GNSS based services on cloud environment

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***Abstract*—The ionosphere is the single largest contributor to the GNSS (Global Navigation Satellite System) error budget and ionospheric scintillation (IS) in particular is one of its most harmful effects. The Ground Based Scintillation Climatology (GBSC) has been recently developed by INGV as a software tool to identify the main areas of the ionosphere in which IS is more likely to occur. Due to the high computational load required, GBSC is currently used only for scientific, offline, studies and not as a real time service. Recently, a collaboration was initiated between ISMB and INGV in order to identify which cloud service model (IaaS, PaaS or SaaS) is most suitable for implementing the GBSC technique within the cloud computing environment. The aims of this joined effort are twofold: i) to optimize the computational resources allocation strategy/plan for the GBSC service, ii) to fine tune the algorithm for dynamic and real time application, towards a service contributing to high precision professional applications for the GNSS-reliant business sectors. Preliminary result of the implementation of GBSC within the cloud environment will be shown.**

***Keywords*-cloud computing; virtualization; space weather; GNSS; ionospheric scintillation;**

I. Introduction

A. Space Weather and GNSS

In general, it can be said that Space Weather is the physical and phenomenological state of natural space environment. According to [1], Space Weather is defined as the solar driven variability in particle and electromagnetic conditions of the near-Earth space that may harm the performance of ground-based and space-borne technology. In any case, the associated discipline aims, through observation, monitoring, analysis and modeling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them. Space Weather presents climatological features which vary over time scales ranging from days (i.e. diurnal variations resulting from the rotation of the Earth) to the 11-year solar cycle as well as longer periods such as in the case of grand solar maxima and minima [2]. The main focus is then on the forecasting and nowcasting of its potential impacts on biological and technological systems.

With two fully operational systems, i.e. the American *GPS* and Russian *GLONASS*, and two more on deployment state, the European *GALILEO* and the Chinese *Compass*, Global Navigation Satellite Systems (GNSSs) have recently achieved a huge penetration in many different business sectors that rely on precise positioning for their business processes. This growing dependence of modern societies on such complex technologies comes with a price. The vulnerability of GNSS on Space Weather has also left the businesses exposed to its effects and more specifically the ionosphere [3].

From the physics point of view, satellite based technologies are particularly threaten by Space Weather, first because they are exposed to bursts of high energy particles rapidly deteriorating or directly disrupting the hardware, and second from outages in which they could occur as a consequence of the turbulence induced in the ionosphere, i.e. the upper ionized layer of Earth's atmosphere. At the application level, the sole presence of the ionosphere induces a delay which is the main contribution to the GNSS error budget on positioning. Moreover, under disturbed condition of the near Earth space induced by space weather events, the robustness and availability of the GNSS signals are also threatened (see, e.g. [4]). In case of space weather events, the state of the ionosphere can be very erratic, depending on the prevailing solar activity and on the geomagnetic field conditions. Trans-ionospheric signals, like those from GNSS, can encounter sudden fluctuations of phase and amplitude induced by random variations of the refractive index of the ionosphere due to ionospheric irregularities. This kind fluctuations is called ionospheric scintillation (IS, see, e.g., [5] and references therein). The IS is real threats and, under extreme conditions such as in the case of a solar superstorm, GNSS can become partially or completely inoperable from one up to three days [6].

However, as Hapgood argues in his recent report on Space Weather [7], the risks posed by Space Weather also present a range of business opportunities. The mitigation of businesses exposure to space weather risks through specialist services, and incorporation of space weather awareness into the business processes are two such examples. Previous studies from the European Space Agency (ESA) and more specically the market survey carried out in 2000-2001, by Astrium, also found a strong need for such services, focused on specific customer needs [8].

In this paper we pay our attention on a novel solution for the study of IS, known as Ground Based Scintillation Climatology (GBSC), [9], [10], [11]. This technique is able to identify the ionospheric sectors in which the scintillations are more likely to occur, reproduce it in two dimensional maps using different systems and further investigate the scintillation in relation to the main ionospheric parameters, like the total electron content (TEC) and its rate of change (ROT). GBSC is also able to map the main GNSS signal quality and features parameters, like the carrier to noise ratio and the standard deviation of the code carrier divergence. Due to the high computational load required, GBSC is nowadays used only for scientific, offline, studies and not as a real time service.

To overcome this issue, the GBSC technique has recently been implemented within the cloud computing environment. The aims of this joined effort are twofold. On one side to optimize the computational resources allocation strategy/plan for the GBSC service, while on the other to fine tune the algorithm as a real-time application, adaptable to varying degrees of user loads, towards a service contributing to safety-of-life and high precision professional applications for the GNSS-reliant business sectors. This paper presents the early stages of this integration endeavour, together with some preliminary results, related to computational performance, obtained after implementing and executing the GBSC on a cloud environment.

B. Cloud Computing Approach

Cloud Computing has been considered as a better alternative to Grid Computing for data-intensive scientific applications. This is due to cheaper, on demand, resource provisioning and easier customizability of the environment in comparison to the Grid one. Therefore, many researchers are progressively moving towards the adoption of cloud infrastructures, either private, public or hybrid. They seek for services and platforms that provide data storage and analysis, application development, workflow management and automatic resource scaling. Cloud approaches provide various advantages, including the customization of environments which enable to run applications and try out new computing environments without significant modifications, the ability to quickly surge resources to address more demanding problems, and the benefits that arise from increased economies of scale. The virtualization technology which is the base of Cloud Computing, it allows running several concurrent Operating System (Windows, Linux, etc.) instances inside a single physical machine (called host). The physical device is divided into multiple isolated virtual environments called guest system [12]. A Virtual Machine (VM) is an instance of the physical machine and gives users the illusion of accessing the physical machine directly and each VM is a fully protected and isolated copy of the underlying system.

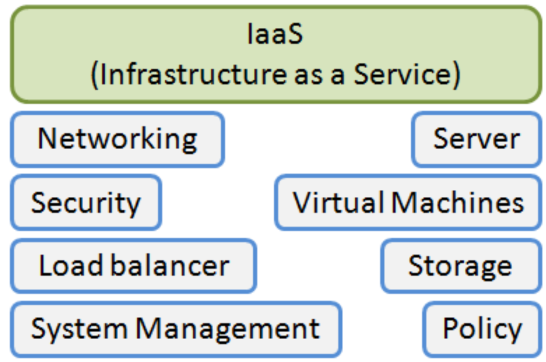

Figure 1. IaaS features

In our infrastructure each VM runs a distribution of Linux. Virtualization has several advantages, the most important are the power consumption reduction, better fault tolerance, improvement of time for device installation. Other benefits include a variety of security enhancements; improved service level management (such as for managing resource allocation against service levels for specific applications); the ability to more easily run legacy systems; greater flexibility in locating repository; and reduced hardware and software costs. Although there are three levels of services: Software as a Service (SaaS), Platform as a Service (Paas) and IaaS (Infrastructure as a Service) in this paper we focus our attention on IaaS level. It offers a virtualized infrastructure to their potential users by means of VM, an abstraction of a physical machine, that have predefined characteristics from a resource catalog. The Cloud platform deploys new virtual machines when the users ask for them and returns to the user complete control over them (see Figure 1). IaaS is offered in three models: private, public, and hybrid cloud [13]. Private cloud implies that the infrastructure resides at the customer; public cloud, is located at data center of Cloud Providers (e.g., Amazon Elastic Computing Cloud, Sun Cloud); and hybrid cloud is a combination of two models and even local infrastructure. In a Cloud environment, a user requests virtual resources over an unbound time period. The user can allocate new resources if needed and any unused ones are automatically freed. Given that Cloud computing offers virtual resources, the Cloud user can sometimes change the virtual hardware specifications of his running resources. For our purposes we used a private cloud, with a pool of virtual machines running on servers at our research institute, without requiring public cloud resources.

II. GBSC

The GBSC is currently able to ingest data from high sampling rate GNSS receivers for scintillation monitoring like the widely used GISTM (GPS for Ionospheric Scintillation and TEC Monitor [14], PolaRxS [15] and SCINTMON (SCINTillation MONitor receiver, http://gps.ece.cornell.edu/

rxdesign.php). By elaborating data acquired by those receiver, the GBSC is able to produce two kind of maps:

1) *Occumap*: maps of occurrence above user defined thresholds of the following parameters (if available): scintillation indices, see (S_4 and σ_Φ [16] and references therein for their definition), TEC, ROT, Carrier to noise, Code carrier standard deviation;
2) *Meanmap*: maps of mean value and standard deviation of the above mentioned parameters.

Maps are expressed in a bi-dimensional coordinate system combining two of the following variables:

- geographic coordinates: latitude and longitude;
- altitude adjusted corrected geomagnetic coordinates (AACGM, [17]);
- universal time;
- magnetic local time;
- azimuth;
- elevation.

Such maps are defined in bins whose size is selectable and expressed by projecting the investigated quantities at 350 km of height, assumed to be representative of the position of the electron density peak of the ionosphere. This is not the case of the horizontal coordinates, i.e. azimuth and elevation, that are defined with respect to the receiver position. Time interval, season and geospace conditions can be also selected to sort and characterize the selected map. The GBSC is fully written in *ROOT* [18], a framework for data processing developed at CERN laboratories (www.cern.ch), and it has been tested against the version 5.26/00. GBSC also requires a data preparation chain to make data ready to be ingested: the conversion to the so called *rootfiles* (see http://root.cern.ch/drupal/content/root-files-1 for further details). This data preparation chain is composed by a mixture of bash scripting routine to organize data in daily file per each receiver and IDL (http://www.exelisvis.com/language/en-us/productsservices/idl.aspx) routines to calculate the AACGM. This data preparation chain is not included in the timing tests here shown.

An example of GBSC maps is reported in Figure 2, where a *occumap* showing the percentage of occurrence of the phase scintillation index above 0.25 radians is shown in geographic coordinates over the Lampedusa (Italy, 35.52°N - 12.62°E) station, where a GISTM receiver managed by INGV is located (Figure 2a). A *meanmap* showing the standard deviation of the ROT acquired in the same conditions of figure 2a is shown in figure 2b. Both maps refer to the period 15 November 2011 to 5 December 2012. It is out of the scope of this paper to go deeper in the description of the presented parameters.

III. Cloud Infrastructure for GBSC Integration

To deliver cloud computing and storage, Infrastructure as a Service, we have built a private Cloud based on OpenNebula3.

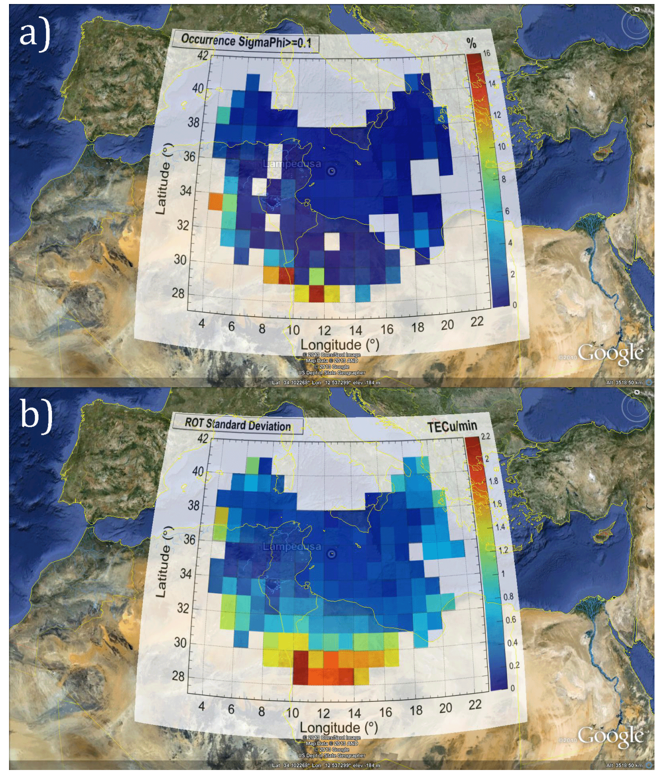

Figure 2. Example of *occumap* (a) and *meanmap* (b) calculated for the period 15 November 2011 to 5 December 2012 by using Lampedusa (Italy) receiver data.

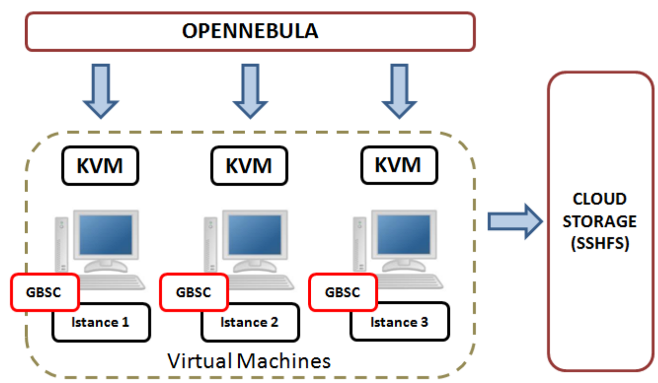

Figure 3. GBSC Cloud infrastructure

OpenNebula[19] is the open-source industry standard for data center virtualization, offering the most feature-rich, flexible solution for the comprehensive management of virtualized data centers to enable on-premise IaaS. Main features of virtualization management is the process of dealing with VM images. OpenNebula aims to be flexible enough to support as many different image storage configurations as possible. It can has two models of image storage and can organize the images uses the following concepts:

- Image Repositories, refer to any storage medium, local or remote, that hold the base images of the VMs.

- Virtual Machine Directory, is a directory on the cluster node where a VM is running. Deployment files for the hypervisor to boot the machine, checkpoints and images being used or saved, all of them specific to that VM will be placed into this directory.

In our platform configuration, these features have implemented:

- KVM (Kernel-based Virtual Machine)[20] is a complete virtualization technique for Linux. It offers full virtualization, where each Virtual Machine interacts with its own virtualized hardware allowing to run multiple virtual machines running unmodified Linux images. Each virtual machine has private virtualized hardware both network and disk.
- Based on elaboration requirements, Cloud Storage with SSHFS has been configured. The shared disk consists in a portion of storage exclusively used for experimentation. SSHFS stands for Secure Shell File System, it allows to mount a remote filesystem. Since trough the operating system we already have a secure tunnel to our server over SSH, it allows to store files securely on the shared disk. Using File System in User Space, it is able to achieve this without the need to load kernel modules a process which would require superuser privileges.

Next we present a test scenario, in which we aim to compare the timing performance of the GBSC on a local PC, i.e. not in a cloud environment, against different templates on virtual machines. The features of the local PC configuration are:

- Processor: 8x Intel(R) Core(TM) i7 CPU, 2.93GHz;
- Memory: 6072MB;
- Operating System: Ubuntu 12.04 LTS.

To perform the timing test, the input sample size has been evaluated by considering different number of days of data analyzed by the GISTM receiver located in Ny-Alesund (Svalbard, Norway, 78.92°N - 11.92°E) between July 2007 and August 2011 and made available by the eSWua database [21]. Table 1 summarizes the periods used as input for the GBSC, the corresponding sample sizes in terms of scintillation data (1 per minute) of the input and the corresponding times needed to produce the GBSC maps by the *meanmap* and *occumap* routines. Figure 4 shows the results of the timing test on the local PC of the two main routines of the GBSC as a function of the input sample size. The red curve is for the *occumap* routine calculating above 0.1 radians threshold occurrence, while the time necessary to the *meanmap* routine to calculate the corresponding mean and standard deviation value is represented by the blue curve. The slight difference in the two timing is expected and it is due to the fact that the mean and standard deviation value extraction (*meanmap*) in each bin of the GBSC map is a single-step procedure, while the occurrence in the *occumap*, being a ratio between two numbers, is a two-steps procedure.

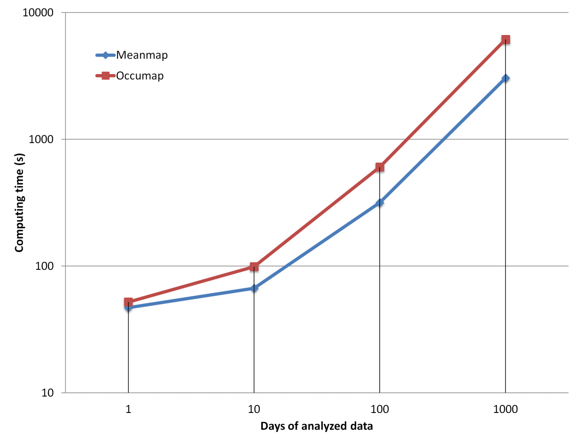

Figure 4. Timing test of the two main routines of the GBSC on the local PC as a function of the input sample size.

The timing performances of the local configuration has been tested against 3 configurations of the cloud templates. Table 2 summarizes the number of vCPU and the amount of RAM allocated for each template, together with the corresponding name of the template.

Name	# vCPU	RAM (GB)
Power4.small	4	8
Power6.small	6	16
Power12.small	12	16

Table II
TEMPLATE CONFIGURATION OF THE TESTED VIRTUAL MACHINES.

To compare the performances of each template against the local PC, the relative time R_T has been investigated, here defined as follows:

$$R_T = \frac{T_{power} - T_{local}}{T_{power}}$$

where T_{power} is the time in seconds measured for the given template and T_{local} is those measured for the local PC. Such ratio is expressed in percent and it $is = 0$ when the time needed is the same, while it $is > 0$ when the template needs more time than local PC. Table III and Table IV summarize the above mentioned relative timing for *meanmap* and *occumap* respectively sorted for all templates and input sample size and in figures 5 and 6 the corresponding plots are shown.

Figures 5 and 6 shows that every template is slower than local configuration. The better performance on larger dataset is given by Power12.medium.

Days of analyzed data	Input sample size	Start date (YYMMDD)	End Date (YYMMDD)	*Meanmap* running time (s)	*Occumap* running time (s)
1	1.E+04	080115	080115	47	52
10	1.E+05	080115	080124	67	99
100	1.E+06	080115	080423	317	604
1000	1.E+07	070701	110817	3049	6134

Table I
SUMMARY OF THE INPUT TO THE GBSC AND CORRESPONDING TIMING ON THE LOCAL PC CONFIGURATION.

Days of analyzed data	R_T Local vs. Power4.small (%)	R_T Local vs. Power12.medium (%)	R_T Local vs. Power6.medium (%)
1	11.3	2.1	7.8
10	34.3	33.0	34.3
100	21.1	25.6	26.3
1000	18.3	6.3	18.6

Table III
SUMMARY OF THE R_T FOR THE *meanmap* ROUTINE OF EACH TEMPLATE CONFIGURATION AGAINST LOCAL PC CONFIGURATION.

Days of analyzed data	R_T Local vs. Power4.small (%)	R_T Local vs. Power12.medium (%)	R_T Local vs. Power6.medium (%)
1	1.9	0.0	3.7
10	30.8	29.3	18.9
100	21.6	26.1	25.2
1000	15.8	5.4	19.5

Table IV
SUMMARY OF THE R_T FOR THE *occumap* ROUTINE OF EACH TEMPLATE CONFIGURATION AGAINST LOCAL PC CONFIGURATION.

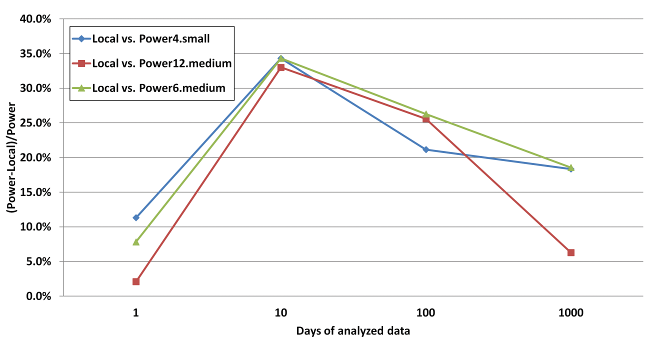

Figure 5. Relative timing R_T for the *meanmap* and each template configuration against local PC configuration.

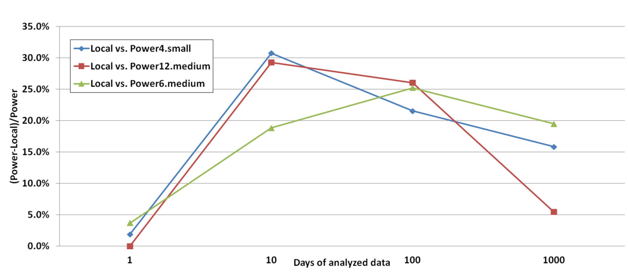

Figure 6. Relative timing R_T for the *occumap* and each template configuration against local PC configuration.

IV. REMARKS

GBSC is currently used only for scientific purposes and it has recently been implemented on the Cloud. The authors envision that such a combination could provide a practical solution to the threats of ionosphere on safety-critical applications, relying on high precision GNSS services. During experimentation it has been monitored the power consumption for each vCPU and the use of memory (RAM) for each virtual machine during the excution of the GBSC application. The authors observed that GBSC runs as a monolithic process without using the multithreading capability of the instances. This explains two aspects:

- first, the fact that, even though power scaling up was attempted using multiple vCPUs, no significant performance improvement was observed.
- second, researchers can use the Power4.small configuration (4vCPU/8GB) to run the GBSC, considering that this environment is configured to run in single-thread mode.

Finally, to take advantage of the Cloud virtualization and gain in terms of computational performance, the GBSC needs to be converted into a multi-threaded application.

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