Observer Interface Analysis for Standardization to a Cloud Based Real-Time Space Situational Awareness (SSA)

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ABSTRACT

The interface analysis from an observer of space objects makes a standard necessary. This standardized dataset serves as input for a cloud based service, which aimed for a near real-time Space Situational Awareness (SSA) system. The system contains all advantages of a cloud based solution, like redundancy, scalability and an easy way to distribute information. For the standard based on the interface analysis of the observer, the information can be separated in three parts. One part is the information about the observer e.g. a ground station. The next part is the information about the sensors that are used by the observer. And the last part is the data from the detected object. Backbone of the SSA System is the cloud based service which includes the consistency check for the observed objects, a database for the objects, the algorithms and analysis as well as the visualization of the results. This paper also provides an approximation of the needed computational power, data storage and a financial approach to deliver this service to a broad community. In this context cloud means, neither the user nor the observer has to think about the infrastructure of the calculation environment. The decision if the IT-infrastructure will be built by a conglomerate of different nations or rented on the marked should be based on an efficiency analysis. Also combinations are possible like starting on a rented cloud and then go to a private cloud owned by the government. One of the advantages of a cloud solution is the scalability. There are about 3000 satellites in space, 900 of them are active, and in total there are about ~17.000 detected space objects orbiting earth. But for the computation it is not a N_{active} to N problem it is more N_{active} to $N_{apo-peri}$ quantity of N_{all}. Instead of 15.3 million possible collisions to calculate a computation of only approx. 2.3 million possible collisions must be done. In general, this Space Situational Awareness System can be used as a tool for satellite system owner for collision avoidance.

Keywords: Space Situational Awareness, ground station, input data, cloud computing

1. INTRODUCTION

Satellites have become more and more a critical infrastructure for the industrial and technological driven countries. Modern societies depend on space based services like navigation, communication or earth observation. But one danger in the thread scenario beside the natural environment is space debris. At this moment there is a so called TLE catalog provided by the United States Space Surveillance Network (US SSN) a part of the United States Strategic Command (USSTRACOM). This Catalog based on observation of 44 sensors (15 optical and 29 radar) located in 25 sites worldwide. The Catalog has about 15,000 entries and store these information's in an object related Two Line Element. Fig. 1 showed an overview about the amount and age of the TLE-set´s in the catalog from 24.01.2013. The oldest epoch in this catalog is about 29 days old.

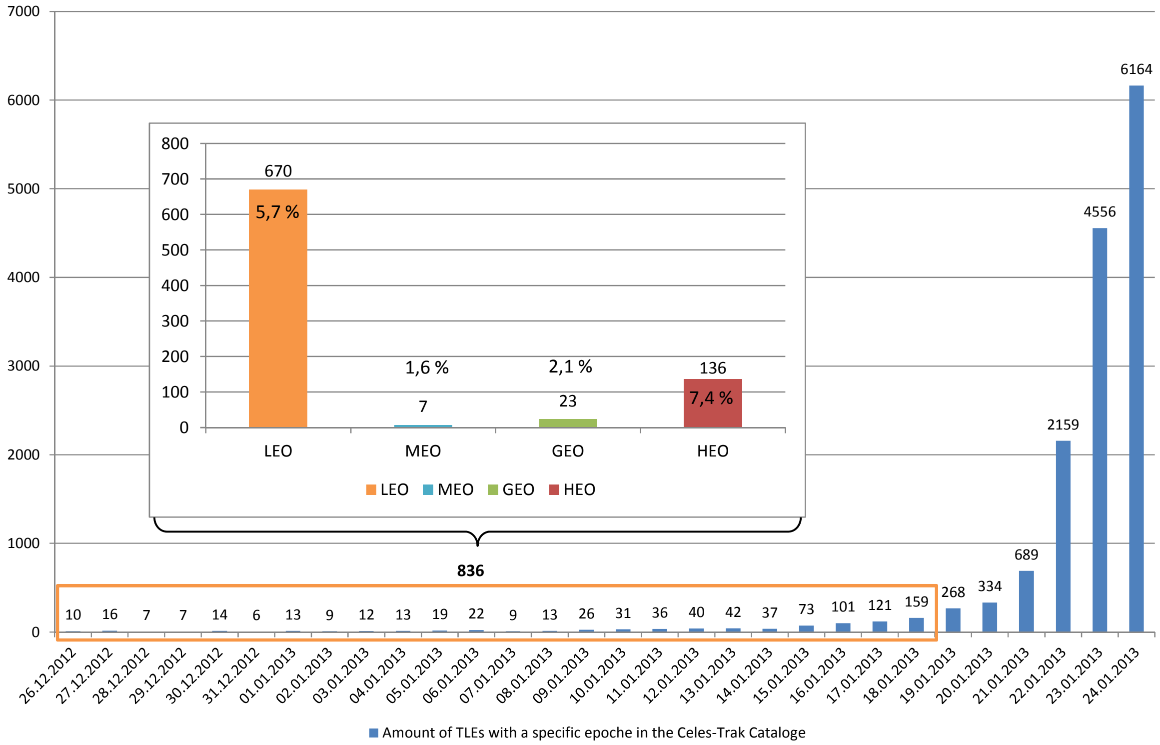

Fig. 1: Age of the TLE data and the distribution over the orbits of older TLEs

To increase the detection capability of such a network it is necessary to increase the number of observers. Other countries like Germany, France, China or Russia have also ground stations to observe objects in space. Beside the political empowerment there are a small amount of technical issues to combine all these observation information.

Fig. 2 give a schema of the whole idea. Different sensors and satellite owner deliver orbit information about objects in space.

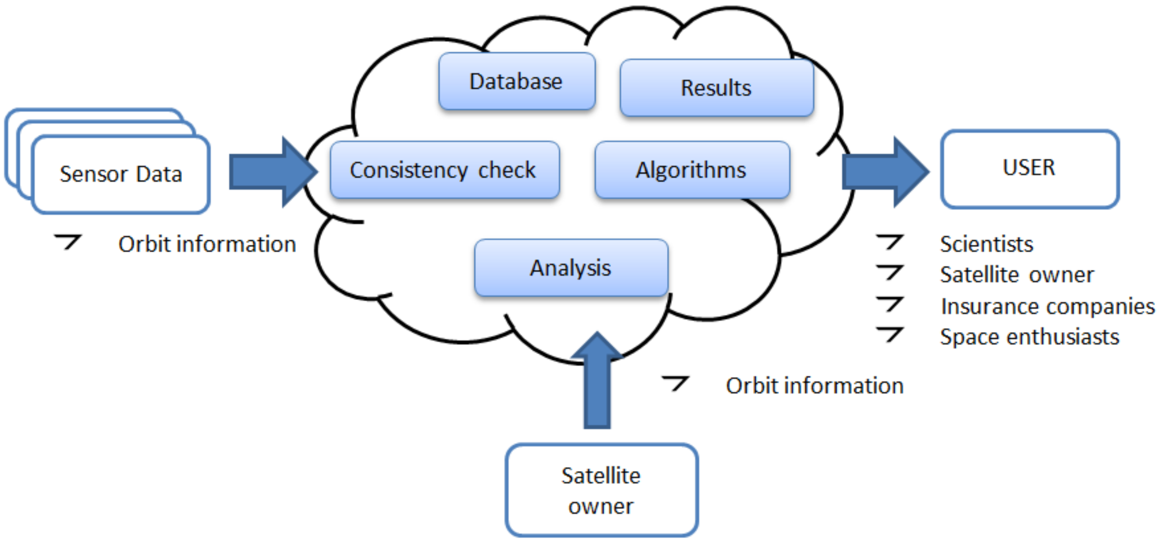

Fig. 2: Schema of the cloud based SSA

After a consistency check an object catalog will be created like the one from the US SSN but with observation based on about 80 ground stations. After this a cloud based conjunction analysis can be achieved. And the results can be presented to the users of the system.

The next chapters are about the interface analysis, the approximations for the computational power and at least the financial models.

2. INTERFACE ANALYSIS

For the standardization of the input data for the cloud the following questions must be answered by the standard.

- What kind of sensors exists? (Sensor description?)
- Are they all terrestrial?
- Where are the sensors located?
- What is the field of view?
- Who is the operator of the system?
- What kind of objects can be detected by the sensor?
- What is the resolution?
- Is the System track able?
- When did the observation happen?
- Is the detected object a new one or already known?
- Is the System manual driven?
- Is the station able to generate valid TLE-DATA?
- …

Analyzing the questions, they can be separated information about the ground station / the observer, information about the sensor and in information about the detected object. This lead to Tables like Tab. 1, Tab. 2 and Tab. 3.

Tab. 1: Observer information

Observer information	
OBS_ID	12345_C
Lat [°]	14.300233
Long [°]	-149.190964
Height [m]	0
Int_ID	N/A
Country	USA
Owner	NASA
Sensors	RADAR, Optical, LASER
Operation status	Semi-automatic
Point of Contact	001 5555 12345 Mr. John Doe
Operation times	24/7
Obs-Level	Expert (10)
Comment	Leave a comment

The Tab. 1 contains all the information about the observer with a specific observer ID (OBS_ID). The Position represented in latitude, longitude and height. As well as an international ID the country and the representing organization as an owner included with a point of contact, the operation times and the operation status. Also interesting are the kind of sensors which are installed on this site (optical, radar, …). For a consistency check a skill level of the observer can be handy.

Tab. 2: Sensor description

Sensor description	
OBS_ID	12345_C
Sensor_ID	A
Lat [°]	14.300233
Long [°]	-149.190984
Height [m]	50.153
Min Elevation	
Max Elevation	
FoV	
Resolution	
Comment	

The sensor description in Tab. 2 gives all the information about the sensor. First the observer ID. The letter stands for the number of sensors at the ground station. The Position represented in latitude, longitude and height. The min and max elevation angle for acquisition of sight and loss of sight as well as the field of view and the resolution.

Tab. 3: Object information

Object information	
OBS_ID	12345_C; 22542_B
Dates UTC (newest first)	
NORAD_ID	N/A
Int_ID	N/A
TLE1	
TLE2	
Pos. Date UTC XYZ	
State Vector Date UTC XYZ X'Y'Z'	
Date UTC Azimuth$_{topo}$ Elevation$_{topo}$ Range$_{topo}$	
Object Type	debris
New	Y
Size	
Mass	
OBS validate value	
Comment	

The last table, Tab. 3, contains the information about the observed object. Every observer of the object is listed under OBS_ID related to the time of observation. If an object is already identified it can carry an NORAD_ID and the associated international ID (Int_ID). Depending on the capabilities of the observer the table can include a processed TLE-set, a time related position, a state vector or a topocentric azimuth, elevation and range information. It is also possible to describe the object type, if the Object is new, old or unknown, the size and the approx. mass. The OBS validate value represents the reliability of the observation. It could contain the number of observations, the date of the last contact the experience level of the observer.

Every table has a field for comments.

3. CLOUD BASED COMPUTATION

The second step after the interface evaluation is a cloud based computation of all analysis and the storage of Information. In this context cloud means, neither the use nor the observer has to think about the infrastructure of the calculation environment. The decision if the IT-infrastructure will be built by a conglomerate of different nations or rented on the marked should base on an efficiency analysis. Also it is possible to think of an approach which starts on a rented cloud and then go to a private cloud owned by the government. This is truly one of the advantages of a cloud solution, it is scalable. To come to the financial numbers we have to approximate the computing power. There are nearly about 3000 Satellites in space, 900 of them are active, and in total there are about ~17.000 detected space objects orbiting earth. But for the computation it is not a N_{active} to N problem it is more N_{active} to $N_{apo-peri} \subset N_{all}$ as seen in Fig. 3. The orbit of interest is described in Fig. 3 (e.g. an active Satellite), the smaller inner orbit and the bigger outer Orbit has no interaction with the orbit of interest. Only the crossing orbits of the possible collision partners interact with the orbit of interest. Instead of 15.3 million possible collisions to calculate a computation of only approx. 2.3 million possible collisions must be done.

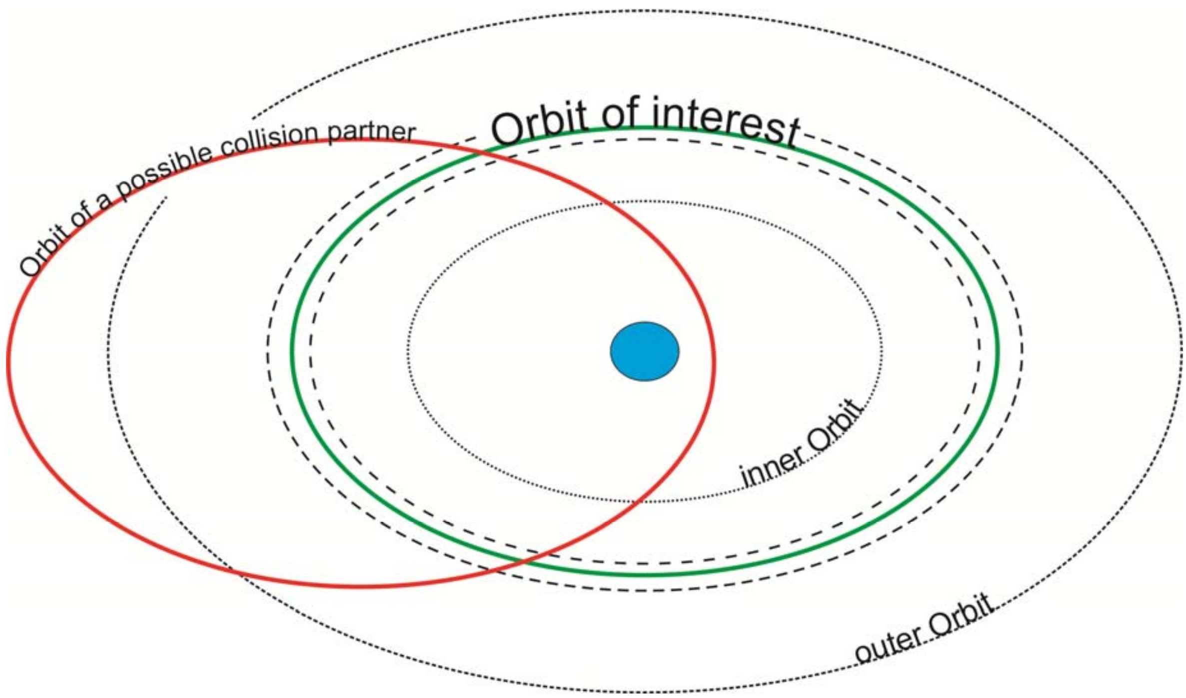

Fig. 3: Constellation between an orbit of interest and a possible collision partner

Fig. 4 shows the numbers of possible collision partners by active satellites in relation to their orbits. A lot of GEO-satellites have only a few potential collision partners. A look to the MEO-satellites shows a similar picture. The LEO-satellites have an increased number of possible collision partners.

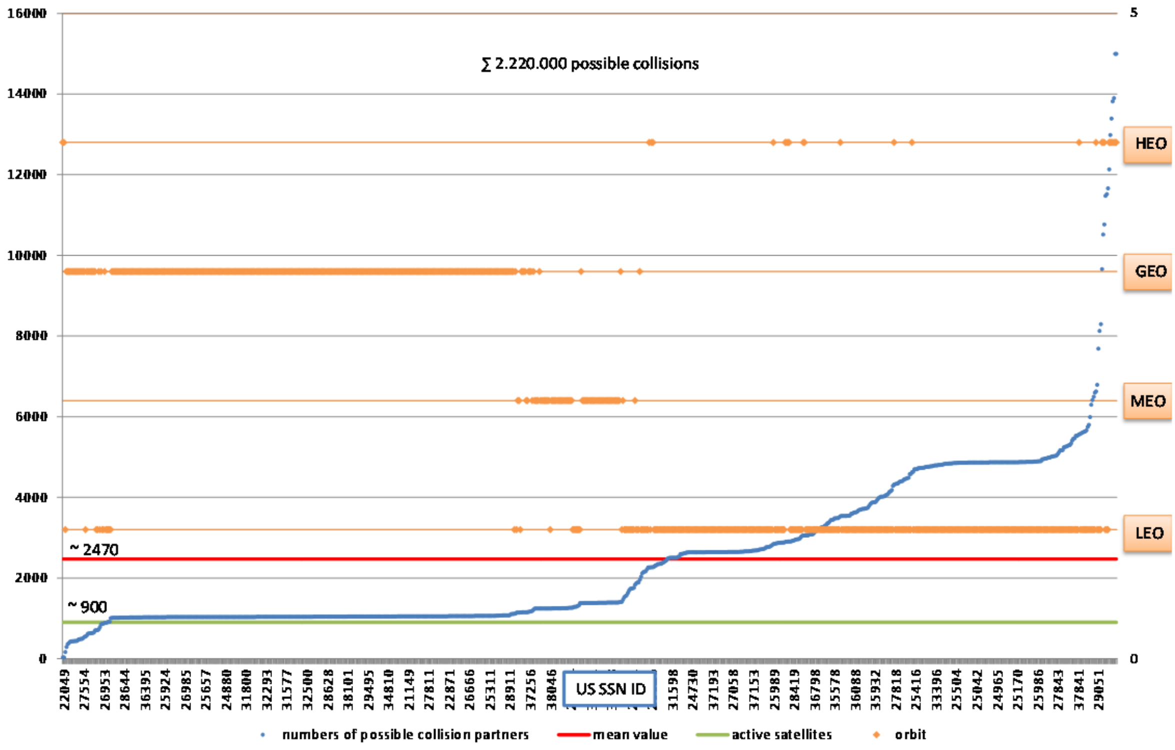

Fig. 4: Numbers of possible collision partners by active satellites (24.01.2013) and its distribution to their particular orbits

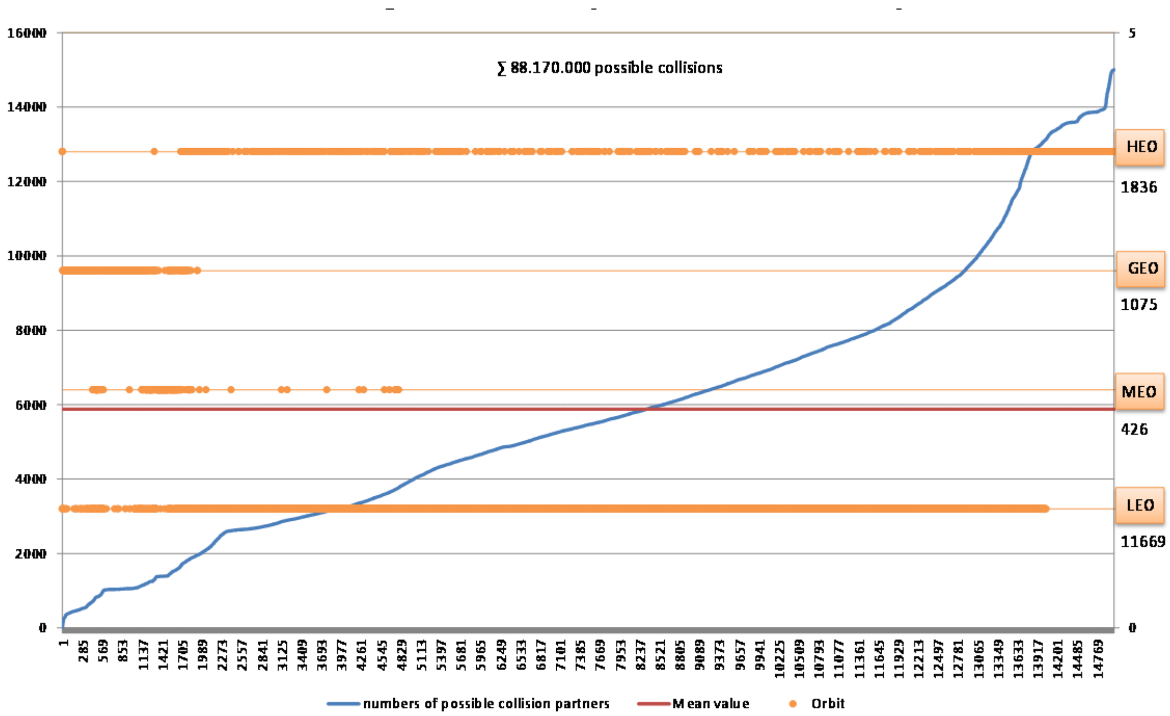

Fig. 5: Numbers of possible collision partners by any object in the space track catalog (24.01.2013)

3.1 Approximation of computer power

For the approximation of the computer power and the data storage, which will lead to a cost model, a look at the dataflow is necessary, which is shown in Fig. 6.

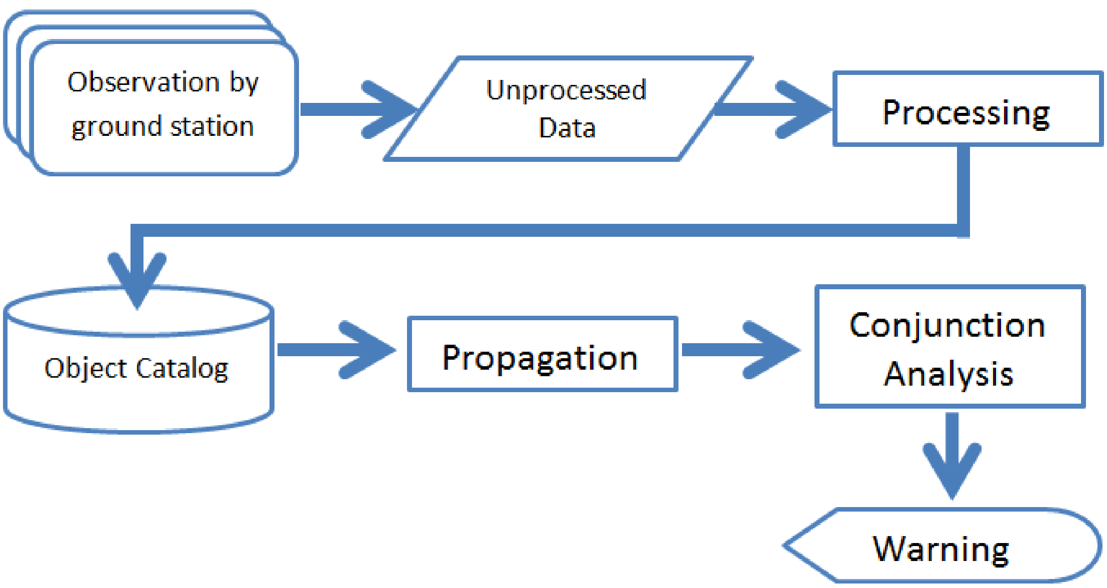

Fig. 6: Dataflow model for cloud based space situational awareness

Every ground station generate, as described, a standardized dataset per observation with a size of ~ 10 Kbyte. Depending on the location, the sensor type and the operation times, the facility can generate from 100 to 5000 observations per day. At this moment there are about 77 ground stations active and 42 of them are radar sensors. This observation data is an amount of 77 Mbyte at the lower boarder to 3.8 Gbyte at the upper boarder per Day.
The processing of the unprocessed data is more likely a validating of the data. The grade of processing complexity is hardly to estimate. It is mainly driven by the numbers of observation and if a loop-back with manual assistant is necessary e.g. to acknowledge that one "new" observed object is an old one. Some other similar use cases can occur. The result of this processing is a validated actual object Catalog. If for each of the 18.000 objects five TLE-datasets per day will be generated after one year the Database has a size of 5 to 6 Gbyte. This data leads to an overview of the situation. How many track able objects are in space on which orbit and how old is the information about the object. Further for every object of interest e.g. active satellites a conjunction analysis with the whole object catalog can be done. This can be used as a warning system for satellite system owner for means of collision avoidance measurements.
A Catalog with 15.000 objects vs. a Leo satellite (4 to 6 thousand possible collision partners) need about 23 minutes on one core of a i7 870 @ 2.93 GHz. On eight cores the calculation need six minutes. Further Approximation about the needed computational time is seen in Tab. 4.

Tab. 4: time for computation of an object catalog with 15000 entrees

Amount of objects	Cores (i7 870 @2.93 Ghz)	Computation time
1	1	23 min*
1	8	6 min*
900	1	8510 min**
900	8	2220 min**
900	256	~60 min **
15000	1	337985 min**
15000	8	88170 min**

* Measurement

** Approximation by the amount of possible collision partners

With these assumptions there is a need of:

- ~ 1.5 Tbyte for traffic in a Year.
- ~ 6 Gbyte data storage in a Year
- ~ 256 CPU Cores

In a commercial cloud like Amazon Elastic Compute Cloud (EC2) this computation costs $ 10,000 to $ 20,000 per month depending on the Operating System (Linux / Windows) with 256 instances “High-CPU Extra Large” for 2 hours / day and 5 instances “Large” at 100% utilization. Also covered in this price are 10 GByte / Day traffic in and out.

4. MODEL OF PAYMENT

The first assumption is that the ground stations already exists and are financed by other institutions. This model has its focus on the funding of the cloud based service. The reason of this cloud based service is to protect spacecraft’s from debris. One philosophy approach is to determine who is responsible for the debris and let him pay. But by the nature of the thing it is hard to tell who is responsible and which part of debris belongs to whom. The other approach aims for the space user, the owner of the satellites. They have a strong interest to protect their systems. Following this thesis there are ~ 900 satellites owned by different protagonist who could share the cost of such a system. Based on the space law the Convention on International Liability for Damage Caused by Space Objects it is also the responsibility of a country to protect space Systems to prevent other satellites from harm [1]. The estimation of the total project costs listed in

Tab. 5: Estimation of the project cost

Item	amount	Cost per year [$]
general project costs	1	1,000,000.- (10 years)
personal	3	200,000.-
cloud service	1	240,000.-
$\sum$		**1,440,000.-**

With~ 900 active satellites, the rate per satellite and year is 1,600 $.

The participants in the space business with active satellites are showed in the pie chart Fig. 7 for each continent.

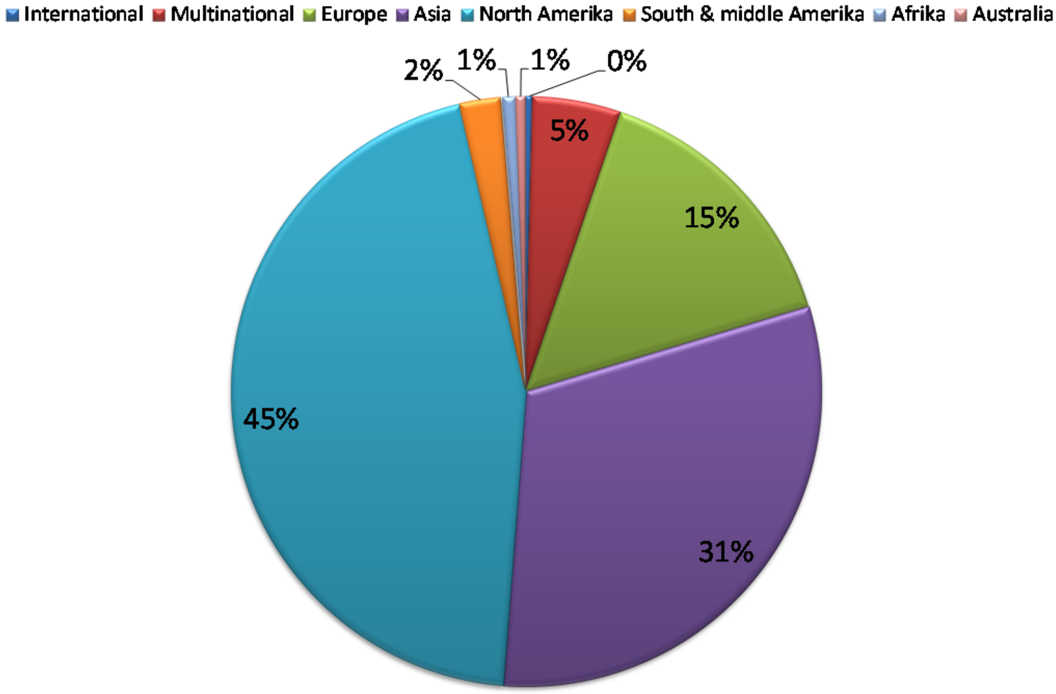

Fig. 7: Distribution of the owner of active satellites by continent

The USA has about 455 active satellites, Europe has 159 active satellites and China has 86. With this model the USA has to pay $ 728,000 Europe $ 254,400 and China $ 137,600 per year for this system. Every year a new calculation of the rates has to be done depending on the active satellites in space. The costs of a satellite system with a designed lifetime of 10 years will increases by $ 16,000. This is a very little amount of money to protect a multi-million dollar system.

5. CONCLUSION

With a standard output for the observing station it is easy to increase the detection capability of space debris and with a cloud based SSA service a near real-time can be established to protect space systems like satellites. The technological risk is very low because all the single components already exist. They “only” must be put together. The approximation of the computer power delivered a financial frame that can be achieved. The only show stopper is the political environment.

6. REFERENCES.

[1] *United Nations Treaties and Principles On Outer Space, related General Assembly resolutions and other documents*, Part one, Page 11

FURTHER INFORMATIONS.

[1] Steven Johnston, Hugh Lewis, Elizabeth Hart, Adam White, Neil O'Brien, Kenji Takeda, Simon Cox: *Space Situational Awareness using a cloud based architecture,* Conference in Bejing 2011 Space Sustainability

[2] Timothy Haynie: *Cloud Based Space Situational Awareness* http://datatactics.blogspot.de/2012/11/space-weather-is-as-dynamic-complexand.html (15.02.2013)