A SURVEY OF SMALL SPACECRAFT IN COMMERCIAL CONSTELLATIONS

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The capabilities that can be built into small spacecraft are increasing to the point that communications and other commercial applications are now possible. Dense electronics, small satellite technology and low cost launch options for small satellites are recent developments that have provided these new opportunities for commercial uses of space. As a result of these changes, several companies are proposing constellations of small satellites for commercial applications such as communications and geolocation. This paper provides various aspects of proposed systems with commercial applications.

Introduction

Small satellites have filled various limited roles in the past and are now growing into more viable commercial roles for the future. Systems which are considered in this paper were selected using the following factors as a guide:

- Spacecraft size -- small; the initial limit (for this paper) was 1000 pounds at beginning of life in the final orbit.

- Constellations of spacecraft -- this factor eliminates one-of-a-kind spacecraft since only constellations of several spacecraft with a common mission will be considered.

- Commercial application -- only systems offering a commercial service (primarily communications or geolocation to date) will be considered.

The goal of this paper is to present, compare, and contrast various aspects of the systems.

Systems

The following systems are in varying states of development:

Archimedes. This system is being studied by the European Space Agency. It would use three or four satellites in Molniya orbits to provide high quality voice communications and digital radio broadcasts anywhere in Europe. (This system is in initial design and no details were available for this paper.)

ARIES. The ARIES system is being developed by Constellation Communications, Inc. They propose a global, digital, low earth orbit satellite system for position determination, voice and data services. The system would include 48 satellites in polar orbit.

ELLIPSO™. Ellipsat Corporation has filed for ELLIPSO I and ELLIPSO II with the Federal Communications Commission (FCC). They are requesting authority to construct 24 satellites for use in low altitude, inclined, elliptical orbits. This system would provide geolocation and mobile voice services.

GLOBALSTAR. Loral Cellular Systems Corporation is developing a 48-satellite GLOBALSTAR system. The satellite constellation uses low altitude, circular, inclined orbits to provide geolocation, voice and data services around the world.

GONETS. Thirty-six satellites in low altitude, nearly polar, circular orbits would use a store and forward technique to provide a data and messaging service. The Consortium of Small Satellite Constructors and Service Providers (COSSCASP) has been formed to market this Soviet system.

Iridium™. The Iridium™ system is being developed by Motorola to provide geolocation, voice, and data services at any time to any place in the world. The system will use 77 satellites in low altitude, circular polar orbits. The system will have satellite-to-satellite

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crosslinks and earth station gateways to provide maximum flexibility in placing a telephone call.

LEOCOM. The LEOCOM system is being developed by ITALSPAZIO as a real time or store and forward communications system. The service would be provided by 24 satellites in low earth orbit.

LEOSAT. The LEOSAT system is a world-wide, digital, satellite-based communication system for a low density user environment. The system uses 18 satellites in low earth orbit to provide bi-directional data channels. LEOSAT, Inc. is developing this system.

Odyssey™. TRW Inc. is developing the Odyssey system. This system would utilize 12 satellites in inclined, circular orbits. The system provides geolocation, voice, and data services. (The satellite is expected to weigh about 2500 pounds.)

ORBCOMM. The Orbital Sciences Corporation is developing the ORBCOMM system to provide geolocation and two-way data communications. The company plans to launch 18 satellites into low altitude, inclined circular orbits and two additional satellites into low altitude, circular polar orbits.

STARSYS. The STARSYS system is being developed by STARSYS Global Positioning, Inc. The system would use 24 satellites in low altitude, inclined circular orbits to provide a two-way positioning and messaging service.

In general these systems are designed to provide two different types of service. GONETS, LEOCOM, LEOSAT, ORBCOMM, and STARSYS are designed primarily for data services using a store and forward technique. The other systems are tailored to provide real-time voice, data, and position location. The services are summarized in Figure 1.

	Voice Kbps	Data Kbps	Geolocation Accuracy
ARIES	4.8	2.4	≈ 5 miles
ELLIPSO	4.8	No	100 meter
GLOBALSTAR	2.4/4.8/9.6	Yes	1-2 miles (1 sat) 275 meters (2 sats)
GONETS	No	Store and forward 100	No
IRIDIUM	4.8	2.4	≈ 1 mile
LEOCOM	No	1.2/9.6/16	No
LEOSAT	No	4.8	GPS option
ODYSSEY	4.8	9.6	400 meter
ORBCOMM	No	4.8	19-1100 meters*
STARSYS	No	Down 8.3 Up 4.2	≈100 meter

* Depends on single/dual frequency and length of time

Figure 1. Services

Constellations

A variety of orbital configurations have been picked for these systems. Inclinations range from 40° to 90°. Most of the systems propose circular orbits. ELLIPSO uses a slightly elliptical orbit and Archimedes is proposing a Molniya or highly elliptical orbit. Features of the constellations are summarized in Figure 2. The primary advantage of the low altitude orbits that are proposed is that voice communications can be accomplished with handheld or mobile, lower power, user units.

	# Sats	# Planes	# Sats/Plane	Inclination	Altitude (nm) Circular	Elliptical Apogee	Perigee
ARIES	48	4	12	90° (polar)	550		
ELLIPSO I	6	2	3	63.5°		675	270
II	18	2	9	63.4°		1567	230
GLOBALSTAR							
CONUS	24	8	3	47°	750		
GLOBAL	48	8	6	47°	750		
GONETS	36	6	6	83°	≈ 755		
IRIDIUM	77	7	11	90°	413		
LEOCOM	24	4	6	90°	421		
LEOSAT	18	3	6	40°	524		
ODYSSEY	12	3	4	55°	5600		
ORBCOMM							
inclined orbits	18	3	6	40°-60°	524		
polar orbits	2	2	1	90°	524		
STARSYS	24	3 (or 4)	8 (or 6)	60°	702		

Figure 2. Constellations

Frequencies

Figure 3 shows the frequencies that are being considered for these systems. User (or subscriber) links, feeder (or gateway) links, and cross links are included. To provide a worldwide service, these systems will need to have frequency approval from nations throughout the world.

Most of the systems use the traditional "bent pipe" approach of having the satellite act like a bent pipe for communications purposes. To communicate beyond a satellite's antenna pattern that type of system requires an earth station gateway to connect to the Public Switched Telephone Network (PSTN) and the associated long distance services.

Only one system, Iridium, is proposing satellite-to-satellite crosslinks in the initial concept. Crosslinks allow mobile users to directly communicate. As a result, they remove the dependency on gateways and the use of existing systems to connect mobile users outside of a given satellite's antenna footprint.

	User		Feeder		
	Uplink	**Downlink**	**Uplink**	**Downlink**	**Cross Links**
ARIES	1610-1626.5	2483.5-2500	6525-6541.5	5150-5166.5	
ELLIPSO I	1610-1616.5	2483.3-2500	1610-1616.5	2483.3-2500	
II	1610-1626.5	2483.5-2500	1610-1626.5	2483.5-2500	
GLOBALSTAR					
Syst A	1610-1626.5	1610-1626.5	6525-6541.5	5199.5-5216	
Syst B	1610-1626.5	2483.5-2500	6484-6541.5	5158.5-5216	
Syst C	1610-1626.5	1610-1626.5	2483.5-2500	2483.5-2500	
GONETS	200-400				Modernization Option
IRIDIUM	1610-1626.5	1610-1626.5	27.5-30.0 GHz	18.8-20.2 GHz	22.55-23.55 GHz
LEOCOM	950-959 960-980	905-914 1000-1020	6 GHz	4 GHz	
LEOSAT	148	137	478	370	
ODYSSEY	1610-1626.5	2483.5-2500	29.5-30.0 GHz	19.7-20.2 GHz	
ORBCOMM	148.0-148.85	137.2-138.0	148.85-148.9	137.0-137.05	Receive only from GPS
STARSYS	148.0-149.9	137-138	148.0-149.9	137-138	

Figure 3. Frequencies (MHz unless noted otherwise)

Satellite Characteristics and Capacity

Figure 4 is a summary of the weight and power for these systems. Weights range from 40 to 2500 pounds with required power ranging from 22 to 1800 watts. The estimated characteristics and capacities for these systems come from the source documents which are sited as references.

	Estimated Weight Pounds	Estimated Prime Power Watts
ARIES	275	107 average 278 peak
ELLIPSO I II	40 385	22 peak 174 peak
GLOBALSTAR	510	150 average 875 peak
GONETS	496	40 average 48 peak
IRIDIUM	851	1429 average
LEOCOM	97	112.4
LEOSAT	50-100	23.4 average
ODYSSEY	2500	1800
ORBCOMM	331	360 average
STARSYS	110-220	120

Figure 4. Satellite Characteristics

Figure 5 indicates the expected capacity in terms of simultaneous transmissions (or available communication channels) per satellite. Properly sizing the system capacity to respond to the needs of the expected market is a critical factor. The system must not be over-designed and too expensive. It also must not be under-designed with too few channels available for use. A flexible design with adequate margins and room for growth is ideal.

ARIES	50 duplex voice channels per satellite
ELLIPSO I II	150 carriers in CONUS 216 simultaneous users per satellite without voice activations 605 simultaneous users per satellite with voice activation
GLOBALSTAR	2600-2800 duplex voice channels per satellite
GONETS	System throughput is 7×10^9 bits per day
IRIDIUM	110 duplex voice channels per cell averaged over 37 cells per satellite
LEOCOM	30 channels per satellite
LEOSAT	Expect to service over 100,000,000 intermittent users
ODYSSEY	4600 simultaneous transmissions
ORBCOMM	Down 18 channels per satellite Up 74 channels per satellite
STARSYS	Due to short messages and auto rebroadcast not limiting factor

Figure 5. Capacity (Subscriber Channels)

Conclusions

This paper shows that several systems are being proposed to provide geolocation, voice, and data services. As this paper demonstrates, these services can be provided using several different system and satellite configurations. Low earth orbiting satellites offer an advantage in being able to close the link and provide personal, mobile, voice communications with a handheld user unit. Many other applications are possible using the unique capabilities of small satellites plus the increasing sophistication of microelectronics. It will be interesting to watch these new possibilities and to observe which can make the difficult transition from the "possible" to the "real."

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