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SATELLITE SEGMENT OF NATIONAL INFORMATION INFRASTRUCTURE. APPROACHES TO IMPLEMENTATION

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СУПУТНИКОВИЙ СЕГМЕНТ НАЦІОНАЛЬНОЇ ІНФОРМАЦІЙНОЇ ІНФРАСТРУКТУРИ. ПІДХОДИ ДО РЕАЛІЗАЦІЇ

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Abstract. *It is proved that the satellite segment is a necessary component of the national information infrastructure. From this position, the state and development trends of satellite telecommunication systems and satellite channel organization technologies are analyzed. It is shown that there are two ways to build a satellite segment: based on the use of leased resources of satellite operators operating in the satellite communications market; based on the resources of the national satellite communications system, which still needs to be created. It is shown that satellite telecommunication systems have a steady tendency to increase the number of spacecraft, until the launch of "heavy" satellites with a payload of more than 70 transponders and to increase the frequency resource. The diagram of satellites location density of in orbit is given. In the case of orientation to rent the resources of active spacecraft, the criteria for their selection is indicated. The arc of the geostationary orbit, on which the satellite should be selected, is calculated. For satellites located on this arc, diagrams of equivalent isotropically radiated power values in the C and Ku bands, which they provide in Ukraine, are shown. A list of satellites that you can focus on, recommendations for selection and a list of recommended for the satellite segment is indicated. The technology standards used in payload and methods for organizing satellite communications channels is noticed. To select the parameters of the satellite segment, the results of calculations of the effectiveness of signal-code structures are provided. Approaches to creating a satellite segment of the national information infrastructure are proposed. It is shown that the orientation to the Lybid national satellite does not make sense; a new frequency-orbit resource is required. The types of platforms that can be used on a national satellite are considered.*

Keywords. *Geostationary satellite systems, system services, platforms, satellite channel organization technologies, satellite telecommunication system resources, resource efficiency, satellite segment, National Information Infrastructure.*

Анотація. *Доведено, що супутниковий сегмент є необхідною складовою частиною національної інформаційної інфраструктури. З цієї позиції проаналізовано стан і тенденції розвитку супутникових телекомунікаційних систем та технології організації супутникових каналів. Зазначено, що є два шляхи побудови супутникового сегменту: на основі використання орендованих ресурсів супутників операторів, що діють на ринку супутникового зв'язку; на основі ресурсів національної супутникової системи зв'язку, яку ще необхідно створити. Показано, що супутникові телекомунікаційні системи мають стійку тенденцію до збільшення кількості космічних апаратів, до запуску "тяжких" супутників з корисною навантагою більш ніж 70 транспондерів та до зростання частотного ресурсу. Приведена діаграма щільності розташування супутників на орбіті У разі орієнтації на оренду ресурсів активних космічних апаратів зазначені критерії їх відбору. Розрахована дуга геостаціонарної орбіти, на якій слід обирати супутник. Для супутників, розташованих на цій дузі наведені діаграми значень еквівалентної ізотропне випромінюваної потужності у діапазонах С та Ku, яку вони забезпечують на території України. Наведено перелік супутників, на які можна орієнтуватися, рекомендації щодо вибору та перелік рекомендованих для сегменту супутників. Вказані технології стандарти,* *що використані у корисній навантазі та методи організації супутникових каналів зв'язку. Для вибору параметрів супутникового сегменту надані результати розрахунків ефективності сигнально-кодових конструкцій. Запропоновано підходи до створення супутникового сегменту національної інформаційної інфраструктури. Наведено, що орієнтація на національний супутник "Либідь" не має сенсу, потребується отримання нового частотно-орбітального ресурсу. Розглянуті типи платформ, які можуть бути застосовані на національному супутнику.*

Ключові слова. *Геостаціонарні системи супутникового зв'язку, системні послуги, платформи, технології організації супутникових каналів, ресурси супутникових систем телекомунікацій, ефективність використання ресурсів, супутниковий сегмент, Національної Інформаційної Інфраструктури.*

Аннотация. *Доказано, что спутниковый сегмент является необходимой составной частью национальной информационной инфраструктуры. С этой позиции проанализировано состояние и тенденции развития спутниковых телекоммуникационных систем и технологии организации спутниковых каналов. Указано, что есть два пути построения спутникового сегмента: на основе использования арендованных ресурсов спутников операторов, действующих на рынке спутниковой связи; на основе ресурсов национальной спутниковой системы связи, которую еще необходимо создать. Показано, что спутниковые телекоммуникационные системы имеют устойчивую тенденцию к и к росту частотного ресурса за счет увеличения количества космических аппаратов, запуску «тяжёлых» спутников с полезной нагрузкой более 70 транспондеров. Приведенная диаграмма плотности распределения спутников на геостационарной орбите В случае ориентации на аренду ресурсов активных космических аппаратов указанные критерии их отбора. Рассчитана дуга геостационарной орбиты, на которой следует выбирать спутник. Для спутников, расположенных на этой дуге приведены диаграммы уровней эквивалентной изотропно излучаемой мощности в диапазонах С и Ku, которою обеспечивают лучи, покрывающие территорию Украины. Даны рекомендации по их выбору спутников, пригодных для построения спутникового сегмента и приведен перечень рекомендованных для него спутников. Проанализирован уровень использования современных и перспективных технологий и стандартов построения спутниковых сегментов телекоммуникационных систем как основы для реализации полезной нагрузки и выбора метода организации спутниковых каналов связи. Для выбора параметров спутникового сегмента предоставлены результаты расчетов эффективности сигнально-кодовых конструкций. Предложены подходы к созданию спутникового сегмента национальной информационной инфраструктуры. Показано, что ориентация на национальный спутник "Лыбидь" не имеет смысла, требуется получение нового частотно-орбитального ресурса. Рассмотрены типы платформ, которые могут быть применены на национальном спутнике.*

Ключевые слова. *Геостационарные системы спутниковой связи, системные услуги, платформы, технологии организации спутниковых каналов, ресурсы спутниковых систем телекоммуникаций, эффективность использования ресурсов, спутниковый сегмент, Национальной Информационной Инфраструктуры.*

INTRODUCTION

The priority of the state policy in the field of telecommunications remains the areas defined by Resolution of the European Parliament A4-0279/97 [1], which declares that the Global Information Infrastructure (GII) will be largely based on the constellations of communication satellites and recognizes that this type of telecommunications must be given priority attention. The special role of satellite telecommunication systems (STS) is due to a number of advantages inherent only to them, associated with a wide service area, the ability to quickly provide communication channels anywhere and anytime. The creation of a National Information Infrastructure (NII) without the development of satellite communications systems in the country is impossible.

On the one hand, the provisions of the current state documents [2 - 4], the needs of Ukraine to access global and regional information networks, the task of providing Ukrainian users (regardless of their location) access to information, including national and regional programs of broadcasting, clearly indicate the need to use STS. On the other hand, the problem is that these provisions are not implemented. Moreover, in the existence of the frequency-orbital resource (FOR) assigned to Ukraine, the question of the National Satellite System of Communications (NSSC), as the alleged main component of the research institute, is practically removed from the agenda. This is despite the attention to relevance of its solution, at least from the standpoint of ensuring national security and the prestige of the country as a space state.

A significant disadvantage of STS is the significant cost of satellite channel resources. The construction and launch of a national spacecraft (SC) requires considerable ($ 200 million - $ 300 million, average spacecraft) funding. It is theoretically possible, but practically not advisable, to create a terrestrial telecommunication network covering the whole territory of the country, to extend to each settlement, to each house an optical line or cable, to deploy a network of base stations of radio access systems. Using this approach takes considerable time and can takes big capital expenditures. Calculations of financial resources and time for the construction of a terrestrial telecommunications network covering the entire territory of Ukraine to the most remote settlement are not yet available. According to experts, the costs of covering by digital broadcasting services inaccessible and sparsely populated areas (about 10 % of the country) can be compared with the cost of covering 90 % of the territory. In Ukraine, where less than 100 people live in more than a fifth of settlements, this problem is compounded.

The influence of this factor can be reduced. First, the cost of the satellite segment can be less than the cost of building terrestrial networks, and secondly, the cost of STS resources does not depend on the size of the territory and the number of users, and when attracting more users, the specific costs may be even lower. It should be emphasized that STS is more receptive to new, more efficient and economically efficient technologies, and the transition to such already existing terrestrial network technologies requires additional financial investments.

In this situation, when the issue of creating an NSST is ignored or, at best, postponed for the long term, the real needs of NII in satellite channels make it necessary to focus on the services of third-party STS. Currently, satellite operators operating in Ukraine use the spacecraft resources of these systems. However, targeting only these spacecrafts is not advisable, satellite communications continue to develop intensively, new STS appear, introduce new methods of organizing satellite communications networks, more powerful spacecraft are put into orbit, with modern technologies and technical solutions embedded in them, which requires a revision of approaches to creating satellite segment of the NII.

These and other factors predetermine the need for an analytical review of the status and trends of the development of the satellite telecommunications market, based on the needs of NII, the capabilities of existing STS, taking into account the existing demand, and the future needs of Ukrainian users in satellite channels with orientation to the introduction of modern economically advisable technical solutions.

GENERAL CHARACTERISTICS OF SYSTEMS

Further we will consider only civilian STS using spacecrafts located in the geostationary orbit (GSO), which allows to provide communication services in a continuous mode and on an ongoing basis. Previous similar reviews were published in [5–9].

As of May 2019, 84 satellite telecommunication systems of 64 operators, registered in 44 countries, including Mongolia and Sri Lanka, using (renting) a part of the resources of third-party spacecraft under their own name, provide satellite channels and channels for rent. The list of STS, indicating the countries of their affiliation or registration, the total number of active spacecraft and plans for replenishment of satellite constellations, are shown in Table 1 [10, 11].

Table 1 – Satellite telecommunication systems (September 2019 p.)

System	Amount SC		Operator	Country of registration
	GSO	plan		
ABS	6	1	Asia Broadcast Satellite	China. Bermuda
ACTS	1		National Aeronautics and Space Administration	USA
Afghansat	1	1	Ministry of Commun. and Inform. Technology	Afghanistan
Alcomsat	1		Agence Spatiale Algerienne (ASAL)	Algeria
Inmarsat, Alphasat	12	3	Inmarsat Plc. European Space Agency (1 KA)	United Kingdom

Al Yah	3		Al Yah Sat. Commun. Company PrJSC	UAE
Amazonas, Hispasat	9		Hispasat	Spain
Astra, SES, AMC, NSS	51	1	SES S. A. SES Astra, SES Americom, SES World Skies	Luxembourg, USA, Netherlands
Amos	3	2	Spacecom	Israel
AMSC, Sky Terra	3		Mobile Satellite Ventures	Canada, USA
Anik, Nimiq, Telstar	13	1	Telesat Canada Ltd	Canada
Apstar	5	1	APT Satellite Holdings Ltd	China. Bermuda
Arabsat, Badr	7	2	Arab Satellite Communications Organization	Saudi Arabia
Arsat	2	1	Empresa Argentina de Soluciones Satelitales Sociedad Anonima	Argentina
AsiaSat	4	1	Asia Satellite Telecommun. Co. Ltd	China
Asiastar	1		Worldstar	USA
AzerSpace	2		Azercosmos, MEASAT Satellite Systems Sdn. Bhd.	Azerbaijan
Bangabadhu	1		Bangladesh Commun. Sat. Co. Ltd (BCSCL)	Bangladesh
Belintersat	1		Belintersat	Belarus
Star One, Brasilsat	5	1	Star One (EMBRATEL)	Brazil
BRIsat	1		Bank Rakyat Indonesia	Indonesia
Bsat	4	1	Broadcasting Satellite System Corporation	Japan
Chinasat, Tiantong	9	2	China Sat. Commun. Co. Ltd	China
Ciel	1		Canadian Ciel Satellite Group.	Canada
COMS	1		Korea Aerospace and Research Institute, KARI	South Korea
Es'hail	2		Es'hailSat	Qatar
Direc TV, Spaceway	12	1	Direc TV Inc.	USA
Echostar, Spaceway	14	1	Echostar Communications Corp.	USA
Eutelsat	29	7	Eutelsat S.A.	France
Express	12	6	Russian Satellite Communications Company	Russia
GSat, Insat	17	4	Indian Space Research Organisation (ISRO)	India
HellasSat	3		Hellas Sat	Greece
Hylas	3	1	Avanti Communications Plc.	United Kingdom
Intelsat, Galaxy	47	2	Intelsat	Luxembourg
JCSat, N Star Horizons	14	2	SKY Perfect JSAT Corporation	Japan
Kazsat	2	1	JSC Kazsat	Kazakhstan
Kizuna	1		JAXA (Japan Aerospace Exploration Agency)	Japan
Koreasat	4		Korea Telecom Sat.	South Korea
Laosat	1		Lao Satellite Joint Venture Co.	Laos
Measat	3		Measat Satellite Systems Sdn. Bhd.	Malaysia
Mexsat	2		Secretaria de Commun. y Transportes of México	Mexico
Monacosat	1		Space Systems International-Monaco S.A.M.	Monaco
MongolSat	1		Asia Broadcast Satellite	Mongolia
Sky Muster	2		NBN Co Limited	Australia
Nigcomsat	1	2	Company Nigerian Commun. Sat. Ltd	Nigeria
Optus	5		Sing Tel Optus	Australia
Paksat	2		Space and Upper Atmosphere Research Commission	Pakistan
Palapa. PSN. Telkom	5	2	Palapa Satelit Nusantara Sejahtera	Indonesia
QuetzSat	1		QuetzSat, S.R.L. de C.V.	Mexico

Rascom	1		Regional African Sat. Commun. Organization	Mauritius

End of Table 1

System	Amount SC		Operator	Country of registration
	GSO	plan		
Sirius FM, XM	6	2	XM Sat/Radio Holdings Inc./Sirius Sat. Radio	USA
Sky-Mexico	1		DirecTV Latin America	Mexico
ST	1		Singapore Telecom, Chunghwa Telecom.	Singapore, Taiwan
Superbird	3		Space Communications Corp (SCC)	Japan
SupremeSat	2		SupremeSAT (Pvt) Ltd.	Sri Lanka
Thaicom	4	1	Shin Satellite	Thailand
Thor	3		Telenor	Norway
Thuraya	2		Thuraya Telecommunications Co.	UAE
Tupac Katar	1		Bolivian Space Agency (ABE)	Bolivia
Turksat	3	3	Türksat AS	Turkey
TurkmenAlem	1		Turkmen Ministry of Commun.	Turkmenistan
Venesat	1		Ministry of Science and Technology of Venezuela	Venezuela
ViaSat	2	1	ViaSat Inc.	USA
WildBlue	1		Wild Blue	USA
Vinasat	2		Vietnam Post and Telecomm. Group (VNPT)	Vietnam
Yamal	5	1	Gazprom Space Systems	Vietnam
Angosat		1	AngoSat	Angola
GapSat		1	Terran Orbital	Virgin Islands
GiSat		1	Global IP	Cayman Islands
Silkwave		1	New York Broadband LLC	USA
Techo		1	Royal Group of Cambodja	Cambodia

Since the previous review [9], five STS operators stopped working and 12 new operators were added, including 7 national ones (Afghanistan, Algeria, Bangladesh, Belarus, Bolivia, Laos, Turkmenistan). The number of STS practically did not change (10 stopped working, 12 new ones appeared). Until 2021, it is planned to launch spacecraft for the new STS of Angola, Cambodia, the Virgin Islands, the Cayman Islands, and the United States. Information on previously announced other project of national STS is limited:

– work is ongoing on obtaining FOR for the STS ArmSat spacecraft (Armenia);

– STS AOneSat project (Switzerland) was canceled;

– the launch of the spacecraft STS NicaSat (Nicaragua) was previously planned for 2019, but today it is not in the launch plans;

– work on STS Congosat (Congo) suspended, no funding;

– there is no information on the Iranian QAEM satellite and the status of work on it.

The number of satellites operating on GSOs is the most characteristic indicator that indicates the level of needs for satellite channels and the tendency of system development. The dynamics of growth in the number of active (providing or in reserve) commercial spacecrafts for the 20-year period from 1998 to the end of 2018 is illustrated by the diagram shown in Figure 1. The plans for launching a spacecrafts in the next three years, assuming that during this period will cease the work of the spacecrafts, launched on GSO until 2001. The increase in the number of spacecraft is almost linear.

The tendency for non-uniformity of the annual increase in the number of launched on GSO spacecrafts, which was observed earlier [8, 9], remains. The dynamics of launching spacecraft and the exit of spacecraft from orbit over the twenty years are shown in Figure 2. The annual replenishment of satellite groups - from three to 17 spacecraft. Previously, much of the satellites that exhausted their own resources were replaced, over the last five years much attention has been paid to launching high-tech satellites that make it possible to build economically and technically more efficient telecommunications networks [10].

With the exception of experimental and specialized spacecraft and dual-purpose satellites, as of June 2019, more than 370 civilian telecommunication satellites are located on the GSO, of which 14 spacecraft operate in the mobile satellite service.

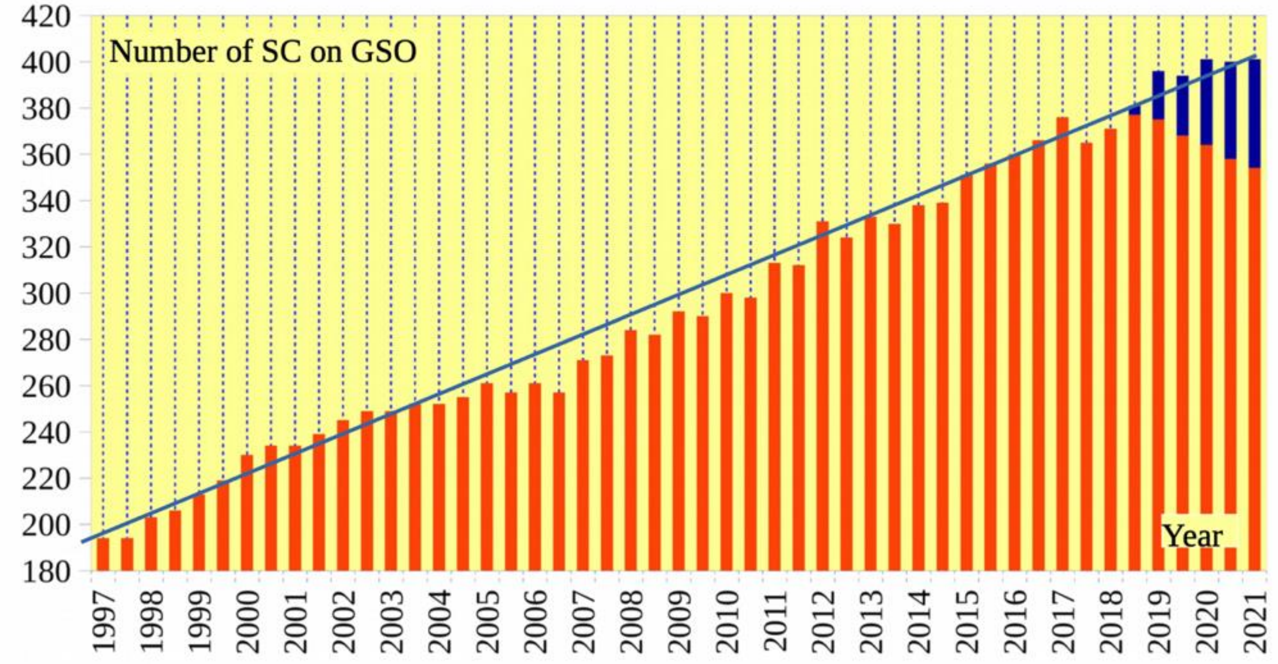

Figure 1 – Number of active geostationary satellites

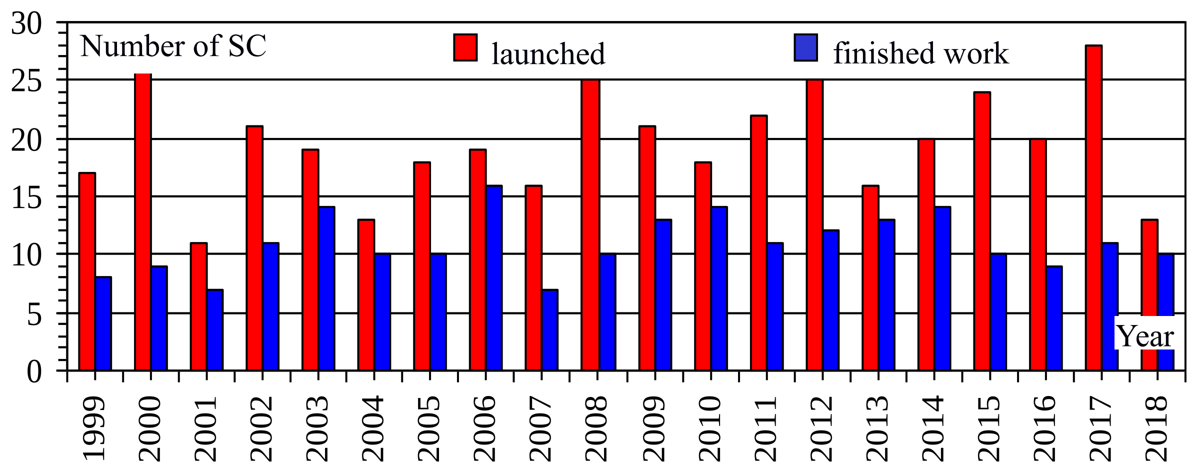

Figure 2 – Dynamics of change in the number of spacecraft

Over the period from the previous analytical review [9] the annual average increase in the number of spacecraft has not changed much and amounts to approximately 2.3 % against 2.5 % [9]. The forecast provided there regarding their number in the next 5 years has practically proved to be true. Over the next 5 years (until 2024), one should expect an increase in the number of satellites per GSO by 428. However, it is not enough to consider this factor as a criterion for the growth of demand for STS channels. Most new spacecraft are launched to replace obsolete ones. Note that spacecraft can vary significantly in terms of payload.

The determining factor in the development of the space industry, directly or indirectly associated with STS, is the economic return on activity. According to information published in the annual reports of the Satellite Industry Association [11], Figure 3 shows data on the income level of the space industry in general (production of satellites, satellite launches, production of earth infrastructure equipment, system services) and on the provision of services, in particular.

About half of the income is provided by the provision of services, mainly telecommunications.

With overall growth over the past three years, the profitability of the provision of services has slightly decreased, mainly due to its redistribution in favor of the production of equipment on the earth infrastructure, which is largely associated with the provision of services.

The distribution of income by services is provided in Figure 4, and by type of telecommunication services in table 2.

Table 2 – Revenue distribution by type of service

Types of services	Revenues, billion dollars.					
	2008	2010	2012	2014	2016	2018
BSS, including	68.1	83.1	93.3	100.9	104.7	102.4
television broadcasting	64.9	73.1	88.4	95.0	97.7	94.2
radio broadcasting	2.5	2.8	3.4	4.2	5.0	5.8
high speed access	0.8	1.1	1.5	1.8	2.0	2.4
FSS, including	13.0	15.0	16.4	17.1	17.4	17.9
provision of resources for rent	10.2	11.1	11.8	12.3	11.2	
network services (VSAT)	2.8	3.9	4.6	4.6	6.2	
MSS	2.2	2.3	2.4	3.3	3.6	4.1
Total	83.3	98.4	112.1	121.3	125.7	124.4

Satellite Broadcasting Service (CCM) provides a larger part of revenue, but in recent years there has been a slight downward trend (3.5 % since 2016). Over the same period, revenues from fixed satellite services (FSS) increased slightly (by 2.8 %), and their increase in the mobile satellite service (MSS) increased significantly by 14 %.).

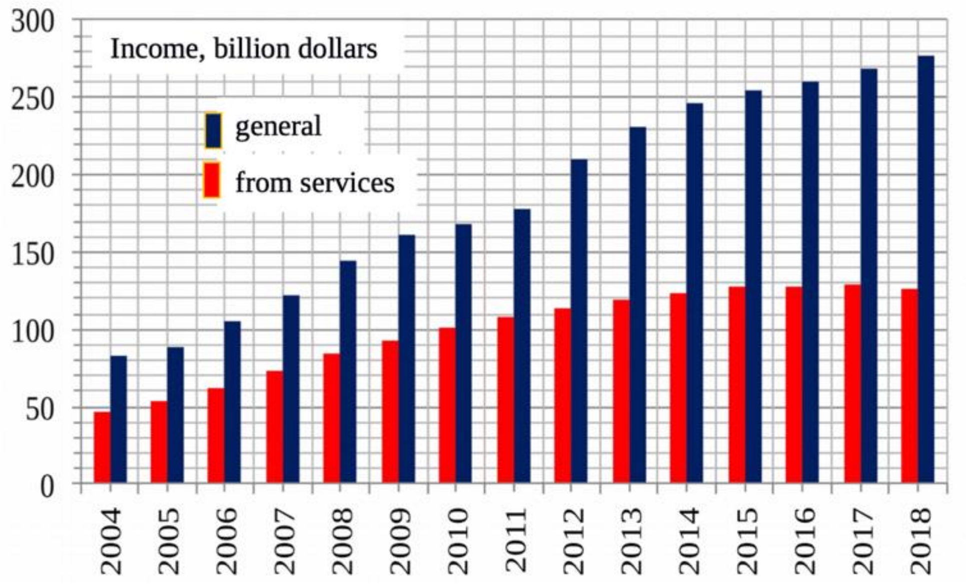

Figure 3 – Revenue level in the space industry

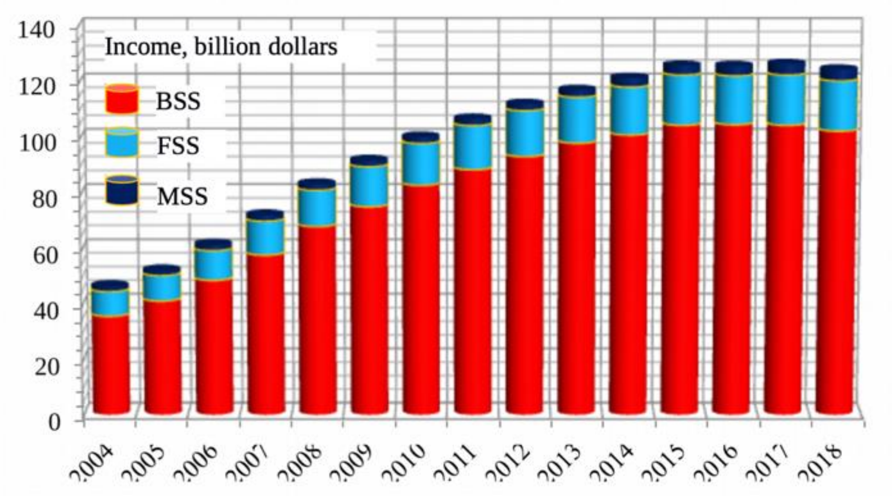

Figure 4 – Distribution of incomes by service

The previously applicable principle of distributing spacecrafts in terms of payload into three conditional classes: small (up to 20 transponders), medium (up to 50 transponders), heavy (more than 50 transponders) with using the new principles of constructing STS networks (for example, multi-zone coverage) is somewhat outdated. A new section on four spacecraft types is proposed for payload:

- small ones – up to 30 equivalent transponders;
- medium – from 30 to 70 equivalent transponders;
- large or heavy – from 70 to 100 equivalent transponders;
- superheavy – more than 100 equivalent transponders.

By definition, the equivalent transponder is transponder with a frequency band of 36 MHz.

The origin of the term "heavy" is directly related to the weight of the equipment installed on the satellite. This primarily refers to the platform, which is characterized by the following indicators: a powerful power supply unit with large solar panels, payload (transponders) with either a large number of transponders or with a large output power; several antenna systems, which may include large-diameter antennas (up to 12 m – 18 m); other auxiliary equipment. The distribution of active spacecraft by type from the position of the payload volume is shown in Figure 5.

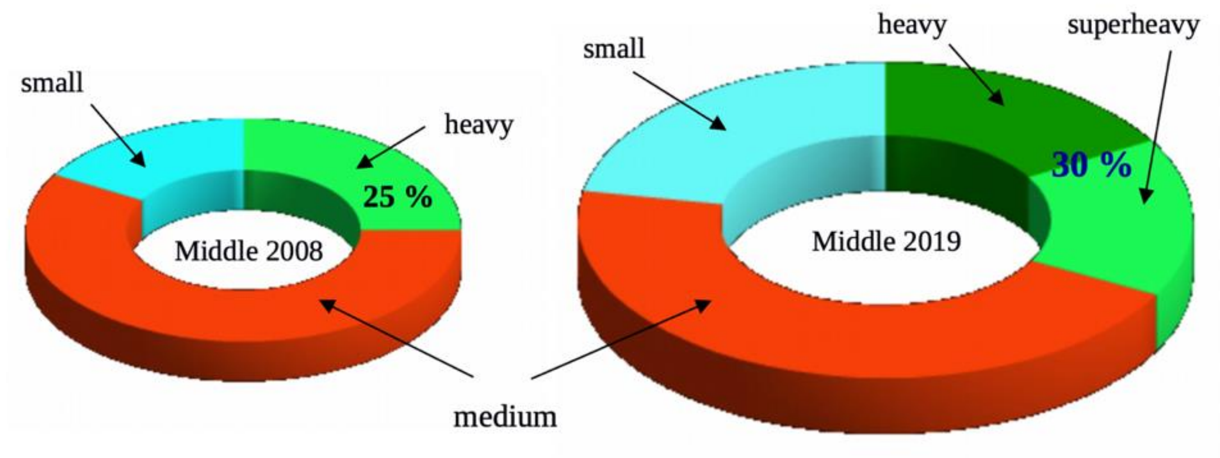

Figure 5 – Distribution of spacecraft by payload volume

At sufficiently high costs for the manufacture and launch of heavy and superheavy spacecraft (up to $ 600 million), the cost of a unit of its frequency resource (FR) is much lower than that of other types of satellites. For example, the cost of 1 MHz of the frequency band of the satellite ABS 2 (cost of 320 million dollars, 230 equivalent transponders in the C, Ku, Ka bands, FR 8200 MHz) is three times lower than that of the small GSat 10 spacecraft (cost 155 million dollars, FR 1170 MHz). In addition, heavy spacecraft are able to provide services in a much larger volume. This explains the current tendency to launch more efficient profit/price heavy spacecraft. If in 1998 the share of heavy spacecraft was slightly less than 6 %, then by 2019 it had grown to 30 %. So, if possible, to build a satellite segment, you should choose a heavy spacecraft, provided it is loaded.

From the position of providing telecommunication services, the most important indicators that determine the resource of satellite channels are:

− energy of channel or power that can be used to transmit information. The ability to provide a particular type of service, such as television, and its quality depend on it;

− frequency resource (FR) or frequency band, which determines the amount of information transmitted by satellite channels and, to some extent, the ability to provide a specific service, such as high-speed access.

As will be given below, exchange relations between the energy and frequency resources are possible.

Note that satellite channels frequencies are assigned divided into bands under the conventional names (line down / line up), GHz:

L – 1.452–1.550 / 1.610–1.710;

S – 1.930–2.700 (in both directions);

C – 3.400–5.250 / 5.725–7.075;

X – 7.250–7.750 / 7.900–8.400;

Ku – 10.700–12.750 / 12.750–14.800 and 17.300–18.100;

Ka – 15.400–26.500 / 27.000 GHz–30.200;

V – 40.000–75.000 (distribution by directions not determined)

W – 75.000–111.000 (distribution by directions not determined).

The frequency range L is used in mobile communication systems, the range S is mainly used in radio broadcasting and mobile communication systems. X – range of military use. Ranges V and W are not yet used, left for the future, but information has appeared on the development of the STS project in range V (GapSat 1). For these reasons, consideration is limited only to systems operating in the C, Ku, Ka bands. Trends changes in the size of the FR in each of the ranges are illustrated by the dependencies shown in Figure 6.

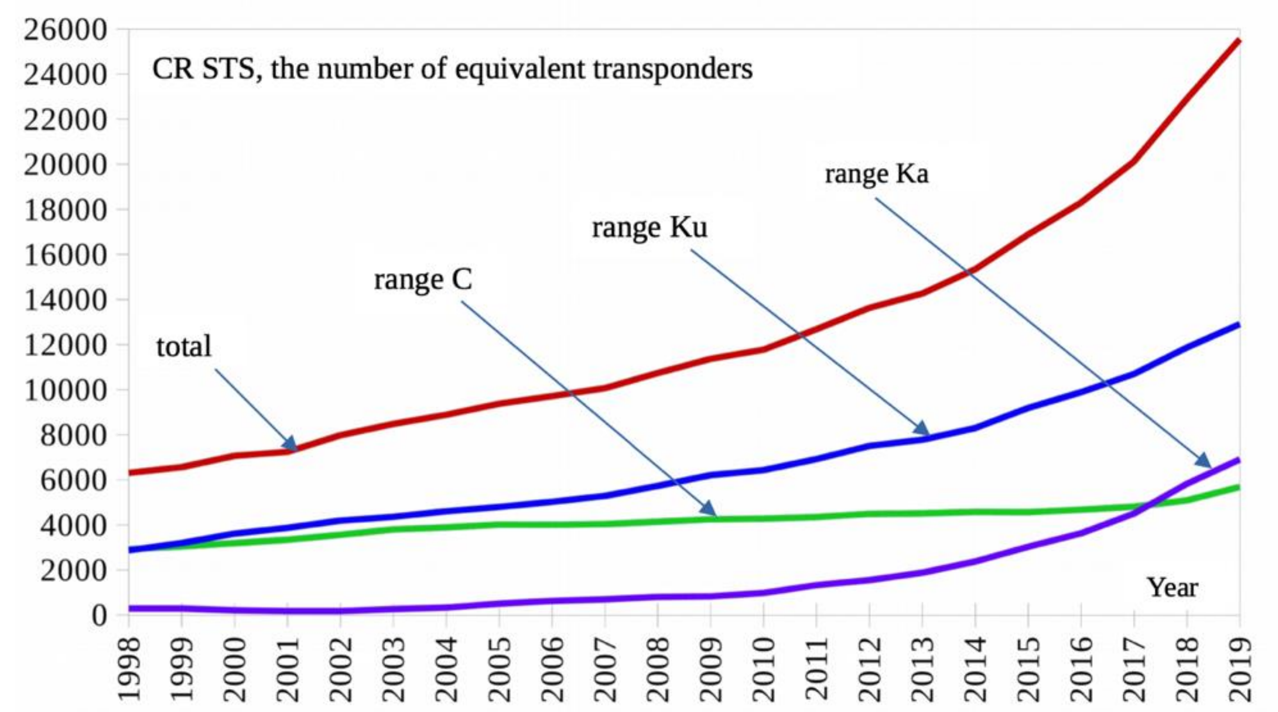

Figure 6 – Distribution of frequency resource by years

The resources of the STS as a whole or an individual spacecraft in particular determines the number of transponders, their power and parameters of the antenna equipment (gain factors). Depending on the type of platform in modern satellites, the number of transponders vary from 10 to several hundred. The transponder frequency band, usually 24 MHz, 27 MHz or 36 MHz, or a multiple of these values. If necessary, other arbitrary values of the frequency band are possible. Since satellites can be equipped with transponders with different frequency bands, to illustrate the growth trend in the total capacity of satellite channels of all STS, the concept of equivalent transponder is used in Figure 6.

For the analyzed period, the frequency resource of the spacecraft in the range C increased slightly (by 70 % in 20 years).

In range Ku until 2013 FOR also grew linearly, but at a high rate (270 % over 15 years), then an exponential increase was observed. This is primarily due to the launch High Throughput Satellite (HTS) into orbit.

In Ka range also observed exponential resources growth. Since 2013 the increase FR is quite significant, more than 4 times. The observed trend is due not only to an increase in the number of physical transponders, but also to the reuse of the frequency band for multi-zone coverage (see [10] for more details). The change in the ratio between FR of different ranges that occurred over 10 years is illustrated by the diagram in Figure 7.

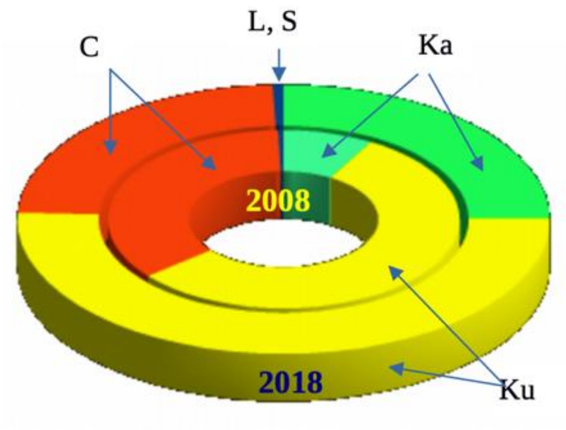

Figure 7 — Distribution FR by ranges

During this period, the total frequency resource of the STS increased from 390 GHz to 920 GHz, and the ratio between the ranges changed in the direction of the Ka range:

- C: from 38.0 % to 21.8 %,
- Ku: from 53.6 % to 50.5 %,
- Ka: from 7.5 % to 27.0 %.

On the one hand, given the pace of implementation of the Ka band and its advantages in organizing networks with multi-zone coverage, its use is preferable when building a satellite segment. On the other hand, Ukraine already has terrestrial infrastructure operating in the Ku band, and for the Ka band it still needs to be built.

Regarding energy capabilities, we note that the output power of transponders of modern spacecraft has significantly increased and reaches:

- C range: 60 W – 90 W,
- Ku range: 150 W – 200 W,
- Ka range: 100 W – 200 W.

In the future, as more applicable to NII, we will consider options for building a segment in the Ku, Ka ranges.

OPTIONS OF THE SATELLITE SEGMENT IMPLEMENTATION

There are three possible options for construction a satellite segment of a national telecommunications network:

- on the basis of the National Satellite System of Communications (NSSC), the creation of which was announced about 20 years ago [2–4] and ended in complete failure, despite the financial means spent and the satellite already produced;
- based on leased resources of a third-party spacecraft under its own name, examples of which are STS SupremeSat or MongolSat;
- based on part of the resources of different spacecraft.

If we take into account world experience and assume that the desire to create an NSSC will be restored, then the question will arise of obtaining a new frequency-orbit resource for the reasons given below.

According to information that appeared on the website www.lyngsat.com, an intention was announced in early 2020 to bring to the position of 48.0 °E GSO KA “Lybid”. Then the launch date was moved to 2021. But neither this position, nor other parameters of the ChOR for Ukraine are beneficial [12, 13], especially considering the period elapsed from the NSSC project to the now announced beginning of its implementation (2021).

Of the three beams embedded in the existing FOR can be loaded by Ukrainian operators of the Euro-Ukrainian beam capacity. Note that in the area of coverage of this beam services provide about 90 SC, of which more than 30 provide the best technical and economic parameters (see Table 3 for an example).

Table 3 – Comparison of SC parameters (examples)

Parameter	Europe, Ukraine		India			West Africa	
	Lybid	Turksat 4A	Lybid	NSS 6	GSat 10	Lybid	Nigcomsat 1R
e.i.i.p, dBW	48–53	44–55	48–51	46–56	51–52	48–50	52–56
Beam resource, MHz	342	516	342	450	432	342	315
Cost of 1 MHz band (thousand dollars)	320	170	320	100	140	320	200

The resources of the Indian beam will most likely not be used, since more than 40 spacecraft, including 17 satellites of the Indian operator ISRO, already provide services in the region (see Table 1). A significant number of these satellites in terms of technical and economic parameters exceed the capabilities of the Indian beam of the proposed Ukrainian spacecraft (for examples, see Table 3).

Regarding the West African beam, we note that in connection with the beginning of the widespread introduction of satellite telecommunication systems in West Africa, probably counted on the demand for its resources. Now these prospects are lost. The issue of launching the Lybid spacecraft was not resolved. At the same time, the demand for satellite channels in the region has increased interest in the African market for leading STS operators (especially Eutelsat and SES). In addition, in addition to the NSSC Nilesat (Egypt) (see Table 1), on the market began to operate the African regional system Rascom, the NSSC of Nigeria, Algeria. Next in line (2021) is the creation of STS in Angola (the launch of the first spacecraft was unsuccessful). In the future (upon opening financing), the NSSC Congo will appear. In terms of technical and economic indicators, the Ukrainian spacecraft has no advantages (see Table 3 for an example).

Note that there are 6 satellites already in place around position 48.0° E (see Figure 8), which may create some obstacles to the operation of the National spacecraft. From this point of view, it is preferable to use the previous version of the frequency orbital resource (38.2° E), which was opposed by the French Administration, with two nearby spacecrafts.

The national satellite using the FOR assigned to Ukraine is inferior in characteristics to other spacecraft with the same coverage area. In relation to them, the cost of a unit of the frequency band (1 MHz) of the transponder at the SC «Lybid» is higher (see Table 3). The answer to the question whether the resources of the national satellite will be in demand is obvious.

Work should be started on obtaining a new frequency orbital resource with more attractive characteristics both in the coverage area and in technical parameters.

Regardless of the implementation option, the first step should be to select a position for the spacecrafts of NSSC or satellite(s) in the case of using a third-party spacecraft. Information on locations of satellites on the GSO, determined with an accuracy of ± 0.5 °, and data on the number of SC at a given point of the GSO are given in Figures 8 (eastern hemisphere) and 9 (western hemisphere).

If we take into account military, meteorological, navigation and other special satellites, then there is practically no free space in the geostationary orbit. Even with a uniform distribution of telecommunication spacecraft on the GSO, the angular distance between satellites is less than one degree. In addition, user density must be considered. For example, over a part of the Pacific Ocean (from 184 ° to 220 °, see Figure 9) there are no satellites, since there is practically no demand for services.

On the other hand, the needs of the users of densely populated areas of the Earth lead to the need to place several spacecrafts at one point the of GSO or around, for example (see Fig. 8): 19 ° (Europe area) – 5 spacecrafts; 26 ° (Europe area) – 7 spacecrafts; 48 ° (regions Europe, Middle East) – 6 spacecrafts; 74 ° (India area) – 5 spacecrafts; 110 ° (China, Japan) – 8 spacecrafts and (Figure 9): 253 ° (US area) – 6 spacecrafts; 259 ° (USA, Mexico) – 6 spacecrafts; 299 ° (district of Brazil) – 5 spacecrafts; 330 ° (Brazil area) – 5 spacecrafts. The parameters of the co-located spacecrafts differ in coverage, frequency and/or polarization. The FOR for the new NSSC of Ukraine is recommended to be based on a free position in the GSO (in the absence of rights of other communications administrations) or to use the FOR agreed upon by the Communications Administrations of other countries. An example of this is STS TurkmenAlem 52 / MonacoSat (Turkmenistan / Monaco), Azerspace 1 / Africasat (Azerbaijan / Malaysia). The use of the second or third options places the task of selecting one (option 2) or multiple (option 3) satellites.

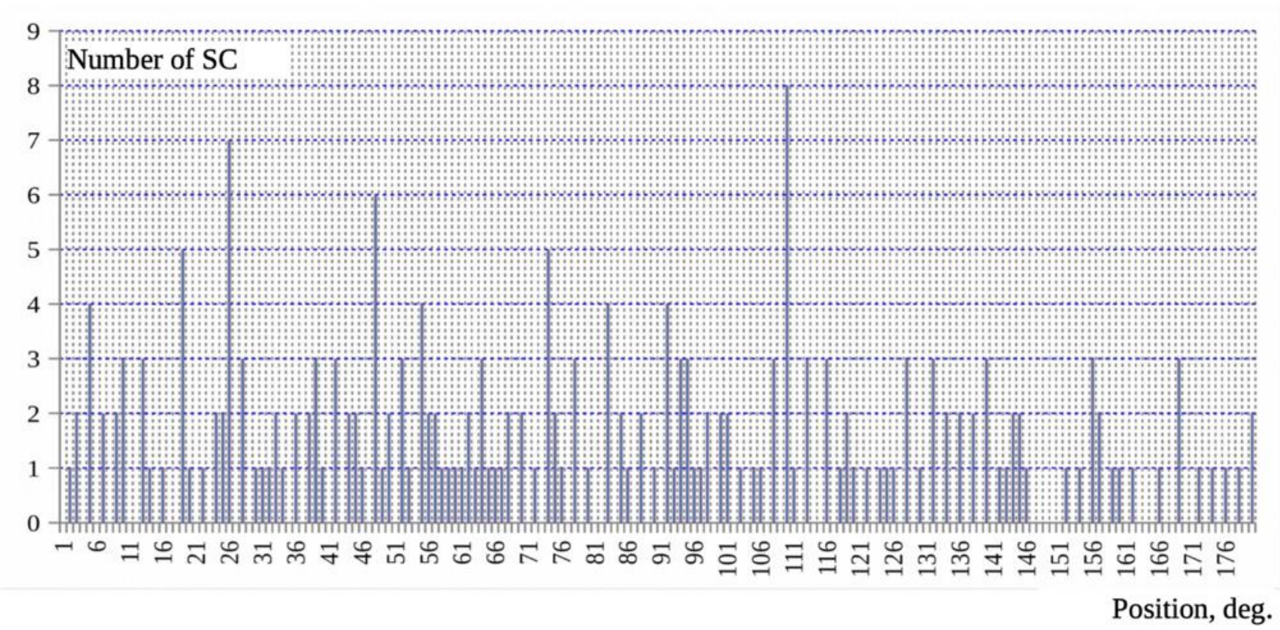

Figure 8 – Location of the SC on the GSO (eastern hemisphere)

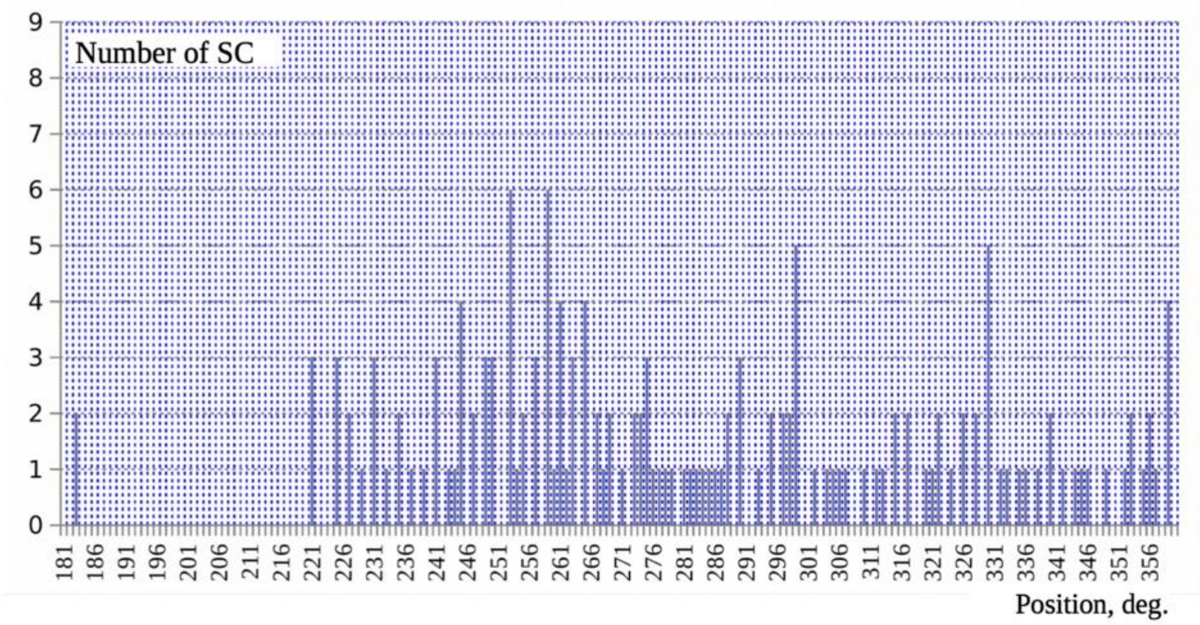

Figure 9 – Location of the SC on the GSO (western hemisphere)

The question of choosing a position for a new FOR or satellite(s) when working in the framework of other STS, we will consider further, after taking into account the angle of the user's location.

The next criterion for selecting a frequency orbital resource is the duration of its life span.. The guaranteed life of modern geostationary spacecraft is on average 15–18 years. A further increase in the spacecraft life is technically possible, but impractical, since during this period new more effective technologies come to replace that necessitate the replacement of the spacecraft. Quite rightly, when creating networks with a satellite segment or when choosing a spacecraft to receive a certain type of telecommunications services, you should focus on new, recently launched satellites. This provides the prospect of using modern technical solutions and long-lasting work by satellite.

At creating networks with a satellite segment or when choosing a spacecraft to receive a certain type of telecommunication services, it is advisable to focus on new, recently launched satellites. This makes it possible to use modern technical solutions and longer work over the satellite.

In Figure 10 shows diagrams characterizing the separation of active spacecrafts by the operating life. Conditionally accepted for the guaranteed period of active existence of the satellite, 15 years is divided into four periods (from the moment of its launch): up to 5 years; from 5 years to 10 years; from 10 years to 15 years; more than 15 years. There, for comparison, a similar diagram of 10 years ago is given.

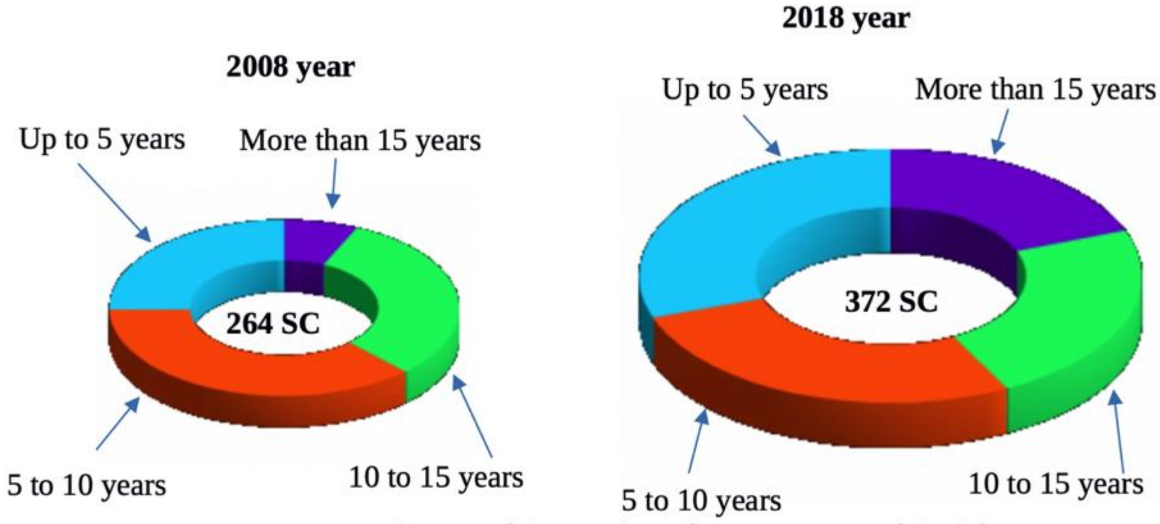

Figure 10 – Distribution of the number of active spacecraft by lifetime

Compared to the end of 2008, the proportion of spacecrafts that exceeded the guaranteed service life increased markedly (from 7 % to 20 %). This is mainly due to the high reliability and large power reserve of satellite equipment (for moving to the GSO position after launch, for adjusting the satellite position during operation). Note that most of the “old” spacecrafts are reserved for channel reservation.

For the satellite segment, it is preferable to use spacecraft operating on GSO for less than 5 years, and, to a lesser extent, from 5 years to 10 years. The share of such satellites has not changed over 10 years (about 60 %). This is due to the fact that the number of SC with a life of more than 15 years has increased. The number of spacecraft that can be recommended for building the satellite segment increased from 164 (end of 2008) to 214 SC (June 2019).

Further selection from 214 spacecraft should be carried out according to other criteria: coverage area, type of service, frequency range, frequency resource, energy characteristics etc.

CHOOSING OF A SATELLITE FOR A NSSC OR A POSITION ON A GSO FOR A NATIONAL SATELLITE

For operators, providers using or planning to use satellite channels to provide telecommunication services in Ukraine, or users receiving these services, data on the satellites whose coverage area covers the country are of great interest.

Firstly, the elevation angle ψ (angle of location) of the antennas of earth stations and terminals (ES) of the direction to the satellite should be at least greater than 0º. The angle should be such that the reliefs of terrain, high-rise buildings, etc. do not interfere with the reception / transmission of signals from / to the satellite. For these reasons, the angle of location, which will determine the position of the SC on the GSO, should be chosen slightly larger, for example. $\psi = 10º$.

The elevation angle is calculated using a topocentric coordinate system. The corresponding relations between the coordinates ES and the parameters of pointing the antenna in a topocentric coordinate system are illustrated in Figure 11, where:

- O is the center of the Earth;
- R is the radius of the Earth, $R = 6370$ km;
- P – planes of the local horizon, tangent to the Earth's surface at the location of the ES or user terminal;
- A is the location of the user terminal / ES on the surface of the Earth;
- S – location of the spacecraft on the GSO;
- N – direction to the North;
- S_1 is the projection of the vector directed to the satellite on the plane P;
- ψ is the elevation angle, the angle between the direction to the satellite and the projection of this direction onto the surface tangent to the Earth's surface ($0 < \psi < \pi / 2$).

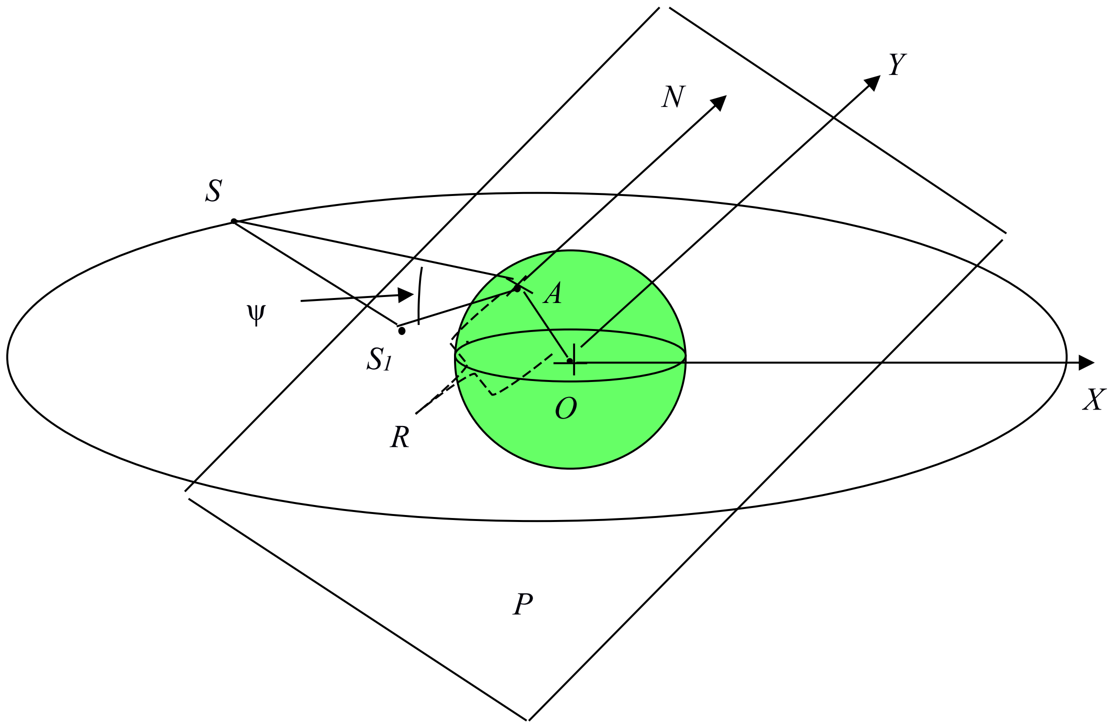

Figure 11 — Coordinate system for determining the arc of satellites location

In a top centric coordinate system, the elevation angle can be calculated by the formula (1) [14]:

$$\psi = \arcsin\left(\frac{H\times\cos v_{ш}\times\cos(\varphi_c - v_{д}) - R}{\sqrt{H^2 + R^2 - 2\times H\times R\times\cos v_{ш}\times\cos(\varphi_c - v_{д})}}\right) \quad (1)$$

where H – the height of the GSO relative to the Earth's surface;

$\varphi_{д}$ – the longitude of the SC location;

$v_{д}$ – longitude of the ES location;

$v_{ш}$ – latitude of the location of the ES (negative for the southern hemisphere).

In order for a satellite to provide telecommunication services throughout Ukraine, the spacecraft must be “visible” at an angle ψ > 10º from the extreme point in the west of the country to the extreme point in the east. The coordinates of the extreme points are as follows:

− western: 48.43 ºE, 22.16 ºN;

− eastern: 49.26 ºE, 40.20 ºN.

According to (1), at an antenna elevation angle at the extreme points of the ES ψ> 10 °, the satellite should be selected on the GSO arc from 83 ° E to 20 ° W. A schematic diagram of the arc on which spacecraft are located that can provide services in Ukraine is shown in figure 12.

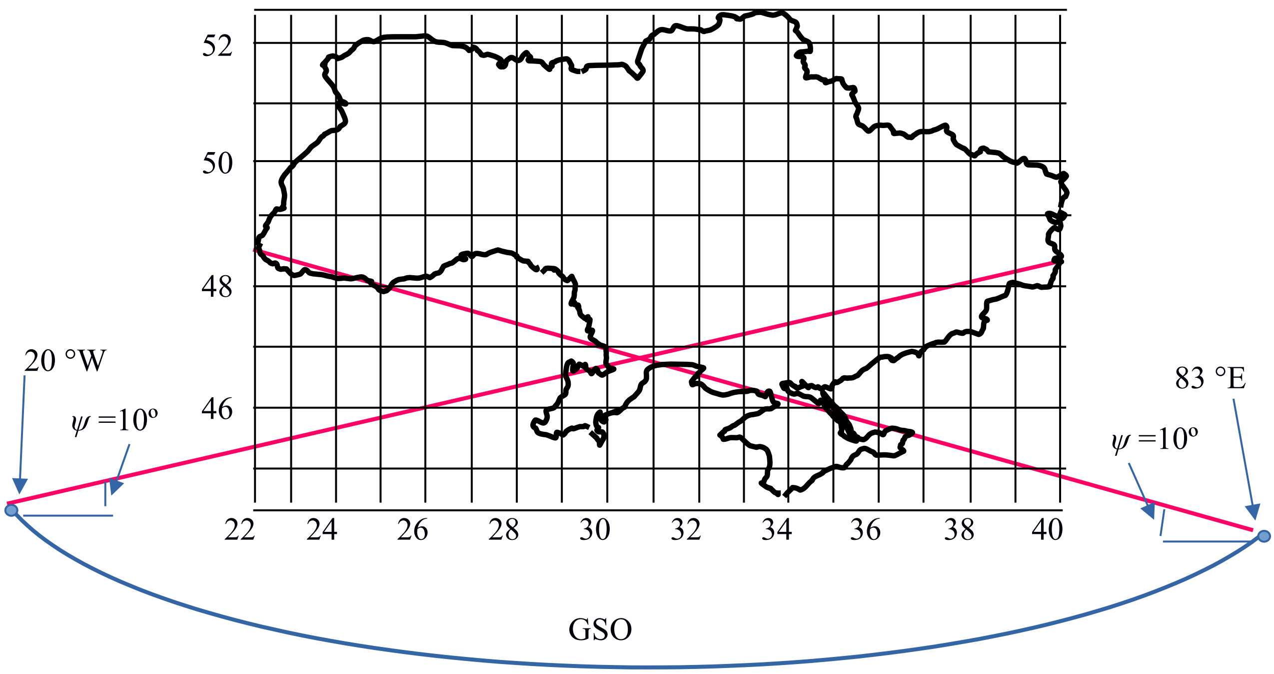

Figure 12 — To determining the arc of the spacecraft location on the GSO

Secondly, the coverage area of the satellites should include the entire territory of Ukraine, excluding perhaps some areas, and, thirdly, the payload parameters, first of all, the level of equivalent isotropic radiated power (EIRP), should provide the services of the specified quality.

The distribution diagrams of equivalent isotropic radiated power, emitted to the territory of Ukraine, (maximum and minimum value) by satellites by the positions of spacecraft on in the GSO are shown in Figures 13 (C range) and 14 (Ku range) for satellites "visible" from the territory of Ukraine at an location angle $\psi > 10^{\circ}$. In the diagrams show the minimum (blue) and maximum (red color) levels of the EIRP provided by satellites covering the entire territory of the country.

The names of satellites that are “visible” at an angle $\psi > 10^{\circ}$, the designations of the beams covering the territory of Ukraine, and the EIRP levels are shown in Table 4. Spacecraft are added to it, providing coverage of 80 % — 90 % of the country's territory:

– Astra 1L – except for the east (Donetsk, Lugansk, Kharkov regions);

– Astra 1N – except for the east (Donetsk, Lugansk regions);

– Astra 2G – except for the southeast (Donetsk, Lugansk, Zaporizhzhya regions).

The life of the satellite is shown in column 7 of Table 4.

Data on satellites with a similar coverage in the Ka band are given in Table 5.

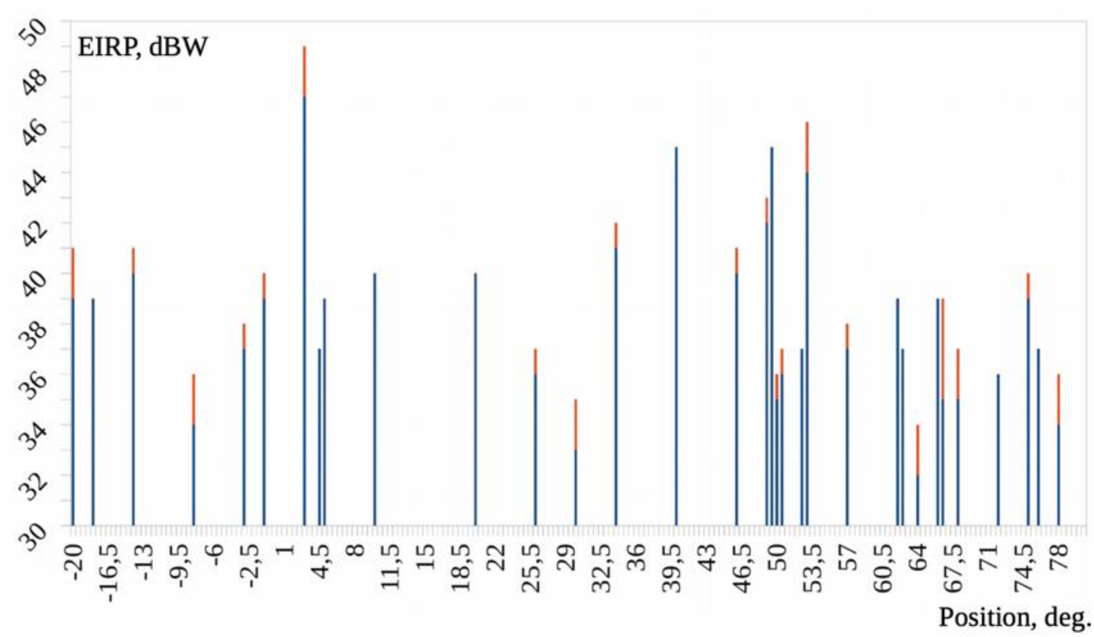

Figure 13 – Distribution of spacecraft EIRP by positions on GSO (range C)

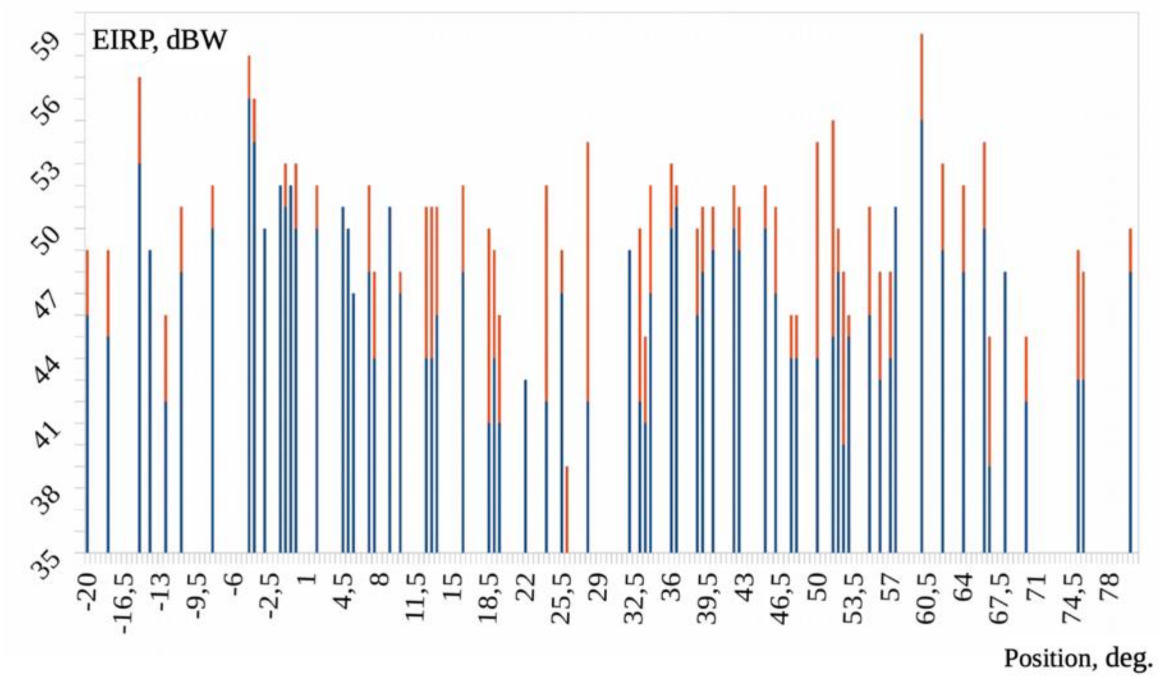

Figure 14 – Distribution of spacecraft EIRP by positions on GSO (range Ku)

Table 4 – List of telecommunication SC with full coverage of the territory of Ukraine

Position	SC	C		Ku		Life. years
		Beam	EIRP. dBW	Beam	EIRP. dBW	
20°W	NSS 7	East Hemi	38–39	Europe ME	46–49	> 15
		SE Zone	39–41			
18.0°W	Intelsat 37E	Africa Europe	39.3	Spot 02	31–47	< 5
				Spot 05	45–49	
				Spot 06	41–49	
				Spot 27	41–49	
15.0°W	Telstar 12 V			Europe ME	50–51	< 5
				Euro Spot 4	53–57	
14.0°W	Express AM8	Africa Europe	39.5–40.5	Europe ME	48.4–49.4	< 5
12.5°W	Eutelsat 12 WB			Europe	44–50	> 15
11.0°W	Express AM44			Europe	48–51	5–10
8.0°W	Eutelsat 8 WB	Global	34–36	Europe	50–52	< 5
5.0°W	Eutelsat 5 WA	Pan Atlantic	39	Wide	47	> 15
4.0ºW	Amos 3			EUH 3	56–58	10–15
				EUV 3	50–56	
4.0ºW	Amos 7			CEE	55–57	5–10
				Pan European	54–55	
3.0°W	ABS 3A	East Hemi	37–38	Europe	50	< 5
		Global	35			
0.8°W	Intelsat 1002	East Hemi	38–39	Spot 1	49.7–52.7	10 -– 15
		East Zone	38.5–39.5	Spot 3	45.7–52.7	
		NE Zone	38.5–39.5			
0.8°W	Thor 5			T2	52	10–15
0.8°W	Thor 6			K2	50.7–52.7	5–10
0.8°W	Thor 7			CEE	52	< 5
1.9°E	Bulgariasat 1			Europe	50–52	< 5
3.0°E	Eutelsat 3B	Global	37	Europe	47–49	< 5
4.9°E	Astra 4A			Europe BSS	50	10–15
				Europe FSS	46 –47	
4.9°E	SES 5	Global	33–34			5–10
		WH	37–38			
7.0°E	Eutelsat 7A			Europe A	46–48	5–10
				Europe B	48–51	
				Europe C	48–52	
7.0°E	Eutelsat 7B			Europe A	48	5–10
				Europe C	48–52	
7.0°E	Eutelsat 7C			West	50.5–51.5	< 5
9.0°E	Eutelsat 9B			Nordic Baltic	50–51	< 5
				Wide	48.5–50.5	
10.0°E	Eutelsat 10A	Global	40	Europe	47–48	5–10
13.0°E	Eutelsat HB 13B			Europe	44–51	10–15
13.0°E	Eutelsat HB 13C			Europe	44–51	10–15

Continuation of Table 4

Position	SC	C		Ku		Life, years
		Beam	EIRP, dBW	Beam	EIRP, dBW	
13.0°E	Eutelsat HB 13E			Wide	46–51	10–15
16.0°E	Eutelsat 16A			Europe A	47–49	5–10
				Europe B	48–50	
				Europe C	48–52	
19.2°E	Astra 1L			1LFSS	41–50	10–15
19.2°E	Astra 1M			1MEurope	46.8–50	10–15
				1MWide	44–50	
19.2°E	Astra 1N			PE	44–50	5–10
20.0°E	Arabsat 5C	Extended	38–40			5–10
		Wide	40			
21.5°E	Eutelsat 21B			Wide	46–47	5–10
23.5°E	Astra 3B			Pan European	42–52	5–10
25.8°E	Badr 6	High 6	39–41			10–15
		Medium 6	37–38			
25.8°E	Es`hail 1			East	40–44	< 5
28.2°E	Astra 2G			Europe	42–54	< 5
30.5°E	Arabsat 5A					5–10
31.5°E	Astra 5B	App30B	35–37	CEE	53	< 5
		MEA	35–37	Wide BSS	51	
33.0°E	Eutelsat 33C			Fixed	42–50	< 15
33.0°E	Eutelsat 33E			Wide	41–45	5–10
36.0°E	Express AMU1			Russia	50–53	< 5
36.0°E	Eutelsat 36B			Eurasia	46–47	5–10
				Russia	52	
39.0°E	HellasSat 3			Europe	45–49	< 5
				ME	48–51	
39.0°E	HellasSat 4			Europe BSS	48–54	< 5
40.0°E	Express AM7	Fixed	45			< 5
42.0°E	Turksat 3A			East 3A	45–47	10–15
				West 3A	50–52	
42.0°E	Turksat 4A			East BSS	37–50	< 5
				Europe	40–49	
				West BSS	49–51	
45.0°E	Galaxy 11			Europe NA	46.7–48.7	> 15
45.0°E	AzerSpace 2			EA	50–52	< 5
45.1°E	Intelsat 904	West Hemi	38.5			> 15
46.0°E	AzerSpace 1	AsiaEurope	40.1–41.1	Europe	46.8–50.8	5–10
47.5°E	Intelsat 10			Europe Stans	44.1–46.1	> 15
48.0°E	Afghansat 1			Steerable	44–46	10–15
49.0°E	Yamal 202	C	42–42.5			> 15
49.0°	Yamal 601	C	45			< 5

End of Table 4

Position	SC	C		Ku		Life, years
		Beam	EIRP, dBW	Beam	EIRP, dBW	
50.0°E	Turksat 4B	Africa	35–35.5	Eastern	41–50	< 5
				Turkey	44–54	
				Western	50–52	
50.5°E	NSS 5	East Hemi	33–35			> 15
		Nord East	35			
51.2°E	Belintersat 1	Global	36	Europe	45–55	< 5
52.0°E	TurkmenAlem52			West	48–50	< 5
52.5°E	Al Yah 1	Global	37	Europe	42–46	5–10
52.7°E	Astra 1G			Europe	51	> 15
53.0°E	Express AM6	F1	44–46	FK2	48–49	< 5
		F2	38.6–39.6			
		Global	33.3			
54.9°E	Yamal 402			Northern	45.8–50.8	5–10
56.0°E	Express AT1			Wide	48–53	< 5
57.0°E	NSS 12	Global	33	Middle East	44–48	5–10
		West Hemi	39–40			
60.0°E	Intelsat 33E	CGRD	33.3	U33	55–59	< 5
				Eurasian	43	
				U29	49.6–55.6	
62.0°E	Intelsat 902	Global	31	Spot 2	49–53	> 15
		West Hemi	38.7			
62.2°E	Intelsat 26	Landmass	37			> 15
64.0°E	Intelsat 12			Europe	48–52	> 15
64.2°E	Intelsat 906	Global	31			> 15
		West Hemi	37.8–39.8			
66.0°E	Intelsat 17	Global	34.6	Russia	50.5–53.5	5–10
		LMCH	36.2	Europe ME	41.6–49.6	
		WHCL	39.2			
66.2°E	Intelsat 9	C Africa	34.8–38.8	Africa China	30–34.6	> 15
68.5°E	Intelsat 20	Landmass	35.1–37.1	EU Africa	44.8–45.8	5–10
				EU MECA	46–48	
				Russia	50.1	
70.5°E	Eutelsat 70 B			Wide	42–45	5–10
72.1°E	Intelsat 22	WH	35.8			5–10
75.0°E	ABS 2	WH	39–40	MEHA	43–49	< 5
		Global	34–35			
75.0°E	ABS 2A			Russia	47–52	< 5
76.5°E	Apstar 7	Global	37			5–10
78.5°E	Thaicom 5	Global	34–36			10–15
80.1°E	Express AM22			Wide Europe	48–50	> 15

Table 5 – List of telecommunication KAs with full coverage of the territory of Ukraine (Ka range)

Position	SC	Beam	EIRP, dBW	Life, years
7.0°E	Eutelsat 7A	Europe C	48–52	5–10
7.0°E	Eutelsat 7B	Europe C	48–52	5–10
9.0°E	Eutelsat Kasat 9A	59 – 61. 66 – 69. 73	55 – 61	5–10
39.0°E	Turksat 4A	KaEurope	40–49	< 5
60.0°E	Intelsat 33E	Global	37	< 5
65.0°E	Amos 4	Russia (Ka)	47–50	5–10
62.6°E	Inmarsat 5F1	19, 27, 28	62–66	< 5
68.5°E	Intelsat 20	KLDL	31.3–36.3	5–10

In total, services for users located in Ukraine can be provided (tables 4, 5):

- in range C – 35 spacecrafts,
- in Ku range – 68 spacecrafts,
- in range Ka – 8 spacecrafts.

Note: Considering the prospect of using the Ka band, we note that in this frequency band from 30 % to 70 % of the territory of Ukraine are covered by Express AM6, ABS 2, Thor 7, Astra 4A, Express AMU1.

Thus, there is ample opportunity to choose a satellite to build a satellite segment of national information infrastructure. Among the 83 spacecrafts given in tables 4 and 5:

- 16 satellites have worked out their guaranteed lifetime, their resources are practically unused;
- 27 SC withdrawn from GSO less than 5 years ago;
- 24 satellites have already worked out 2/3 of the warranty period

The provision of services to users in Ukraine is provided by:

- in the range C – 52 beams,
- in the Ku range – 94 beams,
- in the Ka band, the set of beams (multi-zone coverage) two satellites and one beam of six KA. The possibilities of using Intelsat 33E, Intelsat 20 satellites are limited by low channel energy.

The maximum elevation angle is provided by a satellite whose position on the GSO coincides with the longitude of the center of Ukraine (31.2º E) and, according to (1), lies in the range from 30.0 º (for the north of the country) to 39.0º (for the south of the country).

As for the “free space” on the GSO for a hypothetical CHOR, then within the GSO arc from 20 ºW to 83 ºE. There are 20 positions in which the nearest spacecraft are at a distance of 1 ° from each other, and 5 positions with an angular interval of 2 º (see Figure 8). Note that it is more appropriate to choose the position of the spacecraft on the GSO, which provides a greater elevation angle and, accordingly, a shorter distance to the satellite.

To increase the value ψ, the position for the national spacecraft should be selected within the GSO arc corresponding to the coordinates of the end points in the territory of Ukraine (22.2º E, 40.2 E), and there are only 3 vacancies there. The elevation angle of earth stations for SC on such an are arc is within $28^o < \psi < 30^o$ (1).

Given the significant number of spacecraft (more than 100), on the basis of which it is possible to build a satellite segment of a research institute, we introduce several restrictions:

- exclude from consideration of the satellite, exceeding the guaranteed service life or a period close to it (more than 10 years);

− to increase the elevation angle, we choose the position of the spacecraft within the arc (10º east - 50º east), which differs by about 10º from the coordinates of the extreme points of the territory of Ukraine. According to (1), the elevation angle for them lies in the range 26º <ψ <39º

− we select satellites with EIRP levels: in the C band - EIRP ≥ 40 dBW, in the Ku band - EIRP ≥ 50 dBW.

Taking into account the restrictions introduced, in Table 6 given the spacecrafts recommended for the creation of a satellite segment of NII or other applications of satellite channels, and their main technical characteristics necessary for further calculations of the satellite network.

Table 6 – Spacecrafts recommended for the satellite segment of the NII

Location	Spacecraft	Beam	Frequency , GHz		Resource, MHz trunk/band	EIRP, dBW
			up	down		
10,0°E	Eutelsat 10A	Global	5.850–6.280	3.625–4.065	10/72	40
20,0°E	Arabsat 5C	Wide	5.925–6.406	3.740–4.200	4/72+16/36	40
40,0°E	Express AM7	Fixed	5.925–5.325	3.600–4.000	16/40	45
46,0°E	AzerSpace 1	AsiaEurope	5.925–6.425	3.700–4.200	12/36	40–41
49,0°E	Yamal 601	C	5.925–6.425	3.700–4.200	38/36	45
9,0°E	Eutelsat 9B	Nordic Baltic	17.690–18.100	12.090–12.500	9/33+1/49,5	50–51
16,0°E	Eutelsat 16A	Europe C	18.100–18.400	10.700–10.965	6/36	48–52
31,5°E	Astra 5B	CEE	17.300–18.100	11.700–12.500	20/33	53
36,0°E	Express AMU1	Russia	17.300–18.100	11.700–12.500	32/33	50–53
36,0°E	Eutelsat 36B	Russia		11.700–12.190	24/33	52
39,0°E	HellasSat 4*	Europe BSS	13.750–14.500	11.700–12.500	44/36	48–54
42,0°E	Turksat 4A	West BSS	17.300–18.100	11.700–12.750	2/72+3/54+8/33	49–51
45,0°E	AzerSpace 2*	EA		11.700–12.500	35/36	50–52
46,0°E	AzerSpace 1	Europe	13.750–14.000	10.950–11.200	12/36	47–51
50,0°E	Turksat 4B	Western	14.000–14.500	10.95–11.20; 11.45–11.70	14/36+4/72	50–52
51,2°E	Belintersat 1*	Europe		11.70–12.50	14/36+4/54	45–55

* Parameter data needs clarification

The restrictions mentioned above are not optional. If you select from another Table 3 another spacecraft or satellite “visible” at a lower elevation angle ψ, information about the parameters of the satellite and its payload can be found on the sites:

– https://www.tbs-satellite.com;
– https://www.satbeams.com;
– https://www.lyngsat.com;
– https://frequencyplansatellites.altervista.org;
– https://space.skyrocket.de

and on the sites of satellite telecommunication systems operators.

CHOICE OF A SATELLITE ON EFFICIENCY PARAMETERS

Broadening the scope of broadcasting, the intensive introduction of new audiovisual services, the rapid development of the Internet, the introduction of other multiservice services - lead to a significant increase in the flow of information that must be transmitted through communication channels. The growing need for satellite channel frequency resources in the conditions of its limited and considerable cost necessitates the introduction of such technologies of digital streams and signals formation, which will allow without loss of quality to organize the transportation of information with lower channel speed, i.e. reduce the frequency resource requirements.

The efficiency of using any channel resource is determined by two parameters: β and γ [15]. The parameter γ indicates the degree of use of the channel frequency band (frequency efficiency) and is determined by the number of information bits transmitted by a single signal (bit/symbol). The parameter β characterizes the degree of signal power utilization and is determined by the ratio E_b/N_0 – ratio of the energy of the signal E_b consumed to transmit one bit of information to the spectral density of the noise power N_0, necessary to provide a predetermined error probability in the received digital stream.

Measures aimed at increasing the efficiency of using satellite channel resources in the construction of satellite information systems are divided into three main areas:

− the use of information compression methods that allow the same amount of information to be transmitted at a lower speed without compromising its quality;

− the choice of the format of signal-code structures for transmission of the digital stream with the maximum possible speed for the communication channel of the specified energy without loss of quality;

− the application of effective network organization principles and multi-station access methods.

The first of these areas relates primarily to broadcast systems and is implemented by using efficient algorithms for compressing audio-video information generated in the form of a digital stream. However, redundancy elimination related to the procedure of forming digital streams, and the task of satellite telecommunication systems is the delivering them to the consumer, but the compression procedure applied imposes requirements on the characteristics of the transmission channel, for example, when using the algorithm of the MPEG family, it is necessary to ensure the error probability in the received digital stream is not worse than $P_o = 10^{-11}$.

In satellite channels of fixed communication (FSS), the CCM format, the probability of errors in the channel are not regulated by any documents. Channel requirements, type of modulation, code parameters are determined by the user and the capabilities of the equipment that he uses. Limitations are associated only with the technological aspects of the implementation of a certain algorithm and the capabilities of the satellite channel (limited frequency band, low power). CCMs are based on the signals FM-4, FM-8, less often KAM 16 (see Figure 15) and a cascade connection of the correction Reed-Solomon code (RS) and a convolutional code (CC) of variable speed. The relative code rate of the convolutional code is set by perforation of the basic code with the velocity R = 1/2, but in principle its smooth (programmable) adjustment in a certain range is possible.

Unlike other services, the signal-code structures parameters of satellite broadcasting systems are regulated by international standards. Mainly use (more than 90 % of channels) signal-code structures are formed according to DVB standards: DVB-S (ETSI EN 300 421 [16]), DVB-DSNG (ETSI EN 301 210 [17]), DVB-S2 (ETSI EN 302 307-1 [18]), DVB-S2X (ETSI EN 302 307-2 [19]). Standards determine the type of signal, the parameters of the codes from that the efficiency of the channel's resources depends. Signal-code structures DVB are focused on using compression algorithms and meeting their error probability requirements ($P_o \leq 10^{-11}$), but this does not limit the ability to use them in other services for which, for example, 10^{-6} is sufficient.

If the use of multi-position signals in signal-code structures improves frequency efficiency with some reduction of energy efficiency, the use of corrective (noise-resistant) codes allows not only to compensate for this decrease in energy efficiency, but also to obtain a significant gain in energy. The correlation between the performance parameters for different signal and code combinations, including those described in [18 – 20], is shown in Figure 16. The graphs are based on the simulation results given in [22].

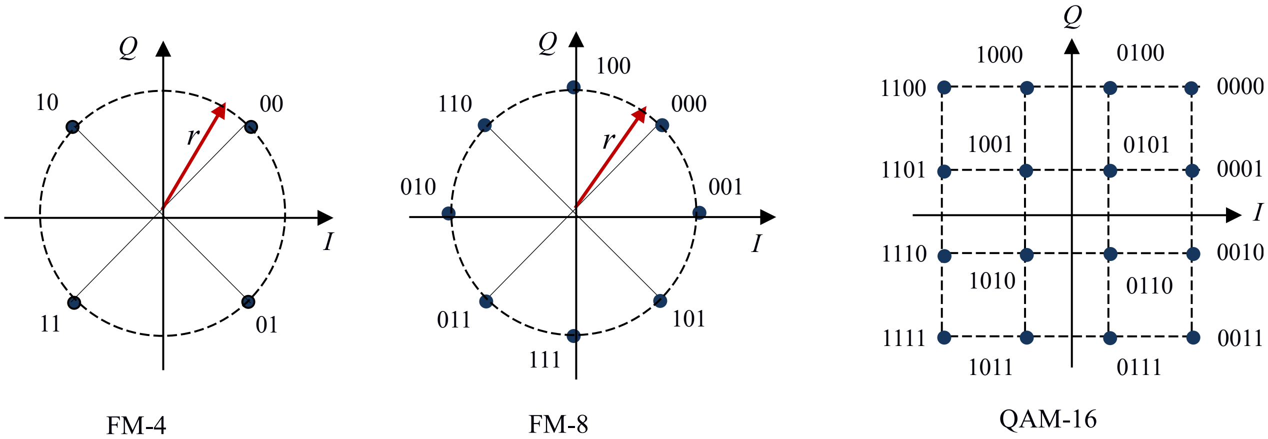

Figure 15 – DVB Signals (DVB-S, DVB-DSNG)

From the comparison of the graphs it follows that in the same channel, at a fixed signal-to-noise ratio, the use of the DVB-S2 standard in the same band of the repeater trunk allows to transmit the information flow at about 1.3 – 1.4 times higher speed, or at the same bit rate reduce as same times the frequency band.

With fixed frequency efficiency using a system built on the DVB-S2 standard provides the necessary accuracy of reception at signal to noise ratio of 2.0 dB–4.0 dB less. This allows the transmitter power to be reduced by almost 1.6–2.5 times, which is of great importance, especially for the repeater satellite equipment, or to reduce the antenna aperture size accordingly.

The use of low-speed codes in combination with FM-4 signals allow the reception of information of the required quality in a channel with a noise level exceeding the signal level by 2.4 dB.

The significant advantage of the DVB-S2 is not only for its more efficient signal-code structures, but also for its continuous input flow capability. When using DVB-S2, separate data transmission and voice information can have a more noticeable effect. DVB-S2 incorporates adaptive modulation coding. Depending on the channel situation (signal-to-noise ratio), the signal type and code rates may vary during operation.

It should be emphasized that the scope of DVB standards for the introduction of advanced telecommunications services should be taken much broader than the standard for digital television broadcasting, that is confirmed by a number of telecommunication technologies that use DVB technologies but are not related to broadcasting, such as DirecWay, MPLS, Satlynx, D-STAR and more.

The application of effective network organization principles is primarily concerned with the methods of forming coverage areas. Due to the use of a multi-beam antenna on spacecraft board, it is possible to apply the cellular principle of satellite network construction, which allows to reuse the allocated frequency spectrum, thereby increasing the frequency efficiency of the system. Examples of implementation of multi-zone coverage are given in [10], and a hypothetical variant of such coverage of the territory of Ukraine in [13].

The relationship between channel energy (E_S/N_0) and frequency efficiency γ is the basis for further calculations and the choice of satellite that will provide the desired type of services of the required quality.

Let the transmission is a digital stream of speed V_{st} (bit/s). The calculations for the broadcasting services will be considered separately based on their channel requirements.

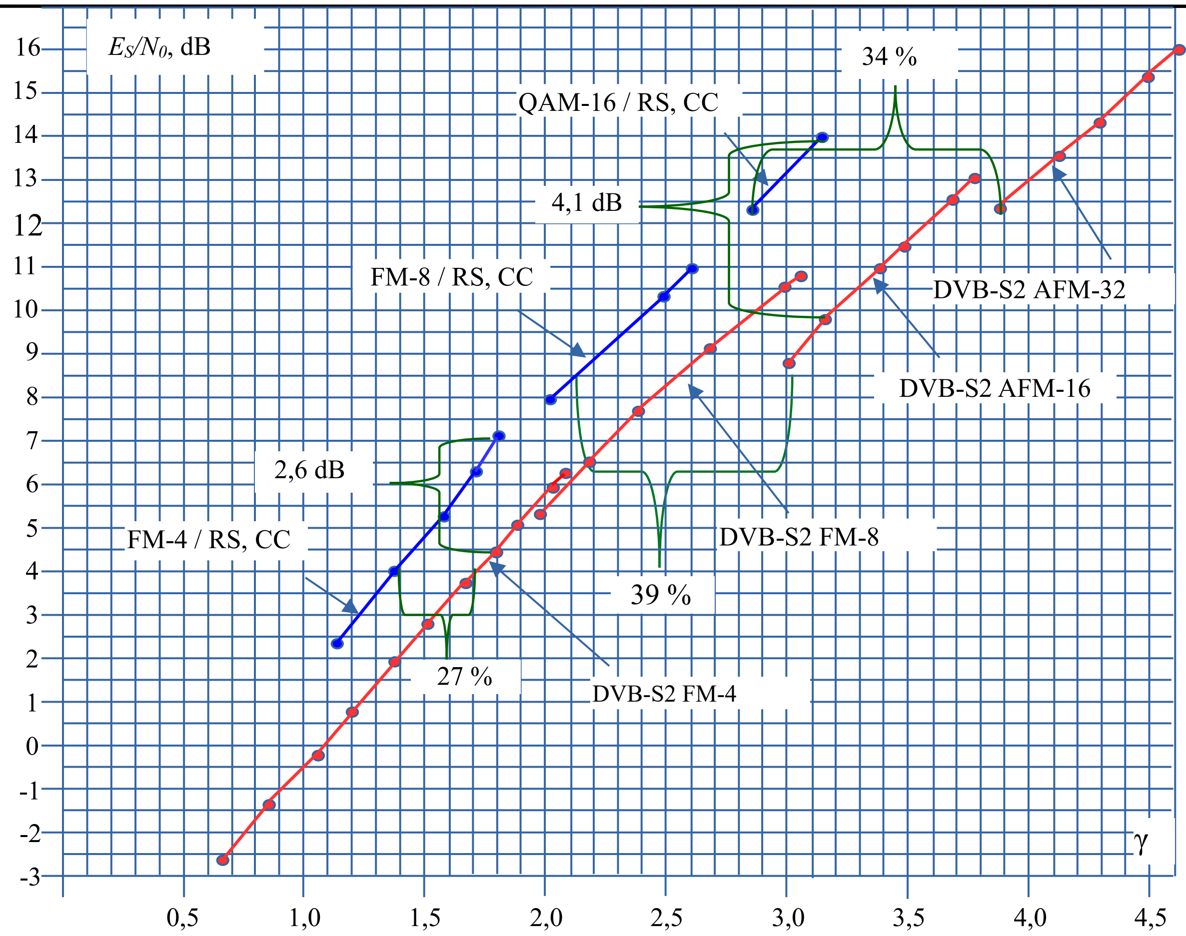

Figure 16 – Efficiency of signal-code structures of FSS channels

The V_{ch} (Baud or symbols/s) channel velocity required for transmitting the bitrates V_{st} is defined as [15]:

$$V_{ch} = V_{st} \times \gamma \qquad (3)$$

The frequency band F_s, occupied by the signal (modulator output) and which determines the frequency resource of the satellite channel required to transmit the digital stream:

$$F_s = V_{ch} \times (1+\alpha), \qquad (4)$$

where α is the decay coefficient of the amplitude-frequency response of the channel filter. For satellite channels, the value α is fixed α = 0.35. Depending on the type of service, α for channels based on signal-code structures of DVB-S2 standards [18, 19] can be selected from the following values: 0.35; 0.25; 0.2.

It is important to focus on signal-code structure, which has a highest frequency efficiency, which will save the expensive bandwidth of the channel, but its use depends on the energy of the channel (see Figure 16).

The input to calculate the signal-to-noise ratio (channel energy) is the location of the spacecraft on the GSO, the spacecraft parameters, some of which are listed in Table 6 or 4 (if applicable).

Signal input power of the demodulator of the receiving part of the earth station [14, 15]:

$$P_s = P_{rec} = P_{tr} \times G_{tr} \times \eta_{tr} \times G_{rec} \div \eta_{rec} / L, \qquad (5)$$

where P_{tr} is the signal output power of the transmitter;

$P_s = P_{rec}$ – power of the received signal;

G_{tr}, G_{rec} — the gain coefficients of the transmitter on-board and receive (earth station) antennas, respectively;

η_{tr}, η_{rec} — the transmission coefficients of the antenna feeder path of the transmitter and receiver, respectively. Since the power amplifier on board the satellite and the low noise converter or amplifier in the receiving path are located directly near the antennas, we assume $\eta_{tr} = \eta_{rec} = 1$;

L – attenuation (loss) of the signal on the satellite-Earth route.

Signal to Noise Ratio E_s/N_0 (Figure 16):

$$\frac{E_s}{N_0} = \frac{E_s \times T \times F_s}{N_0 \times T \times F_s} = \frac{P_s \times T \times F_s}{N_0 \times F_s} = \frac{P_s \times (1+\alpha)}{N_0 \times F_s} \tag{6}$$

By definition

$$EIRP = P_{tr} \times G_{tr} \tag{7}$$

$$P_n = N_0 \times F_s \tag{8}$$

Since noise in satellite channels is additive, their power can be determined by the formula 5.22 [14]

$$P_n = k \times T_n \times F_n , \tag{9}$$

where $k = 1{,}38 \times 10^{-23}$ W/Hz×deg – Boltzmann constant;

T_n – equivalent noise temperature of the entire receiving system, taking into account internal and external noises;

$F_n = F_s$ – equivalent (noise) band of the receive.

After substitution (5), (7), (8), (9) in (6)

$$\frac{E_s}{N_0} = \frac{EIRP \times G_{rec} \times (1+\alpha)}{k \times T_n \times F_s} . \tag{10}$$

Signal path losses on the propagation path (space-Earth) consist of losses: in free space L_o and additional losses L_d.

$$L = L_0 \times L_d \tag{11}$$

The level of signal attenuation Lo, in free space on the space-to-Earth (line down) or Earth-to-space (line up) path is calculated by the formula (10) [14]:

$$L_o = 20 \times \log(4 \times \pi \times d/\lambda), \tag{12}$$

where $\lambda = c/f$ is the wavelength;

$c = 3 \cdot 10^8$ м/с – velocity of propagation of electromagnetic waves;

d – distance to the satellite,

f – the frequency at which the signal is transmitted.

In the same coordinate system (Figure 11) from formula (2), the distance d from the ES to the satellite (oblique range) is equal to:

$$d = \frac{1}{\sin\psi}\left(H \times \cos(\upsilon_ш) \times \cos(\varphi_c - \upsilon_д) - R\right) \tag{13}$$

In addition to attenuation in free space, the signal is further attenuated for the following reasons:

- absorption of signal energy in the troposphere, namely in oxygen and water vapor;
- losses in the atmosphere due to rain and other precipitation;
- refraction losses and inaccuracies in antenna direction;
- losses due to mismatch antenna polarization;
- depolarization of radio waves in the atmosphere;
- influence of atmospheric noises, radiation of planets, other systems, etc.

The largest contribution to the additional losses in the Ku range is due to atmospheric absorption and signal attenuation in hydrometeors. These losses depend, first of all, on the frequency, the angle of the earth station location and the statistical parameters of precipitation at the earth station location.

The procedures defined in [14] and [21] can be used to calculate signal energy losses in oxygen and water vapor and in the troposphere in general. In the worst case, when operating in the Ku range, at an location angle of 10º, they do not exceed 0.4 dB.

The methodology for determining additional losses in precipitation is discussed in [22]. For the climatic zone to which Ukraine enters, under the conditions of operation defined above, with a given channel availability of 99.95 %, the rainfall intensity does not exceed 15 mm/h practically regardless of the rainfall zoning of Europe. In this case, the additional losses (within the territory of Ukraine) will not exceed 5 dB.

If the ratio E_S/N_0 calculated according to (10) does not correspond to the value required by the dependencies in Figure 16 to achieve the plotted value γ, then either a higher gain antenna or a frequency efficiency requirement should be used.

PAYLOAD

In the case of targeting on the satellite segment based on the national satellite, the task of selecting the payload of the spacecraft becomes the next after receiving the frequency orbital resource. The total payload depends on the frequency orbital resource and is determined by the parameters and the number of transponders. of the GSOs, including those intended for reservation.

As already stated above from the point of view of providing telecommunication services the most important, defining resource of satellite channels, indicators are:

– channel energy or power that can be used to transmit information;
– frequency resource or frequency band of the trunks, which affects on the amount of information transmitted through the communication channel.

Procedures for calculating these figures is given in the previous section. The frequency orbital resource and the results of calculations based on it determine the payload requirements of the spacecraft, in other words to the satellite telecommunication platform.

There are two possible directions for further work:

– development of the platform on its own and its manufacture;
– ordering the platform from third-party vendors or using already developed developments.

Own platforms were developed and used by: Argentina (ArSat), India (IK), Israel (Amos), China (DFH), Russia (Express, MSS), Japan (DS) and Turkey (TAI). For Ukraine, this path has no prospects for implementation for at least two reasons:

– the lack of technical capabilities,
– long term of development in case of emergence of technical capabilities.

For the national satellite (the hope is that it will still remain) the platform should be ordered. For these reasons, Table 7 lists the platforms installed on active spacecrafts, the concise characteristics of the platforms, and their manufacturers.

Table 7 – Application platforms

Platforms	Modifications	Number	Manufacturer	State
A 2100	A, AX, AXS	30	Lockheed Martin	USA
LM2100		2		
AS 4000		4		
AS 7000		2		
Amos	HP	2	Israel Aerospace Industries	Israel
ARSat		2	Invap	Argentina
BSS 376	HP	3	Boeing Space Systems	USA
BSS 601	HP	20		
BSS 702	SP, HP, MP, GEM	35		
DFH-3 Bus	B	1	China Academy of Space Technology	China
DFH-4 Bus	S, E	14		
DS 2000		6	Mitsubishi Electric of Japan	Japan
ES 2000	+	5	EADS Astrium	France, Germany
ES 3000	S, EOR, GM,HL	45		
Alphabus		1		
AstroBus-G		1		
Express 1000	K, NTB, NTA	5	ISS Reshetnev	Russia
Express 2000		3		
GEOStar 2	2.3, 2.4	32	Orbital Science Corp.	USA
GEOStar 3		2		
I-1K		1	Indian Space Research Organization	India
I-2K		6		
I-3K		11		
I-6K		1		
Luxor bus		2	OHB System	Germany
MSS 2500		5	NPO Prikladnoi Mekhaniki	Russia
SB 3000	A, B2, B3, C2	11	Thales Alenia Space	France, Italy
SB 4000	B2, B3, C1, C2, C3, C4	26		
Italsat bus		1		
Alphabus		1		
SSL 1300	LL, S, SL, X, HL	91	Space System Loral	USA
USP		1	RSC Energia	Russia
Yachta		1	Krunichev Center	Russia

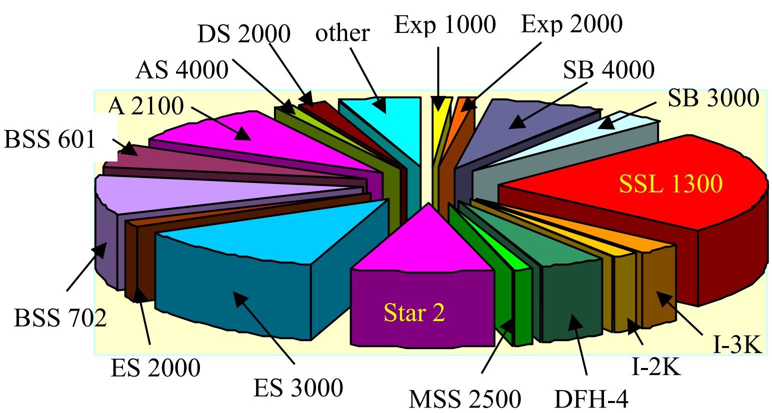

Figure 17 – Types of platforms used

The 34 main types of platforms are used. Given the modifications, the number of different types of platforms increases to 62. Modifications are indicated in column 2 of Table 7 in addition to the name of the base platform, for example AXS appendix A 2100 corresponds to modification A 2100AXS. The distribution of platforms by their frequency of use in active spacecrafts, including those for which the warranty period has expired to mid-2019, is illustrated in Figure 17.

The design and production of platforms is focused in 17 firms, with 59,4 % of the platforms manufactured in the US, in Europe – 28,8 %. the rest are in India, China, Japan, Israel, Argentina. Turkey is building a national satellite Turksat 6A (launch in 2020) on its own TAI platform (20 transponders of Ku band)

Platforms:

– LS1300, A2100, BSS702, ES3000, SB4000 – are the basis of super heavy spacecrafts;

– LS1300, A2100, BSS702, ES3000, SB4000, SB3000, GeoStar 3, Ekspress 2000 – heavy spacecrafts;

– GeoStar 2, DS2000, BSS601, I-3K, I-6K, DFH-4, Ekspress 1000, ES2000, Luxor bus, MSS2500 – medium spacecrafts;

– AstroBus-G, I 2K, I 1K, Star 1, DFH-3, SB2000, Amos, ArSat, Yachta, USP – small spacecrafts.

Table 8 provides some information on the platforms of active satellites as of September 2019, which may be useful in the process of designing a currently hypothetical Ukrainian spacecraft. They also provide data on the reliability of these platforms, as the ratio of the number of platforms that have failed in part or completely in the operation to the total number of platforms produced and put into orbit.

Table 8 – Platform Resources

Platform	Power supply, W	Trunk power, Вт			ЧР [1)]	Number		Reliability
		C	Ku	Ka		Launches	Foils [2)]	
A2100	≤ 13000	20 - 85	40 - 150	80 - 200	≤ 140	45	3	93,3 %
Amos	≤ 3000		≤ 95	≤ 105	≤ 40	4	0	
ArSat	≤ 3500				≤ 45	2	0	
BSS376	≤ 1600	≤ 40				58	2	96,6 %
BSS601	≤ 10000	≤ 65	≤ 140	≤ 100	≤ 60	60	18	70,0 %
BSS702	≤ 18000	≤ 65	≤ 140	≤ 100	≤ 400	44	6	86,4 %
DFH4 Bus	≤ 10500				≤ 60	21	2	90,50 %
DS2000	≤ 11800				≤ 75	12	0	
ES2000	≤ 7000	40 - 80	90 - 135		≤ 60	23	0	
ES3000	≤ 19000	≤ 80	≤ 150		≤ 280	50	0	
EX1000	≤ 5900	≤ 110	≤ 140		≤ 70	13	0	
EX2000	≤ 14200	≤ 80	≤ 150		≤ 130	7	0	
I-2K	≤ 4700		≤ 140		≤ 30	26	1	96,2 %
I-3K	≤ 7000	≤ 35	≤ 140		≤ 50	15	0	
MSS2500	≤ 6000	≤ 100	≤ 150		≤ 40	14	1	92,3 %
SB3000	≤ 10500	≤ 90	≤ 150	≤ 120	≤ 80	24	2	91,7 %
SB4000	≤ 15500	≤ 120	≤ 150		≤ 140	36	2	94,4 %
SSL1300	≤ 20000	≤ 100	≤ 210	≤ 200	≤ 600	131	9	93,1 %
Star 2	≤ 6700	≤ 65	≤ 150		≤ 80	34	2	94,2 %
Star 3	≤ 8000			≤ 140	≤ 140	3	0	
Yakhta	≤ 4600		≤ 90		≤ 30	1	0	

[1)] number of equivalent trunks
[2)] excluding accidents at startup of spacecrafts

CONCLUSIONS AND RECOMMENDATIONS

There are three possible options for building a satellite segment of a national telecommunications network based on:

- the national satellite telecommunication systems;
- sharing of spacecraft resources of another operator (lease);
- parts of the resources of different spacecrafts.

As of September 2019, the GSO had 372 active civilian spacecrafts, 84 satellite telecommunication systems of 64 operators registered in 44 countries. About 20 % of spacecrafts have already worked out a guaranteed lifetime; their resources are not being used and are in reserve. 30 spacecrafts are involved in the mobile satellite service.

There is a growing trend towards increasing the number of geostationary satellites for civilian use. Compared to 2008, the increase is 1.4 times.

Over the last 10 years, 17 new operators of Satellite Telecommunication System have emerged, three of which lease resources from other satellite systems.

Total frequency resources of systems have increased 2.3 times over the past 10 years to the 828 GHz band. The portion of the C band is 21.6 %, the Ku band is 52.5 %, and the Ka band is 25.3 %.

In the case of orientation to the leasing of spacecraft resources, it is recommended to select the satellite in the following sequence:

- position on the GSO: the location angle for a user located in the territory of Ukraine should be at least 10º. If possible, the location angle should be selected within an arc that differs by approximately 10º from the coordinates of the extreme points of the territory of Ukraine, with the location angle: $26^o < \psi < 39^o$;
- coverage area: territory of Ukraine;
- term of work on GSO up to 10 years;
- type of service (fixed satellite service , satellite broadcasting service , mobile satellite service);
- frequency band;
- channel energy (EIRP);
- frequency resource;
- efficiency of the laid (selected) signal-code structure;
- other parameters (by types of information).

The satellite should be selected provided that the selected angle of location is $\psi \geq 10^o$ among the spacecrafts in the arc of the GSO from 83º N to 20º N;

The coverage area should be at least 90 % of the country.

For $\psi \geq 10^o$ the first two positions of the selection sequence correspond to: in the C band – 35 spacecrafts, in the Ku band – 68 spacecrafts , in the Ka band – 8 spacecrafts.

It should focus on the use of: near-term Ku band; in the further Ka band; for needs the C band. The use of the Ka band has not yet been addressed due to the limited choice of the spacecrafts.

Whenever possible, the satellite should provide an EIRP level in the coverage area: in the C band EIRP ≥ 40 дБВт, in the Ku band EIRP ≥ 50 дБВт,

To the criteria defined above with $\psi \geq 25^o$ on arc from 50º W to 10º W correspond to: in the C band - 5 spacecrafts, in the Ku band - 11 spacecrafts.

To improve channel resource efficiency (energy, frequency band), it is recommended to use DVB-S2 signal-code structures or, where possible, DVB-S2X. The number of signal positions, the location of the signal points, the speed of the code should be selected according to the EIRP level or the signal-to-noise ratio derived therefrom at the point where the signal is received.

In case of orientation to the National Satellite Telecommunication System, the implementation of the Lybid project is not appropriate, its payback is doubtful. Available frequency orbital resource at position 48º W will have no demand both in coverage area and in technical characteristics.

Work should be started on obtaining a new frequency orbital resource with parameters (coverage area, EIRP, frequency band, etc.) that will compete with the existing satellite telecommunication systems. Given the rapid development of the Ka range and its benefits, especially with respect to the forming a multi-zone coverage, mast be provide a resource in the Ka band.

The position on the GSO should preferably be selected in an arc of 50ºE up to 10ºE preferably at a point free from other spacecrafts on the GSO.

The choice of the national satellite platform depends on the results of the frequency orbital resource coordination

The work on obtaining the frequency orbital resource must be aimed at building the National Satellite Telecommunication System with high efficiency of use of the resources contained in the spacecraft (on-board payload), which requires prior scientific and technical studies and appropriate justifications.

REFERENCES

1 Satellite communications. A4-0279/97. Resolution on the communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on the “EU Action Plan: Satellite communications in the Information Society” (COM(97)0091 – C4-0131/97).

2 Концепція створення та розвитку єдиної супутникової системи передачі інформації (ESSPI) // Постанова Кабінету Міністрів України № 1434 від 02.12.96 р.

3 Про Національну космічну програму України на 2003 - 2007 роки // Постанова ВР №203-IV від 24.10.02.

4 Про заходи щодо створення національної системи супутникового зв’язку // Постанова Кабінету Міністрів України від 3 травня 2007 р. № 696.

5 Мельник А.М. Сучасний рівень розвитку супутникових телекомунікаційних систем та їх впровадження в Україні / А.М. Мельник // Зв'язок. – 2001. – № 4.

6 Мельник А.М. Сучасний рівень розвитку супутникових телекомунікаційних систем та їх впровадження в Україні (продовження) / А.М. Мельник // Зв'язок. – 2001. – № 5.

7 Мельник А.М. Сучасний рівень розвитку супутникових телекомунікаційних систем та їх впровадження в Україні (закінчення) / А.М. Мельник // Зв'язок. – 2001. – № 6.

8 Мельник А.М. Супутникові телекомунікаційні технології у світі та в Україні / А.М. Мельник // Зв'язок. – 2009. – № 5 – 6.

9 Мельник А., В. Дзуін, І.Небосенко Аналітичний огляд стану та тенденцій розвитку супутникових телекомунікаційних систем /А. Мельник, В. Дзуін І. Небосенко // Медіасат. – 2015.

10 Ільченко М.Ю., Капштик С.В., Мельник А.М., Нарітник Т.М. Стан та перспективи використання та розвитку супутникових телекомунікацій у світі та Україні. Частина 2 /М.Ю. Ільченко, С.В. Капштик, А.М. Мельник, Нарітник Т.М. // Цифрові технології. – 2017. – № 21.

11 https://www.sia.org.

12 Мельник А., А. Богданов. Історія, ілюзії та реальність національної системи супутникового зв’язку /А. Мельник, А. Богданов // Медіасат. – 2014. – № 11 - 12

13 Ільченко М.Ю., Капштик С.В., Мельник А.М., Нарітник Т.М. Стан та перспективи використання та розвитку супутникових телекомунікацій у світі та Україні. Частина 3 /М.Ю. Ільченко, С.В. Капштик, А.М. Мельник, Нарітник Т.М. // Цифрові технології. – 2017. – № 22.

14 Спутниковая связь и вещание. /Под ред. Л. Дж. Кантора // Радио и связь. – М., 1997

15 Помехоустойчивость и эфективность систем передачи информации /Под ред. А. Г. Зюко// – М.: Радио и связь, 1985.

16 ETSI EN 300 421 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services.

17 ETSI EN 301 210 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite.

18 ETSI EN 302 307-1 Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 1: DVB-S2.

19 ETSI EN 302 307-2 Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 2: DVB-S2 Extensions (DVB-S2X)

20 A. Morello, V. Mignone DVB-S2: The Second Generation Standard for Satellite Broad-band Services // Proceedings of the IEEE, vol. 94, №. 1, January 2006.

21 Recommendation ITU-R P.676-5 Attenuation by atmospheric gases.

22 Recommendation ITU-R P.838-2 Specific attenuation model for rain for use in prediction methods.

REFERENCES

1 Satellite communications. A4-0279/97. Resolution on the communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on the "EU Action Plan: Satellite communications in the Information Society" (COM(97)0091 – C4-0131/97).

2 The Concept of Creation and Development of the Unified Satellite System for Information Transmission (ESSPI). Resolution of the Cabinet of Ministers of Ukraine No. 1434 of 02.12.96

3 Pro Natsionalnu kosmichnu programu Ukainy na 2003 - 2007 roky (On the National Space Program of Ukraine for 2003 – 2007). VR Resolution No. 203-IV of 24.10.02

4 Pro zachody schodo stvorennya nacionalnoi sistemi suputnikovogo zvyazku (On Measures to Establish a National Satellite Communications System). Resolution of the Cabinet of Ministers of Ukraine. No. 696 of May 3, 2007.

5 Melnik, A.M. "Suchasniy riven rozvitku suputnikovych telekomunikatsiynich sistem ta ich vprovadzhennya v Ukraini (Modern level of development of satellite telecommunication systems and their introduction in Ukraine)." *Zvyazok*. № 4, 2001.

6 Melnik, A.M. "Suchasniy riven rozvitku suputnikovych telekomunikatsiynich sistem ta ich vprovadzhennya v Ukraini (Modern level of development of satellite telecommunication systems and their introduction in Ukraine). (continued)" *Zvyazok* № 5 2001.

7 Melnik, A.M. "Suchasniy riven rozvitku suputnikovych telekomunikatsiynich sistem ta ich vprovadzhennya v Ukraini (Modern level of development of satellite telecommunication systems and their introduction in Ukraine). (ending)" *Zvyazok (*Communication) № 6 2001.

8 Melnik, A.M. "Suputnikovi telekomunikatsiyni technologii u sviti ta v Ukraini (Satellite Telecommunication Technologies in the World and in Ukraine)." Communication № 5-6, 2009.

9 Melnik, A., V. Dzuin, and I. Nebosenko "Analitichniy oglyad stanu ta tendenciy rozvitku suputnikovych telekomunikatsiynich sistem (Analytical review of the state and tendencies of development of satellite telecommunication systems)." *Mediasat.* 2015.

10 Ilchenko, M.Yu., S.V. Kapshtik, A.M. Melnik, and T.M. Naritnik. "Stan ta perspektivi vikoristannnya ta rozvitku suputnikovych telekomunikatsiy u sviti na Ukraini (Status and prospects of use and development of satellite telecommunications in the world and Ukraine). Part 2." *Digital Technologies*, No. 21 2017.

11 https://www.sia.org Acsessed 15.07.2019

12 Melnyk, A., and A. Bogdanov. " Istoriya, ilyuzii ta realnist nacionalnoi sistemi suputnikovogo zvyazku (History, Illusions and Reality of the National Satellite Communication System)." *Mediasat*, No. 11-12, 2014.

13 Ilchenko, M.Yu., S.V. Kapshtik, A.M. Melnik, and T.M. Naritnik. "Stan ta perspektivi vikoristannnya ta rozvitku suputnikovych telekomunikatsiy u sviti na Ukraini (Status and prospects of use and development of satellite telecommunications in the world and Ukraine). Part 3" *Digital Technologies*, No. 22, 2017.

14 *Satellite communication and broadcasting*. Edited by L.J. Cantor. M.: Radio and communication, 1997.

15 *Pomechoustoichivost i efektivnost sistem peredachi informacii (Immunity and Efficiency of Information Transfer Systems).* Ed. A.G. Zyuko. M.: Radio and Communication, 1985.

16 *ETSI EN 300 421 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services.*

17 *ETSI EN 301 210 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite.*

18 *ETSI EN 302 307-1 Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 1: DVB-S2.*

19 *ETSI EN 302 307-2 Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 2: DVB-S2 Extensions (DVB-S2X).*

20 Morello, A., and V. Mignone. "DVB-S2: The Second Generation Standard for Satellite Broad-band Services." *Proceedings of the IEEE*, vol. 94, №. 1, Jan. 2006.

21 *Recommendation ITU-R P.676-5 Attenuation by atmospheric gases.*

22 *Recommendation ITU-R P.838-2 Specific attenuation model for rain for use in prediction methods.*