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INCREASE OF GEOSTATIONARY ORBIT EFFICIENCY IN THE Ku BAND BASED ON CHANGES OF ITU THRESHOLD VALUES

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The article is devoted to the estimation of threshold values, regulated by ITU, which determine the necessity of satellite networks coordination in the Ku band. Maximum capacity of geostationary orbit (GEO) for different diameters of earth station antennas, operating in standard DVB-S2 accounting the limitations caused by the parameters of existing satellite networks equipment, is determined. Optimal values of satellites’ orbital separation, relative increase in allowable noise $\Delta T/T$ and the signal to single-interference ratio C/I were identified for maximum GEO capacity.

Introduction

Before starting communication satellite operation it is necessary to obtain a frequency-orbital resource with appropriate energy parameters and service areas [1]. This requires coordination of frequency-orbital resource with the affected satellite networks. In coordination the potential interference between satellite networks is calculated and the impact on their performance quality is appraised. Coordination may be achieved only in the case of mutual consent.

To determine the affected ITU networks, standard threshold values were developed. If a satellite network does not compliant them, it means that the network is affected.

The threshold conditions must meet conflicting requirements: be sufficient to avoid harmful interference, and allow efficient use of GEO radio frequency resource.

Nowadays it is necessary to revise the threshold values in the Ku band. ITU currently conducts research in this area [2], and included the revision of the threshold conditions in the agenda of the World Radio Conference in 2015.

Urgency of the thresholds conditions revision is caused by [3-6]:

— the beginning of mass exploitation of DVB-S2 and DVB-RCS2 satellite network standards;

— the lack of frequency-orbital resource in the Ku-band;

— a bundle of "paper" networks in ITU coordination and planning databases, which complicate coordination processes.

The goal of the paper is to substantiate the possibility of GEO capacity increase in the Ku band on the basis of changing the ITU threshold values. ITU uses such threshold conditions in the Ku band [1]: the orbital separation of satellites in GEO, the relative increase of the allowable noise $\Delta T/T$, the signal to single-interference ratio C/I.

Problem statement

To assess the relationship of the threshold conditions and the efficiency of GEO, the following is done in the paper:

— maximum possible capacity of GEO and optimal values of the orbital diversity $\Delta T/T$ and C/I are determined;

— orbit capacity matching the threshold conditions regulated by ITU is determined;

— orbit capacity for existing location and parameters of satellites are determined.

For correctness of assessments the calculations will be made with current satellite networks parameters.

As a criterion of GEO efficiency we accept its capacity:

$$\varepsilon_{GEO} = \sum_{i=1}^{n} \varepsilon_i, \text{ Bit/s/Hz} \quad (1)$$

Here n is a number of satellites in orbit, ε_i— capacity of the i-th satellite. In an additive white Gaussian noise channel a maximum value is determined by the expression:

$$\varepsilon_i = log_2(1 + S/N), \text{ Bit/s/Hz} \quad (2)$$

S/N is a signal to noise ratio at demodulator input. Most modern satellites operate to transfer a signal without signal processing on the board, so a signal/noise ratio value at demodulator input depends on (Fig. 1, 2):

— uplink and downlink thermal noise;

— uplink and downlink inter-beam interference;

— interference from other satellites on uplink and downlink;

— non-linear characteristic of output stage of the satellite amplifier;

— cross-polarization interference;

— co-channel interference.

According to the latest the signal-noise ratio on the demodulator input is determined by the following expression [1]:

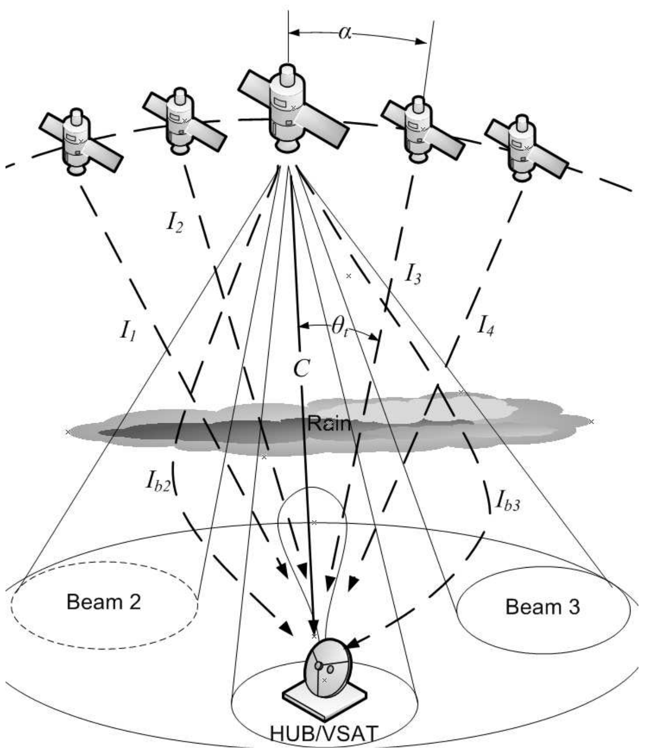

Fig. 1 Interference from other satellites and own beams on the downlink

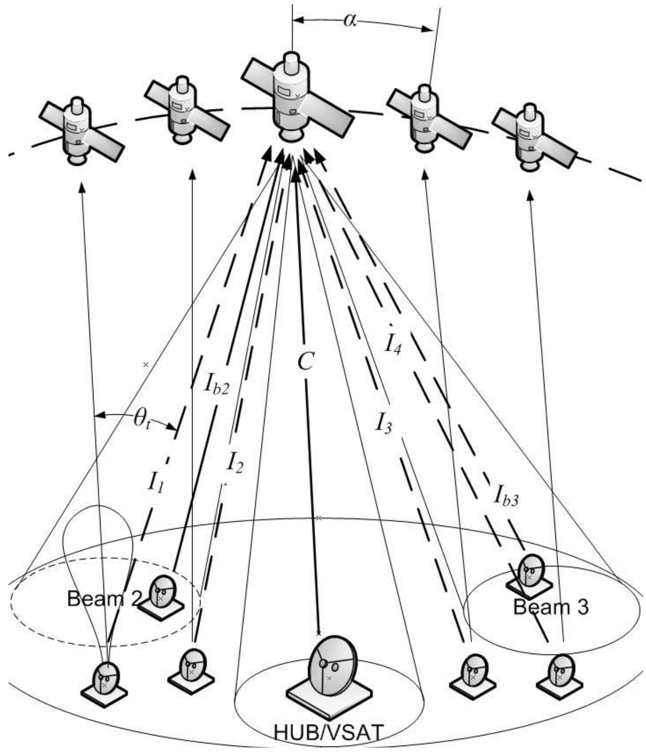

Fig. 2 Interference from other satellites and own beams at uplink

$$\left(\frac{S}{N}\right)^{-1} = \left(\frac{C}{N}\right)^{-1}_{DL} + \left(\frac{C}{N}\right)^{-1}_{UL} + \left(\frac{C}{I}\right)^{-1}_{TWTA} + \left(\frac{C}{I}\right)^{-1}_{BUL} + \left(\frac{C}{I}\right)^{-1}_{BDL} + \left(\frac{C}{I}\right)^{-1}_{UL} + \left(\frac{C}{I}\right)^{-1}_{DL} \quad (3)$$

Where: $(C/N)_{UL}$, $(C/N)_{DL}$ — signal/noise ratio on uplink and downlink correspondingly; $(C/I)_{BUL}$, $(C/I)_{BDL}$ — signal/interference ratio due to the uplink and downlink inter-beam interference; $(C/I)_{TWTA}$ – signal to interference ratio that occurs as a result of non-linear characteristic of traveling wave tubes; $(C/I)_{UL}$, $(C/I)_{DL}$ — signal to interference ratio from neighbouring terrestrial and space stations on uplink and downlink. In the expression (3) cross-polarization and co-channel interference between transponders are not taken into account due to their small impact on resulting ratio.

Note that the expression (3) depends on technical implementation of communication satellite, as well as on interference from other satellites which is directly dependent on its position in space. It will be assumed that satellites in orbit are evenly spaced, as this will ensure the maximum capacity of GEO. Limits of interference between satellites and, as a consequence, their separation in different Ku sub-bands are regulated [1] according to the threshold values shown in Table 1.

Table1

Sub-band	Orbital separation	$\Delta T/T$	C/I
Plan FSS	9°	-	26,65dB
Plan BSS	9°	-	21dB
Non-Plan	7°	6%	-

Limitations due to satellite networks parameters, adopted in calculations

On the basis of actual technical parameters we assume that the signal is retransmitted through satellites in accordance with channel DVB-S2 [7], so the expression 2 becomes:

$$\varepsilon_i = SE(MODCOD)/(1+\alpha), \quad (4)$$

where $SE(MODCOD)$ is a spectral efficiency, depending on the coding and modulation unit; α — roll-off factor, in standard DVB-S2 [7], it is usually taken equal to 0.25. Spectral efficiency values for different modulations and coding are shown in Table 2 [7].

Table 2

MODCOD	Spectral efficiency	Es/No, dB	MODCOD	Spectral efficiency	Es/No, dB
QPSK 1/4	0,490	-2,35	8PSK 5/6	2,478	9,35
QPSK 1/3	0,656	-1,24	8PSK 8/9	2,646	10,69
QPSK 2/5	0,789	-0,30	8PSK 9/10	2,679	10,98
QPSK 1/2	0,988	1,00	16APSK 2/3	2,637	8,97
QPSK 3/5	1,188	2,23	16APSK 3/4	2,966	10,21
QPSK 2/3	1,322	3,10	16APSK 4/5	3,165	11,03
QPSK 3/4	1,487	4,03	16APSK 5/6	3,300	11,61
QPSK 4/5	1,587	4,68	16APSK 8/9	3,523	12,89
QPSK 5/6	1,654	5,18	16APSK 9/10	3,567	13,13
QPSK 8/9	1,766	6,20	32APSK 3/4	3,703	12,73
QPSK 9/10	1,788	6,42	32APSK 4/5	3,951	13,64
8PSK 3/5	1,779	5,50	32APSK 5/6	4,119	14,28
8PSK 2/3	1,980	6,62	32APSK 8/9	4,397	15,69
8PSK 3/4	2,228	7,91	32APSK 9/10	4,453	16,05

To ensure quality of chosen MODCOD value it is necessary to provide the signal to noise ratio at the demodulator input not below the threshold $(S/N)_{tr}$. It can be calculated from the expression [7]:

$$(S/N)_{tr} = Es/No - 10\log(1 + \alpha) + R_{mod} \quad (5)$$

Here, *Es/No* is a ratio of symbol energy to noise power spectral density (see Table 2), R_{mod} – modem margin implementation, in modern satellite receivers it does not exceed 1 dB.

Calculation of signal to noise ratio at the demodulator input by the expression (3) was made with the following considerations:

— satellite transponder EIRP by interfering and desired signal span in 50-54dBW (50 is taken for a desired and 54 for interfering – as the worst case). These values correspond to actual values of majority of satellite networks in the Ku band [8, 9].

— EIRP in the service area is irregular. Difference between EIRP at the boundary of service area and at the point of maximum radiation is 3dB. It is assumed that when interferense a maximum EIRP value is taken, and for the desired signal — a boundary EIRP value.

— Calculations are performed for three subscriber antenna diameters: 0.6, 0.9, 1.8 m. For calculation of earth stations antenna gain, expressions of the reference pattern in the Appendix 30B of the second volume of Radio Regulations [1] are used. Antenna diameter at the hub station we consider to be 6 m.

— It is assumed that the main amplifiers of satellite transponders are linearized traveling wave tube (LTWT). As it is shown in [10] LTWT is a nonlinear element, in which noises occur. In most cases LTWT operate in nonlinear mode close to saturation point, as their efficiency in this mode is higher. Values of the ratio $(C/I)_{TWTA}$ are adopted [10] equal to 20 dB for QPSK and 8PKS modulations, 19dB for 16APSK and 18dB for 32APSK modulation. In this case, for modulation QPSK (8PKS) we assume that LTWT works at the saturation point, for 16APSK modulation – with a capacity of 1 dB below the saturation point and for 32APSK modulation – of 2 dB below the saturation point. Herewith the EIRP will decrease by the same value.

— While calculating the values $(C/I)_{UL}$ and $(C/I)_{DL}$ we consider only the interference of 4 neighbouring satellite systems (as shown in Fig. 1 and Fig. 2), suggesting that satellite systems, which are farther along the GEO arc, will interfere less, so their values can be ignored. Calculations are made in accordance with the procedure described in the second volume of the Radio Regulations [1].

— We assume that the satellites are in their orbital positions with a hold accuracy 0.1˚. And when calculating the topocentric angular separation between the satellites, we assume that the earth station is located at a latitude of 60˚ (the worst case).

— Taking into account the interference between the beams, we assume that $(C/I)_{BUL}$ and $(C/I)_{BDL}$ are equal to 17 dB in the worst spot. This allows us to have up to 4 independent regional beams from one orbital position as in satellite "Lybid" [11].

— The calculation of $(C/N)_{UL}$ and $(C/N)_{DL}$ are made according to the recommendations [12].

Analysis of calculation results

GEO capacity values, ratios *C/I*, *S/N*, etc., depending on the separation of satellites in GEO were calculated in MathLab software environment. The calculations were made considering all limitations outlined above. The calculation results are represented below in a form of graphs.

Figure 3 shows the resulting dependence of *S/N* and orbital separation. It can be seen that for a small separation happens a sharp increase of *S/N*. This is due to the reduction of interference from adjacent satellites on downlink at the expense of the earth station antenna directivity.

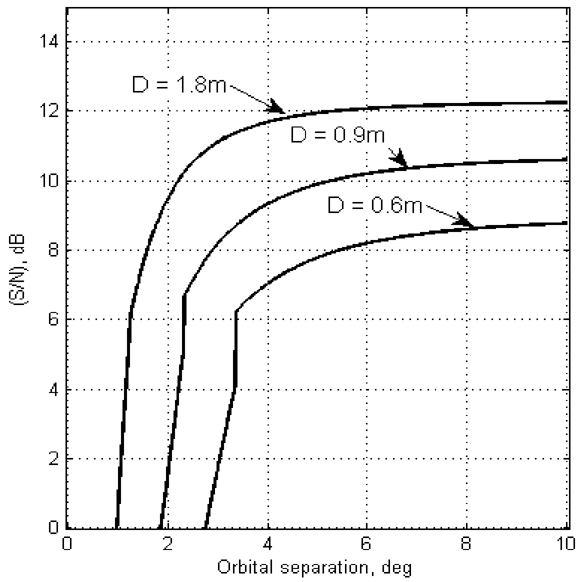

Fig. 3. S/N ratio on demodulator input

However, further separation does not increase the *S/N*, in spite of the fact that the interference from adjacent satellites decreases, as it is seen from Fig 4. The reason is that the *S/N* ratio does not grow owing to the influence of thermal noise in the downlink interference between rays and LTWT noise.

Fig. 5 shows the dependence of the GEO capacity calculated by the expression 1 for optimum modulation and coding system standard DVB-S2 (using the expression 5) for *S/N* values performed in Fig. 3. Line breakpoints characterize the S/N values in which its level rises sufficiently letting it go to a higher MODCOD. This result correlates with the theoretical GEO capacity limit obtained earlier [3]. To obtain current values the GEO capacity shown on Fig. 5 can be multiplied by 8, since it is possible to have in one position up to 4 independent regional beams working in two orthogonal polarizations.

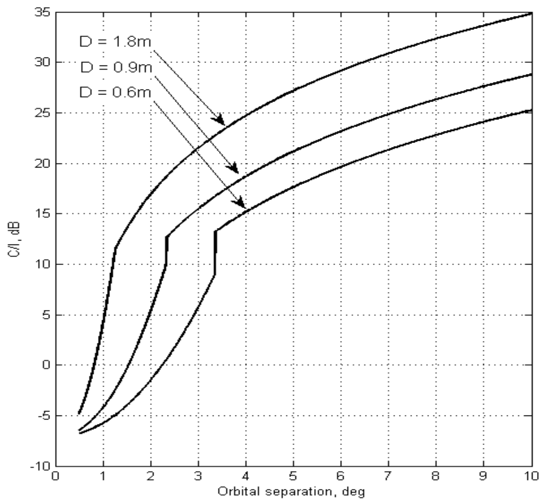

Fig. 4. Signal to single-interference ratio on downlink

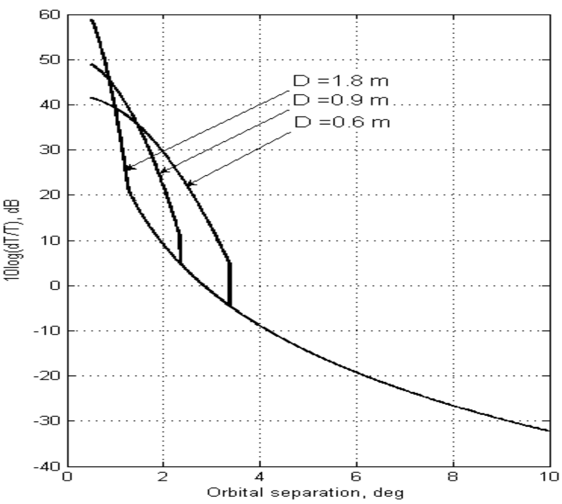

Fig. 5. Capacity dependence of the GEO orbital separation

The dependence of $\Delta T/T$ on the orbital separation is shown in Fig. 6

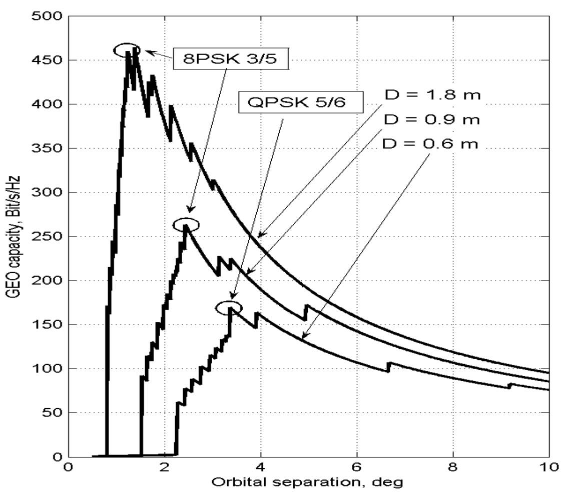

Fig. 6. Allowable relative noise increasing

From Figure 5 it is clear that there is an optimal value of the satellites positioning in orbit with the corresponding values: MODCOD, the level of interference from adjacent satellites and $\Delta T/T$ depending from the earth station antenna diameter (ES). Optimum values for the considered limitations are shown in Table 3.

Table 3

Antenna diameter, m	Orbital separation, deg	MODCOD	C/I, dB	$\Delta T/T$ %
0.6	3.369	QPSK 5/6	13,23	35
0.9	2.438	8PSK 2/3	13,12	241
1.8	1.3835	8PSK 2/3	12,63	7603

The conclusions based on results shown in Table 3 are the following: $\Delta T/T$ criterion is unacceptable as the threshold condition; its restriction will result in a coordination necessity with networks with high levels of useful signal which are not influenced by current interference; the meaning of $\Delta T/T$ = 6% is overrated.

Figure 5 shows that the use of subscriber antennas with small diameter leads to inefficient use of the orbital frequency resource. Typically, antennas used in the Ku band should have a diameter from 0.6 m to 1.8 m. If antennas' diameter is larger, it causes costs increase. It can be noted that GEO efficiency will rise if we abandon antennas of less than 0.9 m diameter.

Results shown on Figure 5 and Table 3, are significantly affected by the following restrictions: EIRP values, uniform signal coverage area, imperfect LTWT, interference between beams. EIRP values increase is improbable in the near future, since it requires increasing power relay board, which is a significant problem for a satellite. Obtaining uniform signal coverage is also practically impossible. However it is possible to withdraw LTWT in linear mode and bring it closer to ideal parameters. Few rays may be retracted or their configuration may be improved to reduce interference between them significantly. For such an ideal case (Fig. 7) GEO capacity was valued and the optimal values of orbital separation, MODCOD and C/I (Table 4) were calculated.

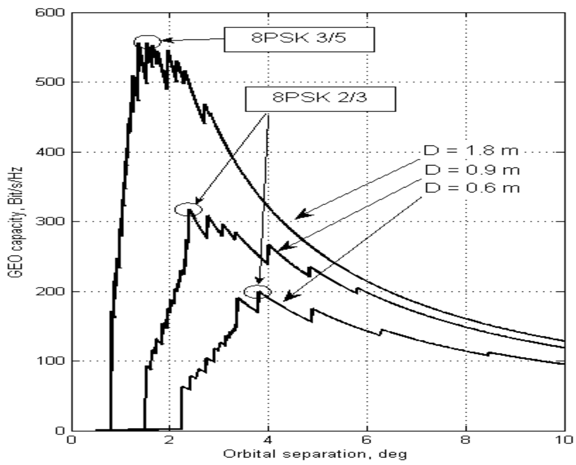

Fig. 7. Dependence of GEO capacity and orbital separation

Table 4

Antenna diameter ES, m	Orbital separation, deg	MODCOD	C/I, dB
0.6	3.806	8PSK 2/3	14,60
0.9	2.3905	8PSK 2/3	12,89
1.8	1.3645	8PSK 3/5	12,46

Comparison of Tables 3 and 4 and Figures 5 and 7 indicates the increasing of GEO capacity. However, conversion of LTWT in linear mode and minimization of interference between the beams gave no significant effect. C/I optimal values are virtually unchanged.

Table 5 shows GEO capacity values in case of existing thresholds, and in case of coordination failure for customers with antennas of 0.9 m diameter. Maximum capacity value is given in the last column for comparison.

Table 5

Range	Min. orbital separation, Grad	Coordination criterion values	GEO capacity, bit/s/Hz	Max. GEO capacity bit/s/Hz
Plan FSS	8.23	C/I =26,65dB	103.8	263.2
Plan BSS	4.93	C/I =21dB	160.5	
Non-Plan	4.54	$\Delta T/T$ = 6%	167.3	

Actual use of GEO can be evaluated on the base of sources analysis [8, 9]. Among the satellites, that are disposed chaotically, satellites operating on the same frequencies in the Ku band through 3 degrees with QPSK 3/4 or 8PSK 3/4 are discernible. Orbital capacity then is 143 or 219 bit/s/Hz. Comparing these results with the data in the Tables 3, 4 and 5 we can state the following:

— current $\Delta T/T$, C/I threshold values in the Ku band, are too rigid and do not contribute the optimal use of GEO;

— performing satellite networks use GEO in some areas more efficiently than ITU provides it;

— coordination of networks, located with orbital separation of more than 5 degrees, can be declined in the Ku band, which do not cause unacceptable interference;

— threshold of relative increase in the allowable noise $\Delta T/T$ should be avoided and replaced by the criterion *C/I*;

— current values of *C/I* can be reduced to 15 dB.

Conclusion

We received maximum GEO capacity depending of earth station antenna diameter when working in channel standard DVB-S2 taking into account the limitations imposed by the equipment parameters of satellite networks.

Optimal values of orbital separation, allowable relative increase of noise $\Delta T/T$, the signal to the single-interference ratio C/I for maximum GEO capacity are identified in the article.

Current threshold values regulated by ITU are estimated, GEO capacity value for their implementation are stated.

The possibility of frequency-orbital resource efficiency increase by changing ITU threshold values is stated.

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