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Via Satellite, September 1998

Iridium: From Concept to Reality

by Robert A. Nelson

On the 23rd day of this month, a revolutionary communication system will begin service to the public. Iridium will be the first mobile telephony system to offer voice and data services to and from handheld telephones anywhere in the world. Industry analysts have eagerly awaited this event, as they have debated the nature of the market, the economics, and the technical design.

As with any complex engineering system, credit must be shared among many people. However, the three key individuals who are recognized as having conceived and designed the system are Bary Bertiger, Dr. Raymond Leopold, and Kenneth Peterson of Motorola, creators of the Iridium system.

The inspiration was an occasion that has entered into the folklore of Motorola. (The story, as recounted here, was the subject of a *Wall Street Journal* profile on Monday, December 16, 1996.) On a vacation to the Bahamas in 1985, Bertiger's wife, Karen, wanted to place a cellular telephone call back to her home near the Motorola facility in Chandler, AZ to close a real-estate transaction. After attempting to make the connection without success, she asked Bertiger why it wouldn't be possible to create a telephone system that would work anywhere, even in the remote Caribbean outback.

Bertiger took the problem back to colleagues Leopold and Peterson at Motorola. Numerous alternative terrestrial designs were discussed and abandoned.

In 1987 research began on a constellation of low earth orbiting satellites that could communicate directly with telephones on the ground and with one another -- a kind of inverted cellular telephone system.

But as they left work one day in 1988, Leopold proposed a crucial element of the design. The satellites would be coordinated by a network of "gateway" earth stations connecting the satellite system to existing telephone systems. They quickly agreed that this was the sought-after solution and immediately wrote down an outline using the nearest available medium -- a whiteboard in a security guard's office.

Originally, the constellation was to have consisted of 77 satellites. The constellation was based on a study by William S. Adams and Leonard Rider of the Aerospace Corporation, who published a paper in *The Journal of the Astronautical Sciences* in 1987 on the configurations of circular, polar satellite constellations at various altitudes providing continuous, full-earth coverage with a minimum number of satellites. However, by 1992 several modifications had been made to the system, including a reduction in the number of satellites from 77 to 66 by the elimination of one orbital plane.

The name Iridium was suggested by a Motorola cellular telephone system engineer, Jim Williams, from the Motorola facility near Chicago. The 77-satellite constellation reminded him of the electrons that encircle the nucleus in the classical Bohr model of the atom. When he consulted the periodic table of the elements to discover which atom had 77 electrons, he found Iridium -- a creative name that has a nice ring. Fortunately, the system had not yet been scaled back to 66 satellites, or else he might have suggested the name Dysprosium.

The project was not adopted by senior management immediately. On a visit to the Chandler facility, however, Motorola chairman Robert Galvin learned of the idea and was briefed by Bertiger. Galvin at once endorsed the plan and at a subsequent meeting persuaded Motorola's president John Mitchell. Ten years have elapsed from this go-ahead decision, and thirteen years since Bertiger's wife posed the question.

In December 1997 the first Iridium test call was delivered by orbiting satellites. Shortly after completion of the constellation in May 1998, a demonstration was conducted for franchise owners and guests. The new system was ready for operation, and Iridium is now on the threshold of beginning service.

REGULATORY HURDLES

In June, 1990 Motorola announced the development of its Iridium satellite system at simultaneous press conferences in Beijing, London, Melbourne, and New York. The Iridium system was described in an application to the Federal Communications Commission (FCC) filed in December of that year, in a supplement of February 1991, and an amendment in August 1992.

At the time, an internationally allocated spectrum for this service by nongeostationary satellites did not even exist. Thus Motorola proposed to offer Radio Determination Satellite Service (RDSS) in addition to mobile digital voice and data communication so that it might qualify for use of available spectrum in the RDSS
L-band from 1610 to 1626.5 MHz. A waiver was requested to provide both two-way digital voice and data services on a co-primary basis with RDSS.

Following the submission of Motorola's Iridium proposal, the FCC invited applications from other companies for systems to share this band for the new Mobile Satellite Service (MSS). An additional four proposals for nongeostationary mobile telephony systems were submitted to meet the June 3, 1991 deadline, including Loral/Qualcomm's Globalstar, TRW's Odyssey, MCHI's Ellipsat, and Constellation Communications' Aries. Collectively, these nongeostationary satellite systems became known as the "Big LEOs". The American Mobile Satellite Corporation (AMSC) also sought to expand existing spectrum for its geostationary satellite into the RDSS band.

At the 1992 World Administrative Radio Conference (WARC-92) in Torremolinos, Spain, L-band spectrum from 1610 to 1626.5 MHz was internationally allocated for MSS for earth-to-space (uplink) on a primary basis in all three ITU regions. WARC-92 also allocated to MSS the band 1613.8 to 1626.5 MHz on a secondary basis and spectrum in S-band from 2483.5 to 2500 MHz on a primary basis for space-to-earth (downlink).

In early 1993 the FCC adopted a conforming domestic spectrum allocation and convened a Negotiated Rulemaking proceeding. This series of meetings was attended in Washington, DC by representatives of the six applicants and Celsat, which had expressed an intention to file an application for a geostationary satellite but did not meet the deadline.

The purpose of the proceeding was to provide the companies with the opportunity to devise a frequency- sharing plan and make recommendations. These deliberations were lively, and at times contentious, as Motorola defended its FDMA/TDMA multiple access design against the CDMA technologies of the other participants.

With frequency division multiple access (FDMA), the available spectrum is subdivided into smaller bands allocated to individual users. Iridium extends this multiple access scheme further by using time division multiple access (TDMA) within each FDMA sub-band. Each user is assigned two time slots -- one for sending and one for receiving -- within a repetitive time frame. During each time slot, the digital data are burst between the mobile handset and the satellite.

With code division multiple access (CDMA), the signal from each user is modulated by a pseudorandom noise (PRN) code. All users share the same spectrum. At the receiver, the desired signal is extracted from the entire population of signals by multiplying by a replica code and performing an autocorrelation process. The key to the success of this method is the existence of sufficient PRN codes that appear to be mathematically orthogonal to one another. Major advantages cited by CDMA proponents are inherently greater capacity and higher spectral efficiency. Frequency reuse clusters can be smaller because interference is reduced between neighboring cells.

In April, 1993 a majority report of Working Group 1 of the Negotiated Rulemaking Committee recommended full band sharing across the entire MSS band by all systems including Iridium. Coordination would be based on an equitable allocation of interference noise produced by each system. The FDMA/TDMA system would be assigned one circular polarization and the CDMA systems would be assigned the opposite polarization. This approach required that each system would be designed with sufficient margin to tolerate the level of interference received from other licensed systems.

Motorola issued a minority report which stated that the Iridium system must have its own spectrum allocation. It proposed partitioning of the MSS L-band spectrum into two equal 8.25 MHz segments for the FDMA/TDMA and CDMA access technologies, with the upper portion being used by the FDMA/TDMA system where it would be sufficiently isolated from neighboring frequencies used by radio astronomy, GPS, and Glonass.

Faced with this impasse, the FCC in January 1994 adopted rulemaking proposals which allocated the upper 5.15 MHz of the MSS L-band spectrum to the sole FDMA/TDMA applicant, Iridium, and assigned the remaining 11.35 MHz to be shared by multiple CDMA systems. However, if only one CDMA system were implemented, the 11.35 MHz allotment would be reduced to 8.25 MHz, leaving 3.10 MHz available for additional spectrum to Iridium or a new applicant.

The response to the Commission's proposals from the Big LEO applicants was generally favorable. Without this compromise, the alternative would have been to hold a lottery or auction to allocate the spectrum. The Iridium system was designed to operate with the full spectrum allocation. However, with 5.15 MHz, the system is a viable business proposition. The additional 3.10 MHz, should it become available, further adds to the system's attractiveness.

The FCC also proposed that the MSS spectrum could be used only by Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellite systems. Therefore, the geostationary orbit (GEO) systems of AMSC and Celsat would not be permitted in this band. To qualify for a Big LEO license, the Commission proposed that the service must be global (excluding the poles) and that companies must meet stringent financial standards.

In October, 1994 the FCC issued its final rules for MSS, closely following language of the January proposed rulemaking. However, it allowed the CDMA systems to share the entire 16.5 MHz of downlink spectrum in S-band. The Commission gave the Big LEO applicants a November 16 deadline to amend their applications to conform to the new licensing rules.

On January 31, 1995 the FCC granted licenses to Iridium, Globalstar, and Odyssey but withheld its decision on Ellipsat and Aries pending an evaluation of their financial qualifications. The latter companies finally received licenses in June last year, while in December TRW dropped its Odyssey system in favor of partnership with ICO, the international subsidiary of Inmarsat which entered the competition in 1995.

Outside the United States, Iridium must obtain access rights in each country where service is provided. The company expects to have reached agreements with 90 priority countries that represent 85% of its business plan by the start of service this month. Altogether, Iridium is seeking access to some 200 countries through an arduous negotiating process.

FINANCING

Iridium LLC was established by Motorola in December, 1991 to build and operate the Iridium system, with Robert W. Kinzie as its chairman. In December, 1996 Edward F. Staiano was appointed Vice Chairman and CEO.

Iridium LLC, based in Washington, DC, is a 19-member international consortium of strategic investors representing telecommuni-cation and industrial companies, including a 25 percent stake by its prime contractor, Motorola, Inc.

In August 1993, Motorola and Iridium LLC announced they had completed the first-round financing of the Iridium system with $800 million in equity. The second round was completed in September, 1994, bringing the total to $1.6 billion. In July of last year $800 million in debt financing was completed. Iridium World Communications, Ltd., a Bermuda company, was formed to serve as a vehicle for public investment in the Iridium system. In June 1997 an initial $240 million public offering was made on the NASDAQ Stock Exchange.

TECHNICAL DESCRIPTION

The Iridium constellation consists of 66 satellites in near-polar circular orbits inclined at 86.4° at an altitude of 780 km. The satellites are distributed into six planes separated by 31.6° around the equator with eleven satellites per plane. There is also one spare satellite in each plane.

Starting on May 5, 1997, the entire constellation was deployed within twelve months on launch vehicles from three continents: the U.S. Delta II, the Russian Proton, and the Chinese Long March. The final complement of five 700 kg (1500 lb) satellites was launched aboard a Delta II rocket on May 17. With a satellite lifetime of from 5 to 8 years, it is expected that the replenishment rate will be about a dozen satellites per year after the second year of operation.

The altitude was specified to be within the range 370 km (200 nmi) and 1100 km (600 nmi). The engineers wanted a minimum altitude of 370 km so that the satellite would be above the residual atmosphere, which would have diminished lifetime without extensive stationkeeping, and a maximum altitude of 1100 km so that the satellite would be below the Van Allen radiation environment, which would require shielding.

Each satellite covers a circular area roughly the size of the United States with a diameter of about 4400 km, having an elevation angle of 8.2° at the perimeter and subtending an angle of 39.8° with respect to the center of the earth. The coverage area is divided into 48 cells. The satellite has three main beam phased array antennas, each of which serves 16 cells.

The period of revolution is approximately 100 minutes, so that a given satellite is in view about 9 minutes. The user is illuminated by a single cell for about one minute. Complex protocols are required to provide continuity of communication seamlessly as handover is passed from cell to cell and from satellite to satellite. The communications link requires 3.5 million lines of software, while an additional 14 million lines of code are required for navigation and switching. As satellites converge near the poles, redundant beams are shut off. There are approximately 2150 active beams over the globe.

The total spectrum of 5.15 MHz is divided into 120 FDMA channels, each with a bandwidth of 31.5 kHz and a guardband of 10.17 kHz to minimize intermodulation effects and two guardbands of 37.5 kHz to allow for Doppler frequency shifts. Within each FDMA channel, there are four TDMA slots in each direction (uplink and downlink). The coded data burst rate with QPSK modulation and raised cosine filtering is 50 kbps (corresponding to an occupied bandwidth of 1.26×50 kbps / 2 = 31.5 kHz). Each TDMA slot has length 8.29 ms in a 90 ms frame. The supported vocoder information bit rate is 2.4 kbps for digital voice, fax, and data. The total information bit rate, with rate 3/4 forward error correction (FEC) coding, is 3.45 kbps ($0.75 \times$ (8.28 ms/90 ms) $\times$ 50 kbps = 3.45 kbps), which includes overhead and source encoding, exclusive of FEC coding, for weighting of parameters in importance of decoding the signal. The bit error ratio (BER) at threshold is nominally 0.01 but is much better 99 percent of the time.

The vocoder is analogous to a musical instrument synthesizer. In this case, the "instrument" is the human vocal tract. Instead of performing analogue-to-digital conversion using pulse code modulation (PCM) with a nominal data rate of 64 kbps (typical of terrestrial toll-quality telephone circuits), the vocoder transmits a set of parameters that emulate speech patterns, vowel sounds, and acoustic level. The resulting bit rate of 2.4 kbps is thus capable of transmitting clear, intelligible speech comparable to the performance of high quality terrestrial cellular telephones, but not quite the quality of standard telephones.

The signal strength has a nominal 16 dB link margin. This margin is robust for users in exterior urban environments, but is not sufficient to penetrate buildings. Satellite users will have to stand near windows or go outside to place a call. Handover from cell to cell within the field of view of an orbiting satellite is imperceptible. Handover from satellite to satellite every nine minutes may occasionally be detectable by a quarter-second gap.

Each satellite has a capacity of about 1100 channels. However, the actual number of users within a satellite coverage area will vary and the distribution of traffic among cells is not symmetrical.

CALL ROUTING

The Iridium satellites are processing satellites that route a call through the satellite constellation. The system is coordinated by 12 physical gateways distributed around the world, although in principle only a single gateway would be required for complete global coverage. Intersatellite links operate in Ka-band from 23.18 to 23.38 GHz and satellite-gateway links operate in Ka-band at 29.1 to 29.3 GHz (uplink) and 19.4 to 19.6 GHz (downlink).

For example, a gateway in Tempe, Arizona serves North America and Central America; a gateway in Italy serves Europe and Africa; a gateway in India serves southern Asia and Australia. There are 15 regional franchise owners, some of whom share gateway facilities. The constellation is managed from a new satellite network operations center in Lansdowne, Virginia.

As described by Craig Bond, Iridium's vice president for marketing development, the user dials a telephone number with the handset using an international 13 digit number as one would do normally using a standard telephone. The user presses the "send" button to access the nearest satellite. The system identifies the user's position and authenticates the handset at the nearest gateway with the home location register (HLR).

Once the user is validated, the call is sent to the satellite. The call is routed through the constellation and drops to the gateway closest to the destination. There it is completed over standard terrestrial circuits.

For a call from a fixed location to a handset, the process is reversed. After the call is placed, the system identifies the recipient's location and the handset rings, no matter where the user is on the earth.

It is projected that about 95 percent of the traffic will be between a mobile handset and a telephone at a fixed location. The remaining 5 percent of the traffic represents calls placed from one handset to another handset anywhere in the world. In this case, the call "never touches the ground" until it is received by the handset of the intended recipient.

By comparison, a "bent pipe" satellite system, such as Globalstar, requires that a single satellite see both the user and the nearest gateway simultaneously. Thus many more gateways are needed. For example, in Africa Globalstar will require about a dozen gateways, while Iridium has none at all. Globalstar advocates would counter that this is not a disadvantage, since their system places the complexity on the ground rather than the satellite and offers greater flexibility in building and upgrading the system.

HANDSET

The Iridium handsets are built by Motorola and Kyocera, a leading manufacturer of cellular telephones in Japan. Handsets will permit both satellite access and terrestrial cellular roaming capability within the same unit. The unit also includes a Subscriber Identity Module (SIM) card. Major regional cellular standards are interchanged by inserting a Cellular Cassette. Paging options are available, as well as separate compact Iridium pagers.

The price for a typical configuration will be around $3,000. The handsets will be available through service providers and cellular roaming partners. In June, Iridium finalized its 200th local distribution agreement.

Information on how to obtain Iridium telephones will be advertised widely. Customers will also be actively solicited through credit card and travel services memberships. Distribution of the handsets and setup will typically be through sales representatives who will interface with the customer directly. Rental programs will also be available to give potential customers the opportunity to try out the system on a temporary basis.

MARKET

Iridium has conducted extensive research to measure the market. As described by Iridium's Bond, the intended market can be divided into two segments: the vertical market and the horizontal market.

The vertical market consists of customers in remote areas who require satellites for their communications needs because they cannot access conventional terrestrial cellular networks. This market includes personnel in the petroleum, gas, mining, and shipping industries. It also includes the branches of the U.S. military. In fact, the U.S. government has built a dedicated gateway in Hawaii capable of serving 120,000 users so that it can access the Iridium system at a lower per minute charge.

The horizontal market is represented by the international business traveler. This type of customer wants to keep in contact with the corporate office no matter where he or she is in the world. Although mindful of the satellite link, this customer doesn't really care how the telephone system works, as long as it is always available easily and reliably.

It has been consistently estimated that the total price for satellite service will be about $3.00 per minute. This price is about 25 percent to 35 percent higher than normal cellular roaming rates plus long distance charges. When using the roaming cellular capability, the price will be about $1.00 to $1.25 per minute.

The expected break-even market for Iridium is about 600,000 customers globally, assuming an undisclosed average usage per customer per month. The company hopes to recover its $5 billion investment within one year, or by the fourth quarter of 1999. Based on independent research, Iridium anticipates a customer base of 5 million by 2002.

PROBLEMS

As might be expected for a complex undertaking, the deployment of the constellation and the manufacture of the handsets has not been without glitches. So far, a total of seven spacecraft have suffered in-orbit failures. In addition, Iridium has announced delays in the development of the handset software.

Of the 72 satellites launched, including spares, one lost its stationkeeping fuel when a thruster did not shut off, one was damaged as it was released from a Delta II launch vehicle, and three had reaction wheel problems. In July two more satellites failed because of hardware problems. Delta II and Long March rockets, scheduled to begin a maintenance program of launching additional spares, were retargeted to deploy seven replacement birds to the orbital planes where they are needed in August.

Investors are also nervous about final software upgrades to the handsets. Following alpha trials last month, beta testing of the units was scheduled to commence within one week of the September 23 commercial activation date. The Motorola handsets are expected to be available to meet initial demand, but those made by Kyocera may not be ready until later. [*Note added:* On September 9, Iridium announced that the debut of full commercial service would be delayed until November 1 because more time is needed to test the global system.]

The fifteen gateways have been completed. Equipment for the China gateway, the last one, was shipped recently. Like a theatrical production, the players are frantically completing last minute details as the curtain is about to go up and Iridium embarks upon the world stage.

THE FUTURE

Iridium is already at work on its Next Generation system (Inx). Planning the system has been underway for more than a year. Although details have not been announced, it has been suggested that the system would be capable of providing broadband services to mobile terminals. In part, it would augment the fixed terminal services offered by Teledesic, which Motorola is helping to build, and might include aspects of Motorola's former Celestri system. It has also been reported that the Inx terminal would provide greater flexibility in transitioning between satellite and cellular services and that the satellite power level would be substantially increased.

As customers sign up for satellite mobile telephony service, the utility and competitive advantage will become apparent. Information will flow more freely, the world will grow still smaller, and economies around the world will be stimulated. There will also be a profound effect on geopolitics and culture. Just as satellite television helped bring down the Berlin Wall by the flow of pictures and information across international boundaries, the dawning age of global personal communication among individuals will bring the world community closer together as a single family.

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