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CHOICE OF FDMA/SCPC ACCESS TECHNIQUE FOR AERONAUTICAL SATELLITE VOICE SYSTEM

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ABSTRACT

A worldwide aeronautical mobile satellite system is about to become operational. The system architecture and access methods have been debated extensively, resulting in the selection of TDM/TDMA access for packet data, and SCPC for voice. These have become standards for airline use, and also satisy the known requirements of ICAO for safety related communications. Voice communications are expected to absorb a high proportion of satellite bandwidth and power in the future, and this paper explains why INMARSAT selected FDMA/SCPC satellite access for this application.

1. INTRODUCTION

Two proposed system architectures are examined in this paper. In one case, voice and data service satellite access schemes are different: packet-data communications use TDM/TDMA while voice uses SCPC, both services using relatively low transmission rates of up to 21kbit/s. The alternative architecture is based on a common TDMA satellite access scheme for voice and data, with transmission rates up to 320kbit/s.

The main criteria considered in INMARSAT's selection of a voice access scheme were:

(a) operate, and back-up, services on existing and planned satellites

(b) use satellite power and bandwidth resources flexibly and economically

(c) permit a range of avionics options suited to the requirements of a wide range of different users

(d) handle the propagation conditions of aeronautical mobile-satellite communications

(e) take progressive advantage of improved satellite performance as it becomes available, not limiting user choice of satellite provider.

The comparison shown in this paper caused INMARSAT to select the SCPC voice access scheme. Voice places large demands on satellite power and bandwidth, but SCPC access is able to exploit voice properties to minimize its demands (points b and d). SCPC was also found to permit an orderly growth path (points a, c, and e).

2. COMPARISON BETWEEN SPECIFIC FDMA AND TDMA DESIGNS FOR VOICE SERVICES

A general comparison of SCPC and TDMA is beyond the scope of this paper, but specific access proposals may be examined. Two specific system designs which have been considered by the Airlines Electronic Engineering Committee (AEEC) and which are based on different voice access methods were compared, one using SCPC satellite access, the other a TDMA design using (ground-to-air) single carrier per transponder operation with a multiple of 30 voice channels per satellite beam. The main parameters of the system designs are summarized in Table 1, which references the sources of the quoted parameters. Tables 2 and 3 have been derived from these parameters using some assumptions on satellite performance. In particular, where a 'global' beam satellite is quoted, the reference is to INMARSAT-2 satellite performance, and for 'spot-beam' satellites the assumptions on performance are based on an effective satellite antenna gain of about 25 dBi corresponding to a beam diameter of about 7 degrees. It is assumed that FORWARD LINK (to-aircraft) and RETURN LINK (from aircraft) L-band satellite antennas have identical coverage. Table 2 shows the number of voice channels (9.6 kbit/s or 8 kbit/s for these SCPC or TDMA designs respectively) which can be transmitted from aircraft to ground, as a function of the aircraft HPA power, the aircraft antenna gain, and the spacecraft antenna gain. Table 3 shows the number of channels which can be transmitted from a single satellite beam of a given EIRP (irrespective of whether spot or global) to aircraft fitted with high gain (12dBi) or low gain (0dBi) antennas.

3. ANTENNA REQUIREMENTS ON AIRCRAFT AND SATELLITE

Tables 2 and 3 show that the TDMA design provides no service unless satellite spot beams are available, and aircraft carry high-gain antennas. They also show that SCPC will provide voice service to aircraft fitted with high-gain antennas by means of global-beam satellites, and with spot-beam satellites will provide limited service to aircraft fitted with only 0dBi antennas. When the higher-gain antennas are available on both the satellite and the aircraft, the SCPC system is able to provide more channels than the TDMA design in the same situation.

This analysis strongly points to FDMA as the basis for the voice system architecture, in terms of ability to take advantage progressively of available and future satellite and aircraft resources.

4. RETURN LINK - AIRCRAFT HIGH-POWER AMPLIFIER REQUIREMENTS

An SCPC system requires a quasi-linear HPA on the aircraft, except for single-channel installations. The power needed from the amplifier depends on the satellite sensitivity or G/T and on the number of return-link voice channels the avionics must support. These are interrelated. A linear amplifier to AEEC requirements (40 Watt) will allow transmission of four 9.6 kbit/s voice channels using INMARSAT second-generation satellites. The same amplifier would permit at least 14 channels to be carried through a spot-beam satellite. On the other hand, a much smaller amplifier, say 12 Watts, would provide one voice channel worldwide through an INMARSAT-2, and at least four channels in regions where satellite spot beams are available. (Table 2).

The TDMA design requires an aircraft HPA of 40 Watts, but this can be of the efficient, saturating type. However, the TDMA access method limits the HPA to the designed maximum number of voice channels - even when the aircraft is working into a more sensitive satellite.

5. FORWARD LINK VOICE ACTIVATION

Satellite L-band power in the forward direction is limited, but a voice channel may be switched off during speech pauses. An SCPC system is amenable to this type of operation, reducing the average transponder power for a given number of voice channels - or equivalently, increasing the number of channels supportable by a given transponder. Voice activation advantage depends on the transponder non-voice-activated channel capacity: where this is 60 or more, and the voice activity factor is 40%, the transponder power (capacity) advantage is about 4dB. This figure is used in Table 3.

This improvement is not available in the TDMA design which assumes saturated transponders. To gain some equivalent improvement, digital speech interpolation would be needed. Even then, the advantage achieved would be limited to the maximum bundle size of a single TDMA carrier - about 30 in this specific TDMA case (equivalent to about 22 average simultaneous channels) - whereas for the SCPC design the advantage arises from the total forward link traffic load in the relevant transponder, typically in excess of 100 channels.

6. FORWARD LINK POWER CONTROL AND EIRP DISTRIBUTION ADVANTAGE

A satellite antenna gain is typically 3dB higher at the beam centre than at its edge, and enough satellite power must be provided per voice carrier, in the satellite to aircraft direction, to support reliable operation at beam edge. In the SCPC design, the power per voice carrier for those aircraft near beam centre is reduced by applying 'forward-link power control'. Averaging the power per carrier over the coverage area of the beam, an effective power saving of 1.5 - 2dB is typically achieved, giving a corresponding transponder capacity increase.

Power control is entirely automatic, and does not need knowledge of the location of aircraft, because the system measures the signal quality and adjusts the power it allocates accordingly. This also means that the system will allocate more satellite power to aircraft in disadvantaged regions, especially at low elevation angles where propagation is affected adversely, and this in turn means that the general system margins can be reduced - thus increasing the number of voice channels which can be carried by a given transponder. A TDMA system design must be able to provide enough power in each transponder transmission burst to give reliable service to the most disadvantaged aircraft - and since the power has to be there, it is pointless to reduce it for service to the less-disadvantaged aircraft.

In Table 3 the assumed total EIRP distribution advantage was conservatively taken as 1.5dB, to include the effects of both satellite beam and differential propagation variations.

7. FORWARD LINK CHANNEL-TO-SATELLITE-BEAM ASSIGNMENT

The capacity of each L-band satellite beam must accommodate the planned number of offered traffic channels including statistical variations. It is standard practice in international telephony to accept a maximum of 1 in 50 rejected calls due to statistical sharing blockages, normally expressed in percentage as a 'Grade of Service' of 2%.

In the TDMA design, ground-to-air channels are grouped into bundles of 30 channels. For a grade of service of 2%, 30 physical channels can only handle an average offered traffic load of 22 Erlangs - a peak Erlang efficiency of 73%.

Traffic in any spot-beam satellite is always 'bundled' by the capacity of each beam, but a minimum bundle of 30 channels leads to inflexibility in matching channel-to-beam assignments to traffic loading. The SCPC design permits more precise channel-to-beam assignment, possibly including use of satellite on-board switching of small groups of channels between beams.

A flexible way of assigning power (channel capacity) between different spots uses a phased array satellite antenna driven by a set of linear power amplifiers. Their total power is shareable at will between different spot-beams. The single-carrier per transponder approach of the TDMA design assumes efficient, saturated power amplifiers, but saturated power amplifiers are not suitable for driving a phased array.

8. INTERMODULATION EFFECTS

Intermodulation caused by nonlinearities in satellite or aircraft HPAs affects an SCPC system. In the SCPC design, intermodulation is accepted as a system degradation, and is designed-in to link margins, as shown in Table 1. It does not force inefficient frequency plans to be adopted, because it is a rather small part of the total link impairments owing to the use of coding.

9. GUARD BAND REQUIREMENTS.

Given that other factors such as intrinsic frequency instabilities or residual (after compensation) Doppler frequency errors are a small fraction of the modulation rate (which is true for voice channels), the guard-band is a fixed fraction of the modulation rate, irrespective of whether the signal is a TDMA or SCPC signal. In this respect, therefore, there is no difference between the two access techniques.

10. NUMBER OF 'CHANNEL UNITS'

In the SCPC design, voice channels each require a separate RF carrier, which means they each need their own "channel unit" (modulator, demodulator synthesizer, and FEC codecs). A TDMA system permits all services to go through a single unit. However, the low bit rate of the SCPC design permits almost all channel-unit processes to be implemented in software, and with the availability of inexpensive LSI direct digital synthesizers the cost of providing multiple channel units for a multi-voice-channel installation does not appear to be a significant disincentive.

11. SPECTRUM MANAGEMENT

As an international satellite service provider, INMARSAT is keenly aware of the increasing pressures on satellite spectrum. Coordination is becoming more difficult, spectrum is increasingly fragmented as spot beams are introduced, and additional spectrum controls for applications such as air safety service are expected to arise. In this situation, SCPC access for voice communication offers a high degree of flexibility in spectrum management compared to alternatives.

TABLE 1

TDMA/SCPC COMPARISON ASSUMPTIONS*

	FDMA	TDMA
AIRCRAFT EIRP (12 dBiC) antenna)	P + 9.5 dBW	P + 9.5 dBW
(0 dBiC antenna)	P - 2.5 dBW	P - 2.5 dBW
(P=HPA power in dBW)		
RF transmission rate	21 kbit/s	FWD/RET = 320/64 kbit/s
Voice channel carrier to noise requirements (BER=10^{-3})	E_s/N_o = 4.7dB (1)	E_b/N_o = 9dB (2)
Voice coded rate	9.6 kbit/s	8 kbit/s
Voice activation advantage	4 dB (FWD)	N/A
GES to satellite C/N_o	75.3 dBHz	83.2 dBHz
Satellite to GES C/N_o	54.1 dBHz	73.1 dBHz
Forward link C/IM_o	60 dBHz	N/A
Return link C/IM_o	60 dBHz	? (oo)
Satellite spot beam G/T	-3.5 dB/K	-3.5 dB/K
Satellite spot beam eirp (eoc) (4)	39 dBW	39 dBW
EIRP distribution advantage (3)	1.5 dB	N/A

* Based upon INMARSAT System Definition Manual (FDMA); and AvSAT System Technical Description (ARINC Quick Check 39) (TDMA)

(1) Includes margin to accommodate carrier to multipath ratio (C/M) of 7 dB = worst case at 5º elevation angle. At 20º, C/M = 12 dB, required E_s/N_o = 2.4dB

(2) No provision for multipath fade margin: ie, this is best-case

(3) FDMA system averages over non-uniform satellite coverage pattern. (Advantage exceeds this figure when global beam is used.)

(4) Corresponds to satellite HPA of 25W (quasi-linear for FDMA), beam dia. $\simeq$ 7º (eoc: edge of coverage)

TABLE 2

TDMA/FDMA COMPARISON: NUMBER OF AIR TO GROUND VOICE CHANNELS PER AIRCRAFT AS A FUNCTION OF HPA POWER

AIRCRAFT ANTENNA GAIN (SAT. ELEVN.)	12 dBIC (>20º)		12 dBIC (>5º)		0 dBIC (>20º)	
SPACECRAFT ANTENNA GAIN (EOC)	'GLOBAL'(17 dBIC)		Spot (25 dBIC)		Spot (25 dBIC)	
HPA POWER*	FDMA	TDMA	FDMA	TDMA	FDMA	TDMA
40 W (AEEC)	4	0	14	6	2	0
30W	3	0	10	6	1	0
20W	2	0	7	6**	1	0
12W	1	0	4	0	0	0
6W	0	0	2	0	0	0
3W	0	0	1	0	0	0

*Linear HPA needed for FDMA, <u>except</u> nonlinear (Class-C) may be used for single-carrier cases

** Marginal

System Designs: TDMA: as per ARINC Quick Check 39 (AvSAT System Technical Description-8.0kbit/s voice)
FDMA: as per INMARSAT System Difinition Manual - 9.6 kbit/s voice

Related Assumptions: See accompanying Table 1

TABLE 3

TDMA/FDMA COMPARISON: NUMBER OF GROUND TO AIR VOICE CHANNELS PER SATELLITE ANTENNA BEAM

AIRCRAFT ANTENNA GAIN	12 dB		0 dB	
Satellite Beam EIRP (dBW, eoc)	Number of voice channels		Number of voice channels	
	FDMA	TDMA	FDMA***	TDMA
36	100	-	4	0
39**	200	30	9	0
42	400	30+30*	20	0

* Requires 2 transponders
** AvSAT nominal (approx)

*** Reduced voice activation advantage

System Designs: TDMA: as per ARINC Quick Check 39 (AvSAT System Technical Description-8.0kbit/s voice)
FDMA: as per INMARSAT System Difinition Manual - 9.6 kbit/s voice

eoc: edge of coverage = 5º elevation