SURVEY OF KA-BAND SATELLITES FOR WIDEBAND COMMUNICATIONS

James Yoh, Charles C. Wang and Gary W. Goo
The Aerospace Corporation
2350 E. El Segundo Blvd., El Segundo, CA 90245-4691
Tel: (310) 336-8846 Fax: (310) 336-6225 E-Mail: james.yoh@aero.org

Abstract - The interim generation of wideband military communications satellites will be the Wideband Gapfiller Satellites (WGS) which will preserve and augment the legacy missions of the Defense Satellite Communications System (DSCS) and the Global Broadcast Service (GBS), and add the new so-called Two-Way Ka. In order to provide for conceptual design of these satellites and plan for their acquisition, a survey has been conducted on currently operational and planned communications satellites that operate in the Ka-band. Our search has been performed to identify articles in the open literature on the description of the Ka-band satellites. Of particular interest are the salient features that pertain to the communications subsystems of these satellites. These features include frequencies, data rates, waveforms and frame structures. Data was obtained for the communications satellites from Italy, Germany, Japan and the European Space Agency (ESA), as well as some satellites from the United States (US). Many US Ka-band communications satellites are currently being developed. Unfortunately, information on waveforms and frame structures is not readily available in open literature on all of them. This article gives brief descriptions of these satellites. Feature parameters are presented in tabular format for comparison among different systems.

1. INTRODUCTION

The Wideband Gapfiller Satellites (WGS) are currently in the early phase of acquisition as the interim system between the legacy Defense Satellite Communications System (DSCS) and the Global Broadcast Service (GBS), and the next generation of tactical and infrastructure military communications satellites, the Advanced Wideband System (AWS). The WGS introduces the new Two-Way Ka (TWKa) service, and as such raises question as to the architecture of the service to be adopted in the transition era to AWS. DoD is relying on the explosion of commercial endeavors to define the future architecture for the wideband mission. This is germane to the WGS TWKa where there is tabula rasa, i.e., less “legacy drag” in the terminal segment to consider. Here we consider the commercial systems that are slated to be operational in the WGS timeframe as candidates for TWKa implementation.

The frequency bands being considered is the Ka-band with uplink and downlink frequencies at 30 GHz and 20 GHz, respectively. There has been considerable work on experimental, operational and planned operational communications satellites in the Ka-band by foreign and domestic organizations [1]. Of particular interest are the salient features for the operational satellites, including frequencies, data rates, waveforms and frame structures. We have conducted a survey over the open literature on the foreign and domestic communications satellites that have operations in the Ka-band. Table 1 summarizes the major operational satellites that will be addressed in this article. The German, Italian and Japanese systems have been operational, while the system by the European Space Agency (ESA) is being developed. The United States systems are in various stages of development and deployment. Data collected during the survey will be presented in the following sections.

2. GERMAN COMMUNICATIONS SATELLITES

The German communications network is called the Deutsches Fernmelde Satellitensystem (DFS)-Kopernikus [2,3,4]. It consists of two satellites, one being a stand-by satellite to the other. They are located in geostationary orbits, positioned at longitudes of 23.5^0E and 28.5^0E. The DFS-Kopernikus system has been operational since the launch of the second satellite in 1992. The Ka-band, operating at 29.58 GHz for uplink and 19.78 GHz for downlink, is used for point-to-point connections for voice and data transmission. The first satellite was intended for testing and gathering of experience in the Ka-band during the initial phase. The DFS-Kopernikus satellites serve as non-regenerative repeaters. The transponder has a bandwidth of 90 MHz, allowing for a maximum data rate of 140 Mbps using the QPSK waveform.

The DST-1100 time division multiple access (TDMA) system, a demand assigned random access system, has been developed by COMSAT Corporation for the DFS-Kopernikus Network [5,6]. Its frame structure consists of five segments. The Primary Reference Burst (PRB) and Secondary Reference Burst (SRB) are transmitted by the primary and secondary reference stations, respectively. They cover the conditions of weather interference and sun-outages at the reference stations and contain commands and data to each of the traffic terminals.

The use of redundant reference stations improves operation reliability. The third segment is set aside for traffic reservation. The Main Traffic Burst (MTB) contains storage space for transmitting data and voice calls. Calls with FEC are placed at the beginning of the storage and calls without FEC are placed at the end, while maintaining contiguous free space in the middle. Finally, Single Channel Per Burst (SCPB) segment handles special call types, such as calls blocked from the MTB, wideband calls and multidestination calls.

3. ITALIAN COMMUNICATIONS SATELLITES

The Italian telecommunication network, the Integrated Services Digital Network (ISDN), includes ITALSAT as the main communication satellite program [1,7,8,9]. Two Italsat satellites, F1 and F2, were launched in 1991 and 1996. F1 was experimental with limited operational characteristics while F2 was an operational satellite. The satellites are in geostationary orbits with longitudes of 10.2^0E and 13.2^0E for F1 and F2, respectively. Each satellite contains three payloads, two of which involve the Ka-band exclusively[1]. The Multibeam Payload provides six beams to cover the elongated landmass of Italy. It includes six regenerative repeaters, one for each beam, each of which has a data rate of 147.5 Mbps with an available bandwidth of 110 MHz. A satellite-switched TDMA (SS-TDMA) system is employed for access and routing to provide point-to-point and point-to-multipoint communications within and beyond beam coverage regions. The six beams operate at different uplink and downlink frequencies. The frequencies occupy ranges of 27.5-30 GHz for uplinks and 18.5-20 GHz for downlinks. QPSK waveform is used. The Global Coverage Payload, also using a QPSK waveform, produces a single beam for coverage over the entire Italian landmass. It provides transparent (nonregenerative) operation via three channel transponders that can operate either at saturation (Mode 1) or linearly (Mode 2). The transponders have a capability of 25 Mbps per channel, with a channel bandwidth of 36 MHz. The channel frequencies are in the ranges of 29.5-30 GHz for uplinks and 19.7-20.2 GHz for downlinks.

The SS-TDMA system has a frame time of 32 msec, with 3072 Frame Units (FUs) in each frame [10,11]. At the data rate of 147.5 Mbps with QPSK waveform, there are 768 symbols per FU. There are two types of bursts to handle the 32 Kbps channels[2]: a short burst using one FU to carry one 32 Kbps channel and a medium burst using 3 FUs to carry four 32 Kbps channels. There are five segments in a 32-msec frame:

- 6 FUs for Reference Burst and Switching Matrix Burst
- Medium bursts for point-to-point services
- Medium bursts for video-conferencing
- Short bursts for spot-to-spot trunks
- Short overhead bursts for the internal satellite service network

The boundaries between different segments may be changed in a flexible manner according to the required utilization. Within each burst, 256 symbols are used for preamble and postamble, leaving 512 and 2048 data symbols for short and medium bursts, respectively. Note that 512 and 2048 quaternary symbols in the short and medium bursts correspond to one frame (32 msec) of data from one and four 32 Kbps channels, respectively.

4. ESA COMMUNICATIONS SATELLITES

The European Space Agency (ESA) has been developing a data relay system for the purpose of transferring high speed data from low-orbit user satellites directly to the user ground stations. The space segment of the data relay system consists of two Data Relay Satellites (DRSs) in geostationary orbits. Their longitudes are selected to provide ground coverage over all of Europe and maximize contact opportunities with low-orbit satellites. Even though the DRSs have yet to be deployed, an experimental satellite, Olympus, was launched to perform many experiments and technology demonstrations. In 1992, Olympus was used to demonstrate the two-way transfer of data in the Ka-band between the user satellite Eureca and a ground station [12] at a data rate of 512 Kbps from Eureca.

A preoperational satellite, Artemis, is scheduled for launch in the winter of 1999/2000 [13]. It will be used to transfer extremely large volumes of scientific data from the earth-observing Polar Platform/Envisat satellite to the User Earth Terminal [14]. It is intended that Artemis should provide demonstration of the data relay services for low earth orbiting users, as well as providing spare operational capacity in the Ka-band [15]. Artemis is a geostationary satellite positioned at a longitude of 16^0E. For the Ka-band, it has three 250 MHz channels centered at 26.85, 27.10 and 27.35 GHz to relay data from user satellites. Two channels can be used simultaneously, each of which having data rates of 100 Mbps with QPSK modulation or 50 Mbps with BPSK modulation. Hence the maximum data rate is 200 Mbps.

The operational DRS satellites are expected to be similar to Artemis, although the maximum data rate from user satellites may need to be increased to 300 Mbps to accommodate a future user, Polar Platform PPF-2 [14]. There are four operating frequencies.

[1] The third payload for ITALSAT F1 is the Propagation Payload, which includes a 20 GHz beacon generator. For ITALSAT F2, this Propagation Payload was replaced by a European Mobile Services Payload [1].

[2] A third type of burst requires 1459 FUs to carry a 70 Mbps TV signal.

The preferred frequency ranges are: 29.5-30.0 GHz for the forward Feeder Link from the ground, 17.7-20.2 GHz for the return Feeder Link to the ground, 23.15-23.55 GHz for the forward Inter-Orbit Link to the user satellite, and 25.25-27.5 GHz for the return Inter-Orbit Link from the user satellite [16]. Since, this is a data relay system, a simple switch matrix is foreseen for traffic routing and redundancy management [17].

5. JAPANESE COMMUNICATIONS SATELLITES

Japan has a long history of experimenting and operating in the Ka-band [1]. The CS satellite [1], launched in 1977, was used to perform experiments and preoperational system demonstrations. The CS-2 satellites [18,19], launched in 1983, have limited operational capabilities, serving Nippon Telegraph and Telephone Corporation as well as some public and governmental organizations. Portions of the CS-2 satellite capabilities were also used in the CS-2 Pilot Program to promote future usage of communication satellites. The CS-3 satellites [1,20], launched in 1988, incorporated more Ka-band transponders and channels, and new technologies over the CS-2 satellites. The increased capacities allowed the CS-3 satellites to serve the large Japanese metropolitan areas. All these satellites were launched into geosynchronous orbits, at various longitudes. Each of the CS-2 and CS-3 satellites has 6 and 10 Ka-band bentpipe transponder channels, respectively. Each transponder channel has a bandwidth of 100 MHz supporting a data rate of 65 Mbps. The modulation is either BPSK or FM, depending on the type of service.

The CS satellites were replaced by two N-Star satellites [1,21,22], launched in 1995 and 1996. These satellites are located in geostationary orbits, positioned at longitudes of 132^0E and 136^0E. Each satellite has two Ka-band payloads. The multibeam payload has eight uplink beams and three downlink beams covering the landmasses of Japan. Each beam, uplink or downlink, has two 200-MHz bandwidth channels, using different frequencies. The uplink and downlink frequencies are in the ranges of 28.305-30.425 GHz and 18.505-20.145 GHz, respectively. The multibeam payload provides SS-TDMA communications and adopts an onboard IF beam switching. The shaped beam payload, which is a bentpipe transponder, covers Japan with a single beam, using five 100-MHz bandwidth transponders. The uplink and downlink frequencies for the shaped beam payload are in the ranges of 27.575-28.155 GHz and 17.775-18.355 GHz, respectively.

Another Japanese operational communication satellite network employs the Superbird satellites [1,23]. The two currently operating satellites were launched into geostationary orbits in 1992, at longitudes of 158^0E and 162^0E. Multiple feed horns generate a beam that is shaped to approximate Japanese landmass. Another feed horn generates a spot beam for Tokyo. Ten 100-MHz bandwidth transponders are employed in the Ka-band. The uplink and downlink frequencies are in the ranges of 27.5-30 GHz and17.775-19.315 GHz, respectively.

6. US COMMUNICATIONS SATELLITES

In the United States (US), there has not been an operational Ka-band communications satellite system. However, in 1993 NASA[3] has launched the Advanced Communications Technology Satellite (ACTS), an experimental and demonstration satellite [1]. ACTS was located in a geosynchronous orbit at a longitude of 100^0W. The operating frequencies are in the ranges of 29.24-29.68 GHz for uplink and 19.45-19.7 GHz for downlink. In the TDMA system used, ACTS supports two beams, each of which has an uncoded downlink data rate of 110 Mbps. Signals are typically serial minimum shift keyed (SMSK), but other waveforms can be tested as well. As a demonstration satellite, it is capable of supporting different protocols for direct connections into the terrestrial network. Through its many experiments, measurements and demonstrations, ACTS became the foundation for the proposal and the development of the many commercial enterprises of today.

In 1997, thirteen organizations have been granted licenses by the Federal Communications Commission (FCC) to build Ka-band satellite systems [24]. Several of these systems are in various stages of development. A good summary of the systems that provide global coverage is given by Evans [25]. His Table 2 summarizes much of the information not addressed in this article. Most of the systems have their satellites located in geosynchronous orbits. The satellites cover large areas through multiple beams. All the systems specify broad ranges for their operating frequencies. Most of the systems utilize TDMA for access. They employ gateway ground terminals to connect to external networks, thereby supporting different external protocols. Beyond these generalities, it is difficult to obtain specifics on many of the systems. Information on the global systems available in open literature is summarized in Table 2[4]. The referenced articles are also contained in this table. Note that there is no information on GE*Star, Morning Star and Millennium. Readers are referred to Evans' Table 2 [25] and the FCC filing applications referenced therein.

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[3] NASA has also included an additional Ka-band service in the 23- to 28-GHz spectrum in the Advanced TDRSS program [1]. However, this spectrum is different from the 20- and 30-GHz regions used by other Ka-band systems addressed in this paper.

[4] For cases in which parameter values may differ from amongst the references, the value from the latest reference is accepted.

7. SUMMARY OF DATA

Table 3 summarizes the salient features discussed in the previous sections. It is apparent that most of the Ka-band operational systems are in evolution from transponded to processed waveforms and generally employ QPSK waveforms and TDMA schemes. Multiple beam coverage with frequency reuse becomes desirable to achieve higher throughputs. All of the US systems examined utilize multiple beams. Even satellites for regional coverage, such as ITALSAT and N-Star have multibeam payloads. With multiple beam coverage, onboard switching is needed for point-to-point communications. In the era of WGS the major satellite builders should be able to offer very capable processing satellites for the TWKa mission.

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Table 1. Major Preoperational and Operational Systems in Ka-Band

Country/Agency	Experimental/Preoperational	Operational
Germany	DFS-Kopernikus (First Satellite)	DFS-Kopernikus
Italy	ITALSAT (First Satellite)	ITALSAT
ESA	Olympus, Artemis	Data Relay Satellites (DRS)
Japan	CS	CS-2 (Pilot Program), CS-3, N-Star, Superbird
United States	Advanced Communications Technology Satellite (ACTS)	13 Systems Including: Astrolink, Teledesic, Spaceway, CyberStar, Celestri

Table 2. Major US Global Communications Systems

System	Astrolink	Teledesic	Spaceway	CyberStar	Celestri
References	[26,27,28]	[29,30]	[30,31,32]	[33,34]	[35]
Orbit/Altitude	GEO (9 satellites at 5 locations)	1375 Km Alt (288 satellites in 12 planes)	GEO (16 satellites at 4 locations)	GEO (3 satellites at 3 locations)	1400 Km Alt (63 satellites in 7 planes)
Uplink Freq (GHz)	27.5-30.0 (4 freq reuses)	28.6-29.1 (7 freq reuses)	27.5-30.0 (12 freq reuses)	28.35-30.0	28.6-29.1 29.5-30.0
Downlink Freq (GHz)	17.3-21.2 (4 freq reuses)	18.8-19.3 (7 freq reuses)	17.7-20.2 (12 freq reuses)	18.3-20.2	18.8-19.3 19.7-20.2
Waveform	QPSK	QPSK (8-ary for Gigalink)	QPSK	QPSK	Not Available
User Data Rate (Kbps)	16-9216	16-23000	16-1544 (USAT) 6000 (broadband terminal)	16-6000	64-155520
Uplink Capacity for User Link	20~330 Mbps/beam (96 fixed beams; variable bandwidth)	64 Mbps/beam (cell) or 10Gbps per satellite	Not Available	Not Available	Not Available
Downlink Capacity for User Link	99 Mbps (16 hopping beams)	64 Mbps per beam (~120,000 cells for system)	92 Mbps/beam/ polarization (48 beam/polarization pairs/satellite)	92 Mbps/beam/ polarization (72 beams per satellite)	Not Available
User's Access Scheme	U/L: FDMA/TDMA D/L: TDM	U/L: FDMA/TDMA D/L: TDM	U/L: FDM/TDMA D/L: TDM	U/L: FDM/TDMA D/L: TDM	U/L: FDM/TDMA D/L: FDM/TDMA
Capacity for Gateway Link	50-150 per gateway (eight 3-way hopping beams per satellite)	Not Available	Not Available	Not Available	Not Available
Network Architecture	ATM/DAMA	Satellite-Based Fast Packet Switching (To other 8 nodes)	Circuit-Switched and Packet-Switched; ATM/DAMA	Bandwidth-On-Demand	Satellite-ATM

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Table 3. Summary of Features for Systems Examined

System	Coverage/ Altitude	Uplink Freq (GHz)	Downlink Freq (GHz)	Waveform	User Data Rate (Kbps)	Architecture/ Network Structure
DFS-Kopernikus (Germany)	Regional/ GEO	29.58	19.78	QPSK	64-2048	TDMA/18 msec Frame Divided into 5 Segments
ITALSAT (Italy)	Regional/ GEO					TDMA/32 msec Frame Divided into 3072 Frame Units
Multibeam Payload		27.5-30.0	18.5-20.0	QPSK	32-128	
Global Coverage Payload		29.5-30.0	19.7-20.2	QPSK	32-128	
DRS (ESA)	Regional/ GEO	29.5-30.0	17.7-20.2	QPSK	2×500	Not Available
CS-2/CS-3 (Japan)	Regional/ GEO	27.515 -28.995	17.775 -19.195	BPSK Or FM	192-6144	TDMA,FDMA,DAMA
N-Star (Japan)	Regional/ GEO	28.305 -30.425	18.505 -20.145	Not Available	Not Available	SS-TDMA, On-board IF Switching
Superbird (Japan)	Regional/ GEO	27.5-30.0	17.775 -19.315	Not Available	Not Available	Not Available
Astrolink (US)	Global/ GEO	27.5-30.0	17.3-21.2	QPSK	16-9216	U/L: FDMA/TDMA, D/L:FDM; ATM,DAMA, On-board Processing,
Teledesic (US)	Global/ 1375Km	28.6-29.1	18.8-19.3	QPSK	16-23000	U/L: FDMA/TDMA, D/L:FDM; Satellite-Based Packet-Switched
Spaceway (US)	Global/ GEO	27.5-30.0	17.7-20.2	QPSK	16-1544	U/L: FDMA/TDMA, D/L:FDM; Circuit-Switched and Packet-Switched, On-board Processing
CyberStar (US)	Global/ GEO	28.35-30.0	18.95-20.2	QPSK	16-6000	U/L: FDMA/TDMA, D/L:FDM; Bandwidth-on-Demand, On-board Processing
Celestri (US)	Global/ 1400Km	28.6-29.1 29.5-30.0	18.8-19.3 19.7-20.2	Not Available	64-155520	U/L: FDM/TDMA, D/L:FDM/TDMA; Satellite-ATM

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