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Overview of IRIDIUM® Satellite Network

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Abstract
The IRIDIUM system is a satellite-based, wireless personal communications network designed to permit a wide range of telephone services—voice, data, fax, paging—to conne ct to destinations virtually anywhere on earth. The 66 satellite interlinked constellation system will track the location of the telephone handset, determine routings through a network of ground gateways, establish the path of the telephone call, initiate connections, and terminate the telephone call with appropriate revenue tracking. This activity provides global communication even if the subscriber's location is unknown to the caller. The global communications network will provide revenue to all parties of each telephone call, including the country of origin or termination. There will be no bypass of sovereign territory due to the licensing agreements around the globe. The phones of the IRIDIUM system use L-Band frequencies, with Frequency Division Multiple Access and Time Division Multiple Access (FDMA/TDMA) multiplexing to make the most efficient use of a limited spectrum. Other communications links use EHF and SHF bands for communications between satellites and communications to the satellites for telemetry, command, and control, as well as routing the digital voice packets to/from the gateways. The IRIDIUM phone will enable the subscriber to connect either to the local cellular infrastructure or to the space constellation in a manner called "dual mode." This interoperability gives the subscriber of the IRIDIUM system the best of the telephone world, both space and terrestrial: communicating anywhere, anytime, and anyplace.

Overview
Motorola is the pioneer in developing one of the commercial Low Earth Orbit (LEO) systems for worldwide telephone service that will provide a dial tone anywhere at anytime. Between 1987 and 1990, Motorola's visionaries created a new industry that projected continuous telephony throughout the globe. The original concept as visualized in 1988 contained 77 satellites networked together [1]. Hence, the name "IRIDIUM" was selected, since the element iridium in the periodic table has the atomic number 77. After subsequent design trades and performance optimization, the constellation evolved to 66 satellites with a System Control Facility, gateways, intersatellite links, and handheld phones [2]. The first set of satellites will be launched in 1996, with full constellation deployment and operation beginning in 1998.

The IRIDIUM program was granted a full Federal Communications Commission (FCC) license in January, 1995 for construction and operation in the United States. Contracts have been awarded to three separate launch providers in China (Great Wall Industry Corporation), Russia (Khrunichev), and the U.S. (McDonnell-Douglas). Construction of the satellite bus by Lockheed-Martin is underway. The main mission L-Band antenna is being completed by Raytheon, while Scientific Atlanta has delivered the Earth terminal test bed to Chandler, Arizona. Motorola is assembling the electronic payload of digital switches, microprocessors, modems, and converters. As the prime contractor, Motorola Satellite Communication Division (SATCOM) will initiate a revolutionary production line for spacecraft assembly with a planned throughput of four

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satellites every 22 days [3,4,5]. This process will commence in the fall of 1995.

The IRIDIUM system (see Figure 1) uses a GSM-based (Groupe Special Mobile) telephony architecture to provide a digitally switched telephone network and global dial tone to call—and receive calls—from any place in the world. This global roaming feature is designed into the system. A subscriber will be assigned a personal phone number. He will also receive only one bill, no matter what country he visits, whenever a subscriber places or receives a call. The IRIDIUM system determines the user location and in turn, the network charges the appropriate rate for that location [6]. Besides voice traffic, IRIDIUM will provide other services such as paging, data messaging, and facsimile [7,8]. The key system design feature is a constellation of low earth orbiting spacecraft interconnected with four crosslinks per satellite. By using the lower altitude in this revolutionary manner, path delay is minimized. The IRIDIUM phones—called Subscriber Units—will operate directly with the satellites or through the terrestrial cellular system. This "dual mode" capability enables low-cost service.

The IRIDIUM project will have a satellite and network control facility in Landsdowne, Virginia with a backup facility in Italy. A third engineering control complex is at Motorola's SATCOM location in Chandler, Arizona. This site will handle the first 40 satellites before transferring full operations to the Virginia Center. It will utilize the tremendous availability of new computational tools to reduce the workload of the operations center personnel in a nontraditional approach. The remote stations, called tracking, telemetry, and control (TTAC) stations, are located in northern Canada, with backup stations in Iceland. One facility will provide both operational support of the global network and satellite constellation.

Sixty-six operational satellites are configured in six near-polar orbital planes, in which 11 satellites circle in one plane. This allows IRIDIUM to cover all areas of the Earth. The satellites are phased appropriately in co-rotating planes up one side of the earth, across the poles, and down the other side of the earth. The first and last planes rotate in opposite direction, creating a "seam." Co-rotating planes are separated by 31.6 degrees, and the seam planes are 22 degrees apart. The orbits have a mean altitude of 780 Kms.

Full Earth coverage is the enabling factor behind the IRIDIUM system. Three L-Band antennas form a honeycomb pattern of 48 beams below each satellite. As the satellite beam footprint moves over the ground, the subscriber signal is switched from one beam to the next or from one satellite to the next in a hand-off process. As the satellites approach the poles, their footprints converge and

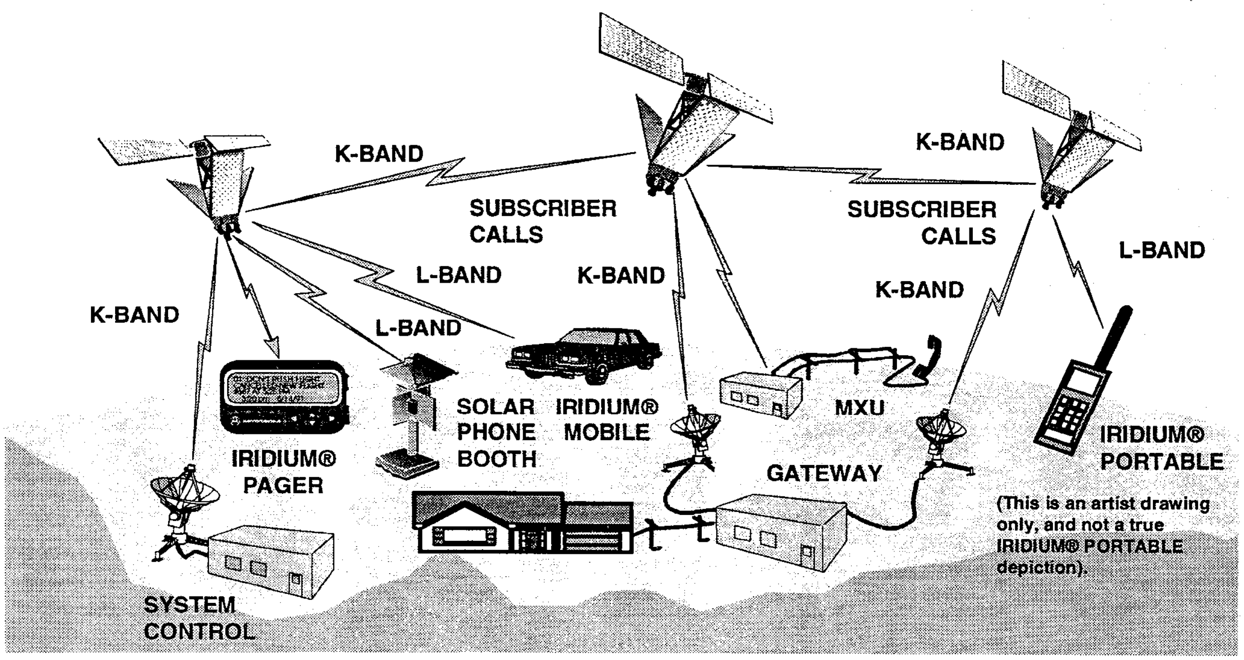

Figure 1. System Overview of IRIDIUM

the beams overlap. Outer beams are then turned off to eliminate this overlap and conserve spacecraft power.

The telecommunication networking aspect using satellite crosslinks is the unique key to the IRIDIUM system and is the primary differentiator from traditional transponder or "bent-pipe" systems (see Figure 1). IRIDIUM is the first mobile satellite system to incorporate sophisticated digital onboard processing on each satellite and the crosslink capability between satellites. The four crosslinks, and the feeder links connecting satellites to gateways, operate at K-Band frequencies. These intersatellite links, together with the gateway links, operate in packetized Time Division Multiplexing (TDM) mode. The service links connecting subscriber units to the satellites operate in L-Band frequencies in the narrowband TDMA/FDMA mode.

Regulatory Aspects

The U.S. Federal Communication Commission (FCC) issued a Report and Order Dockett No. 92-166, dated 14 October 1994, which defined L-Band sharing in the 1,610 - 1,626.5 MHz band. Mobile Satellite System spectrum cellular communications are assigned 5.15 MHz in the upper-end of this L-Band spectrum for TDMA/FDMA service band. Systems using the Code Division Multiple Access (CDMA) mode of access are assigned the remaining 11.35 MHz of L-Band spectrum for their service uplinks, and a proportionate amount of S-Band spectrum at 2,483.5 to 2,500 MHz for their downlinks. If only one CDMA system is put into operation, then the CDMA spectrum would be cut back to 8.25 MHz. The remaining 3.1 MHz of L-Band spectrum would then be assigned either to the IRIDIUM system or to a new TDMA/FDMA entry [9]. In January 1995, the FCC issued a U.S. license to construct and operate a constellation of satellites called the IRIDIUM system, and two other systems in the CDMA mode. These two decisions have ensured that the global network can be launched and operated promptly with full operational capability during 1998.

System Description

Handsets. Subscriber units range from a portable phone to data modems or fax centers as well as pager units. They are similar to terrestrial models, with added features. For example, the telephone can be paged through the IRIDIUM satellite system. The phone also works in dual mode, making it compatible with both local terrestrial cellular systems and the IRIDIUM space system. When the terrestrial cellular system is not available, the IRIDIUM dial tone is selected, since a satellite is overhead at all times.

These phones will contain programmable features found in conventional portable phones such as storing phone numbers or call waiting. Furthermore, these units provide full-duplex voice and 2,400 baud operations, with direct ringing to the location of the phone. A vocoder is used for digital voice.

Spacecraft. IRIDIUM satellites are long and slender, and triangular in shape, approximately two meters high, and weigh approximately 700 kg (see Figure 2). Three L-Band antenna panels provide the 48 beams of the footprint for subscriber communication (Figure 3). Each satellite has four, 23 GHz satellite-to-satellite crosslinks to relay digital information around the globe. These crosslink antennas point to the nearest spacecraft in the same plane (fore and aft) and in the two adjacent co-rotating planes. "Feeder link" antennas relay information to the terrestrial gateways and the System Control Segment earth stations. The spacecraft payload is the dominant element in the architecture, with high-speed digital switching handling complex telephony routing. Motorola's SATCOM developed the payload, tested the routing of phone calls, and is producing payloads with the highest quality designed into the process.

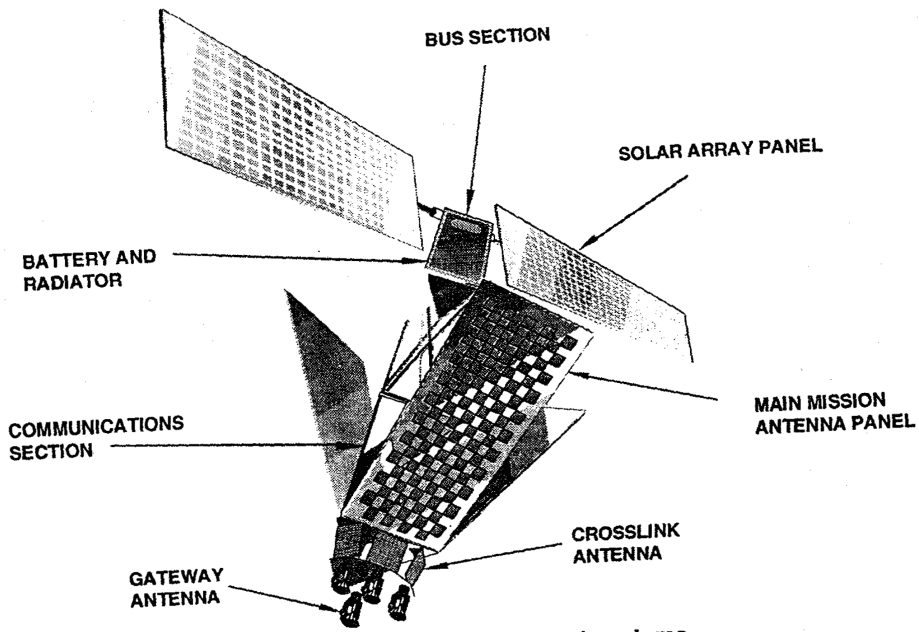

Figure 2. Satellite Subsystems

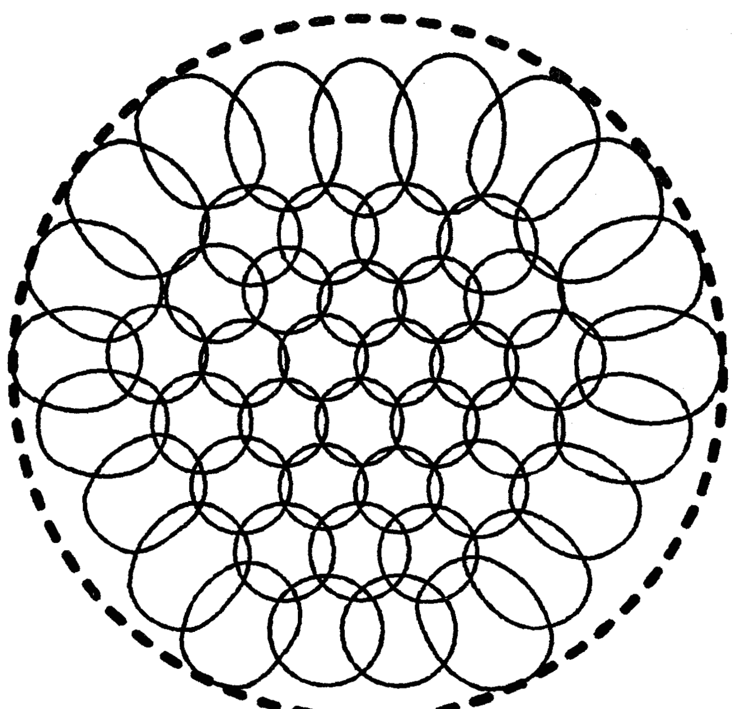

Figure 3. Subscriber Coverage

With 66 satellites in the constellation, there is a need for a high-quality production line assembly. Motorola, using key manufacturing technology with its partners, is establishing the first large-scale production line for satellite manufacturing. The commercially significant manufacturing approaches, perfected in Motorola assembly plants around the world, will include quality initiatives, continuous improvement processes, and cycle time reduction activities. This revolution in spacecraft manufacturing is being led by the innovators at Motorola's SATCOM production facility.

Communications Architecture

The L-Band communication service links operate in the 1,610 - 1,626.5 MHz band. The total occupied bandwidth is 5.15 MHz. Modulation is quadrature phase shift key (QPSK). The maximum numbers of L-Band channels are 3,840, with right-hand circular polarization. Both uplinks and downlinks operate in the L-Band, using Time Division Duplexing (TDD).

All K-Band links—uplink, downlink, and crosslinks—are packetized TDM/FDMA using QPSK modulation. These links use FEC rate 1/2 convolutional encoding with Viterbi decoding. Coded data rates are 6.25 Mbps for the gateways and satellite control facility links, with the crosslinks at a higher data rate of 25 Mbps. The frequency bands are listed below:

K-Band down-link	18.8 - 20.2 GHz
K-Band up-link	27.5 - 30.0 GHz
Crosslink	22.55 - 23.55 GHz

Both uplink and downlink occupy 100 MHz bandwidths and use right-hand circular polarization. The intersatellite links use 200 MHz bandwidth with vertical polarization. Because crosslinks are used, the gateway Earth stations need only process the information designated to them. Crosslinks allow for reduced ground infrastructure requirements, enabling least cost routing, and permit full global coverage (including the oceans).

Ground Infrastructure

System Control Segment. The System Control Segment (SCS) manages the IRIDIUM constellation, including maintaining a telephony network infrastructure and a satellite constellation (Figure 4). The primary function of the SCS is to manage the vast IRIDIUM communications network. For example, one task is to reroute phone calls around a loaded crosslink. An additional function of the System Control Facility is constellation maintenance, such as placing satellites in maintenance orbits, monitoring health and status, and maintaining and troubleshooting of malfunctioning satellites.

Gateways. Figure 5 shows the terrestrial gateways interconnecting the IRIDIUM constellation with the Public Switched Telephone Networks (PSTN). These gateways handle call setup and tear-down, position determination of the subscriber, and collect necessary data to support billing. Gateways use two to four 3.3 meter antennas. Separation of the ground antenna terminals overcomes adverse effects of thunderstorm cells that could interrupt service. At least two antenna terminals are needed with one always acquiring the next spacecraft. Using the Groupe Special Mobile (GSM) telephone architecture and geographic-controlled system access, this total network permits backup arrangements between gateways to safeguard against catastrophic events such as earthquakes or fire. Each IRIDIUM subscriber is assigned a home gateway when buying the subscriber unit. When the subscriber travels away from this gateway, a visitor gateway is assigned based on location. The IRIDIUM system could start service with only one Gateway worldwide. However, when fully implemented, the IRIDIUM system will have over 10 gateways distributed around the Earth.

Services

Voice. Through the dual-mode telephones, the IRIDIUM subscriber has use of both a local terrestrial system (when available) and an IRIDIUM spacecraft overhead, 24 hours a day, to ring, page, or transmit calls. High-quality transmission provides quality digital voice service with lower time delays than found in geosynchronous satellite systems. Furthermore, the L-Band cellular links are designed for robust channels. Access to the IRIDIUM satellite constellation is through FDMA/TDMA techniques, using a low-profile antenna. The subscriber unit itself is low-powered as compared with current phones used in satellite-supported telecommunications. GSM protocol, combined with IRIDIUM unique protocol, routes voice calls to the appropriate destinations.

Paging. The IRIDIUM system includes a global messaging service that delivers numeric or alphanumeric messages to paging units similar in form to the familiar pagers widely used today. The message delivery function uses FDMA/TDMA multiplexing to share the L-Band links with voice

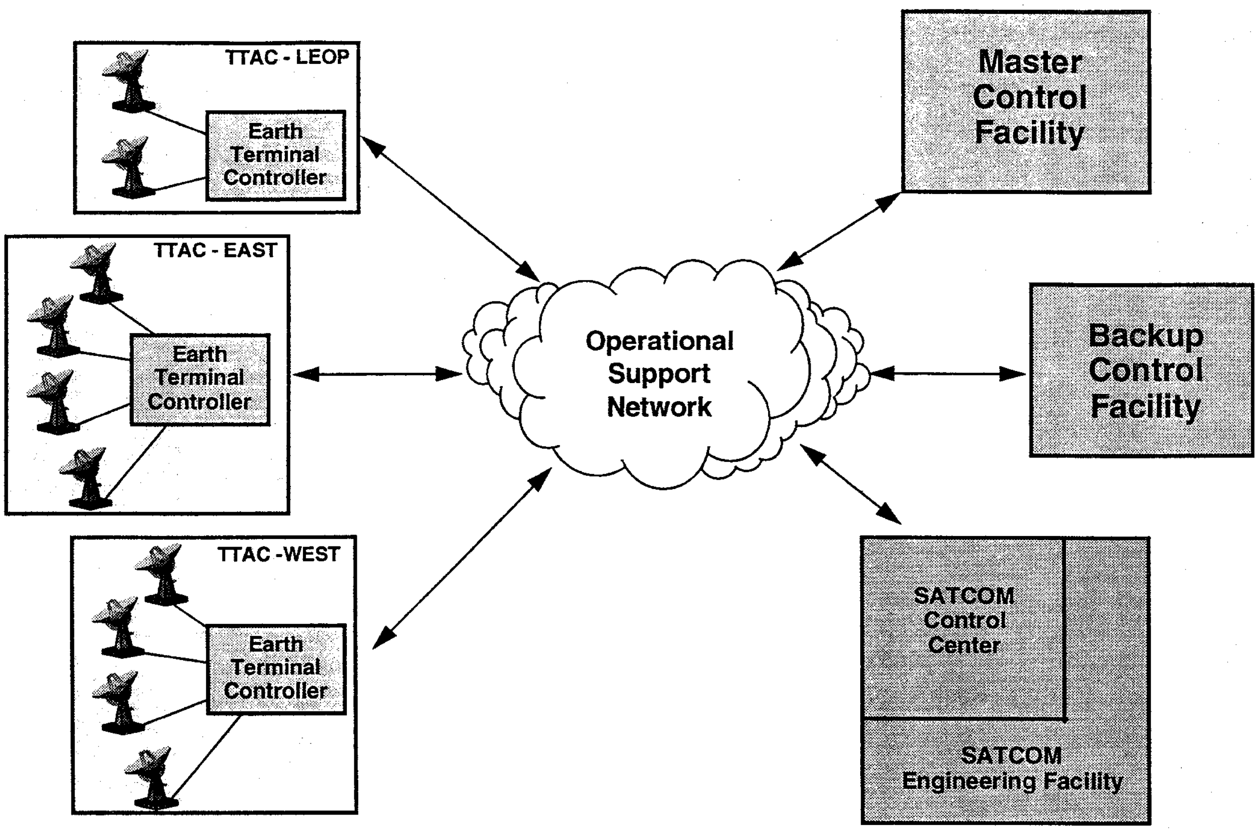

Figure 4. System Control Segment Infrastructure

and other IRIDIUM services. For paging transmission a spatial diversity is used to achieve high message character accuracy in the presence of fading and adverse pager unit orientation. The flexible message format accommodates variable-length messages as required by several different pager unit types. The messaging system infrastructure is used for certain supplementary functions, including notifying a subscriber that a voice-mail message is waiting. Other related supplementary services are message diversion, group messaging, and deferred message.

Fax. The IRIDIUM network can communicate Group-3 facsimile messages. Faxes are formatted much like the digital voice packets using the same protocol and routing interfaces as the IRIDIUM subscriber units. Subscriber units will have a built-in data port for interface with an external fax unit. As an alternative, standard fax machines can be matched through IRIDIUM hardware and protocol.

Operation - Reliability, Convenience, and Flexibility

Robust design of the IRIDIUM network, combined with global coverage and location determination, provides user convenience and required capability. The 66 satellite constellation circling the Earth provides one satellite always within view of the subscriber at any time of the day and night. Two ground control facilities with backup capability means high reliability and integrity of the entire IRIDIUM system. With 48 beams per spacecraft, robust coverage is ensured.

With a worldwide, convenient voice and data service, subscribers can send faxes, data files, and pages. A dial tone anywhere on earth means high reliability communication. As an added incentive, all countries receive revenue from IRIDIUM services used in their country. One concept to provide low-cost access to remote areas is location of a solar-powered telephone booth where electrical power is not readily available. This highly reliable telephone service also comes to the aid of

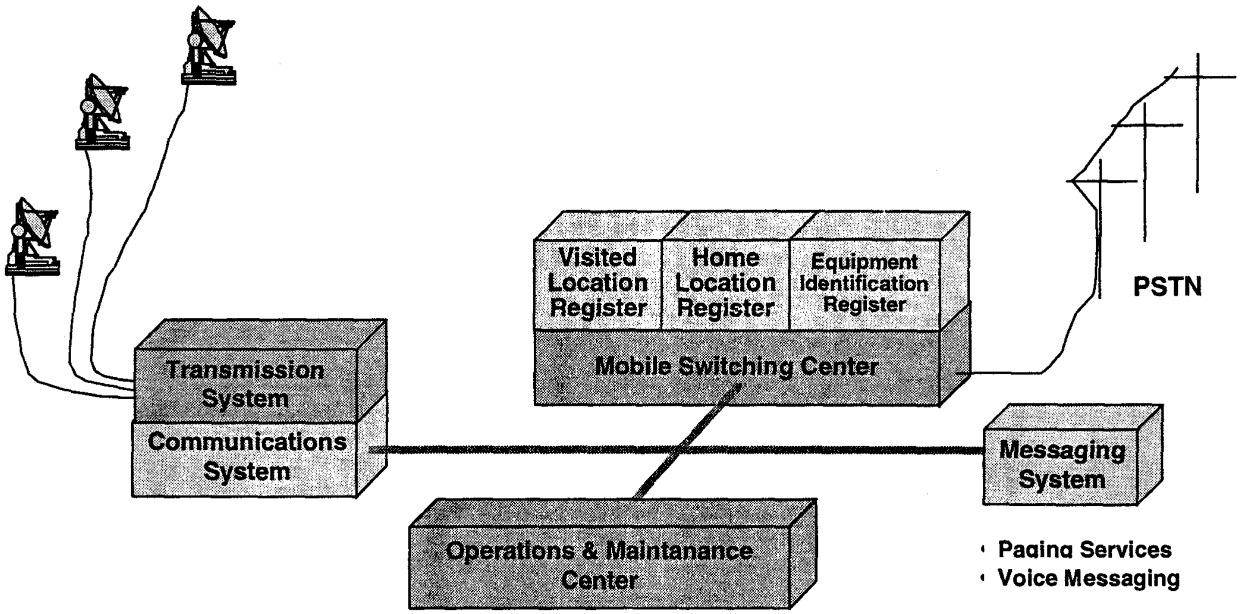

Figure 5. Gateway Subsystem Overview

disaster relief with immediate, portable communication not dependent on local power or terrestrial telephony.

Summary

The IRIDIUM communication satellite system is pioneering global digital satellite-based personal communications. Its principal mission is to provide portable telecommunications service through small subscriber units capable of working with either terrestrial cellular systems or the IRIDIUM system. These subscriber units employ low-power phones with a low profile antenna. Calls are transmitted and received throughout the world using L-Band frequencies in an FDMA/TDMA access system. Paging, fax, and data services are also available through the IRIDIUM constellation. Intersatellite links provide "switching in the sky," relaying voice calls over the Earth.

Most important is that the IRIDIUM system is a vision of a portable, high-quality, worldwide digital communication system that will provide a dial tone anywhere on Earth.

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