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ECONOMIC METHODS OF SPECTRUM/ORBIT MANAGEMENT FOR SATELLITE NETWORKS

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Satellite systems continue to play an important role in developing of telecommunication and broadcasting services market by offering an effective technical solution for the transmission and dissemination of various types of information to mobile and fixed subscriber receivers. This trend is raising demand for the spectrum-orbit resource (SOR) which provides the operation of any radio-electronic system and this leads to a shortage of this valuable resource. The international administrative management system, based on technical and normative principles and procedures set in the Radio Regulations, which successfully coped with its tasks of SOR distribution under conditions when several satellite nations have an insignificant number of satellites in the geostationary orbit, under conditions of current loading, shows its inefficiency. The procedure of obtaining authorization to use the resource involves considerable expenditure of time and material resources raising transaction costs on development of satellite projects and increasing financial risks, which makes investment in satellite projects less attractive. In this regard there is a question of the necessity of stimulating rational use of SOR methods introduction.

We are considering the possibility of introducing economic methods into the international SOR management system as an additional tool to encourage the rational use of the resource. An analysis of the existing approaches of contemporary economic theory has identified some basic options for applying economic methods to the SOR management system. For the planned frequency bands, distributed for satellite services, the introduction of national assignments rent system is offered. For unplanned frequency bands, the introduction of payments for the SOR use is being considered. On the basis of electromagnetic compatibility of satellite communication systems assessment analysis, the methods to determine payments for SOR based on assessments of a satellite system aggressivity in terms of creating interference and of its sensitivity to interference from other systems are offered.

Keywords: satellite communication; orbit capacity; transactional costs; economic methods of spectrum management; spectrum pricing.

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ЭКОНОМИЧЕСКИЕ МЕТОДЫ УПРАВЛЕНИЯ ИСПОЛЬЗОВАНИЕМ ОРБИТАЛЬНО-ЧАСТОТНОГО РЕСУРСА СПУТНИКОВЫМИ СИСТЕМАМИ

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Спутниковые системы продолжают играть важную роль в развитии рынка услуг связи и вещания, предоставляя эффективное техническое решение для передачи различного рода информации на мобильные и фиксированные абонентские приемники. Такая тенденция повышает спрос на использование орбитально-частотного ресурса (ОЧР), обеспечивающего работу любого космического аппарата, что ведет к феномену нехватки этого ценного ресурса. Международная административная система управления, основанная на технических и нормативных принципах и процедурах, изложенных в Регламенте радиосвязи, успешно справлявшаяся со своими задачами по распределению ОЧР в условиях существования нескольких спутниковых держав с незначительным количеством спутников на геостационарной орбите, в условиях текущей загрузки демонстрирует свою неэффективность. Процедура получения разрешения на использование ресурса требует больших временных и материальных затрат, что повышает транзакционные издержки на развитие спутниковых проектов и риски, что, в свою очередь, снижает привлекательность инвестирования в спутниковые проекты. В этой связи встает вопрос о необходимости внедрения методов, стимулирующих рациональное использование ОЧР.

[*] ***The opinions expressed herein are those of the author and do not reflect an ITU official position.***

Рассматривается возможность внедрения в международную систему управления ОЧР экономических методов в качестве дополнительного инструмента, стимулирующего оптимизацию использования ресурса. Проведенный анализ существующих подходов современной экономической теории позволил определить основные варианты применения экономических методов к системе управления ОЧР. Для плановых полос частот, распределенных для спутниковых служб, предлагается введение системы аренды национальных присвоений. Для неплановых полос частот рассматривается введение платы за использование РЧС. На основе анализа оценки электромагнитной совместимости систем спутниковой связи предложена методика определения платы за РЧС, основанная на оценке агрессивности спутниковой системы с точки зрения создания помехи и ее чувствительности по отношению к помехам от других систем.

Ключевые слова: спутниковая связь, емкость орбиты, транзакционные затраты, экономические методы управления использованием РЧС, ценообразование радиочастотного спектра.

Introduction

Satellite systems in the 21st century allow to provide efficient decisions on delivering modern communication services and broadcasting, successfully creating the competition to terrestrial telecommunication systems or even dominating in a number of markets. The latest achievements in the field of satellite technologies development, in particular increase in a total spacecraft (SC) capacity up to 1 Tbit/s, introduction of all-electric satellites, increase in the maximal efficient loading of launch vehicles and a possibility of their reuse, decrease in time of satellites production lead to the considerable decrease in specific cost of satellite capacity, stimulating strengthening of satellite technologies competitiveness. The prospects of satellite operators development to a large extent depend on availability of the spectrum-orbit resource (SOR) protected from harmful interference. In this regard under conditions of the geostationary orbit (GSO) current loading, the questions of SOR international management system improvement necessity are more often brought up [1; 2].

The measures directed to increase in effectiveness of SOR use which are being considered at the moment, in particular, by the relevant Study Groups of the Radiocommunication Sector of the International Telecommunication Union (ITU) are administrative or technical. Nevertheless, some research and existing experience show that economic methods are one of the potent instruments to improve efficiency of natural resource use [3; 4]. In this article the definition and criteria of SOR use efficiency are discussed, the assessment of SOR use influence on economic indicators of satellite communication project is carried out, the main shortcomings of the developed control system of SOR use are presented and offers on application of economic methods of SOR management for the purpose of increase in economic effect of its operation are made.

The efficiency of the spectrum-orbit resource use by satellite communication systems

It is possible to recognize the combined channel capacity created by the satellites located on a particular GSO arc as efficiency of SOR use, that it is possible to write in the generalized form as [5]:

$$E = C / \Delta\theta \, \Delta f, \qquad (1)$$

where E – effectiveness of OFR use; C – system total capacity, Mbit/s; $\Delta\theta$ – angular width of a GSO arc; Δf – frequency bandwidth occupied by satellites.

As technical solutions directed to efficiency increase, application of homogeneous systems, minimally admissible angular spacing in an orbit, a polarization isolation, increase in accuracy of keeping the satellite in the given position, optimum admissible interference level were considered. Nevertheless, the analysis of satellite communication projects components leads to the interesting conclusion – possibilities of OFR use are defined not only by technical, but also by economic criteria.

Let us explain the foresaid. We will consider the typical project of a satellite system. The main components of capital costs are expenses on satellite designing and production, its launch, including insurance, creation of a necessary ground segment. The satellite cost is determined by the requirements to technical parameters, defined by the required services in the specified service area with wanted quality. Nevertheless, with grow of SOR utilisation, more and more influence on system parameters is exerted by the need to provide electromagnetic compatibility (EMC). In particular, it demands the increase in receivers protection from interference, increase of diameter of the Earth station (ES) antenna, optimization of radio signals processing methods, the adaptive transceivers use recustomizing working parameters depending on a specific electromagnetic situation. It leads to the considerable rising of equipment costs and, in general, to the increase in the required capital investments. Another negative result of incompatibility leading to larger economic losses is the impossibility of all satellite system capacity use in connection with harmful interference. In addition, there is a growing influence of one more component on economic efficiency of satellite communication systems projects – expenses on registration of the corresponding assigning frequences of an orbital position in ITU. Whether this problem is objective or it is related to inefficiency of the applied methods of management? To answer this question it is necessary to consider the existing international control system of use of SOR.

International management system of the orbital-frequency resource use

According to the Radio Regulations (RR) [6] all frequency bands used for satellite communication systems are divided into two types – planned and unplanned. The management of SOR use in them is based on different technical principles and regulation procedures, but they have to pursue one objective – provide the access to SOR to the greatest possible quantity of systems on the condition of harmful interference lack. The choice of the procedure is defined in RR by the frequency band in use and the type of radio service.

The criticism of planned approaches is that they are practically not used per se. The main plans drawback for the majority countries of the world is the restriction of a service area by the national territory. It deprives satellite communication of its main advantage – an opportunity to provide services in larger areas and leads to the fact that realization of satellite systems within national allocations will be economically unprofitable for the majority of countries of the world.

As a result it turns out that plans are interesting only to a limited number of national administrations. Application of additional to plans modification procedures allows them to get advantages at the expense of others which do not use it and, for the reasons stated above, most likely, will never use. In practice modification in most cases leads to deterioration in conditions or impossibility of national allocations use in the Plans.

The main objectives of various procedures explained in RR concerning unplanned frequency bands application are effective SOR use and the greatest possible satisfaction of the real requirements of administrations for their use. Consideration of applications in this case is based on the principle "first came – first served".

The existing approach was being developed in the conditions of satellite communication birth. In the process of a resource loading and increase in demand for satellite communication services the so-called problem of "paper" satellites started to appear. Administrations of some countries tried to occupy a resource for the purpose of access complication to it by others and reservation for the future particular and indefinite requirements. In this regard some international measures directed to the solution of the existing problems have been taken.

First of all, temporary restrictions of all procedures completion date were set, now it is 7 years since the date of application for SOR registration in ITU, and confirmation obligation of system input was assumed. In addition, practically for all satellite networks to which the procedure of coordination is applied, administrations have to submit the request of a specified form confirming the reality of the plans for network development to ITU. In particular, it has to contain the data on a satellite manufacturer and launcher, the reference to the contract and also the information on launch time and place. Also the payment for satellite applications processing, based on recovery of ITU costs on this activity was introduced.

The adopted decisions have yielded some positive results, the number of "paper satellites" decreased, but they have not disappeared. Administrations still have no effective incentives to abandon unused positions, emissions and frequencies. Moreover, there are apparent prerequisites to creation of technical obstacles for competitors access to the spectrum and the orbit that is directed to market protection or, what is even worse, to the subsequent registered position speculation that recently happens even more often. In practice it results in the following:

– in the Master International Frequency Register (MIFR) of ITU there are applications which underwent all required procedures to a decision making to combat paper satellites, but they were either never really used or the actual operation of the corresponding satellites already ended;

– the data entered in applications for SOR in ITU defines the worst situation for compatibility, usually indicating the maximal and minimal modes which are not put into practice;

– often bilateral negotiations on coordination conduct to particular concessions on restriction or change of the stated network parameters. In most cases the corresponding applications do not reflect these agreements, they still contain initially stated and obviously not used modes;

– some administrations provide information on launch confirmation to the Bureau and, according to the administrative procedure due diligence, it does not correspond to reality.

Such practice does not make MIFR to reflect an actual reality of SOR use and unreasonably increases the number of networks with which an applicant has to be coordinated.

Current situation conducts to the fact that the international spectrum management system in itself imposes the considerable additional costs for satellite projects, reducing their investment attractiveness, and, thus, limiting possibilities of SOR use. Its inefficiency causes the growth in necessary initial investments, reduces net profit and increases the project discount rate. Let us explain this conclusion.

As later an operator of satellite communication addresses for a necessary resource, as higher its costs of carrying out calculations, the EMC analysis for the purpose of an optimum position choice, working parameters, used frequency bands and coordination are. A number of researches have considered this phenomenon of satellite projects growing expenses which in economic terminology was named "latecomer's expenses" [7]. By different estimates "latecomer's expenses" for the satellite project make about 5–10 million US dollars and they are growing in the process of SOR loading It is also necessary to note that ITU regisration on average demands more than 5 years, that is often longer than a production cycle itself, from the moment of contract signing to SC launch to an orbit.

In addition, the increase in actual and paper orbit loading leads to the fact that, starting the project, the operator does not know conditions of getting access to a resource use, what depends on agreements with the concerned administrations. The answer to a question whether it will be possible to provide the intended services in the certain area on particular diameter antennas with the guaranteed quality is very uncertain. Indeterminacy is a serious obstacle to any investment project implementation, it involves risk and credit rate increase. Thus, the successful future of satellite communication is closely related to the international regulation procedures which create serious obstacles on the way of modern satellite projects development now. In these conditions taking actions directed to efficiency of SOR use increase is required.

General provisions of the modern economics of social welfare

The main task of economics of social welfare is rational economy management, rational activity, that is optimum resources distribution for achievement of goals [8–10]. The inefficiency arising when using sharing resources, with free access, has been the problem under study in economy for a long period. The lack of proper mechanism

of access to a resource regulation at increase in demand leads to inefficiency of distribution and use, exhaustion, overfilling or pollution.

The choice of economic methods is first of all caused by the choice of the ownership form. So far there are three approaches which allow to solve a problem of the "tragedy of the commons", in particular:

– centralized administrative-command management;

– private property;

– collective property.

According to the single Soviet Nobel prize winner in Economics L.V. Kantorovich research results, in the conditions of state property for the resource use, the optimality of its use can be reached due to introduction of the differentiated rent determined by the state planning authority [11]. Besides a differential payment the state, in case if it is possible, can establish particular quotas for a resource use and maintain justice, that is rules of a resource use at the expense of heavy fines.

Under certain conditions market economy and private property also lead to effective use of restricted resources. So, according to the principle of "the invisible hand" particular solutions of separate institutes in the conditions of perfect economy (that is the competition without monopolies) are socially optimum [12], leading to the growth of social welfare. Distribution of resources in a situation of competitive equilibrium is economically efficient. Deepening of this principle has led to the development of the first theorem on economy of social welfare, according to which it is considered that "if the market where all participants of trade act is competitive, then all mutually beneficial commercial transactions will be concluded sooner or later, and the equilibrium distribution of resources arising as a result will be economically efficient" [13]. It is considered that a cumulative effect of it for the society is maximum if it is impossible to redistribute it so that at least it is better for someone and it is worse to nobody. Such distribution of resources is known as "Pareto optimality criteria". However the unambiguous adherence to this criteria, when making a decision, considerably limits the choice of optimization options because there is always someone to whom it is worse at any decision, therefore in some cases practical use of this criteria is difficult.

The optimality of competitive economy according to Pareto depends on various prerequisites. They become apparent in the course of market failure consideration, it is when the perfect competition does not lead to economic optimum. Direct influence of the negative externalities is the main reason of a market failure. Besides, market failure in some cases is bound to non-performance in most cases of the main condition of economy of welfare theorems – competition optimality, for example, in connection with the existence, due to various technological, economic reasons, of companies having the dominating positions in this or that market which received their positions at the initial resource distribution. In this case there are many possible optimal situations according to Pareto, the choice of one of them demands participation in the process of the regulator authority helping the market to cope with fiasco causing unefficient resources use. Therefore, less strict "Pareto potential optimality criteria" is more achievable [14]. This criterion establishes that redistribution of resources leads to the social welfare gains in general, and, therefore, has to be carried out if those who get better after the redistribution can completely compensate for losses of those to who get worse, and at the same time to benefit more from a resource use than before redistribution. It should be noted that besides the competitive environment existence, a condition of market criteria realization is the possibility of legible determination of the property rights to the used resource with a possibility of their sale.

Later economic research showed that the collective property in some cases can cope with a problem of unefficient resource use [15]. The main conclusion is that under certain conditions collective management of a resource of the physical or legal entities pursuing personal benefit can result in the greatest economic effect. To these to conditions, in particular, belong:

– clear definition of resource boundaries and each owner's shares with the right to withdraw them from collective use;

– the rules of distribution limiting place, time, technology and/or quantity of a resource;

– possibility of each owner participation in definition of instructions for a resource use;

– control of implementation of the established rules from owners;

– sanctions against violators of the adopted rules;

– definition of procedures for conflicts solutions both in collective community and between community and the authorities;

– absence of external intervention, in particular the state institutes, in a decision-making process concerning collective property.

Practically all developed countries of the world in a varying degree apply economic methods in a management system of a radio-frequency spectrum use applied by the terrestrial radio communication systems and broadcasting [16; 17]. Let us consider whether their use to OFR used by satellite networks is possible.

Application of economic methods of the orbital-frequency resource use management options

Planned frequency bands. From the economic point of view SOR management in planned frequency bands is administrative, administrations divided a resource among themselves on the basis of the particular technical and regulatory principles, after their realization the national operator can acquire the right to use SOR from the administration by the agreed basic principles – providing equal access to this natural resource for all countries. According to the economic theory, if a management system is not changed, then the introduction of a differential fee has to stimulate effective SOR use. Nevertheless, introduction of a payment for national assignments in the Plans will not achieve this result and will not be supported by administrations. The principles of effectiveness were already initially underlain in the basis of the Plans, the most admissible channel capacity in a particular frequency band was defined and the choice of technical parameters and orbital positions was based on providing EMC on the condition of national territory covering. The unified technical parameters that are all

homogeneous systems were applied to planning, what provides optimal SOR loading.

For increase in effectiveness of planned bands use it is possible to consider two possible methods:

1. Cancellation of plans. Plans as it was considered above, do not work and create considerable administrative difficulties, partially bureaucratic, not related to the technical condition of RFS or orbit loadings, as in some cases coordination has to be carried out with paper systems, which are retained by a number of administrations proceeding from positions of uncertain future use and sometimes from purely political ambitions.

2. Replanning for the purpose of creation of conditions for the market of the rights to use SOR. Procedures of planned frequency bands use create very good basis for the secondary market of the rights to use SOR development. One of market mechanisms operating conditions is legible determination of property rights. Concerning the property rights to use SOR, they were formulated as follows [18]:

– definition of the used frequency bands;

– maximal power or spectral mask;

– a service area and the maximal power outside a service area.

The analysis of the existing satellite plans shows that all these conditions are already consolidated by the international legislation, only legal permission to a possibility of sale or rent is necessary. Nevertheless the mechanism does not work and it is explained by the same drawback mentioned earlier – restriction of a service area of the planned assignment with a national covering. The problem can be solved due to replanning on the basis of a regional covering. The optional version of replanning is presented in fig. 1. Orbital positions can be defined on GSO uniformly, proceeding from practical reasons it is possible to establish, over 3 degrees. At the same time the administrations which received a resource in one point must have the right to use an arc in ±1.5º from the nominal position. Realization of a particular technical mask has to providethe lack of interference for networks in the neighboring clusters.

The plan can be used as follows:

1. Administration can keep a possibility of the position planned use in case of future needs. Capacity of national assignment will decrease, due to the service area expansion, but at the same time the national system of any administration can be commercially viable having a potential of a service area choice up to regional. At the same time two main planned advantages – equal access of all administrations to an orbit and a possibility of national satellite system realization without the need for carrying out coordination remain.

2. Neighbors in a cluster in one orbital position can combine their capacity, jointly realizing more broadband systems on the basis of mutual arrangement.

3. In case of plans for the development of characteristic system absence, the administration will have a possibility of the rights rent to administrations which need an additional resource, on a temporary basis at the mutual agreement and on condition of technical restrictions of the plan realization (a position A7’). The ITU Radiocommunication Bureau can undertake a task of information collection from administrations which are ready to lease the rights to SOR use to make it publicly available. The present possibility establishes conditions for the secondary market of the rights to RFS use creation.

4. Bases for more effective use of an arc in a cluster are created. If new operators (for example, positions of A7 and A8) are able to provide compatibility with satellites in a nominal position and to satisfy conditions of systems protection in the neighboring clusters on the basis of technical masks realisation or arrangements with administrations in the neighboring clusters, they can have an opportunity to use other orbital positions in a cluster, different from the nominal. Even in case if the administration already has its national system, it will be interested in carrying out the research directed to combination of two or several systems within the national assignment to gain additional benefits from a resource use.

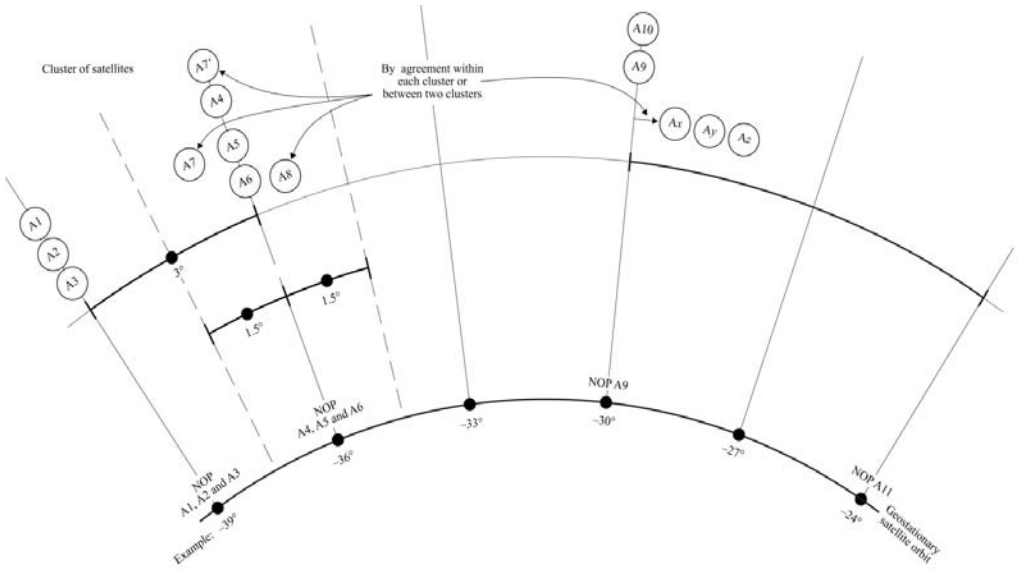

Fig. 1. Option of Satellite planned bands

Рис. 1. Вариант плана для спутниковых служб

The offered approach allows to keep advantages of the plan and to eliminate its defects. Administrations will be interested in achievement of the arrangement with operators striving to use their planned resource. It will force them to publish actual parameters of their systems in case they exist, or not to preserve the national assignment in case of uncertain future use. It will be stimulated with an opportunity to get actual material compensation. Even if there is the need, carrying out coordination will be executed between a very restricted number of negotiators, at the same time each of them will be interested in the positive agreement. The registration of new assignments by the Bureau of a radio communication can be carried out on the basis of the notification of the administration owning the right to use the corresponding national allocation. All these procedures in a complex will promote realization of economic conditions of restricted resource use effectiveness according to a potential criterion according on Pareto.

The main problem when compiling a plan, as it is offered above, is that it has to be created for SOR which it is not occupied with existing systems yet. One of the simplest probable options of introduction is the use of new frequencies distributions for satellite services in higher and not loaded yet frequency bands for planning. Another more composite opportunity is replanning of the existing plans with the term of realization of 15 years that will allow to finish operation to all satellites which already use the discussed frequency band. In addition, a new plan has to contain regulatory provisions describing actions of administrations concluding renting transactions of their frequency assignments.

Unplanned frequency bands. Unlike the planned, the unplanned frequency bands are not suitable for introduction of the market approach as it is quite difficult to define the property rights. Each frequency filing is developed for the specific project, that it must have the parameters corresponding to the requirement specification for the particular satellite. In practice there have already been several transactions when the position notified by one administration has already been used for the SC belonging to another administration. It leads to the fact that the notified parameters considerably differ from actually used, complicating protection of the used assignments as the filing was developed for another satellite. Also it is necessary to consider thatunplanned frequency bands are really very loaded and the change of SOR management procedure can create considerable difficulties for a large number of operators.

One of the most optimal ways to improve EMC of satellite systems among themselves is the ban on expansion of the stated service areas and satellite antenna strengthening diagrams, which often happens in practice. Modern RR text contains only appeals to cover zones restriction without legible definitions and restrictions. As a result there are such applications where a service area – the territory of a small country, but an aiming point of SC – on the equator, and a contour of the antenna gain countur (AGC) – global. Let us illustrate on the example how the notified service area influences a number of networks which have to be involved in coordination process. Calculations results of requirements for coordination on the basis of the criterion of noise temperature $\Delta T/T$ of actually notified system using Ku-range on the line down are given in table At the reduction of a service area with the global (fig. 2), that is the minimal angle of arrival is equal 0º (a contour of an external ellipse) to a service area with the minimal angle of arrival 40º (a contour of an internal ellipse) requirements for coordination decrease in total by 7 %.

Impact of service area reduction to number of coordination concerned networks

Minimum arrival angle	0º	10º	25º	30º	40º
A number of coordination concerned networks	260	258	253	248	231

One more approach to increase SOR use efficiency is the achievement of the greatest possible uniformity of satellite systems. Such two satellite systems which meet the condition are homogeneous:

$$\theta_{1\text{-}2} = \theta_{2\text{-}1}, \quad (2)$$

That is the minimal necessary spacing $\theta_{1\text{-}2}$ between satellites 1 and 2 from the point of view of interference from system 2 on system 1 is equal to a spacing angle $\theta_{2\text{-}1}$, necessary for preservation on the given interference level from system 1 to system 2. Proceeding from these conditions, the homogeneous systems provide equality of the required angular spacing on the relation to each other that allows to avoid creation of an excess margin on the protective relation in the direction of one of these systems, less sensitive to interference and to realize a minimal spacing angle between considering SC. Ratios between power parameters of two homogeneous systems show that conditions of uniformity can be satisfied for systems with different parameters, for example, with different sizes of service areas, AGC of ES and etc.

Fig. 2. Illustration of satellite service area decreasing

Рис. 2. Иллюстрация уменьшения зоны обслуживания спутника

Based on above mentioned it is possible to come to conclusion that the payment for SOR use has to be proportional to the size of an occupied resource that will force the operator not to occupy (and not to declare) an excessive resource. Let us consider a problem of increase in SOR use efficiency from the technical point of view. It is defined that the technical factors influencing efficiency of GSO use and providing conditions EMC of satellite communication systems and broadcastings are in particular [19]:

– the improved space selectivity of AN antennas;

– the improved space selectivity of the SC onboard antennas;

– increase in accuracy of SC keeping in a calculated position of GSO;

– application of different polarizations – simultaneous work of a SC on two orthogonal (circular or the linear) polarizations;

– application of efficient methods of signals transfer and reception, low-sensitive to interference;

– development of new, more high-frequency ranges.

The angular spacing on GSO between the adjacent SC working in the common frequency ranges in the modern networks usually does not exceed 2º–3°, in certain cases it is possible to reduce it to 1° and even to 0° (at not combined cover zones). At coordination of satellite networks and calculation of interference of the ES modern antennas with the improved space selectivity in the direction other than a principal axis, it is recommended to define by reference antenna diagram (AD) as described in [20]. In case the operator of satellite network assumes to use simpler ES, it is necessary to apply the AD from [21]. For ES used in old satellite systems, the AD mathematical description is presented in [22].

Now in practice in overwhelming number of notified n antennas is defined on the basis of [20]. It should be noted that the choice of AD providing higher selectivity can slightly facilitate achievement of agreement for coordination. The carried-out calculations of the required angular spacing on criterion C/I between two randomly chosen systems with identical parameters showed that when using ES with AD presented in [20], the required angular spacing is 3.8 degrees, in [21] – 4.95 degrees and in [22] – 5.6 degrees.

Similarly the increase in space selectivity of the SC onboard antennas on GSO promotes decrease of interference between geostationary satellite systems if their service areas are not overlapped. For this purpose the notified AGC has to repeat the necessary service area as accurately as possible and to degrade quickly beyond its limits.

Accuracy of SC keeping is normalized in RR as $\delta \le \pm 0.1^{\circ}$. Such tolerance of SC does not lead to noticeable degradation of a GSO channel capacity when using standard angles of spacing between SCs. Requirements of high accuracy of keeping are still limited by resource opportunities of position correction system of the satellite on GSO therefore when considering effectiveness increase factors of SOR they can be not viewed.

The effect of mutual interference decrease between satellite networks can be reached by using of different polyarizations. It leads to the significant increase in a channel capacity.

The analysis of EMC when sharing SOR satellite systems and technical means of increase in efficiency of GSO use, leads to the conclusion that as an reference parameter defining satellite system aggression from the point of view of creation of interference and requirements for protection it is possible to consider C/N value, the required relation of a signal to thermal noise of a communication link in the lack of interference. The less the required C/N at the invariability of other parameters of satellite systems, the larger SOR efficiency can be reached. The calculations of the required angular spacing on C/I criterion between two randomly chosen systems with identical parameters showed that the decrease in C/N by 0.2 dB leads to the decrease in the required spacing arc by 0.1 degrees. Technically it is possible to reach it due to the choice of optimal signal scrambling and application low-sensitive to interference signals. Besides stimulation of signal interference immunity, the regulator's task is to stimulate the operator to provide data on C/N value close to actual that will give the possibility to clear away the database of the frequency assignments and to simplify coordination.

As discussed above, in the conditions of administrative centralized management by a restricted resource an important role in creation of incentives for SOR efficiency use can play the introduction of a differential fee. A following formula to stimulate SOR efficiency use could be considered:

$$\text{Fee}_{\text{down(up)}} = \sum_{i=1}^{n} \Big(C/N_{\max} \cdot \Delta F \cdot K_{sa} \cdot K_{gc} \times \times K_{gd} \cdot K_{pl} \cdot K_{es} \cdot C_s \Big)_i, \quad (3)$$

where $\text{Fee}_{\text{down(up)}}$ – payment for SOR use for one beam, up or down directions; $C/N_{\max}$ – the maximal value of the relation of a signal to the noise for this beam, dB, respectively for the transmitting or receiving beam. The C/N value can be the generalized indicator which is best reflecting assessment of satellite system interference potential and sensibility. The higher the stated C/N, the more is SOR which the system occupies. Besides that this value use will stimulate the operator to introduce more interference-resistant operating modes, it is more important that they will have the economic reasons to make available the data on SOR loading closer to those which are used in practice; ΔF – the frequency bandwidth occupied by one beam, down or up, the Hz; K_{sa} – the coefficient considering the size of service area $K_{sa} = S_{sa}/S_e$, where S_{sa} – the stated service area; S_e – Earth surface area seen from the satellite; K_{gc} – the coefficient considering the AGC SC, $K_{gc} = S_{-3}/S_{sa}$ representing the relation AGC SC of the main beam (–3 dB) S_{-3} to notified service area size S_{sa}; K_{gd} – the coefficient considering contours of power degradation, $K_{gd} = S_{-3}/S_{-20}$ representing the relation of AGC SC size on the contour (-3 dB) to the size of AGC SC on contour (–20 dB) S_{-20}; K_{pl} – the coefficient considering polarization use can be accepted $K_{pl} = 1$ if both types of polarization are used and $K_{pl} = 0.5$ if only one type; K_{es} – the coefficient considering the AD of ES type. On the basis of the explained above reasons and calculations, it is

possible to accept K_{es} = 1 at application of AD defined in [20], K_{es} = 1.3 in [21] and K_{es} = 1.5 in [22]; C_g – the monetary value determining the cost of a spectrum resource measure unit, US$ · K/dB · Hz. Determination of this value demands the statistical data analysis related to activities of satellite networks operators for receiving necessary SOR. Introduction of SOR fee does not considerably raise operators expenses, it is necessary to carry out an operators economic benefit assessment in case of the SRS-all database clearing. At the same time it is necessary to consider not only cut in time expenditure and the material resources in carrying out coordination, but potential decrease in risk of investment that was discussed above due to possession of more precise information about SOR use as well. This value has to be different for different ranges, reflecting their current loading and stimulating use of higher, less loaded frequency ranges. The corresponding studying has to be carried out within the research commissions of ITU-R in an attentive dialogue with satellite networks operators. All other required payments for SOR payment definition are obligatory for representation in applications at coordination and registration of satellite networks and are available for all comers registered in SRS-all.

The procedures of unplanned bands description shows that protection of the notified resource starts not from the moment of the actual start of satellite system operation, but from the date of receipt of corresponding coordination request by ITU Radiocommunication Bureau. This date defines date of protection of notified SOR from following applicants. Thus, the payment has to be charged annually for all applications which are registered in SRS-all.

Conclusion

1. The existing international management system of SOR in the conditions of increase in demand for its use does not provide its use efficiency. Implementation of international registration requirements demands considerable resources, raising cost of projects on the development satellite communication and broadcasting networks and, respectively, the risk of investment in their development. All this exerts negative impact on the development of the telecommunication services market and their availability and quality.

2. The management of SOR for satellite communication networks use is based on two procedures: planned and unplanned. The carried-out analysis shows that both of them are not efficient, in most cases without providing realization of the principles which were underlain in their basis.

3. The planned approach is intended to provide equal access to all countries to SOR. The problem of planned distribution of SOR first of all is that national allocations have restrictions of the national territory cover zone. It leads to the fact that for many countries implementation of the satellite project within the resource assigned according to the plan has no economic benefit. The current use of plans is carried out through additional procedures allowing service area expansion by conducting coordination with affected administrations. On the one hand, the systems registered according to such procedure gradually absorb a resource of planned assignments that leads to the fact that their practical use becomes impossible. On the other hand, the administrations trying to receive a resource, which in most cases is not used and it will never be used according to the plan, spend time, financial and human resources, providing paper protection of phantom national assignments and obtaining consent from administrations which own them.

4. The main problems of unplanned frequency bands are paper satellites and paper parameters brought by administrations for protection in the international satellite networks frequency assignments database of MIFR for their subsequent international legal protection. Operators and the administrations which received the registered resource earlier have no incentives to refuse really not used positions, frequency bands and operating modes. On the other hand, due to administrative procedures they have very good potential to considerably complicate competitors life, limiting them in obtaining necessary SOR without any actual technical reason.

5. It is possible to achieve the increase in planned bands efficiency due to replanning, creating conditions for of the market relations development. The planning principles in which in particular the main existing drawback is excluded are offered, the covering of national assignment has to be regional. Terms providing a possibility of trading of rights to use SOR between administrations are offered. At the same time two main advantages of the plan remain – a possibility of providing equal access to SOR and lack of coordination when performing technical restrictions of planned assignment.

6. As the economic method directed to efficient use of SOR it is offered to introduce an annual differential payment for its use for all applications introduced in MIRF. On the basis of the analysis of increase in effectiveness technical methods the formula is developed for such payment definition and recommendations for its components determination are formulated. Technical parameters of satellite networks accounting in the formula will allow to stimulate operators to introduce more efficient in relation to RFS use technologies, and to declare closer parameters to actually used for registration. It will simplify in turn negotiations on coordination and to facilitate access of new satellite systems to invisible but very valuable natural resource.

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