SPREAD SPECTRUM TT&C
FOR THE SKYBRIDGE CONSTELLATION

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ABSTRACT

The SKYBRIDGE constellation will establish telecommunication and TTC links in Ku-band, without any exclusive allocation of spectrum: jamming avoidance techniques are used in order to protect the geostationary satellites and associated ground stations that work in the same band. This paper presents the studies that have been carried out at system level.

KEY WORDS

SkyBridge, Constellation, Spread Spectrum, TT&C System.

INTRODUCTION

The SKYBRIDGE system consists in a low Earth orbit satellite system, that provides a wide range of data, voice and video broadband services in the Commission's Fixed-Satellite Service (« FSS »).
The Skybridge system will employ a constellation of 80 satellites at an altitude around 1469 km.
The corresponding ground segment will consist of:

- « User Terminal » earth stations, providing user access to the Skybridge system
- « Gateway » earth stations, providing interconnection, through broadband switches, with local servers and terrestrial broadband and narrow band networks.

The Skybridge satellites, via multiple « bent pipe » transponders and spot-beam antennas, will provide « Service Links » between each Skybridge user and a designated gateway.

The Telecommunication links, together with the TTC links, will be established in Ku-band. However, the System does not need any exclusive allocation of spectrum. The Skybridge System employs a novel system architecture, designed to ensure that it will not interfere with any other service, including the geostationary orbit satellite systems and terrestrial systems, operating in the Ku-band. Before describing this system architecture, it is necessary to give an overview on regulatory aspects.

REGULATORY ASPECTS

WRC-97 has introduced regulatory mechanisms to ensure the coexistence of geostationary (GSO) and non-geostationary (NGSO) satellites in the 10-18 GHz band. As a consequence, NGSO are subject to provisional limits, which are currently reviewed by ITU-R study groups. In the light of these studies, the final limits will be adopted by WRC-99. NGSO satellites in the 10-18 GHz band have to meet these limits in order to be compliant with Radio Regulations.

These limits are defined considering aggregate power flux density and equivalent power flux density criteria. The **Aggregate Power Flux Density (APFD)** is defined as the summation of the power flux densities produced at a point in the geostationary satellite orbit by all the earth stations of a NGSO satellite system.

The **Equivalent Power Flux Density (EPFD)** is defined as the sum of the power flux densities produced at a point of the Earth's surface by all space stations within a NGSO satellite system, taking into account the off-axis discrimination of a reference receiving antenna assumed to be pointing towards the GSO orbit.

Examples of flux limits are given hereafter:

- the APFD due to NGSO earth stations has to be always (i.e. 100 % of the time) lower than -186 dBW/m²/4 kHz in the 12.75 GHz-13.25 GHz and lower than -170 dBW/m²/4 kHz in the 13.75 GHz-14.5 GHz
- the EPFD has to meet the following limits for the 10.7-11.7 GHz band:

Antenna type	EPFD (100% of time) (dBW/m²/4 kHz)	EPFD (time criteria) (dBW/m²/4 kHz)	% of time
0.60 m	-170	-179	99.7
3 m	-170	-192 -186 -173	99.9 99.97 99.999
10 m	-170	-195 -178	99.97 99.999

The compliance to the limits in the column « EPFD (time criteria) » has to be guaranteed over the given percentage of time.

SKYBRIDGE SYSTEM DESCRIPTION

Overall description

A system architecture overview is presented in Figure 1. The Skybridge system covers all the terrestrial zones located between 65°S and 65°N. A User Terminal (UT) communicates via satellite with a gateway (GW), which connects it to the terrestrial broadband infrastructure. Each gateway routes the traffic of all the subscribers located within a 350 km radius in its service area. The primary function of the satellites is to provide a radio repeater service between user terminals and gateways. Multiple spot-beam coverage is used to achieve high antenna gain and maximum frequency reuse. Each satellite creates steerable spot beams, which can illuminate Earth-fixed zones i.e. gateway service areas.

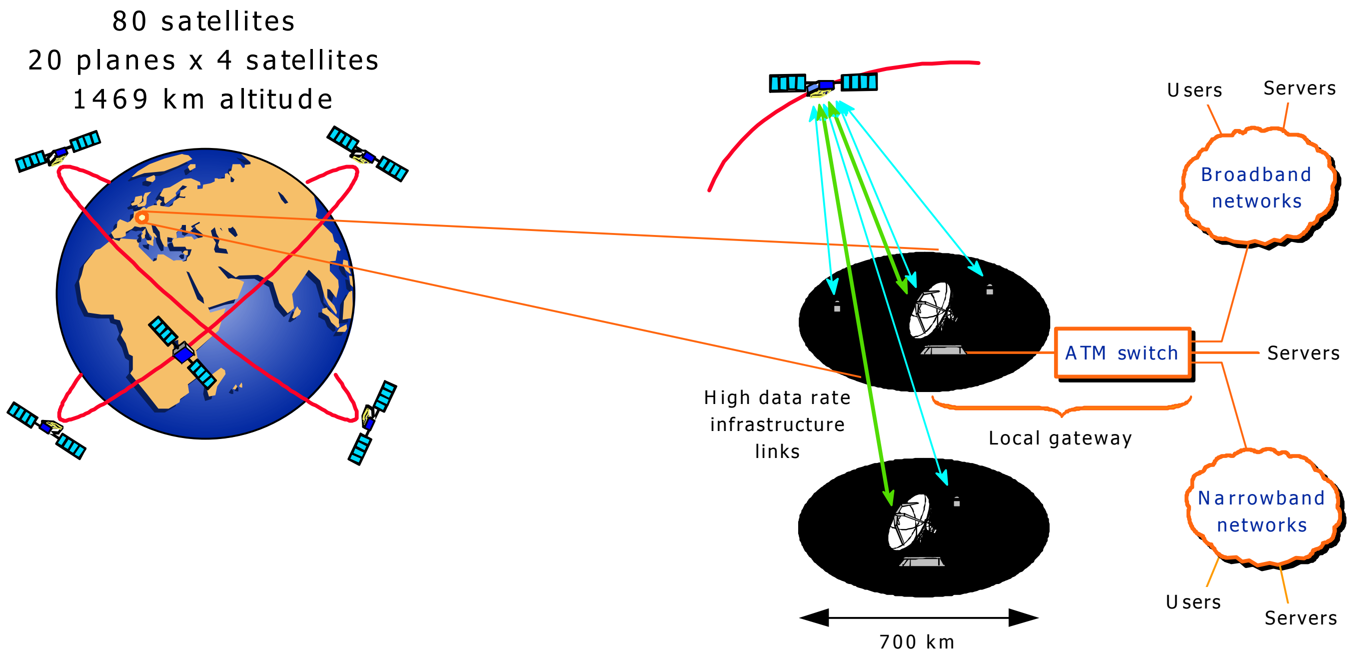

Figure 1 - Skybridge system architecture

Frequency reuse principle

The frequency reuse between the Skybridge system and GSO systems is the result of spatial separation, suppression of transmissions, reduction of residual interferences and satellite diversity.

User terminals of both systems use directive antennas. A GSO terminal, pointing towards a GSO satellite, could be interfered by a Skybridge satellite if the Skybridge satellite is also viewed from this terminal in a direction close to that of the GSO satellite. To avoid creating this interference on GSO systems and to conform to the above-mentioned pfd rules, an exclusion zone of the Skybridge system is defined around the GSO arc (i.e. all the transmissions from the gateways, the satellites and the terminals are stopped). The whole GSO arc (GSO satellites and GSO ground stations) is taken into account. The size of the non-operating zone is ±10° around this GSO arc viewed with an elevation angle greater than 5°.

In order to avoid any service interruption due to this exclusion zone, a satellite diversity technique is applied, which is now described. Before the signal coming from the Skybridge satellite creates on the reception of a geostationary terminal an interference above the levels given previously, the beam coming from this satellite and illuminating the zone under consideration is switched off so that there is no transmission from the satellite in that direction and this part of the traffic is handed over to another satellite of the constellation. The system is thus designed to provide, whenever the transmissions from a satellite have to be interrupted in the direction of a terrestrial area, another satellite, not interfering in visibility of this region.

SKYBRIDGE TTC LINK

General

The principle which has been adopted for the Skybridge telecommunications cannot be directly extrapolated to the TTC link, mainly because:

- onboard wide coverages are needed during Launch and Early Orbit Phases and in case of emergency.
- an onboard global coverage of ±54°, rather than a steerable spot beam, has been preferred when on station, mainly for reliability, mass and cost reasons.

As a consequence, it is not possible to apply to the Telemetry link the satellite diversity technique described above. Another possible solution could have been to switch off the telemetry transmission as soon as a Skybridge satellite is in the line of sight of GSO ground stations: as GSO ground stations latitudes range from 76°S up to 76°N, the time left available for the observability would have been far too short.

In compensation, the principle which has been adopted for the Skybridge telecommunications can be directly extrapolated to the Telecommand link: the TTC ground station will have to take into account a non-operating zone of ±10° with respect to GSO arc.

The following frequency plan is the current baseline:

- telecommand: around 12890 MHz
- telemetry: 10950-10980 MHz. This bandwidth has to allow the simultaneous telemetry reception from satellites that are launched at the same time (up to 10 with Ariane5).

Telemetry flux computation

On station

Simulations have been carried out, considering that all the satellites transmit the telemetry signal permanently. It has been shown that the EPFD limits which are associated to time criteria are the most stringent requirement.

The conclusion of these simulations is that the telemetry pfd on ground corresponding to one satellite shall not exceed -177 dBW/m²/4 kHz: this applies to the whole operating constellation.

LEOP (Launch and Early Orbit Phases) & Emergency

As the corresponding duration of these phases is relatively short, cumulative effects over time is not preponderant. Only EPFD limits corresponding to 100% of time have to be taken into account. The conclusion of the simulations is that the maximum pfd generated by a group of satellites in injection orbit, or in case of emergency shall be lower than -171 dBW/m²/4 kHz.

Telecommand flux

For the selected frequency band, the flux at GSO arc has to be lower than -186 dBW/m²/4 kHz (100% of time).

Satellite-ground interface definition

Main TTC link characteristics

The following paragraphs give the characteristics of the telecommand and telemetry links during the different phases, i.e. LEOP & emergency on one hand and on station on the other hand.

The bit rate for telecommand is 10 kb/s whatever the mission phases. This corresponds to the bit rate need when on station: in fact, the bit rate need during the other phases is lower, but a fixed bit rate for all the phases simplify the on board receiver design.

The bit rate for telemetry is:

- 15.7 kb/s (on station)
- 1 kb/s (LEOP & emergency)

No requirement for ranging applies as the satellite will be equipped with a navigator that will perform the positioning of the satellite during all phases, except at the very beginning of the injection phase.

In order to reach the required pfd, spread spectrum techniques have been used. As there is no requirement for a ranging function, a simple Direct Sequence/BPSK modulation has been retained. The PN code family is of maximal length type. The PN code is synchronous with bit rate: a PN code occupies exactly the duration of one bit. The following table summarizes for each mode the code length, the corresponding chip rate and the type of coding:

	Code Length in Chips	Chip Rate in MChip/s	Coding
TC	255	2.5	None
TM			
• on station	511	1	Conv(7,1/2)
• other phases	127	4	Conv(7,1/2)

The on board coverage is:

- ±65° over +Z and -Z axis during LEOP and emergency.
- ±54° when on station.

The acquisition and tracking of the satellites has to be achieved on the telemetry spread spectrum signal. It is to be noted that this approach is new as most of satellites up to now make use of telemetry modulation with residual carrier, and acquisition and tracking of the satellites by the ground station is achieved using this residual carrier.

Up to ten satellites can be launched at the same time (with Ariane 5). The satellites first acquisition consists of a « waiting point strategy » followed by a searching phase that mixes elevation and azimuth sweep around the nominal trajectory if the waiting point acquisition is not successful.

Main equipment requirements

The main characteristics of the on board receiver are:

- threshold: 53 dB.Hz
- physical Doppler: 12 kHz
- acquisition time < 1 s at threshold
- BER: 10^{-6}

The main characteristics of the on board transmitter are:

- frequency stability: 1 ppm under all conditions
- residual carrier: -30 dBc
- power stability: ±0.5 dB
- two output powers (8 mW and 40 mW) selectable by external telecommand
- the transmitter frequency has to be selected externally among 10 values.

The main characteristics of the ground telemetry and tracking receiver are (worst case conditions, i.e. at first acquisition):

- threshold: 37 dB.Hz
- Doppler: 51 kHz
- acquisition time: 1s

Nota: the acquisition time requirement is mainly driven by the first acquisition strategy.

The ground station main characteristics are:

- EIRP: 56 dBW
- G/T: 29.6 dB/°K, including rain degradation.
- pattern: 29-25*LOG(θ) where θ represents the off-axis angle.

The pattern requirement allows to comply to pfd rules at GSO arc.

CONCLUSION

At the end of studies at system level and further to the equipment feasibility assessment, the conclusions are the following:

- the TTC SKYBRIDGE link is feasible for the different phases of the mission (i.e. first acquisition, on station and in case of emergency)
- this TTC link can make use of Ku-band, without any exclusive allocation of spectrum