Matters of satellite queuing network design in K_a-band for Republic of Kazakhstan

A Aitmagambetov[1]*, Yu Butuzov[2], S Torekhan[1]

[1] *International IT University, Department of Computer Technologies and Telecommunications, Manasa 34, 050040, Almaty, Kazakhstan*

[2] *Almaty University of Power Engineering and Communications, Baitursynov 126, Almaty, Kazakhstan*

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Abstract

This work was carried out within the framework of research opportunities of using K_a - band satellite communication systems in the Republic of Kazakhstan. The paper deals with the multi-beam coverage in Kazakhstan (the distribution of beams in area and determine their capacity), as well as evaluation of the main parameters of subscriber channels. The need for this research was due to the fact, that the design of multibeam network for Kazakhstan is important to consider a distinct uneven distribution of the population (or potential users), low average density (about 6 persons / sq km.) and a fairly significant differences rain intensity in some areas of the territory.

Keywords: satellite networks, K_a-Band, multi-beam antennas, bandwidth, signal-code constructions

1 Introduction

Recent years, the accelerated development of Ka-band as a global trend is observed in satellite communication. A considerable number of works devoted to the review of existing and planned satellite queuing systems [1-3], operating experience [4] and the results of research on the optimization of their parameters [5-7]. Before application of multi-beam technology the provision of broadband services to the mass consumer in Ka - band was considered less profitable because of the need for a super-cheap VSAT - terminals. With an advent of queuing systems, which are based on the technical application of multi-beam receiver and transmitter onboard antennas, the above mentioned problem has been solved.

The present work was carried out within the framework of research opportunities for application of Ka-band satellite communication systems in the Republic of Kazakhstan. The work is devoted to the study of multi-beam coverage in Kazakhstan (the distribution of the beams of the grounds and the determination of their capacity), as well as the evaluation of the main parameters of subscriber channels. The need for these studies is due to the fact that the design of multi-path network for Kazakhstan it is important to take into account the pronounced uneven distribution of the population (potential customers), lower average density (about 6 persons / sq km.) [8] and is quite a significant difference on the territory of the individual zones of intensity rain.

The most densely populated region, where 1 sq.km for about 20 people, is the South-Kazakhstan region, and the most sparsely populated region with a minimum density of 2.3 people per 1 sq. km. km - is Aktobe region.

Levels of rainfall intensity exceeding the 0.01% of the year duration change from 10 mm / h in the western and central regions of up to 30 mm / hour in the East Kazakhstan region [9].

When choosing a geostationary satellite orbital position 58.5 E stage by stage was taken into account the fact that Kazakhstan submitted to the ITU in the Ka-band for this position 3 applications [9] (the latter KAZSAT-1R with a priority date of 11.14.2012 and was valid until 30.03.2018).

2 Formation of the working area of the satellite

Among three options forming of working area and satellite distribution capacity in the beams considered in [5, p.1] for Kazakhstan (considering the uneven population density) is set equal distribution of the beams of the grounds and the uneven distribution of capacity in the beams.

In accordance with the documents of ITU and CEPT for projected satellite network, the frequency bands listed in Table 1 were selected.

TABLE 1 Frequency bands for Kazakh satellite

The transfer hub (CES)	The transfer ST
29.0 – 29.7 GHz	30.0 – 30.5 GHz
The reception hub (CES)	The reception ST
18.3 – 19.0 GHz	19.2 – 19.7 GHz

Note: The hub – central earth station (gateway); ST – subscribe (user) terminal.

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* Corresponding author - Tel: +7(701)-204-09-21
E-mail: altayzf@mail.ru

In Kazakhstan satellite repeater is supposed to apply separate receiving and transmitting multi-beam antennas (MBA), which will optimize the antenna maximum gain (MG), lower level of the side lobes (LSL) and reduce the cross-polarization radiation, and more precisely, sustain mutual consistency of the viewing zones at the reception and transmission. The distribution of the beams on the territory of the Republic of Kazakhstan is shown in Figure 1.

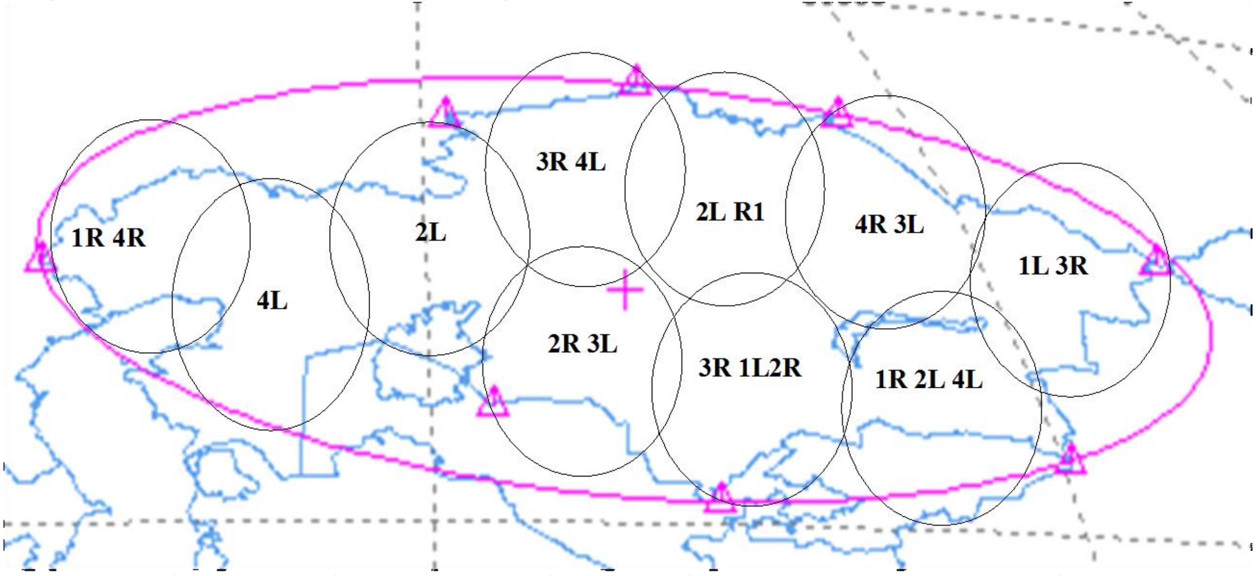

FIGURE 1 The uniform distribution of beams on the territory of the Republic of Kazakhstan and the unequal distribution of capacity in the beams

Working frequency range of 500 MHz, of the band 30,0-30,5 / 19,2-19,7 GHz, is divided not by 4 but 8 litters (125 MHz each) with polarization (circular - left L and right R). The integrated frequency resource will be 2500 MHz (2 beams to 1 Liter, 6 - 2 letters and 2 - to 3 letters). Ten beams with an angular size 0.75° were obtained.

3 Rating bandwidth

To assess the throughput (C) of the forward and reverse subscriber channels their energy potentials EP and the threshold ratio of received binary symbols energy E to the power spectral density of the noise - $N_o\ h_p^2$ were used [7, p.48]:

$$C = \frac{EP}{h_p^2} \ . \tag{1}$$

Since it was important to determine the throughput of channels not only in clear weather, but in the rain, the calculations of the attenuation of radiosignals with circular polarization in the rain (0.1 percent of time) for Ust-Kamenogorsk at frequencies 20 and 30 GHz were conducted, in accordance with the procedure of the ITU [11]. Let us consider the work area of the satellite uplink beams (reverse link), namely channel subscriber terminal (ST) – a satellite transponder (SR). The main characteristic of the receiving path of SR is the quality factor Q = G_{res} / T, where G_{res} = 27843 / θ ² = 27843 / 0.75² = 49498.7 (46.9 dB) - the gain of the receiving antenna of SR and T - noise temperature of the receiving path of SR which according to [7, p.118] can be taken as 1000 K (30 dBK). Thus, the work area will be characterized by quality factor Q = 46.9 - 30 = 16.9 dB / K. To estimate the throughput of the channel it is necessary to consider its energy budget (Table 2).

Let us define the throughput C of the channel, provided, that the probability of erroneous reception is not more than 10-7. Table 2 shows that in this channel at the same time frequency and energy resources are limited - output power of 1 W and bandwidth Δf = 125 MHz. Therefore, a joint performance of two inequalities is required:

$$C \le C1 = \frac{Pc}{\left(N_0 \times h_p^2\right)}, \qquad [7, p.117] \tag{2}$$

$$C2 = C \le \frac{\Delta fs \times m \times r}{\left(1+\alpha\right)}, \qquad [12, p.96] \tag{3}$$

where h_p^2 - threshold ratio of energy of received binary symbols E to noise power spectral density N_0; Δfs - bandwidth occupied by the transmitted signal; m - spectral efficiency modulation method; r – code relative velocity; α - rounding figure. When α = 0.25 formula (3) takes the form:

$$C \le C2 = 0.8 \times \Delta fs \times m \times r \ . \tag{4}$$

TABLE 2 Energy budget channel ST – SR

Parameters	Symbol	Value
Angular size of the beam, deg		**0.75**
Frequency range, GHz		30(Ka)
Output power of the ST, W		1
Diameter antenna of the ST, м		0.6
Gain of a transmitting antenna of the ST, dB		43.3
Signal losses on the transmission side, dB		1
E.I.R.P channel, dBW		42.3
Channel frequency band, MHz	Δf	125
Loss of the antenna pointing, dB		2.5
Free-space transmission loss, dB		213.8
Signal loss in the atmosphere gases, dB		0.4
Gain of a receiving antenna of the SR, dB		46.9
Noise temperature of a receiving path of the SR, K		1000
Transmission loss in rain (time percent 0.1), dB		7.9
Power of the desired signal at the receiver input of SR in clear weather, dBW	P_c	
Noise power spectral density, dBW/Hz	N_0	-127.5
Energy potential of a radio channel ST–SR, dBHz	EP	-198.6

Note: ST – subscribe (user) terminal, SR – satellite transponder

The throughput of the channel is equal to C = min (C1, C2). When C = C1 the throughput is determined by the energy capabilities of ST and the bandwidth is used partially. When C = C2 throughput of the channel is limited by frequency resource. Calculations show that with the initial data (Table 2) in clear weather, and when using signal-code structure (SCS) in the standard DVB-S2 [QPSK (m = 2), FEC (r = 9/10), α = 0.25, h_p^2 = 3.89 dB] throughput of reverse channel will be equal 5.26 Mbit / s. In this case, the required frequency resource in accordance with (4) will be 3.65 MHz. The resulting throughput value corresponds approximately to the project parameters of Inmarsat-5, where it is established maximum speed of 5 Mbit / s for the reverse channel having an antenna diameter of 0.6 m.

Table 2 shows that the signal loss in the rain (0.1 percent of time) amounts 7.9 dB. In such weather conditions, the channel throughput is significantly reduced (to a value of 853 kbit / s). Transition in the rain on a new option (QPSK, r = 1/4, α = 0.25, h_p^2 = 0.75 dB) will increase this value approximately twice (up to 1.76 Mbit / s). Usually the loading of reverse channel is relatively low, which makes it possible to use unclaimed reverse channel resource for organization of video surveillance systems [4, p.51-52].

Let us consider the work area of the satellite downlink beams, namely channel SR - ST. The initial data for calculation of energy potential of the radio channel are given in Table 3.

The calculations show that with the initial data (Table 3) in clear weather, and when using the SCS in DVB-S2 standard [8 -PSK (m = 3), FEC (r = 8/9), α = 0.25, h_p^2 = 6.46 dB] the throughput of forward channel will be 224 Mbit / s. Wherein the required frequency resource will be 105 MHz. Table 3 shows that the signal losses in the rain (0.1 percent of the time) amount 3.4 dB. In such weather conditions, the channel throughput is reduced to a value of 102 Mbit / s. Transition in the rain on a new option (8 - PSK, r = 3/5, α = 0.25, h_p^2 = 3.00 dB) could restore its original value of throughput.

TABLE 3 Energy budget channel SR – ST

Parameters	Symbol	Value
Angular size of the beam, deg		0.75
Frequency range, GHz		20(Ka)
E.I.R.P channel, dBW		60.16
Channel frequency band, MHz	Δf	125
Loss of the antenna pointing, dB		2
Free-space transmission loss, dB		210.2
Signal loss in the atmosphere gases, dB		0.4
Gain of a receiving antenna of the ST, dB		39.8
Noise temperature of a receiving path of the ST, K		400
Transmission loss in rain (time percent 0.1), dB		3.4
Power of the desired signal at the receiver input of SR in clear weather, dBW	P_c	-112.64
Noise power spectral density, dBW/Hz	N_0	-202.6
Energy potential of a radio channel SR–ST, dBHz	EP	89.961

The total throughput of forward user channels in clear weather will be C_Σ = (2*224 +6*448+2*672) = 4480 Mbit/s. The specific rate determines the number of subscribers, who can be connected to the network. If to focus on the specific rate adopted for cable networks, such as 30 kbit/s, it is possible to connect approximately 149 thousand subscribers. If to provide a service similar to Wild-Blue and available in the U.S. today, it is possible to connect the 44.8 thousands subscribers [4, p.1].

The total throughput could be increased by increasing of ST EIRP, but it may be that the frequency resource is not enough. Analysis of the formulas (2) and (4) shows that C1 = C2 = 265.5 Mbit / s by transponder EIRP 60.9 dBW. In this case total throughput is C_Σ = 5310 Mbit / s.

It is also necessary to verify compliance with the rules on the allowable values of power flux density (PFD) of ST signals at the earth's surface. For the usable frequency range of ST transmitter the limit of PFD reference bandwidth of 1 MHz and in a range of elevation angles ε = 5° -25° are defined by the formula [12, p.131]:

$$PFD\ allowable = -115 + 0.5(\varepsilon - 5),\ dB\ (W/m^2), \qquad (5)$$

For the example (Table 3) the elevation angle is ε = 23.8° and PFD allowable = - 105.6 dB (W / m ²), and the actual value of PFD allowable is - 125.1 dB (W / m ²). As the actual value of PFD significantly below the permissible level, the norms will be implemented for the other elevation angles.

4 Conclusions

10 beams with an angular size of 0.75º are determined in the practical creating of multi-beam satellite operating area in the territory of Kazakhstan.

The selection of beam size eliminates the need of direction finders used for holding the aiming point and, at the same time, provides a gain of approximately 10.5 dB in radio line power for subscriber station as compared with a single-beam coverage area.

The multi-beam coverage area permits to increase the efficiency of spectrum using considering the uneven population density in Kazakhstan territory.

The application of adaptive coding and modulation (ACM) allows to reach a maximum bit rate in all weather conditions.

The calculation results of reverse subscriber channels throughput have shown that by choosing of signal-code structure it is possible to provide amounts of 5-6 Mb/s, which corresponds to, for example, design parameters of Inmarsat-5 satellites [1, p.1].

The total throughput of forward subscriber channels amounts 5310 Mb/s in condition of full use of declared power data (EIRP = 60.9 dBW) and frequency resource (125 MHz).

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Authors

	**Altay Aitmagambetov, born in July 4, 1948, Almaty, Kazakhstan** **Current position, grades:** Professor of Computer science and Telecommunications Department, Candidate of technical science **University studies:** Moscow Technical University of Communication and Information **Scientific interest:** satellite communications, mobile communications, spectrum monitoring **Publications:** more than 100 **Experience:** Head of radio communications department in Almaty university of power engineering and telecommunications (1981-2007), General Director of Republican State Telecommunication Inspectorate (1995-1999), Member of Director’s Board of JSC “Transtelecom” and JSC “Nursat”
	**Yuri Butuzov**, born in November 1, 1937, Irkutsk region, Russia **Current position, grades:** Professor of radio engineering department, Almaty university of power engineering and telecommunications, Candidate of technical sciences. **University studies:** Tomsk polytechnical institute **Scientific interest:** wireless communications, satellite communications **Publications:** more than 80 **Experience:** radio engineering enterprises, scientific-research institute, universities
	**Sypatay Torekhan**, 29 September 1992, Almaty, Kazakhstan **Current position, grades:** bachelor studies **University studies**: International IT University **Scientific interest:** satellite communication systems, mobile communications, adaptive arrays **Publications:** 2