PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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African satellite communication systems and their implications

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Eurospace, founded in 1961, is the Organization of the European Space Industry. Its members are 80 major industrial companies, banks and operators from 13 countries in Western Europe. The Association is the mouthpiece of industry to the European Space Agency (E.S.A.), in particular with regard to future European space programmes. In the course of its other promotional activities it has applied and sustained successful efforts to promote a regional communication satellite system serving the African continent.

Introduction

The size of the African continent and, in general, the poor situation of its communication facilities almost inevitably call for solutions that use satellites and, for a long time, many proposals for such solutions have been made. This paper will deal only with the so-called Afsat project promoted and studied by Eurospace and which, at this stage, appears to be the most promising approach to a regional African communication system.

Initially, the Afsat concept arose from the conjunction of thoughts of the U.A.P.T. (African Post and Telecommunications Union), a group of 12 French speaking countries and Eurospace. This concept is based on a triangular arrangement that involves U.A.P.T. in the role of the African customer, with the European Development Fund of the E.E.C. providing the finance and the suppliers. Eurospace and its group of consultants (E.S.A., Detecon, General Technology Systems, Satel-Conseil, Safritec and Telespazio) have so far acted as study 'suppliers'. When the studies are completed industry will take over from the consultants and will supply the required hardware and services.

It is worth noting that from the outset U.A.P.T. undertook to widen the scope of its approach by involving English speaking countries. This led to the setting up of an *ad hoc* Afsat Committee to which seven English speaking countries (including Kenya and Nigeria), Cameroon and Zaïre participated in addition to the 12 U.A.P.T. member countries. Two studies made in accordance with this scheme are now available: a study of the telecommunication, radio and television requirements of the countries participating in the Afsat Committee, and a parametric feasibility study covering the whole continent. The latter was delivered to, and approved by, the customer in November 1983. These studies will be now summarized. The current problems regarding the next steps will then be reviewed and some conclusions drawn.

Current situation and needs of communication in Africa

Except for the links provided by Intelsat, and submarine cables between certain African capitals and between them and other continents, current communications in Africa are far from being satisfactory for both telecommunications proper (telephone, telex, data) and for radio and television.

For telecommunications proper, in spite of the efforts undertaken to implement the Panaftel network, a system of microwave links aimed at providing communication between the countries and at creating a communication 'axis' inside each of them, the situation remains difficult. It is almost impossible for many African capitals to call each other on the telephone except through Paris or London! Inside the various countries, the density of direct exchange lines (d.e.l.) is very small (seven d.e.l. for 10000 inhabitants in Nigeria, three for 1000 in Senegal, seven for 1000 in Zambia). Moreover, density figures are misleading because they are country-wide averages. One must realize that, in general, 80 % of the telephone sets are in the capitals, the rest in the large cities, almost none are in the rural areas, whereas the latter represent 80–90 % of the population. However alarming these figures may seem they do not fully reflect the very poor situation, because the rate of availability of existing lines is much less than one owing to the line saturation in the large cities and the transmission problems in the inter-urban links.

For television, in general, only the capitals and adjacent areas are provided with service. The radio coverage is better but needs considerable improvement, particularly F.M. broadcasts. The assessment of the communication needs in this context is a challenging exercise. To aim for current European standards – say one d.e.l. line for three to five inhabitants, with three television channels covering the full territory of each country – would be too ambitious. Thus, for telecommunications proper, the Afsat mission definition for the period 1988–1997 took into consideration both the channel requirements assessed by each country and their economic capabilities. This resulted in a mission requirement of 8000 F.D.M. channels, 17000 single channel per carrier (s.c.p.c.) channels, six television channels, which, by using the system presented below, requires a satellite capacity of 20 to 31 active transponders in 1997 (table 1).

Table 1. Summary of the total theoretical satellite capacity envisaged in 1997

service	number of transponders minimum	maximum
interstate telephony	3	3
inter-urban telephony	11	18
rural telephony	2	4
interstate exchanges of radio and television	1	1
national television	3	5
national radio	0.10	0.10
total	20.10	31.10

Interstate telecommunication and television services are provided to the whole continent, whereas domestic similar services will be available only to countries south of the Sahara. Telecommunication quality standards are those in C.C.I.R.–C.C.I.T.T. relevant recommendations. For television distribution, current Intelsat standards were adopted.

Feasibility study of the system

To fulfil the mission described, the study proposes an optimized system comprising a space and a ground segment. Four space segment configurations ranging from 20 to 36 transponders were examined. The reference configuration used later on in economic computations is based on a high power 24 transponder active satellite of the Arabsat or Eurostar class. One idle back-up satellite in orbit and one spare satellite on the ground, ready for launch, are foreseen so as to provide guaranteed services. The launcher will be either Ariane IV or the U.S. Shuttle.

The payload characteristics can be summarized very briefly.

(*a*) Four 'global' beam transponders are allocated to interstate services, each of them covers the whole continent (effective isotropic radiated power (e.i.r.p.) 31 dBW, sensitivity -10 dB K^{-1}).

(*b*) Twenty 'spot' beam transponders cover four to six domestic service zones (e.i.r.p. 37 dBW, sensitivity -3 dB K^{-1}). When using 4.5 m diameter ground stations, the telephone capacity of each transponder is 1333 channels with a companding factor of 13 dB. Alternatively two television channels can be transmitted per transponder in good quality conditions. (One of the configurations offers six higher power dedicated television transponders enabling two televison programmes to be transmitted per transponder with reception by ground stations of less than 3 m diameter.)

For the ground segment, three station classes were adopted.

(i) Class 1 are master stations to be located in the capitals. Typically their diameter is 11 m. They include a tracking system and can handle from 96 to 600 F.D.M. channels and 60 to 200 s.c.p.c. channels for interstate, inter-urban and rural telecommunication purposes. They are capable of transmitting and receiving television signals.

(ii) Class 2 stations will be located in large towns. Their diameter is 8 m and they require no tracking system. Their telecommunication capacity is from 24 to 96 F.D.M. channels and 12 to 60 s.c.p.c. channels. They can receive (but not transmit) television, with a rebroadcasting capability in very good conditions. No tracking is required.

(iii) Class 3A stations are typically 4.5 m in diameter and intended for small towns or large villages. Their telephone capacity ranges from 1 to 12 s.c.p.c. channels, they can receive television with an acceptable rebroadcasting capability. No tracking is required. Class 3B stations are 3 or 3.5 m in diameter and will be mainly located in small villages or company premises. Their capacity ranges from 1 to 5 s.c.p.c. channels. They can receive television with no rebroadcasting capability. No tracking is required. Self-contained power supply units with solar cells are proposed to power the class 3A and 3B rural stations where no electrical network is available.

It is important to note that to optimize a communication satellite system a trade-off is always required. Given certain transponder characteristics large ground stations are complex and expensive in terms of investment cost, but they require less transponder bandwidth and less power transmission per channel than the smaller ones. The Afsat system concept presented is the result of an iterative process that enabled the characteristics of both its space and ground segments to be so determined as to provide an overall combination that is at the same time most economic and best adapted to the African environment.

Economic aspects

A full study of the system's economic viability could not be made because the study budget did not provide for data collection in Africa. So, in particular, income assumptions could be made only for a limited number of countries. However, the investment and operational cost could be assessed precisely for the whole space segment and for the use of Afsat by a reference country (300000 km^2, 10 million inhabitants in 1990, one master station, 29 inter-urban stations and 90 rural stations to be deployed in the last 4–5 years of the period).

Over 10 years the total investment cost of the Afsat space segment for the whole continent is assessed to be \$200 million. The cost of the ground segment over the same period for the reference country amounts to about \$26 million. For such a country, the operating cost of the ground segment would be \$2 million per year. On this basis the total ground segment investment for all Africa will be between \$600 million and 800 million, depending on the number of participating countries.

Based on a maximum transponder leasing cost of \$3 million per year, it was found that the total unit cost per domestic channel (i.e. by combining investment and operational costs of both the space and ground segment) would amount to \$7200 per year per inter-urban or DAMA rural voice channel, \$1600000 per year per television channel (marginal cost of distribution of one television programme to 10 ground stations).

Here it must be emphasized that the economic results mentioned can be considered as very conservative. In particular the leasing cost of \$3 million per year per transponder is based on a comparatively low use rate of the satellite's capacity (70 % on average over the mission period) and a high internal rate of return (14 %). Moreover, no provision was made for the leasing of capacity, on a preemptible basis, in the back-up satellite.

Finally, the cost of using Afsat by the reference country when its ground segment is fully deployed amounts to less than 0.4 % of the country's projected gross national product at the end of the proposed mission period in 1997, a value that can be considered reasonable.

Comparison with alternative solutions

The technical and economic Afsat data will now be compared with alternative space and terrestrial solutions. For space solutions Intelsat appears to offer the most credible alternative to Afsat and, considering their currently existing and planned programmes, a comparison of Afsat was made with leased domestic transponders in Intelsat VI 'zone' transponders (e.i.r.p. 28 dBW, $G/T = -7$ d BK^{-1}); Intelsat VA 'spot beam' transponders (e.i.r.p. 32.5 dBW, $G/T = -18$ dB K^{-1}).

It was found that if the same Earth stations foreseen for the Afsat mission are retained when an Intelsat VI or Intelsat VA satellite is employed, it is necessary to increase the transmitter power by a factor of 10 to 25 and to sacrifice a half or two-thirds of the transponder capacity. Alternatively, if the diameter of the station is changed (from 4.5 to 8 m for the class 3 stations and from 8 m to 11 m for the class 2 stations) a transponder capacity between 50 % and 100 % of that of an Afsat transponder can be obtained, but this will demand the use of an autotrack system for class 2 stations and the increase of transmitter power by a factor of 3 to 10.

In economic terms it was found that for a guaranteed service, the use of the Intelsat space segment would lead to a total network cost: from 32 % to 105 % higher than Afsat for inter-urban services; from 30 % to 64 % higher for rural services; from 34 % to 101 % higher for television services; from 48 % to 63 % higher for the complete network. For the *non-guaranteed* service, the use of the Intelsat space segment would lead to a total network cost: from 19 % to 48 % higher than the *guaranteed* Afsat inter-urban srvice; from 22 % to 60 % higher than the *guaranteed* Afsat rural service.

So it appears that a *guaranteed* Afsat service is economically more advantageous than a *pre-emptible* Intelsat service. In particular, the use of very small rural stations in conjunction with an Intelsat space segment appears to be prohibitive. Moreover, the available capacity on relevant Intelsat satellites is not likely to be sufficient to meet the African mission requirement as defined at the beginning of this paper.

From the study of conventional ground systems it appears that the relation between such systems and an Afsat-type system is more complementary than competitive. In particular, it seems that, in most cases, for distances above 50–100 km for rural telephony and 100–180 km for inter-urban traffic, the satellite is more economical than terrestrial networks. Also, the satellite is advantageous for operational flexibility, deployment speed, alternative routing and vulnerability. Lastly, when a combined television–telephony usage is desirable, the satellite is more advantageous in all respects than ground-based facilities.

Space segment financing and organization

Basically it is considered that the space segment of the Afsat system will be financed under the usual aid schemes, i.e. by means of grants from the European Development Fund (E.D.F.) and from national Aid Agencies. In addition to such grants, privileged loans can be obtained from the European Investment Bank and similar national financial institutes (Caisse Centrale de Coopération, Kreditanstalt, etc.). The features of a privileged loan, it is recalled, are a low interest rate, a long duration and a long reimbursement moratorium. Obviously another substantial part of the funding will come from the investment of capital by the African telecommunication Administrations concerned.

However, other possibilities are also considered, such as investments or instalments by large users – governmental, African or otherwise – needing good telecommunications in Africa. An investigation of such users is currently being made by Eurospace under an E.S.A. contract.

This possibility, however, raises the problem of the legal link between such users and the participating African Administrations, i.e. the problem of the form of the African Organization capable of owning and operating the space segment. In the study, a two-tier scheme is proposed for this Organization, along the Intelsat precedent. This would comprise an Assembly of Parties to which African Administrations only would participate, and an Assembly of investors to which both African Administrations and investors and users would participate. Possibly investors and users could form a holding company that would represent them to the Organization. A Board of Directors would be responsible for administration. Initially it could subcontract the management tasks to a commercial company, as happened with Comsat in the early years of Intelsat.

Conclusion

The study that has been presented enables one to draw a number of conclusions.

(i) A dedicated African communication satellite system would bring a decisive contribution to the improvement of the continent's communications in terms of both increased capacity and better availability and quality of circuits.

(ii) The Afsat system is more economic than alternative space or terrestrial solutions and it is better adapted to the African environmental constraints.

(iii) The economic burden of Afsat appears to be compatible with African budgets.

(iv) External resources from aid and large users can bring major contributions to the funding and financing of the system.

A full scale feasibility study is still required, in particular to evaluate in detail the optimal use that each African country can make of the proposed Afsat system. This implies surveys in Africa to assess the existing networks, to collect information on tariff policies, to work out income assumptions, to propose combined conventional and space network solutions and establish their feasibility.

E.D.F. has already indicated its willingness to fund such a study provided that the application for funding is made by a credible African partner comprising English and French speaking countries, i.e. wider then U.A.P.T. To meet this requirement an Agreement of Intent for the continuation of the studies and the system's implementation will be open by the end of 1983 for signature by all the interested African countries. The group of signatories, it is felt, will form a motivated nucleus of responsible administrations capable of developing in due course into an operational African Organization. For these reasons Eurospace believes that all European countries and organizations concerned should give full support to this promising approach.

Clearly Europe cannot remain indifferent toward this project, which represents a considerable stake for its industry and is an exemplary cooperation exercise between high technology countries and a developing continent.

Discussion

S. Metzger (*Communications Satellite Corporation, Washington, D.C., U.S.A.*). Since the estimated space segment cost is \$200 million while the Earth segment cost is \$600 million to \$800 million is it possible to use a higher powered, more expensive satellite to reduce the Earth segment cost, so that the overall cost is reduced?

What maintenance cost for Earth stations was assumed in Mr Demerliac's analysis?

What source of power was proposed for the remote Earth stations, and what was the estimated cost per station?

Y. Demerliac. Yes, theoretically a more powerful satellite could reduce the Earth segment cost. However, to increase the e.i.r.p. (in 4 GHz/6 GHz) beyond the currently proposed value of 37 dBW would rapidly raise regulatory problems and, on the other hand, may affect the overall system optimization adversely.

The maintenance cost for Earth stations, disregarding operation and training costs, was assumed to be 3% of the installed equipment cost for class 1 and 2 stations and 6% for class 3.

Solar cell generators are proposed to power the remote Earth stations. The power cost per station varies widely according to the number of telecommunication channels and the local insolation. For countries with a high insolation the power cost for one s.c.p.c. channel is assessed to be \$6000 plus \$2500 per supplementary channel.

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