Contemporary Integration of Satellites and Stratospheric Platforms for Improved Distribution of Microwave Bands

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Abstract: This paper describes the development of integration structures of Geostationary Earth Orbit (GEO) satellites and Stratospheric Platform Systems (SPS) or Stratospheric Communication Platforms (SCP) networks in connection with the new signal distribution in the microwave range. It is actually an implementation of the microwave band on the interlinks between GEO satellites and the SPS network that connects terrestrial mobile, cellular and fixed users. The development of this specific structure includes a new aspect of the branch of space technology such as SPS network which is currently implemented by many companies in the world for a huge variety of different tasks. The main interest in this integration is the distribution of microwave bands, which is proposed to be arranged in such a way as to achieve maximum energy savings for signal transmission and reduce the delay in communication between potential mobile, cellular and fixed users with the help of terrestrial telecommunication infrastructures. In this way, this structure makes it possible to extend the lifetime of GEO satellites and provide an energy-efficient solution for mobile, cellular and fixed satellite terminals. In addition, with the help of the integration of GEO satellites with SPS networks, it is possible to minimize the delay in the transmission of data signals by transiting GEO satellites directly through SPS to terrestrial telecommunication users. This paper examines all communication methods take place in accordance with a special proposed algorithm that enables the calculation of optimal communication and data transfer with minimal delay. For each microwave band, calculations and evaluation of signal attenuation are provided for each band in the space between GEO satellites and SPS networks. Such calculations can be signal losses in free space and in the low atmospheric layer between the SPS and the user as oxygen, water vapor and rain absorption will show the approximate attenuation coefficient for each microwave band that should be used in this structure. In addition, the integration of GEO satellites and SPS stations in the new microwave bands distribution, communication delay analysis for microwave band users, evaluation of attenuation and efficiency of microwave bands, and antenna requirements in the network of GEO satellites and SPS stations are also discussed.

Keywords: GEO, SPS, SCP, GPS, GLONASS, HDTV, LEO MEO, FSL, ICT, MathCAD

1. Introduction

Majority of contemporary satellite applications such as the US Global Position System (GPS) or the Russian (former Soviet Union) Global Orbiting Navigation System (GLONASS) receivers, Cellular hand phone, tracking mobile terminals and others which don't demand high data rate operate with help of satellite using the dedicated microwaves bands such as L (1 – 2 GHz), S (2- 4 GHz) and C (4 – 8 GHz), using of particular band depends on requirements to necessary spectrum bandwidth. Such technology for data transmitting as High Definition Television (HDTV) which is currently rapidly emerging in more and more countries of the world, Internet communication through Direct To Home (DTH) and satellite Internet system for maritime Fleet-Broadband and aeronautical Swift-Broadband provided by Inmarsat need more higher spectrum bandwidth due to high information capacity and data rates. Thus, for these purposes can be satisfied frequency bandwidth of Ka-band (12 – 18 GHz), K-band (18 – 26.5 GHz) and Ku-band (26.5 – 40 GHz).

Currently, only two types of satellite constellations are used for satellite communication such as GEO and Non-GEO asynchronous orbit satellites. The height of the constellation of GEO satellites above the Earth's surface is on average about 36,000 km, while the Non-GEO satellite constellation uses Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellite constellations. The height of the satellite constellations LEO and MEO is on average about 1,000 km and 10,000 km, respectively. Due to the high altitudes of GEO satellites above the Earth's surface, signal propagation delays appear that cannot be easily compensated for, which is a problem that needs to be solved. Otherwise, LEO and MEO satellites have less delay in signal propagation, but due to their rapid movement relative to the surface of the Earth, handover technology must be used to prevent interruptions in the satellite communication of mobile, cellular and fixed terminals (users), which is another problem that also requires a solution.

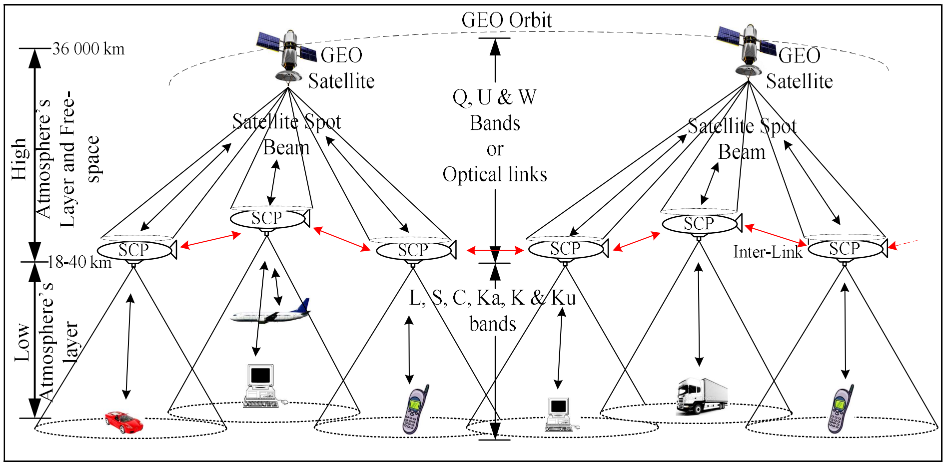

Figure 1. General Structure of Utilizing Integration of GEO Satellites and SPS Stations in the new Distribution of Microwave Bands

All communication between satellites and ground mobile, cellular and fixed terminals occurred with help of radio-communication channels as written above. A signal transmitted by satellites going through free-space and atmosphere layers which make two most significant affection on the propagation of the signal such as free-space loses and absorption respectively. The strongest signal absorption occurred in low atmosphere's layers where high densities of water vapors and gases are consisted. Also important to note that attenuation of a signal directly depends on the signal frequency or signal wavelength. Significant absorption of signal due to atmospherics' components begins above 40 MHz. The rain also makes significant attenuation on the microwave bands and must be considered. In such a way L, S, C, Ka, K and Ku-bands can be used, but even Ka-band forgoing significant attenuation in the atmosphere.

Higher frequency bands above Ka-band cannot be used due to highest absorptions with atmosphere components. Fast growing modern data communication technology demands faster data transmitting and higher data capacity which need to involve higher frequency bands with more broad bandwidths to achieve it. The problem with attenuation of signal can't be solved absolutely, but attenuation losses must be reduced as much as possible to use more efficient energy of mobile terminals and satellites.

Utilizing of high frequency bands means small size of communication antenna and lees weight of satellite payload. On the other hand to transmit a signal and compensate attenuations of the signal must be risen transmitting power of the signal that is critically for satellite's life span. Including all narrated above in this paper will be proposed new structure to organize satellite telecommunication with utilizing combination of GEO satellite constellations and SPS or SCP stations with special distribution of microwave band between them.

2. Integration of GEO Satellites and SPS Stations in the new Microwave Bands Distribution

The proposed structure of utilizing GEO satellitec constelations and SPS stations in integratesd network is shown in **Figure 1.** This hibrid infrastructure consists of an SPS constellation at an altitude of 18 km to 40 km to provide coverage for different users, with an interlink between SPS stations for faster data exchange between points with minimal delay in case the points are covered by different SPS stations. Communication between SPS stations in the distance should be via a multiple beam of GEO satellites at an altitude of about 36,000 km above the Earth's surface.

Distribution of microwave bands in this structure of SPS and satellite has to be such in order to be possible use microwave frequency bands above Ka band in high atmosphere's layer and free space to link satellites and SPS cause of low attenuation of microwave energy there. The Q, U and W bands or optical links allow provide radio communication channels with high capacity what allows provide high data rate exchange. Thus, the usage of microwave frequencies, such L, S, C, Ka, K and Ku-band in low atmosphere layer for communication between satellite applications and SPS where attenuation for such microwave band is not so significant due to water vapors, gases and etc.

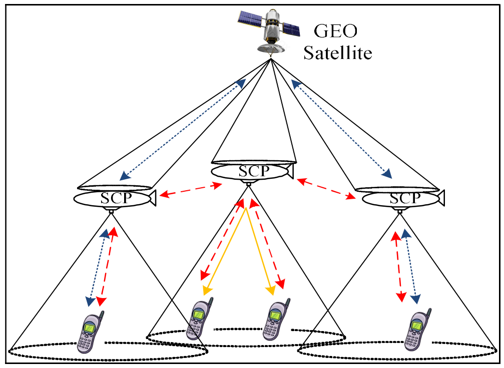

Figure 2. Utilization of GEO Satellite and SPS Stations for Connecting Cellular Phones

The proposed communication network of utilizing GEO satellite constellations and SPS stations in an integrated network is illustrated in **Figure 1.** This hybrid infrastructure consists of an SPS constellation at an altitude of 18 km to 40 km to provide coverage for different users, with an interlink connection between SPS stations for faster data exchange between points with minimal delay in case the points are covered by different SPS stations. However, communication between SPS stations in the distance should be via a multiple beam of GEO satellites at an altitude above the Earth's surface of about 36,000 km.

3. Communication Delay Analysis for Microwave Band Users

In order to perform an analysis of the communication delay of users who need access to the system with such a structure, all possible ways of communication or data flow in the system that use such a structure must first be considered. At this point, a system based on such a infrastructure with the use of GEO satellites and SPS stations in such a way allows of utilizing voice and data communications between two requested users directly through SPS stations bypassing the GEO satellite, but only if they are covered by the same SPS station as shown in **Figure 2** (yellow arrow).
In case the desired users are under the coverage of neighboring SPS stations, then communication can be provided through inter-links from SPS rto SPS (SPS-SPS) exactly as illustrated in **Figure 2** (red arrows). Accordingly, if the potential users are located at a considerable distance from each other, then communication is provided through the GEO satellite to SPS stations and other SPS stations (SPS-GEO-SPS) link as shown in **Figure 2** (blue arrows).
In order to enable users to access the Internet or provide mobile vehicle tracking, communication can be realized in three ways, as in data-voice communication. For users who need access to the Internet are covered by the same SPS station and under the coverage of this SPS stations there is a ground HUB (gateway antenna) connected to the terrestrial network, so communication can be organized directly through the GEO satellite and bypassed SPS stations as shown in **Figure 3** (yellow arrow).

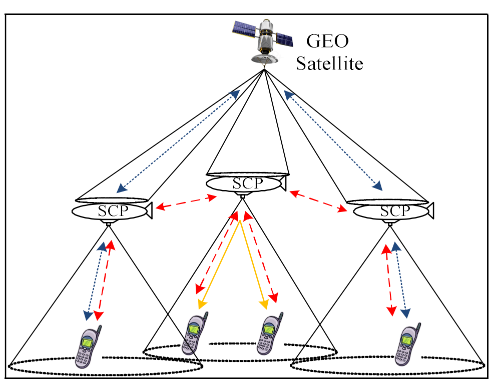

Figure 3. Utilization of GEO Satellite and SPS Stations for Internet Access

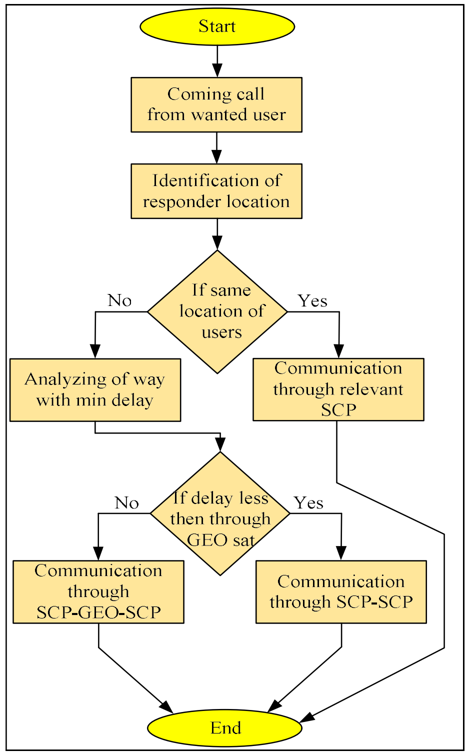

Figure 4. Algorithm for the Shortest Delay

For users covered by one SPS station or in the case of ships, land vehicle (road and rail) or aircraft tracking, when the mobile object is constantly moving, and the ground HUB is covered by another SPS station, communication can be realized as SPS-SPS with the help of inter-links as illustrated in **Figure 3** (red arrows). Finally, for users who are at a considerable distance from each other, it can be communication through SPS-GEO-SPS as shown in **Figure 3** (blue arrows).
The communication methods described in the system based on the proposed GEO satellite and SPS stations can significantly reduce the communication delay in contrast to the usual satellite systems in which communication is realized only directly through the satellite, especially the least delay if two users are covered by the same SPS station. Otherwise, a comparison of user communication delays via GEO satellite and SPS station is presented in **Table 1.**

Table 1. Communication Delays of GEO and SPS

Item	Communication delay (ms)		All round signal trip (ms)	
	Min	Max	Min	Max
SPS Station	0.0003	0.002	<<1	<<1
GEO Satellite	0.0005	0.02	200	270
SPS-SPS Stations	0.0004	0.0005	<<1	<<1
SPS-SPS Stations	0.0008	0.0025	200	280

In **Table 1** is clearly presented that the main contribution to the communication delay is given by the GEO satellite (all round signal trip) due to the long distance of the transmitted signal, but with SPS stations this delay is slightly neglected and can be crossed out ofmconsideration. The delay of user communication through GEO satellite and SPS stations is almost equal. In fact, the Information and Communication Technology (ICT) level of such a structure must ensure the communication of the potential users in accordance with a simple algorithm that enables the identification of the locations of the requested users and finds a more efficient way of communication with the smallest delay before connecting the users. The algorithm for smallest delay of this network is illustrated in **Figure 4.**

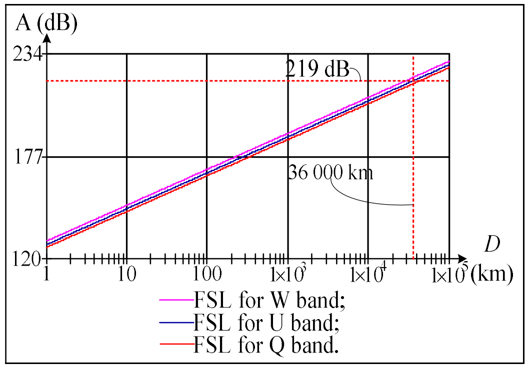

Figure 5. FSL Attenuation of Microwave Bands from 40 GHz to 75 GHz

This algorithm enables the identification of satellite communication methods of possible users with the lowest tracking delay. As an example, the first possible user can provide connections to the integrated system and the location identification of the responding user can be automatically revealed. If the location of possible users is covered by the same SPS station, communication will take place via this SPS station.

Thus, if the location of the possible users is the same or they are covered by the same SPS station, satellite communication will take place through some SPS station. In the event that possible users are not covered by the same SCP station, in such a situation the system automatically searches for the most efficient way of satellite communication. Namely, if there is some satellite communication delay through SCP-SCP inter-link, it can be used through SCP-GEO-SCP inter-link, otherwise in normal conditions without delay communication can be established through SCP-SCP stations.

The execution of this algorithm happens almost instantaneously, so its application can provide faster satellite communication and data transfer. In this way, by proposing an interlink structure of using SPS stations and GEO satellites with this kind of communication algorithm, it is possible to build a system that can solve the problem of saytellite communication delay for users who on the list should communicate directly through GEO satellites that use inter-link through SPS station. Otherwise, with normal satellite communications directly with GEO satellites, there is a significant delay, so by using inter-links, users can connect through SPS stations and avoid these delays.

4. Evaluation of Attenuation and Efficiency of Microwaves Bands

The proposed inter-link structure for the use of GEO satellites and SPS stations should use distributed microwave bands in accordance with that described in the previous subsection and which is shown in **Figure 1**. Such distribution is necessary to achieve the most efficient energy consumption for signal transmission due to the reduction of energy losses in communication radio channels. For a system that can be based on this structure, the main types of attenuation must be considered, suchas: Free Space Losses (FSL) and oxygen, water vapor and rain absorption.

Two optional layers and two groups of distributed microwave bands should be highlighted:

1) The first layer is the covered atmosphere and space (≈36 000 km) for K, U and V-bands used for communication between GEO satellites and SPS stations; and

2) The second layer of the lowest atmosphere (≈ 18 000 — 40 000 km) is for the L, S, C, Ka, K and Ku-bands used for communication between the user and the SPS stations.

The graph in **Figure 5** clearly shows that FSL attenuation for three microwave band approximately equal to 219 dB for 36 000 km distance. Such a high attenuation can be easily overcome with help of high gain antenna system which provides concentration of radiating energy in narrow beam. The approximate distance between GEO satellites and SPS stations can be considered as the same distance between GEO orbits and Earth surface. Thus, finding attenuation of the satellite signal in the first layer is insignificant because water vapor and other gases can be ignored due to their low density. However, there remains an attenuation due to the large satellite communication distance between the GEO satellite and SPS stations, which can be calculated using the well-known equation from:

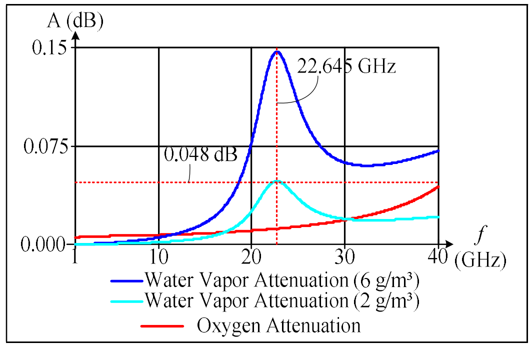

Figure 6. Attenuation of Microwave Bands
1 GHz to 40 GHz in the atmosphere components

$$FSL\left(\text{dB}\right)=32.4+20\lg\left(f\right)+20\lg\left(D\right) \tag{1}$$

Where: D = distance in km; and *f* = central frequency for particular frequency band in MHz.
Using equation (1) and math software "MathCAD" have been plotted graphs of FSL attenuation versus distance for Q, U and W microwave bands, is presented in **Figure 5.**
In the second layer of the atmosphere, which is between the user and the SPS stations, it presented a certain weakening of the propagation due to mutual distance, as was the same case with the FSL value, which in the first layer of the atmosphere had no negative significance. But this layer of the atmosphere consists of water vapor and high concentration of oxygen as well. Attenuations by oxygen and water vapor can be determined with the help of two empirical equations from which are shown with the following relations:

$$\begin{aligned}A_{oxygen}(\text{dB/km})=\Big[&0.05+0.0021\rho+\\&+\frac{3.6}{(f-22.2)^2+8.5}+\frac{10.6}{(f-183.3)^2+9}+\\&+\frac{8.9}{(f-325.4)^2+26.3}\Big]\times f^2\rho 10^{-4}\end{aligned} \tag{2}$$

Where value *f* = central frequency for particular frequency band (GHz); and ρ = water vapor concentration (g/m^3).

$$\begin{aligned}A_{water}(\text{dB/km})=\Big[&7.19\cdot 10^{-3}+\frac{6.09}{f^2+0.277}+\\&+\frac{4.81}{(f-57)^2+1.5}\Big]\times f^2 10^{-3}\end{aligned} \tag{3}$$

Using equations (2) and (3) with the mathematical software "MathCAD", the frequency attenuation graphs of the microwave vase with oxygen and water vapor were plotted, which is shown in **Figure 6.** For the attenuation caused by water vapor, two graphs are drawn: one of them with ρ = 6 g/m3 is the average concentration of water vapor for tropical regions and with ρ = 2g/m3 for other regions.
The graph shown in Figure 6 clearly shows that most significant attenuation due to water vapor for the K-band located around the 22 GHz and average attenuation is between 0.075 dB and 0.15 dB. In addition to the high density of water vapor and oxygen in the second layer, attenuation due to rain can be shown. Thus, the rain attenuation can be carried out with following empiric equation:

$$A_{raim}\left(\text{dB/km}\right)=\left(0.0308f-0.1872\right)R \tag{4}$$

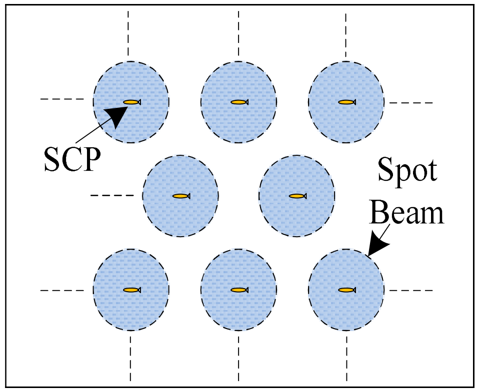

Figure 7. Part of Radiation Pattern of GEO Satellite's Multi Spots Antenna for Satellite Communication with SPS Stations

Where value *f* = operational frequency in GHz; and R = rain rate (mm/hr).
With help of equation (4) carried out results of rain attenuation versus rain heaviness for microwave bands which suppose to be used in second layer for satellite communication between users and SPS stations are gathered in the **Table 2**.

Table 2. Rain Attenuation vs Rain Heaviness

Rain (mm/hr) / Bands	5	15	25	35	45
L	—	—	—	—	—
S	—	—	—	—	—
C	0.296	0.88	1.48	2.072	2.66
Ku	1.836	5.5	9.18	12.85	16.52
K	3.145	9.435	15.72	22.015	28.3
Ka	5.224	15.675	26.12	36.57	47

The most significant attenuation of rain has the Ku, K and Ka-band range. However, heavy rain can significantly increase signal attenuation as presented in **Table 2.** In addition, these bands weaken strongly in high-humidity air layer. The average amount of Ku, K and Ka-band attenuation in the second layer varies between 2 dB/km and 48 dB/km.

6. Antenna Requirements in the Network of GEO Satellites and SPS Stations

The calculation of microwave attenuation in the previous subsection shows that there are presented attenuations in both optional layers of the atmosphere. In such a way, the new application of highly directional antenna systems for communication between GEO satellites and SPS stations and between SPS stations and users should be considered. Such type of antenna system can provide transmission and reception of signals with high signal gain. The satellite communication inter-links between GEO satellites and SPS stations can be implemented in two ways:
1) The first way is implementation of radio communication with help of high directivity multi spot antenna system; and
2) The multi spot antenna system must have high directed beams toward every SPS station and spot beams must not be overlapped with each others as shown in **Figure 7.**
Non-overlapping GEO satellite antenna points do not lack frequency reuse and thus such a system requires a narrow frequency band. In this way, with the help of a multi-spot antenna system, the maximum signal energy can be focused towards each SPS station, and in this way, energy consumption for signal attenuation losses will be reduced, which can generally help to extend the life of the satellite. Whereas for multi-point antenna system with microwave V, U and K-bands inherently smaller size due to shorter wavelength and then for other lower microwave bands.

Another way of satellite communication system is realized with the help of optical connections. Such a way of satellite communication requires relatively small dimensions of optical antenna systems and very low energy consumption. At this point, if optical links are used, then stabilization of the position of SPS stations with the highest precision must be ensured. Optical communication channels can also be used for inter-satellite links for connections between SPS stations and other SPS stations. However, satellite communication between the SPS stations and the user can be deployed with a conventional microwave antenna that is not multiplexed without frequency reuse. Thus, each SPS station can provide as a single site and frequency reuse should be considered between SPS stations.

6. Conclusions

Mobile satellite communication networks are very important systems and platforms for providing successfully commercial and safety radio communications for oceangoing ships, land vehicles (road and rail) and aircraft. The rapid alert, transmission and reception of distress alert messages via ship and aeronautical radio and satellite stations or other distress equipment is the most important task of safety mission at sea, on land and in the air.

This paper describes the integrated proposed system that can be based on the use of GEO satellites and SPS stations with a new distribution of microwave bands that allows the following advantages to be achieved:

1. Minimize the delay in user communication via interlinks between SPS (SCP) stations and a special algorithm for calculating the optimal way of connecting users via SPS-SPS stations or SPS-GEO-SPS inter-link networks;
2. User communication via inter-links between SPS stations and a special algorithm for calculating the optimal user connection method using SPS-SPS stations or SPS-GEO-SPS inter-linls;
3. Reduce propagation losses by using multi-point antennas on the GEO satellite and thereby efficient energy consumption of the satellite, which exteds tt lifetime;
4. A certain system based on such an inter-link structure does not need to use handover technology because such a structure for the use of GEO satellites and SPS stations is fully synchronized with the rotation period of the Earth;
5. Due to the use of SPS stations that are located closer to the ground and the antenna, the Ku, K and Ka-bands can be used to reduce the energy consumption for mobile satellite terminals due to the short signal propagation distance;
6. This inter-link structure can be integrated with already deployed GEO satellites in the Earth's GEO orbit with the deployment of additional SPS stations; and
7. Such inter-link solutions are profitable due to the possibility of reusing SPS stations, which can be grounded at any time for repairs and re-equipment purposes.

Otherwise, SPS stations can be used as a multifunctional platforms for other purposes, such as space CNS and ICT, mobile tracking and detecting systems, meteorological and Earth observations, remote sensing, etc.

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