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PLANNING OF THE USE OF THE GEOSTATIONARY-SATELLITE ORBIT AND PERSPECTIVE OF ITS UTILIZATION

Ilija Stojanović

Abstract. In utilizing different satellite services two natural resources are used. They are the Geostationary-Satellite Orbit and the radio-frequency spectrum. However, these resources are limited. Since they belong to all mankind, they should be used equitably for all nations. To fulfill this, it is necessary to plan them. In this paper a method of planning the orbit based on the acceptable interference has been described. This method is so conceived that it guarantees to each country the freedom to occupy the orbital position when it so decides, avoiding an "a priori" rigid planning and "freezing" of orbital positions and at the same time permitting the application of new technological solutions for the whole period of validity of the plan.

Key words: Geostationary-satellite, INTEL SAT, WARC ORB, interference analysis.

1. Introduction

Successful launching of satellites into the Geostationary Satellite Orbit (GSO) has opened new era in telecommunications. Different satellite services, such as Fixed Satellite Service (FSS), Broadcasting Satellite Service (1955), Mobile Services, Radio-determination and Radio-navigation, Cosmic Operations, Intersatellite Service, Earth exploration, Meteorological Service, Standard Frequency and Time Service, Deep Space Research, Radio- amateur Service and Radio-astronomy, have been developed. Human community has very soon become aware of benefit of using these services. Developed countries launched their own satellites, while the developing countries together with the former have used the service offered by the international satellite organizations such as INTELSAT, EUTELSAT, INTERSPUTNIK and the others.

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The address of author is Cetinjska 9, 11000 Beograd, Yugoslavia.

According to the official data of the International Frequency Registration Board (IFRB), in the period from 1970. to 1993., the number of launched satellites and those for which the procedure of coordination has been completed is 464. In the INTELSAT system, there are 917 earth stations and 17 satellites utilized by 118 member countries.

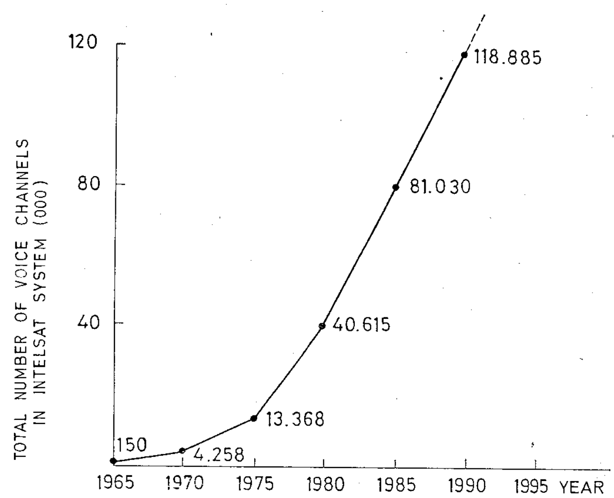

Fig. 1. The total number of telephone channels in the INTELSAT system for a given year

Probably, two sets of data characterize in the best way, successful development and exploitation of Fixed Satellite Service in the INTELSAT system. They are shown in Figs. 1 and 2. So, the number of telephone channels in use has increased 800 times for 25 years reaching something more than 120.000 channels in our days and annual space segment utilization charge has dropped 30 times in the same period reaching these days the cost less than U.S. $2 per day.

From the point of view of technology, in satellite systems two natural resources are used. They are the Geostationary- Satellite Orbit and the radio-frequency spectrum. However, the capacity of each of them is limited. The use of higher frequencies is dependent upon the state of the art of components and equipment. The capacity of the orbit is affected by several factors such as the satellite antenna directivity and side lobe radiation outside the coverage zone, side lobe radiation of the earth station antenna, wave polarization and the frequency reuse, satellite station keeping tolerance, pointing accuracy of the satellite beam, the allowable level of the interference noise

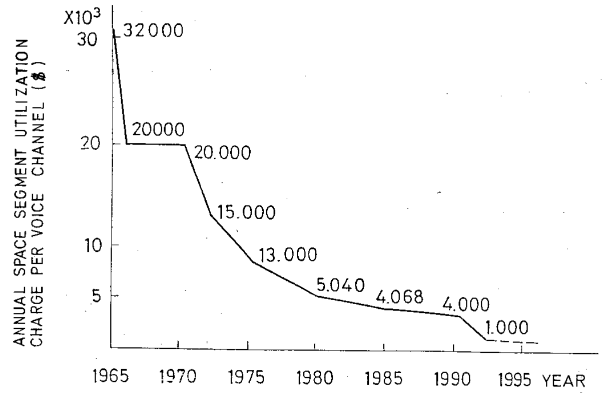

Fig. 2. Annual space segment utilization charge per telephone channel $ in function of the year

and others.

Due to all these facts, in seventies some anxiety began to be felt on the international plan that the GOS could soon become overcrowded and that those not capable to launch their own satellites and occupy their own positions at the Orbit in the future could be deprived of benefit offered by satellite services.

For this reason, the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It, in two sessions, 1985 and 1988 in Geneva (WARC ORB-85, WARC ORB-88), in the frame of the International Telecommunication Union (ITU), was convened.

It was decided to plan only the FSS, while the BSS was planned earlier (1977). As for the other satellite services, they are subject to the usual coordination and registration in the IFRB. The main objective of the Conference (and planning) was to provide equitable and guaranteed access by all countries to the GSO and corresponding radio-frequency spectrum.

2. Problems of the Planning

Planning itself besides its good point of guaranteeing to each country access to the orbit when it so decides, also has another face. Since some of countries for a too long period or even never will have their own satellites, their orbital positions will be "freezed". Hence, inefficient and noneconomic use of two limited natural resources: the GSO and the radio-frequency spectrum. This was just the case of plans for Broadcasting Satellite Service for

Regions 1 and 3 (WARC-BSS, Geneve 1977) and for Region 2 (RARC Sat-R2, Geneva 1983) which are "a priori" plans, characteristic by their "freezed" orbital positions.

There is another problem, as well. To make the plan, it was necessary to assume technical parameters specifying satellite systems, such as antenna diagrams, noise temperature, transmitter powers, above all the permissible level of interference and others figuring in the system design. These parameters are called the standardized parameters.

The main objective of planning is to find such an arrangement of satellites along the orbit using the set of standardized parameters, so that the mutual interference among planned satellite networks be of the acceptable level.

However, the period of the validity of the plan was foreseen to be at least 20 years. During this period, new satellites will be launched. Technology will advance, the system parameters will be improved and the plan based on the former parameters will be inadequate.

Therefore, a special method of planning is needed which will satisfy two conditions: to allow implementation flexibility yet and in addition to guarantee equitable access.

Many efforts have been made in this sense, while finally the following solution has been adopted.

Standardized parameters are a set of technical parameters which describe a typical communication satellite system. A complete set of standardized parameters can be converted to a small set of generalized parameters which characterize only the interference-causing potential and interference susceptibility of the network.

The essential issue in the planning is the avoidance of interference from one network into another. The interference producing capability of a network and similarly its interference susceptibility, are functions of specific implementation parameters. Since many different combinations of implementation parameters can result in the same interference performance, one way of providing flexibility is to plan on the basis of generalized parameters. These describe interference performance directly and specify an envelope within which the implemented system must have been designed.

Such set of generalized parameters chosen for publishing the plan should give the system designer as much flexibility as possible, yet maximize the orbit capacity and minimize the need for subsequent coordination.

3. Generalized Network Parameters

3.1. Interference scenario

Interference scenario is shown in Fig. 3. In the left part of the figure, the desired service zone together with the earth station transmitter T_{ed}, earth station receiver R_{ed} and the relevant satellite S_d form the satellite network to be considered. In its right part, the adjacent satellite network representing the interfering network is shown.

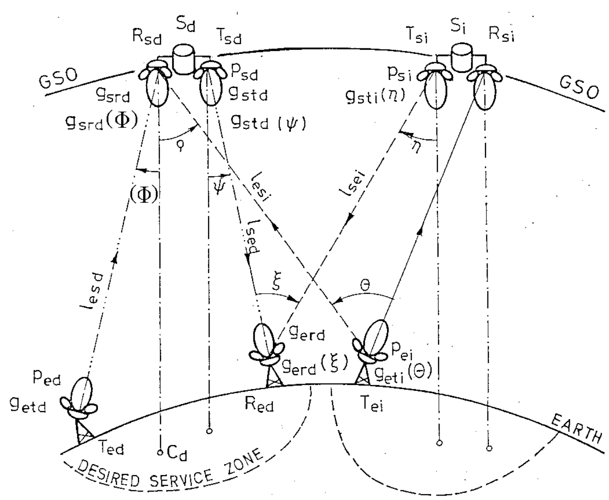

Fig. 3. Interference scenario

There are two interference paths. The first goes from the interfering earth station T_{ei} into the receiver R_{sd} of the desired satellite station, while the second goes from the interfering satellite transmitter T into the receiver of the desired earth station R_{ed}.

This is the case of single interference. If there is more than single interfering network, all of them should be taken into account thus giving aggregate interference.

It is necessary to mention for the analysis that satellite transmitting and receiving antennas are oriented toward center of the service zone and transmitting and receiving antennas of the earth station are oriented toward satellite.

3.2. Interference analysis

In the interference analysis the following symbols are used:

$\xi, \psi, \phi, \rho, \theta, \eta$ - angles defined in Fig. 3;

p - the power density averaged over the necessary bandwidth of the modulated carrier, fed into transmitting antenna (W/Hz);

g - the maximum gain of the antenna;

$g(\xi)$ - the gain of the antenna in the direction ξ;

e - subscript meaning: earth;

s - subscript meaning: satellite;

t - subscript meaning: transmitting;

r - subscript meaning: receiving;

d - subscript meaning: desired;

i - subscript meaning: interfering.

In order to analyze the interference, it is necessary to calculate the power ratio of the desired carrier to total interference at the input to the receiver R_{ed} of the desired earth station, i.e. $(C/I)_{TOT}$. This ratio is composed of two components:

a) $(C/I)_s$ - it is the satellite station receiver $R-sd$ input power ratio of the desired carrier to the interference produced by the interfering earth station transmitter T_{ei} ; this is the case when the interference comes along the first path;

b) $(C/I)_e$ - it is the earth station receiver R_{ed} input power ratio of the desired carrier coming from the satellite station transmitter T_{sd} to the interference produced by the interfering satellite transmitter T_{si}; this is the case when the interference follows the second path.

If the power fed into antenna is denoted by P and the free-space path loss by ℓ, according to the Fig. 3, the ratios from a) and b) will be:

$$\left(\frac{C}{I}\right)_s = \frac{P_{ed} g_{etd} g_{srd}(\phi)}{\ell_{esd}} \frac{\ell_{sei}}{P_{ei} geti(\theta) g_{srd}(\rho)}, \tag{1}$$

$$\left(\frac{C}{I}\right)_e = \frac{P_{sd} g_{std}(\psi) g_{erd}}{\ell_{sed}} \frac{\ell_{sei}}{P_{si} g_{sti}(\eta) g_{erd}(\xi)}, \tag{2}$$

Now, the ratio $(C/I)_{TOT}$ for the whole link at the input to R_{ed} will be

$$\left(\frac{C}{I}\right)_{TOT} = \frac{C_e}{I_s + I_e} = \left(\frac{I_s}{C_e} + \frac{I_e}{C_e}\right)^{-1} = \left[\left(\frac{I}{C}\right)_s + \left(\frac{I}{C}\right)_e\right]^{-1} \tag{33}$$

where is:

C_e - the carrier power at the input to the receiver R_{ed} of the desired earth station;

I_e - the interference power at the input to the receiver R_{ed} of the desired earth station produced by the interfering satellite;

I_s - the interference power at the input to the receiver R_{ed} of the desired earth station originating from the interference at the input to the R of the desired satellite station, produced by the interfering earth station transmitter T_{ei}.

If the spectrum width of the desired carrier is denoted by B_c and the width of the spectrum of the interfering signal with B_i, then multiplying eq.(13) by B_i/B_c, the new equation is obtained in which instead of powers power densities will figure. If the expressions (1) and (2) are introduced in (3), the carrier to interference power density ratio is obtained

$$\left(\frac{C}{I}\right)_{SD} = \frac{B_c}{B_i}\left(\frac{C}{I}\right)_{TOT} = \Big[\frac{p_{ei} g_{eti}(\theta) g_{srd}(\rho)}{p_{ed} g_{etd} g_{srd}(\phi)} \; \frac{\ell_{esd}}{\ell_{esi}} + \frac{p_{si} g_{sti}(\eta) g_{erd}(\xi)}{p_{sd} g_{std}(\psi) g_{erd}} \; \frac{\ell_{sed}}{\ell_{sei}}\Big]^{-1} \tag{4}$$

Now, if the following symbol for antenna discrimination is used

$$\Delta g = \frac{g}{g(\phi)}, \tag{5}$$

and replaced in (4), it becomes

$$\left(\frac{C}{I}\right)_{SD} = \Big[p_{ei} g_{eti}(\theta) \frac{1}{p_{ed} g_{etd} \Delta g_{srd}(\rho)} \Delta g_{srd}(\phi) \frac{\ell_{esd}}{\ell_{esi}} + \frac{p_{si} g_{sti}}{\Delta g_{sti}(\eta)} \frac{g_{erd}(\xi)}{p_{sd} g_{erd} g_{std}} \Delta g_{std}(\psi) \frac{\ell_{sed}}{\ell_{sei}}\Big]^{-1} \tag{6}$$

If the following symbols are introduced:

$$A_{ei}(\theta) = p_{ei} g_{eti}(\theta), \tag{7}$$

$$B_{sd}(\rho) = \frac{1}{p_{ed} g_{etd} \Delta g_{srd}(\rho)}, \tag{8}$$

$$C_{si}(\eta) = \frac{p_{si} g_{sti}}{\Delta g_{sti}(\eta)}, \tag{9}$$

$$D_{ed}(\xi) = \frac{g_{erd}(\xi)}{p_{sd} g_{std} g_{erd}}, \tag{10}$$

and the following approximation is adopted,

$$\ell_{esd} \cong \ell_{esi} \tag{11}$$

$$\ell_{sed} \cong \ell_{sei}, \tag{12}$$

the relation (6) becomes

$$\left(\frac{C}{I}\right)_{SD} = [A_{ei}(\theta) B_{SD}(\rho) \Delta g_{srd}(\phi) + C_{si}(\rho) D_{ed}(\xi) \Delta g_{std}(\psi)]^{-1} \tag{13}$$

This relation indicates how to interpret the introduced parameters:

$A_{ei}(\theta)$ - up-link off-axis e.i.r.p. (equivalent isotropically radiated power) density averaged over the necessary bandwidth of the modulated carrier;

$B_{sd}(\rho)$ - up-link off-axis receiver sensitivity to interfering e.i.r.p. density averaged over the necessary bandwidth of the modulated carrier;

$C_{si}(\eta)$ - down-link off-axis e.i.r.p. density averaged over the necessary bandwidth of the modulated carrier;

$D_{ed}(\xi)$ - down-link of-axis receiver sensitivity to interfering e.i.r.p. density averaged over the necessary bandwidth of the modulated carrier.

Now, analyzing expr. (13), it can be concluded:

- the larger $A_{ei}(\theta)$ and $C_{si}(\eta)$, the larger are the interfering power densities and the ratio $(C/I)_{SD}$ is worse;
- the larger $B_{SD}(\rho)$ and $D_{ed}(\xi)$, the larger are the sensitivities of both the satellite and the earth station receivers and the ratio $(C/I)_{SD}$ is worse;
- the larger discriminations $\Delta g_{srd}(\phi)$ and $\Delta g_{std}(\psi)$ of the coming desired carrier and that transmitted from the satellite toward the earth station receiver, respectively, the less is the ratio $(C/I)_{SD}$.

3.3. Generalized parameters and the flexibility planning

On the basis of (7), (8), (9) and (10), it is possible quite generally define the parameters

$$A = p_e g_{et}(\theta), \tag{14}$$

$$B = \frac{1}{p_e g_{et} \Delta g_{sr}(\rho)}, \tag{15}$$

$$C = \frac{p_s g_{st}}{\Delta g_{st}(\eta)}, \tag{16}$$

$$D = \frac{g_{er}(\xi)}{p_s g_{st} g_{er}}, \tag{17}$$

where, p_e and p_s are the power densities of the earth and satellite station transmitters, respectively. The parameters A and C are related to the transmitters of the earth and satellite stations, respectively, while B and C are related to the receivers of the satellite and earth stations, respectively. In this way, the parameters A, B, C and D are quite general, for giving to two of them "interfering role" ($A = A_{ei}, C = C_{si}$) and to remaining two "suffering role" ($B = B_{sd}, D = D_{ed}$), the complete interference situation is specified and described according to eq. (13). Therefore they are called generalized parameters.

From this equation it is clear that there are many different combinations of the generalized parameters which result in the same interference performance, $(C/I)_{SD}$. That means that the full flexibility in the planning is reached, for in the course of the validity of the plan, new technology can be applied and the parameters A, B, C and D could be changed, however, resulting always in the same $(C/I)_{SD}$ and the coexistence of satellite networks will not be broken down.

On the basis of this, it is possible to draw the pragmatic conclusion how to formulate the plan and to publish it.

As it is evident from eqs. (14), (15), (16) and (17), it is necessary for every satellite network determine in advance four parameters:

$$p_e,\ p_e g_{et},\ p_s g_{st}\ \text{ and } p_s g_{st} g_{er} \tag{18}$$

Now, A, B, C and D parameters are dependent only of the radiation diagrams of the transmitting and receiving antennas of the earth and satellite stations. In each particular case it will be easy to determine whether "newcomer" on the orbit comply with all necessary requirements.

From the analysis performed, two other conclusions can be drawn.

First of all, in the analysis presented, only the case of single interference has been considered. Having in mind that the orbit is "overcrowded", there will be always more than a single interferer. In that case, the aggregate carrier-to-interference density ratio should be determined

$$\left(\frac{C}{I}\right)_{SD}^{ag} = \left[\sum_j \frac{1}{(C/I)_{SDj}}\right]^{-1}, \quad j = 1, 2, \ldots \tag{19}$$

On the basis of the statistical model for more than one interferer, it was concluded that for 5 interferers $(C/I)_{SD}^{ag}$ is by 4 dB smaller than $(C/I)_{SD}$.

The second conclusion is dealing with the type of modulation of carrier.

During the preparatory work for the Conference, the carrier to interference ratios for different modulation required for the acceptable interference level at the output of the base band channel (telephony, 800 pWOp) have been calculated.

For example, in the case of FDM-FM systems, these ratios (C/I) are quite different for different capacities of the interfering and interfered with systems, being between 14 dB and 41 dB. However, if the carrier-to-interference density ratios, $(C/I)_{SD}$, are considered instead the above mentioned, the obtained results almost all are equal and in the vicinity of 30 dB.

On the other hand, when the interference into digital systems has been considered, it is found that the $(C/I)_{SD}$ =30 dB practically for the majority of current examples gives the BER better than 10^{-7}.

Since, the aggregate carrier-to-interference density ratio is for 4 dB smaller than for single interferer, the value of 26 dB for $(C/I)_{SD}^{ag}$ as the requirement for the plan has been adopted.

4. Conclusion and Perspective

On the basis of the considerations presented, the Plan for the FSS has been made, enabling full flexibility for the future and the guarantee for the access to the orbit for all countries. The plan is an allotment plan which comprises: a nominal orbital position, a service area for national coverage, generalized parameters used for establishing the Plan, a predetermined arc within which the definitive orbital position may be chosen and the bandwidth of 800 MHz in the frequency bands listed in the Plan.

When the decision is taken to use the allotment, a definitive orbital position and the specific operating frequencies must be selected. This is called the assignment of the satellite. Satisfying all discussed conditions, no coordination nor special procedure to realize the allotment is needed.

As for perspective of utilization of the orbit, the following may be said.

So far, the BSS and the FSS are planned, it is true, in different way. The problem of the orbit to become overcrowded is always present and can become still worse if the other satellite services, one day, would be considered for planning.

As a solution to this problem, three issues can be envisaged. The first is to use the higher frequencies, the second is to use the switching on board satellites and coverage of "spot" zones, thus enabling the efficient frequency reuse and the third is to apply the new modulation and transmission methods such as different forms of spread-spectrum techniques.

Finally, the situation in principle could be alleviated by using the satellites only for those services for which there is no other solution.

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