International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 18 (2017) pp. 7599-7602

The Analysis of Network Throughput of LEO Communication Satellite System for Priority Coverage of Russian Federation

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Abstract

This system is a further advancement of geostationary personal communication systems providing increased network data transmission and global coverage.

This paper is using the results obtained by the research conducted under the Agreement № 14.585.21.0003, the project identifier RFMEFI58514X0003.

The initial conditions for network throughput calculation

Four types of orbital constellations are considered:

Type 1:

- orbit height – not less than 1500 km;
- orbit plane inclination – 82.5°;
- number of spacecrafts (Nsat_syst) – 48;
- number of planes (n) – 6;
- number of spacecraft in-plane (m) – 8.

Type 2:

- orbit height – not less than 1000 km;
- orbit plane inclination – 82.5°;
- number of spacecrafts (Nsat_syst) – 128;
- number of planes (n) – 8;
- number of spacecraft in-plane (m) – 16.

For type 1 and type 2 two more subtypes (1.1, 1.2 and 2.1, 2.2 respectively) are considered with different longitude of the ascending node and mean anomaly.

Type 3 and type 4 of orbital constellations are considered without overlay over cover areas.

Type 3:

- orbit height – not less than 1500 km;
- orbit plane inclination – 82.5°;
- number of spacecrafts (Nsat_syst) – 360;
- number of planes (n) – 20;
- number of spacecraft in-plane (m) – 18.

Type 4:

- orbit height – not less than 750 km;
- orbit plane inclination – 82.5°;
- number of spacecrafts (Nsat_syst) – 720;
- number of planes (n) – 20;
- number of spacecraft in-plane (m) – 36.

Calculation of network throughput

The results of communications spacecraft orbital constellation simulation given in [1] have been used.

Network throughput calculation results for subtypes 1.1, 1.2, 2.1 and 2.2 are shown in Table 1.

Note – The calculation of network throughput is based only on predicted spectrum/orbit resource calculation and it does not take into account system components energetics parameters. Further research is required to assess available spectrum/orbit resource and calculate radio link capacity to determine system components main energetics parameters [2].

Table 1: Network throughput calculations results for 1.1, 1.2, 2.1 and 2.2 types of constellation.

	Type 1.1 48 satellites in constellation, 15° elevation, with overlay of cover areas			Type 1.2 48 satellites in constellation, 20° elevation, without overlay of cover areas			Type 2.1 128 satellites in constellation, 25° elevation, with overlay of cover areas			Type 2.2 128 satellites in constellation, 33° elevation, without overlay of cover areas		
Main traffic parameters												
Nab_all – number of user terminals	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000
I – simultaneously active users percentage, %	30	30	30	30	30	30	30	30	30	30	30	30
Nab_syst – number of simultaneously active users	150000	150000	150000	150000	150000	150000	150000	150000	150000	150000	150000	150000
c – single user mean calls per hour	4	4	4	4	4	4	4	4	4	4	4	4
t – mean time of one call, minutes	4	4	4	4	4	4	4	4	4	4	4	4
p – acceptable losses probability	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
Aab – mean carried traffic per user, erlang	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666	0,26666666
Aab_syst – total carried traffic, erlang	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Main system parameters												
Nsat_syst – number of satellites in constellation	48	48	48	48	48	48	128	128	128	128	128	128
Nab_1sat – number of users per satellite	3125	3125	3125	3125	3125	3125	1171,875	1171,875	1171,875	1171,875	1171,875	1171,875
Nspot – number of beams per satellite	7	19	37	7	19	37	7	19	128	7	19	128
Nab_1spot_1sat – number of users per beam	446,428571	164,473684	84,4594594	446,428571	164,473684	84,4594594	167,410714	61,6776315	9,15527343	167,410714	61,6776315	9,15527343
Main traffic parameters per 1 spot												
Aab_spot – traffic carried per beam, erlang	119,047619	43,8596491	22,5225225	119,047619	43,8596491	22,5225225	44,6428571	16,4473684	2,44140625	44,6428571	16,4473684	2,44140625
Number of channels per 1 spot												
Nchan_1spot_1sat	122	48	27	122	48	27	48	21	5	48	21	5
Frequency resources of network												
dF – total frequency band, MHz	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
Ndf – number of sub-bands	12	12	12	6	6	6	16	16	16	8	8	8
dfm – frequency range per one sub-band (with 10% frequency margin between adjacent sub-bands), MHz	98,4848484	98,4848484	98,4848484	196,969697	196,969697	196,969697	73,8636363	73,8636363	73,8636363	147,727272	147,727272	147,727272
dfm_spot – frequency range of one beam (with 10% frequency margin between adjacent channels), MHz	12,7902400	4,71219370	2,41977514	25,5804801	9,42438741	4,83955029	9,59268004	3,53414528	0,52459969	19,1853600	7,06829056	1,04919938
dfi – frequency range per one user (with 25% frequency margin between channels), MHz	0,08387042	0,07853656	0,07169704	0,16774085	0,15707312	0,14339408	0,15987800	0,13463410	0,08393595	0,31975600	0,26926821	0,16787190
Network throughput (only FDM)												
Balcc – transmission frequency band (=a*Bocc), MHz	0,08387042	0,07853656	0,07169704	0,16774085	0,15707312	0,14339408	0,15987800	0,13463410	0,08393595	0,31975600	0,26926821	0,16787190
SR – baud rate, MBd	0,08387042	0,07853656	0,07169704	0,16774085	0,15707312	0,14339408	0,15987800	0,13463410	0,08393595	0,31975600	0,26926821	0,16787190
Modulation	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK
R – payload rate + FEC, kbit/s	0,25161128	0,23560968	0,21509112	0,50322256	0,47121937	0,43018224	0,47963400	0,40390231	0,25180785	0,95926800	0,80780463	0,50361570
FEC	0,875	0,875	0,875	0,875	0,875	0,875	0,875	0,875	0,875	0,875	0,875	0,875
Vab – payload rate per user, Mbit/s	0,22015987	0,20615847	0,18820473	0,44031974	0,41231694	0,37640946	0,41967975	0,35341452	0,22033187	0,83935950	0,70682905	0,44066374
Vsyst_fdma – network throughput, Mbit/s	9024,79338	9024,79338	9024,79338	18049,5867	18049,5867	18049,5867	18049,5867	18049,5867	18049,5867	36099,1735	36099,1735	36099,1735
Vsyst_fdma – network throughput, Gbit/s	9,02479338	9,02479338	9,02479338	18,0495867	18,0495867	18,0495867	18,0495867	18,0495867	18,0495867	36,0991735	36,0991735	36,0991735
Network throughput (FDM/TDM; 4 time slots per 1 frequency subchannel)												
Vsyst_fdma_tdma – network throughput, Gbit/s	36,0991735	36,0991735	36,0991735	72,1983471	72,1983471	72,1983471	72,1983471	72,1983471	72,1983471	144,396694	144,396694	144,396694

Note – Uniformly distributed by component beam of 7/19/37 multi-beam antennas load has been assumed. Spectrum/orbit resource may be reallocated to increase bandwidth.

Above calculations bring next conclusions:

– network throughput for 48 satellites constellation with 15° elevation (with overlay of cover areas – Type 1.1) is lower (36 Gb/s) than network throughput for 48 satellites constellation with 20° elevation (Type 1.2, 72 Gb/s) because of lower utilization of spectrum/orbit resource;

– network throughput for 128 satellites constellation with 25° elevation (with overlay of cover areas – Type 2.1) is lower (72 Gb/s) than network throughput for 128 satellites constellation with 33° elevation (Type 2.2, 144 Gb/s) because of lower utilization of spectrum/orbit resource;

– network throughput for 128 satellites constellation with 25° elevation (with overlay of cover areas –

Type 2.1) is the same (72 Gb/s) as for 48 satellites constellation with 20° elevation (without overlay of cover areas – Type 1.2), but the one day mean global coverage percentage is higher (98.25% vs 75.00%);

– payload for each Type 1 satellite is much more complex than for Type 2 satellite due to Type 1 satellite payload requiring a lot more number of channels per beam (by 2 or 3 times).

Network throughput calculation for 360 and 720 satellites constellations communication systems (Type 3 and Type 4) with uniformly distributed ground control stations is given in Table 2 (analysis of constellation must be performed on next stages of research).

Note – The calculation of network throughput is based only on predicted spectrum/orbit resource calculation and it does not take into account system components energetics parameters. Further research is required to assess available spectrum/orbit resource and calculate radio link capacity to determine system components main energetics parameters.

	Type 3 360 satellites in constellation, without overlay of cover areas			Type 4 720 satellites in constellation, without overlay of cover areas		
Main traffic parameters						
Nab_all – number of user terminals	500000	500000	500000	500000	500000	500000
I – simultaneously active users rate, %	30	30	30	30	30	30
Nab_syst – number of simultaneously active users	150000	150000	150000	150000	150000	150000
c – mean calls per hour	4	4	4	4	4	4
t – mean time of one call, minutes	4	4	4	4	4	4
p – probability of losses	0,06	0,06	0,06	0,06	0,06	0,06
Aab – mean carried traffic per user, erlang	0,266666667	0,266666667	0,266666667	0,266666667	0,266666667	0,266666667
Aab_syst – total carried traffic, erlang	40000	40000	40000	40000	40000	40000
Main system parameters						
Nsat_syst – number of satellites in constellation	360	360	360	720	720	720
Nab_1sat – number of users per satellite	416,6666667	416,6666667	416,6666667	208,3333333	208,3333333	208,3333333
Nspot – number of beams per satellite	7	19	37	7	19	37
Nab_1spot_1sat – number of users per beam	59,52380952	21,92982456	11,26126126	29,76190476	10,96491228	5,630630631
Main traffic parameters per 1 spot						
Aab_spot – traffic carried per spot, erlang	15,87301587	5,847953216	3,003003003	7,936507937	2,923976608	1,501501502
Number of channels per 1 spot						
Nchan_1spot_1sat	20	9	6	11	6	4
Frequency resources of network						
dF – total frequency band, MHz	1300	1300	1300	1300	1300	1300
Ndf – number of sub-bands	18	18	18	20	20	20
dfm – frequency range per one sub-band (with 10% frequency margin between adjacent sub-bands), MHz	65,65656566	65,65656566	65,65656566	59,09090909	59,09090909	59,09090909
dfm_spot – frequency range of one beam (with 10% frequency margin between adjacent channels), MHz	8,526826709	3,141462472	1,613183431	7,674144038	2,827316224	1,451865088
dfn – frequency range per one user (with 25% frequency margin between channels), MHz	0,341073068	0,279241109	0,215091124	0,558119566	0,376975497	0,290373018
Network throughput (only FDM)						
Balcc – transmission frequency band (=a*Bocc), MHz	0,341073068	0,279241109	0,215091124	0,558119566	0,376975497	0,290373018
SR – baud rate, MBd	0,341073068	0,279241109	0,215091124	0,558119566	0,376975497	0,290373018
Modulation	8PSK	8PSK	8PSK	8PSK	8PSK	8PSK
R – payload rate + FEC, kbit/s	1,023219205	0,837723326	0,645273373	1,674358699	1,13092649	0,871119053
FEC	0,875	0,875	0,875	0,875	0,875	0,875
Vab – payload rate per user, Mbit/s	0,895316804	0,73300791	0,564614201	1,465063862	0,989560679	0,762229171
Vsyst_fdma – network throughput, Gbit/s	45,12396694	45,12396694	45,12396694	81,2231405	81,2231405	81,2231405
Network throughput (FDM/TDM; 4 time slots per 1 frequency subchannel)						
Vsyst_fdma_tdma – network throughput, Gbit/s	180,4958678	180,4958678	180,4958678	324,892562	324,892562	324,892562

Note – Uniformly distributed by component beam of 7/19/37 multi-beam antennas load has been assumed. Spectrum/orbit resource may be reallocated to increase bandwidth.

As shown in Table 2:

- network throughput significantly increases if there isn't coverage areas overlay:
  - 180 Gb/s for 360 satellites constellation;
  - 360 Gb/s for 720 satellites constellation.
- payload for each Type 3 or 4 satellite is much more simpler than for Type 1 or 2 satellite due to decrease in the number of channels per beam (by 2 to 6 times)

CONCLUSION

This paper shows that communication systems with more than 128 satellites in constellation at 500-1000 km LEO orbit must be designed in order to increase network throughput (assuming constant number of subscribers) and decrease satellite payload complexity.

It is also shown that 720-satellite constellation is the most efficient in terms of throughput.

Next stages of this topic research will require to evaluate:

- the demand for LEO mobile satellite communications;
- the necessary cover area for LEO orbital constellation;
- the minimal number of spacecraft to meet the demand for LEO mobile satellite communications;
- the complexity and costs of payload and a single spacecraft for every orbital constellation type;
- Launch costs and vehicle type for every orbital constellation type;
- Ground station design and build costs

REFERENCES

[1] *Ivanova M.P., Golovkov V.V., Badertdinov A.M., Esipenko A.A., Kuzovnikov A.V.* «Key Parameters Optimization of Spacecraft Orbital Constellations in Low Circular Orbits for Priority Service of the Russian Federation Territory» International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 12 (2017) © Research India Publications. http://www.ripublication.com

[2] *Stepanenko S., Ozhogin O.* Ka-band: history, current state of affairs and future perspectives/ Satellite technologies, "Connect" publisher, 2016, №1-2, p 106-

[3] *Kondratov A.G., Stepanov B.L.* Mobile network throughput calculation features /T-comm, 2009, № 3. p 43-46

[4] *Krylov V.V., Samokhvalova S.S.* Teletraffic theory and its applications. – Saint-Petersburg: BHV-Petersburg, 2005. – 288 pages.