination of sensors, which also obtains its position through its onboard GPS receiver.

Satellite planes A/B/C are designed to maintain a separation of 45° (± 5°) between satellites in the same orbital plane. Planes D/E provide 51.4° spacing between satellites, while highly inclined satellite planes (F/G) are spaced for 180° apart (± 5°). Thus, the springs used to release the satellites from the launch vehicle give them their initial separation velocity. A pressurized gas system will be used to perform braking maneuvers when the required relative in-orbit satellite spacing is achieved. An Orbital Sciences Corporation formation-keeping technique will maintain the specified satellite intra-plane spacing. One of the benefits is that, unlike GEO satellites, it does not affect the satellite's life expectancy in fuel usage.

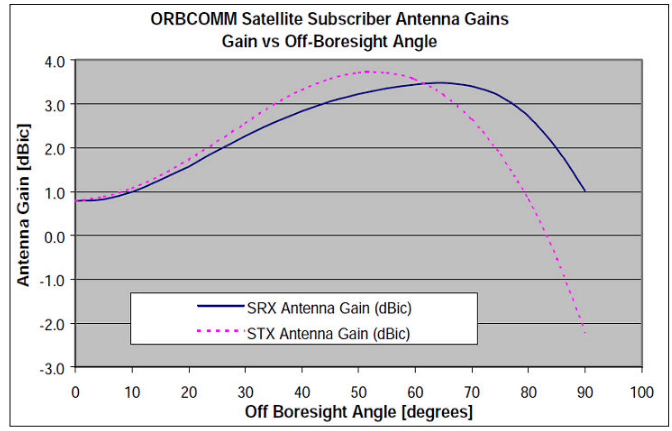
4. Orbcomm Communication Payload.

The communication subsystem is the principal payload flown on the Orbcomm satellite. This subsystem consists of four major parts: the subscriber communications section, the Orbcomm Gateway communications section, the satellite network computer, and the UHF transmitter.

4.1. Subscriber Communication Section .

The Orbcomm subscriber communications section consists of one subscriber transmitter, seven identical receivers, and the associated receive and transmit filters and antennas. Six of the receivers are used as subscriber receivers and the seventh is used as the DCAAS receiver. Therefore, the subscriber transmitter is designed to transmit an operational output power of up to approximately 40 W, although the output is less during normal operation. The power of each transmitter can be varied over a 5 dB range, in 1 dB steps, to compensate for aging and other lifetime degradations.

Figure 4: Satellite Subscriber Antenna Gain Patterns.



Source: Author.

The subscriber transmitter power is controlled to maintain a maximum power flux density (PFD) on the surface of the Earth of slightly less than -125 dB (W/m^2 in 4 kHz).

The output transmitter receives downlink packets from the satellite network computer, modulates and amplifies the signal and feeds it to the antenna subsystem. Symmetric Differential Phase Shift Keying (SDPSK) modulation is used on the subscriber downlink at a data rate of 4800 b/s. Thus, it is capable of transmitting at 9600 b/s. In fact, SDPSK is defined by a "zero" ("space") data state causing a negative 90° phase shift and the "one" ("mark") data state causing a positive 90° phase shift. Raised cosine filtering is used to limit spectral occupancy.

The Orbcomm subscriber receivers are direct conversion Digital Signal Processor (DSP)-driven receivers incorporating a fast Fourier conversion process. The Orbcomm satellite can be configured to have any combination of the seven subscriber receivers act as the DCAAS, random access, or reservation receivers. Each receiver, when selected for DCAAS operation, is designed to scan the uplink band in 2.5 kHz steps in 5 seconds or less. The actual portion(s) of the receiver frequency band used in the DCAAS process depends on which GCC is connected to the satellite. Thus, the remaining subscriber receivers are used to process subscriber uplink traffic.

The subscriber receivers and the Gateway receiver operate through a single uplink antenna. The Low-Noise Amplifier (LNA) associated with SC receivers has been designed to operate linearly in the presence of high levels of interference. Analog and digital filters process the signals after the LNA to reduce the impact of interference due to terrestrial mobile systems on the subscriber receivers. Once received, the subscriber signals are demodulated and routed to the satellite network computer. The uplink modulation is SDPSK, with a data rate of 2400-b/s. Raised cosine filtering is used to limit spectral occupancy.

4.2. Antenna Pattern.

The Orbcomm satellite antenna subsystem consists of a deployable boom containing three separate circularly polarized quadrifilar antenna elements. The Orbcomm antenna patterns with the satellite subscriber antenna gain patterns are shown in **Figure 4.**

The necessary RF power splitters, phase shifters and impedance matching transformers required to feed the various antenna elements are mounted internally in the deployable boom. In the launch configuration, the antenna is folded into a trough measuring approximately 15 x 15 x metricconverterProductID97 cm97 cm (6 x 6 x metricconverterProductID38 inches38 inches). After the solar arrays are released, the antenna is deployed.

The antenna support structure is a series of four boom segments hinged at the ends. In addition to supporting the antenna, the support structure is also used as a mounting point for a three-axis magnetometer used by the satellite Attitude Control System (ACS).

4.3. Attitude Control System (ACS).

The satellite ACS is designed to maintain both nadir and solar pointing. The Orbcomm satellite must maintain nadir pointing to keep the antenna subsystem oriented toward the Earth. Thus, solar pointing maximizes the amount of power collected by the solar cells. The ACS subsystem employs a three-axis magnetic control system that operates with a combination of sensors. The satellite also obtains knowledge of its position through its on-board GPS receiver. Satellite planes A, B, and C are designed such that the satellites maintain a separation of 45° (± 5°) from other satellites in the same orbital plane. Planes D and E are designed for a 51.4° spacing.

The supplementary, highly inclined satellite planes (F and G) are designed such that the satellites are spaced 180° apart (± 5°). The springs used to release the satellites from the launch vehicle give them their initial separation velocity.

A pressurized gas system will be used to perform braking maneuvers when the required relative in-orbit satellite spacing is achieved. An Orbital Sciences Corporation proprietary formationkeeping technique will maintain the specified satellite intra-plane spacing. One of the benefits of this technique is that, unlike geostationary satellites, it does not affect the satellite life expectancy in fuel usage.

4.4. Gateway Communications Section.

Both the Orbcomm Gateway satellite transmitter and receiver are contained in a single package. Separate Right-Hand Circularly Polarized (RHCP) antennas are used for transmit and receive functions. The Orbcomm Gateway transmitter is designed to transmit 5 Watts of RF power. The 57.6 kb/s downlink signal to the GES is transmitted using an Offset Quadrature Phase Shift Keying (OQPSK) modulation in a TDMA format.

The Orbcomm satellite gateway receiver is designed to demodulate a 57.6 kbps TDMA signal with an OQPSK modulation. The received packets are routed to the onboard satellite network computer.

4.5. Satellite Network Computer.

Functionally, the satellite network computer receives the uplinked packets from the subscriber and Orbcomm Gateway receivers and distributes them to the appropriate transmitter. The satellite network computer also identifies clear uplink channels via the DCAAS receiver and algorithm, and interfaces with the GPS receiver to extract information pertinent to the communications system. Several microprocessors in a distributed computer system aboard the satellite perform the satellite network computer functions.

4.6. UHF Transmitter.

The UHF transmitter is a specially constructed 1-Watt transmitter that is designed to emit a highly stable signal at 400.1 MHz. The transmitter is coupled to a UHF antenna designed to have a peak gain of approximately 2 dB.

Conclusions.

The Orbcomm satellite network allows mobile and fixed users to communicate, track, monitor, control and manage mobile, rural and remote assets for purpose of Satellite Asset Tracking and Fleet Management (SATFM), Machine - to - machine (M2M) or Supervisory Control and Data Acquisition (SCADA) command and logistics applications at sea, on the ground and in the air.

These Orbcomm small devices are a very new satellite communications and tracking tools available for all professionals in transportation, business people, oil and gas, agriculture and remote environment to everyone who likes to have satellite messaging, tracking and logistics using Little LEO Orbcomm satellite systems everywhere.

Otherwise, the different nomenclature of LEO satellites is usually known as Non-GEO (Geostationary Earth Orbits) satellites. Compared to the Big LEO systems, the smaller size of the Little LEO system enables simple data processing of non-voice store-and-forward features. The Orbcomm Little LEO system provides low speed data transfer to MSC and fixed machines almost globally. The Orbcomm network is not covering middle areas of African Continent only, while placecountry-regionSouth Africa is covered, and it is in a position to offer low-cost and high-quality service to each mobile or fixed customer.

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