ABSTRACT

On the basis of estimated traffic matrix in the Atlantic Area at the time new D.A. Systems will be operational, satellite efficiency and traffic considerations are examined.

The SPADE d.a. technology are briefly reminded with particular reference to traffic problems.

Calculations are made on the optimum number of preassigned and demand assignment circuits to be supplied for connecting terrestrial access to the Earth Station.

Operational introduction of the SPADE system in the international network and future developments are foreseen as conclusion.

1. EFFICIENCY AND CAPACITY OF SATELLITE COMMUNICATION SYSTEMS.

Satellites to which the present paper refers are the Intelsat IV satellites operating in a global telecommunication satellite system in behalf of a Consortium of more than 83 Countries most of them having their own Earth Station able to transmit and receive via the above satellites.

Each satellite working in a precise Geographic Area (being its rotation synchronous at 36.000 Km from the Earth) has the main function of and converting and amplifying, by means of "transponders", the carriers transmitted from the Earth Stations in the 5.9–6.4 GHz radio frequency band. After amplification and down conversion into the 3.7–4.2 GHz band the RF carriers re-transmitted by the satellite are received, strongly attenuated, at the receiving Earth Stations mixed with thermal and intermodulation noise: this latter caused in particular by the non linearity of the wide-band RF amplifiers of the satellite (generally TWT tubes).

The Modulation system adopted at present is the frequency modulation having the test tone deviation of each carrier optimized in accord with the load, the propagation characteristic of the links and the CCIR, CCITT Recommendations on the signal to noise ratio for the different kind of demodulated signal within the received base-bands.

The Intelsat IV satellites have 12 transponders each at them available for different uses being possible also to switch some transponders to two different kind of antennas: global coverage beam antennas (17° beamwidth at 3 dB point) and spot beam antennas (4.5 beamwidth at 3 dB point). The spot beams have much smaller coverage of the earth surface but increased flux density, allowing higher capacity links.

The efficiency in the use of the satellite links mainly depends on the Earth Station receiving characteristics and in particular on the "merit factor" G/T of the antenna and associated receiving system. The G/T (defined as the ratio between the overall receiving antenna gain and the total noise temperature of the receiving system), has been fixed by Intelsat to be 40.7 dB at 4 GHz frequency, 5° elevation angle of the antenna, and with the appropriate feed polarization.

The main synthetic equation in dB able to characterize the satellite transmission of a frequency modulated carrier is the following [1]:

\[
\frac{G}{T} + \text{EIRP} + 20 \log \frac{\Delta f_0}{f_p} - \frac{N_c}{N_p} = 9.5
\]  

where:

- EIRP = Equivalent isotropically radiated power of the carrier transmitted from the satellite (dBW)
- \(N_c\) = Number of telephony channels
- \(\Delta f_0\) = Test Tone deviation
Using phase locked or F.M.F.B. demodulators at the receiving Earth Station, it can be demonstrated the validity of the following expression in dB:

$$G + E_{IRP} - 10 \log B + I - M = -21.6 \quad (2)$$

where:

- \(B\) = RF band of the modulated carrier
- \(I\) = Threshold demodulator improvement (dB)
- \(M\) = Mandatory margin for the down link (6 dB)

Having in both (1) and (2) assumed an attenuation of 197 dB for the down link and the Boltzman constant \(K = -226.8 \text{ dBW/K Hz}\).

The use of (1) and (2) combined, once fixed the link parameters and the "budget" of the noise, allows the determination for each carrier of the telephone channel capacity.

Being the available band of one transponder INTELSAT IV \(B_N = 36 \text{ MHz}\) and the saturation \(E_{IRP} = 22.5 \text{ dBW}\), the capacity measured in number of channels to be retransmitted by frequency modulated carriers between Standard Earth Stations may vary between \(N = 970\) channels for a single carrier global beam transponder utilization, down to \(N = 350\) channels for a multicarrier utilization (i.e. 14 intermodulating carriers of 2.5 MHz band each).

With the use of PCM/PSK modulation the per carrier capacity may be determined mainly by the following equation (in dB):

$$C_T = \frac{E}{N_0} + R + M - K \quad (3)$$

where:

- \(C_T\) = Per channel carrier to noise temperature ratio at the PSK demodulator threshold for a determined bit error rate (BER = 10\(^{-4}\)) [dB]
- \(E/N_0\) = Energy per bit of information/ noise density for the specified BER = 10\(^{-4}\) [dB]
- \(R\) = Transmission speed per channel (64 Kbit/sec) [dB]
- \(M\) = System Margin [dB]
- \(K\) = Boltzman constant [dBW/K Hz]

The (3), being \(C = C_T/N\), (where \(C\) is the carrier total power) and taking into account the other link parameters, become in dB:

$$G + E_{IRP} - \frac{E}{N_0} - R - M - N_C = -31.6 \quad (4)$$

If we take \(M = 4.3 \text{ dB}\); \(E/N = 12 \text{ dB}\); BER = 10\(^{-4}\), for a coherent 4 phase PSK demodulator, from the (4) results that the maximum theoretical number of channels is about \(N = 1100\) in a single carrier transponder utilization.

For the SPADE system which utilizes one carrier per each channel PCM/PSK modulated, the theoretical global beam transponder reduces down to \(N = 330\) channels, but may increase up to 860 voice channels because of the new technique of carrier suppression during voice absence.

This capacity limitation is clearly due to the strong intermodulation of the many SPADE carriers.

Fig. 1 gives a comparative capacity \((N)\) of different modulation and transmission systems via a transponder of the Intelsat IV satellite versus the G/T of the receiving Earth Station.

Two time division multiple access systems are also indicated.

2. THE TRAFFIC ROLE IN THE NEW COMMUNICATION SATELLITE SYSTEMS.

The number of relations between the many terminals of the satellite network having a center in the satellite is very high also if in some link the traffic is very light.

Fig. 2 illustrates the present international links realized via one of the two Intelsat IV satellites operating in the Atlantic Area.

The bidirectional number relations \(R\) which simultaneously can be realized between \(S\) Earth Stations is:

$$R = \frac{S(S-1)}{2} \quad (5)$$

The present technique used to reduce the number of RF carriers to be transmitted is the FDMA (frequency division multiple access).

With this system the channels, groups and subgroups having different destinations, are altogether assembled in one base-band to be frequency modulated and transmitted by a single high capacity RF carrier from each Earth Station.

The receiving Stations will receive all the other multidestination carriers and take off the appropriate portion of the demodulated base band.
In the near future the traffic over intercontinental links will be separated in low, medium and high density routes.

If the only FM modulation and FDMA will be utilized, satellite efficiency could result strongly reduced.

From the data supplied by the Intelsat document ICSC 51-10E it has been derived the diagram of Fig. 3 relating to 1976 foreseen traffic matrix over the Atlantic Area between S = 59 Earth Stations and for a total of effective relations for voice \( R_v = 230 \) and for data \( R_d = 140 \).

The Earth Stations participating in the SPADE (maximum 49 Countries) have access to a "pool" of couples of frequencies.

Each couple may be associated on demand to a single telephone circuit with fully variable destination; neither end of a channel is permanently associated with any terminal point.

The system does not require a central station for system control, but uses a demand assignment signalling and switching unit (DASS) which comprehend a little processor for self-assignment of the channels based on continually updated channel allocation status data, provided via a common signalling channel (CSC).

The C.S.C. transmitted with time division techniques, continuously apprise each Earth Station DASS of the availability of pool channels and establishes the links directly with the other Stations.

The combined operation of all DASS units is equivalent to that of a transit center (CT) i.e., it monitors the terrestrial telephone signals received from the CT, processes the information and switches the circuit as required to forward the call to the next CT.

Signalling with CCITT no. 4, 5, 5bis and R-2 systems are accepted easily by the Interface Unit of the SPADE to be connected to the nearest CT.

The SPADE system as previously illustrated can realize up to 800 voice channels simultaneously transmitted by an Intelsat IV transponder.

Some increase in the overall traffic carried by SPADE system may be obtained for the following reasons:

a) the low traffic routes are conveyed in a unique traffic route. The equivalent number of channel needed to carry the above overall traffic will be certainly inferior to the one which should have been necessary in case many independent routes had to be provided for.

b) Rational utilization of the busy hours distribution in the time.

Fig. 4[3] illustrate this concept making in evidence that the busy hour of the DA system routes is considerably reduced thanks to the different distribution of busy hours in the time.
4. OPTIMUM NUMBER OF PREASSIGNED CIRCUITS WITH OVERFLOW TO DEMAND ASSIGNMENT.

With the advent of D.A. systems a certain number of routes could request the use of demand assignment circuits in addition to the conventional preassigned circuits. In particular DA circuits may carry the overflow from light current preassigned circuits routes.

The problem is in dimensioning for a certain amount of offered traffic in the busy hour, the optimum number of FA circuits and the equivalent DA circuits. To be connected to the nearest CT.

These FA circuits can be assumed in principle such that the daily load carried by the last (nth) circuit would cost more if the circuit were not provided and the traffic had to be paid for at the DA rate.

In Fig. 5 (4) are indicated two interesting curves A and B, derived from traffic statistics made in the United Kingdom, giving the daily to busy hour traffic ratio (A) on the nth circuits and (B) the daily to busy hour overflow from the nth circuits.

The nth circuits are identified by reference to the percentage of the total traffic which overflows from it in the busy hour.

The diagrams are fully generalized and have been verified for many differently charged routes.

Some doubt remains on the validity of application of these diagrams to the very small routes, being the Erlang diagrams a little difficult to read near the small values of traffic offered.

In these cases (less than one FA channel justified) all the traffic should be applied to DA when the local and remote Earth Station are properly equipped.

For the above consideration, if Ca is the year cost of one FA satellite circuit and Cm is the cost of one minute of utilization of DA, being 365 working days per year, we can define a break even time as:

\[
T_m = \frac{Ca}{Cm \cdot 365} \quad \text{(minutes)}
\]

For optimum distribution of traffic between FA and DA circuits, the daily traffic carried by the nth FA circuit should slightly exceed Tm.

In the following we have assumed three values for Tm: Tm1 = 100 minutes (1,7 Erl); Tm2 = 150 minutes (2,50 Erl); Tm3 = 200 minutes (3,35 Erl).

For the calculation is necessary to use the combination of the curves in Fig.5 and nth circuit load and overflow curves, for the amount of traffic offered in each route in the busy hour.

In particular we need:

- A = total traffic offered in the busy hour (Erl)
- B = traffic carried by the optimum nth circuit in the b.h. \([Erl]\) (the nth circuit must be such that daily load slightly exceeds Tm)
- C = overflow from the nth circuit in the busy hour (Erl)
- D = percentage overflow from nth circuit with respect to total traffic A in the b.h.
- E = day to b.h. ratio of the traffic carried by nth circuit
- F = day to b.h. ratio of the overflow from the nth circuit
- G = E+B = daily traffic on the nth circuit \([Erl]\)
- H = E+C \cdot 60 = daily overflow from the nth circuit \([\text{minutes}]\)

From G and H the optimum number of DA circuits and DA equivalent minutes of utilization can be easily derived.

Table 1 gives an example of calculation obtained on Italian outgoing and incoming satellite traffic, estimated for the Atlantic Area in 1971 and for routes with less than 12 circuits.

Optimum figures for FA and DA equivalent circuits are derived with the assumptions made for Tm. Moreover knowing the traffic distribution during the day and in particular the busy hour times for each route, it is possible to obtain the overall DA traffic distribution and busy hour during the time and consequently to dimension the optimum number of DA circuits (Channel Units for SPADE) to be provided at the Earth Station.

The total traffic in Erlangs to be carried by DA circuits is easily derived from the formula:

\[
E_A = \left[ \frac{B_m + P/2}{T_d - B_m} \right] 1/60 \text{ Erl.}
\]

where:

- \(E_A\) = Total DA traffic in Erlangs
- \(B_m\) = Total minutes in the D.A. busy hour
P = Percentage of traffic in the b.h. (12%)  
T = Total minutes of DA per day  
Tm = Total minutes of DA without reduction of DA  

The number of circuits is thus obtained from the Erlang B formula (at P values of 0.9). It can be shown that, accordingly with different values of the DA charge per minute, the introduction of DA can reduce the number of circuits down to a minimum of about 40%, comprehending PA and equivalent DA circuits (DA circuits are indicated in parenthesis on the bottom of Tm columns of Table 1).

<table>
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<tr>
<th>Countries</th>
<th>A</th>
<th>B hrs</th>
<th>P (%)</th>
<th>FDMA P.A. Ccts</th>
<th>P.A. (ckt)</th>
<th>D.A. (min)</th>
<th>P.A. (ckt)</th>
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TABLE 1 - ITALIAN BIDIRECTIONAL PA AND DA TRAFFIC IN 1971 (LESS THAN 12 CIRCUITS)

5. OPERATIONS AND FUTURE DEVELOPMENTS OF DA SPADE SYSTEM.

It is obvious that the introduction of DA systems like SPADE will be gradual because of previous investments in FDMA equipments. The maximum efficiency of satellite utilization and traffic concentration will be optimized only when near to transponders saturation.

Care should be taken in order not to reduce satellite revenues from one side, but at the same time not discouraging these DA systems reducing their efficiency because little number of Participants.

DA operational introduction and expansion is strictly related to overall satellite operational and financial policies.

In the mean time being so large the information capacity associated to the bit stream of a single SPADE channel, originally designed only for voice, other useful utilizations of SPADE channels and associated satellite transponder (the 10th of Intelsat IV) have been studied; some examples are the following:

- DA alternate voice/data
- Voice or data broadcast (one or two way) in PA mode (one transmit the others receive)
- Multi station information exchange network
- Hot line service
- DA telex or data service
- PA high speed data (point-to-point)
- DA high speed data

As regards the introduction of SPADE system in the international routing plan, no significant variations have been made to the existing CCITT Q 12 Recommendation, except for same more warnings about signalling delay when DA is inserted within a large number of circuits in tandem.

Rerouting among SPADE terminals are not provided at present and basic operational program, for the Signalling and Switching Processor of each terminal, provides transit calls only to any of the other SPADE terminals. The CCITT country codes are normally used for determining the SPADE terminal through which the call is routed.

It will be possible however to support incoming calls transiting, via the local CT to which the SPADE terminal is connected, towards other national or international CTs, also in a selective mode. Many other special features are possible but they are likely to require deep modifications to the basic programs of the SPADE terminals and an increase of memory capacity of the processors.

BIBLIOGRAPHY