Future Developments in Aeronautical Satellite Communications

Peter Wood
Inmarsat
40 Melton Street
London, NW1 2EQ
United Kingdom
Phone: +44 71 387 9089
FAX: +44 71 383 0849

ABSTRACT

Very shortly aeronautical satellite communications will be introduced on a world-wide basis. By the end of the year voice communications (both to the cabin and the cockpit) and packet data communications will be available to both airlines and executive aircraft. During the decade following the introduction of the system there will be many enhancements and developments which will increase the range of applications, expand the potential number of users, and reduce costs. This paper presents a number of ways in which the system is expected to evolve over this period. Among the issues which are covered are the impact of spot beam satellites, spectrum and power conservation techniques, and the expanding range of user services.

INTRODUCTION

Aeronautical satellite communications have been the subject of tests and studies for more than 25 years. The earliest test was in 1964, when communications were successfully established with an PanAm aircraft in flight, using the SYNCOM III Satellite. The most recent occurred earlier this year when an aircraft operated by the U.S. National Science Foundation was able to maintain communications to its home base to within 50 miles of the South Pole. Studies have included the Oceanic Area System Improvement Study[1], the RTCA SC-155 User Requirements for Future Communications, Navigation, and Surveillance Systems[2], and the report of the ICAO Special Committee on Future Air Navigation Systems[3].

Approximately five years ago Inmarsat began to develop the concepts for a global aeronautical satellite service, and contracted for the transponders in its Inmarsat-II satellites to include 6 MhZ allocated to AMSS(R) use (3 MHz in each direction). Since that time the system has evolved to the point where it will enter into service in the very near future, and will provide both voice and data communications to aircraft operating world-wide, with the exception of a limited area near the poles.

The Inmarsat approach has been to use a single-channel per carrier for voice communications to and from the aircraft, a combination of slotted Aloha and TDMA for data communications from the aircraft, and TDM for data communications to the aircraft. During the course of development an alternative to the Inmarsat approach based entirely on TDMA techniques was proposed by the AvSat Corporation, but although the concepts are still retained in some specifications[4], development has been terminated, and it is unlikely that a system based entirely on TDMA will be introduced in the forseeable future.

OUTLINE OF THE SYSTEM

The INMARSAT Aeronautical Satellite System is based upon two types of antenna, a nominally omnidirectional low gain antenna, and a steerable high gain antenna (nominally 12 dB), together with a range of channel transmission characteristics (Table 1) designed to meet a wide range of applications.

Table 1. Channel Transmission Characteristics

Channel Rate (bit/s)	Channel Spacing (kHz)	Modulation
21000	17.5	A-QPSK[a]
10500	10.0/7.5	A-QPSK
6000	5.0	A-QPSK
5250	5.0	A-QPSK
4800	5.0	A-QPSK
2400	5.0	A-BPSK[b]
1200	5.0/2.5[c]	A-BPSK
600	5.0/2.5	A-BPSK

a A-QPSK is Aviation QPSK, a particular form of O-QPSK[5, 6]

b A-BPSK (Aviation Binary Phase Shift Keying) is a from of differentially encoded BPSK in which alternate modulation signals are transmitted in notional In-Phase and Quadrature channels[7]

c 5.0 applies to P-channel, 2.5 to R- and T-channels

Four types of channels are supported:

- P-Channel: Packet mode time division multiplex (TDM) channel, used in the forward direction (ground-to-air) to carry signalling and user data

- R-Channel: Random access (slotted Aloha) channel, used in the return direction (aircraft-to-ground) to carry some signalling and user data (short messages only)

- T-Channel: Reservation Time Division Multiple Access (TDMA) channel, used in the return direction only.

- C-Channel: Circuit Mode single channel per carrier (SCPC) used in both the forward and return directions. The use of the channel is controlled by assignment and release signalling at the start and end of each call The C-channel includes sub-band data fields for signalling purposes.

In the initial system, installations using the omnidirectional low gain antenna will only support low data rate communications over the P-, R- and T-channels. High gain antennas will support both low and high rate data, and voice communications over the C-channel.

The majority of channel types use Forward Error Correction (FEC) coding, consisting of a convolutional encoder of constraint length k=7 and an 8-level soft decision Viterbi decoder. The FEC coding rate is 1/2. Because of the multi-path fading characteristics of the aeronautical transmission path interleaving is applied to all channels using FEC coding in order to preserve the FEC coding gain.

Signalling and user data messages on the P, T, and sub-band C-channels are formatted into standard length signal units of 96 bits. Signalling and user data messages on the R-channel are formatted into extended length signal units of 152 bits. These allow for the most common transactions to be carried out within only one signal unit with a minimum of spare unused capacity. More complex messages (including use data) can be carried by sequence of several signal units, up to a maximum of 64.

Voice signals are digitally encoded using an APC algorithm at a bit rate of 9.6 kbits/s. The encoded voice data is combined with the sub-band signalling channel for transmission over a C-channel. The system is designed to allow operation through the Public Switched Telephone Network, although for operational reasons initially it will only by possible to initiate calls from the aircraft. This restriction does not apply to communications to and from the cockpit or with executive aircraft.

The system design is based upon the use of a linear (class-A) High Power Amplifier in the aircraft. This will support operation with several channels simultaneously. The number of channels that the amplifier can support is dependent upon the satellite through which an aircraft is operating, and the location of the aircraft with respect to the satellite. It is also possible to use a class-C amplifier for single channel installations.

SATELLITES

During the first few months of service aeronautical communications will use the first generation of Inmarsat satellites (Marecs and Intelsat-MCS), and communications will be in the maritime band. The main operational limitation with these satellites is that they will only support two channels simultaneously (reduced to one channel at satellite elevation angles less than 20°).

The first major operational change will result from the relocation of one of the Marecs satellites to 55° West, resulting in the creation of four ocean regions (Atlantic-E, Atlantic-W, Pacific and Indian). The effect of this relocation will be to close the gap that currently exists over part of North America and the eastern Pacific Ocean.

This will be shortly followed by the launch of the first of four Inmarsat-II satellites. Each of these satellites will provide 3 MHz capacity in the aeronautical band and, more importantly, also have greater sensitivity, which will result in doubling the number of channels that can be supported by single HPA.

The third stage in the evolution of satellite support for aeronautical communications will be the launch of spot-beam satellites. Currently AMSC in the United States, M-Sat in Canada, and Inmarsat are planning to launch spot beam satellites. The first two will provide regional coverage; Inmarsat plans to provide global coverage through its Inmarsat-III spacecraft. The first Inmarsat-III spacecraft is expected to enter service late 1994 or early 1995.

Two important operational enhancements will result from the introduction of spot beam satellites. The first is an increase in the number of channels that can be supported by a single aircraft installation that complies with industry standards. The second is the possibility of supporting voice services through a low-gain omnidirectional antenna. Although Inmarsat does not see this as being the primary method of operation (if for no other reason than the increased interference to global beam satellites that would result), nevertheless this would be a method of maintaining a minimum level of voice service for emergency use in the event that the high gain steerable antenna failed for some reason.

SYSTEM DEVELOPMENTS

System Management

Initially each Ground Earth Station (GES) that supports the Inmarsat system will operate on a stand-alone basis, using a dedicated set of frequencies. Each GES will be required to support a high-power P-channel to communicate with aircraft that are only fitted with low-gain antennas.

As usage of the system develops, Inmarsat will be introducing Network Coordination Stations (NCSs) which will allocate frequencies on a dynamic basis according to demand. It would also be possible to use space segment resources more efficiently by providing a common high-power P-channel at NCSs only.

As other satellite service providers begin to offer service, the NCSs will also be responsible for inter-system coordination.

Voice Coding

At the time the concepts for Inmarsat's aeronautical system were maturing, the lowest bit rate at which it appeared an acceptable quality for voice communications could be achieved was in the order of 9.6 kbits/s. Extensive tests were carried out on behalf of the Airlines Electronic Engineering Committee to determine which of the algorithms available had the highest performance in an aeronautical environment, and an APC based algorithm developed by British Telecom Research Laboratories (BTRL) was selected as the industry standard.[8]

Subsequently developments in voice codec technology have led to the possibility that acceptable quality could be achieved at bit rates as low as 4.8 kbit/s. Formal comparative tests between 9.6 kbit/sec and 4.8 kbit/s have still to be performed. If the performance of these lower data rate codecs lives up to their promise then it is probable that they will be eventually selected as a future standard. No major modifications to the basic system design would be required, and the 9.6 kbit/sec codec would continue to be supported while it was in general use. The lower bit rates would, of course, lead to a more efficient use of the available spectrum; a key issue as the uses of aeronautical satellite communications expands to fill the frequencies allotted by the ITU for that use.

Circuit Mode Operation

Circuit-mode data service is an optional enhancement to Inmarsat's aeronautical system. This service provides a basis circuit mode data channel with a call set-up procedure similar to that used for voice calls. The nature of the end-to-end service between the aircraft and the end user depends upon the type of interconnection with the terrestrial network. The use of voice-band analog modems provides an analog-interconnect data service. Digital interconnection is possible where a digital path is available through the terrestrial network (circuit switched digital data network, dedicated digital network, or ISDN).

Each circuit-mode data call utilizes a pair of C-channels for the duration of the call. The digital bit stream of the C-channels, without the use of voice band modems over the satellite channel, is directly employed to transport the data traffic. The voice codecs normally associated with the C-channels are not used during the data transfer state.

Rate adaptation must be performed to match the user data bit rate, taking into account clock rate variations, to the available satellite channel capacity. The bit rate stability of the received data from a PSTN modem is, in general, worse than the required clock rate stability of the satellite channel. It is therefore necessary to implement a plesiochronous interconnection arrangement in the forward direction. A plesiochronous buffer is not required in the return direction provided the PSTN modem is synchronized to the incoming data stream from the C-channel.

NEW SERVICES

When the concepts for the system were originally developed it was considered that there were two basic types of service required; packet mode data for air traffic service and airline use, and voice for public correspondence and, to a more limited extent, for non-routine air traffic service and airline messages. As more users became aware of the potential of aeronautical satellite communications a wider range of services appeared to justify support.

Examples of the services which will be offered in the future are:

Facsimile

One of the earliest to be introduced will be facsimile. An interface unit to permit operation of standard Group-III facsimile equipment is now under development. The ability to successfully transmit facsimile over a satellite link has already been demonstrated.

Broadcast Messages

There is also a demand to broadcast voice and data messages to a group of aircraft. Voice messages can be accommodated quite easily since only reception is required; this allows the service to be introduced without absorbing any of the limited power available from the aircraft HPA. Data messages (similar to the Oracle and Seefax messages currently being transmitted over TV channels in the U.K.) could also be transmitted for subsequent display over the aircraft's video equipment.

Computer-to-Computer Communications

With the increased use of portable and lap-top computers a demand has arisen to support their use by passengers while they are on the aircraft. A simple interface unit would permit this; the main limitation is the feasibility of certifying computer equipment for use by the public on aircraft.

Mobile Telephone Service

There would be considerable benefits to allowing the use of portable telephones on an aircraft. Again, the main problem is related to licensing of the equipment rather than technical problems in its use. If this could be overcome such a service would most likely be limited to the air-to-ground direction.

CONCLUSIONS.

Over the next few years, enhancements to the Inmarsat aeronautical satellite system will be incremental in nature. More exotic developments, such as direct television broadcasts from satellite to aircraft, will eventually be introduced, but will required a switch to a new portion of the spectrum. All projections show that the L-band spectrum currently allocated to aeronautical mobile services will only be adequate for essential demands by the end of the decade. As the amount of traffic required to support safety and regularity of flight increases there will be pressure to move public correspondence to these other frequencies. This could well be the catalyst for introducing these new services.

REFERENCES

1. **Couluris, G.J. and B. Conrad.** 1981 *Oceanic Area System Improvement Study (OASIS)--Volume 1 Final Report* FAA-EM-81-17 (Menlo Park, California, SRI International)

2. ----1986. *Report of RTCA Special Committee 165--User Requirements for Future CNS Systems, Including Space Technology Applications.* DO-193 (Washington D.C., Radio Technical Commission for Aeronautics)

3. ----1988. *Special Committee on Future Air Navigation Systems--Fourth Meeting Report* Doc 9524, FANS/4 (Montreal, Quebec, International Civil Aviation Organization)

4. ---1989. *Aviation Satellite Communication System: Part 2, Equipment Design and Equipment Functional Description.* ARINC Characteristic 741 (Annapolis, Maryland, Aeronautical Radio Inc.)

5. **Gronemeyer, S.A.** 1976. MSK and O-QPSK Communications *IEEE Transactions on Communications* Vol. COM-24, pages 809-830

6. **Fang, R.J.F.** 1981. Quarternary Transmission Channels over Satellite Channels with Cascaded Nonlinear Elements and Adjacent Channel Interference *IEEE Transactions on Communications* Vol. COM-29, pages 567-581

7. **Winters, J.H.** 1984. Differential Detection with Intersystem Interference and Frequency Uncertainty. *IEEE Transactions on Communications* Vol. COM-32, pages 25-33

8. **Crowe, D.P.** 1988. *Selection of Voice Codec for the Aeronautical Satellite Service. (Ipswich, British Telecom Research Labs.)*