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Measurement and Modelling of PlanetLab Network Impairments for Fed4FIRE's GEO-Cloud Experiment

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***Abstract*—Earth Observation with optical satellites is a key field in the space sector. In the last decade optical satellites technologically evolved to increase the resolution of the images recorded of the Earth surface. These systems acquire massive data from Earth recordings, and traditional data centers present some limitations. Cloud computing can overcome those limitations and increase the flexibility, scalability and on demand use of resources for processing, storage and distribution of geo-data. Such a model based in cloud computing highly depends on the network topology and on the network impairments. In this work we used PlanetLab Europe and PlanetLab Central to obtain realistic models of the network impairments to be implemented in the GEO-Cloud experiment deployed in Fed4FIRE, whose major objective is to value if future internet technologies can improve current operational Earth Observation systems.**

I. INTRODUCTION

In the last decade, remote sensing applied to Earth Observation (EO) with optical satellites was a key field in the space industry. New platforms with higher resolution payloads were developed and put in orbit, and a new paradigm arose in the space system design: the use of distributed system. As a consequence, the volume of generated imagery data per day drastically increased becoming a problem the treatment of high amounts of Earth Observation recordings with traditional data centers. Cloud technologies can provide an alternative to traditional on premises data centers, because cloud computing is flexible, scalable, works on demand and it can be used as a distribution channel through the Web [1].

In order to analyze the potential of cloud technologies applied to Earth Observation emerged the GEO-Cloud experiment [2], which simulates as realistically as possible the behaviour of a complete Earth Observation system by using cloud computing to process, store and distribute satellite imagery through high added value services on line, with the objective of evaluating if Future Internet technologies provide viable solutions to be implemented in the Earth Observation field. GEO-Cloud is implemented in Fed4FIRE [3]. It is part of the FP7 Fed4FIRE project [3] (project number 318389). It is constituted of the following modules: i) a simulator of a constellation of 17 optical satellites (implemented in Virtual Wall [4]); ii) a simulator of a network of 12 ground stations distributed around the world to download recordings of the complete Earth's land mass in a daily basis, (implemented in Virtual Wall); iii) a novel data center architecture implemented in cloud which involves an IaaS (infrastructure as a service) with specific image processing software, an Archive and Catalogue, an Image Distribution and Visualization module providing web services and an orchestrator managing the whole data center (implemented in BonFIRE [5]), and iv) simulated users making requests of the web services provided by the platform (implemented in Virtual Wall). Topology networks were designed between the ground stations simulator and the BonFIRE multi-cloud testbed and between the BonFIRE multi-cloud testbed and the simulated end user to emulate the real behaviour of the network. To model those networks we used PlanetLab Europe and Central [6]. PlanetLab's nodes in the same location of the ground stations, were selected. The experiment consisted of measuring the impairments of the network connecting the selected nodes with a node representing BonFIRE. The objective was to model the impairments to implement them in the networks connecting the simulators implemented in Virtual Wall and the cloud in BonFIRE.

In this paper we present the experiment done in PlanetLab and the models of the networks' impairments that were obtained and that will be implemented in the networks connecting Virtual Wall and BonFIRE to realistically simulate the complete Earth Observation system. PlanetLab offers the possibility of testing real networks. We used this characteristic to measure the real impairments of the networks tested. The experiment then consists of communicating 12 real nodes representing the ground stations (the nearest PlanetLab node to the real ground station was selected) and the end users distributed around the world (we selected 31 nodes from different 31 countries) with a node representing the cloud (located at INRIA) to measure the real impairments of the networks and to implement a realistic model of the communications.

II. SYSTEM MODELLING

The real system is modeled into three main components: i) a network of ground stations acquiring imagery data from a constellation of optical satellites, ii) a cloud infrastructure that ingests the data from the ground stations, processes it, stores it and distributes it through web services and iii) end users around the world accessing to the web services offered. The system can be divided into two layers:

1. Layer 1 is constituted by 12 ground stations connecting with a cloud infrastructure. 12 ground stations are required to download all the data acquired by the satellites: images of the whole land mass on Earth at 6.7m GSD acquired in a daily basis; this is more than 20TBytes of data per day. The design of the ground stations networks also takes into account a) the location of each ground station, b) the duration of the accesses of the 17 satellites in constellation required to acquire the data, and c) the data parameters (compression rate,

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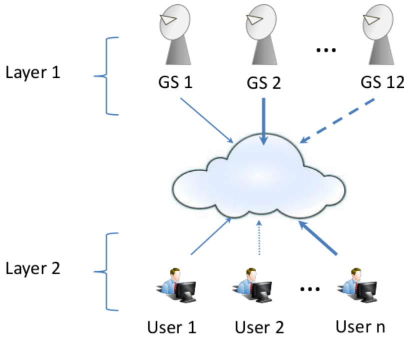

Fig. 1. System Description.

digitalization, number of bands among others). The ground stations communicate with a cloud infrastructure.

2. Layer 2 is constituted by the end users accessing the web services implemented in cloud. These users are distributed around the world and can be governments, emergency services, media and individuals among others.

From the previous layers two networks can be identified: the network between the ground stations and the cloud and the network between the end users and the cloud. The system and the interconnections between components is depicted in Figure 1. The arrows with different line types represent that every connection can have different characteristics and impairments.

We define the network in function of the bandwidth, the latency and the loss rate.

III. EXPERIMENT DESCRIPTION

A. *Platforms and Tools Description*

The experiment presented in this work was completely carried out in PlanetLab. PlanetLab is a global research network that supports the development of new network services [6]. It is split into two platforms: PlanetLab Europe that contains the European nodes and PlanetLab Central which contains the nodes located outside Europe. We used nodes from both of them.

To implement and deploy the experiment we used the following tools:

1. NEPI [7]: It is a Python-based language library [8] used to design and easily run network experiments on network evaluation platforms. It facilitates the definition of the experiment workflow, the automatic deployment of the experiment, resource control and result collection; and has the functionalities of automatic provisioning of resources and automatic deployment of the experiment. In the experiment NEPI is used to provision the nodes and execute the whole experiment.

2. Iperf [9]: It is a tool used to measure the maximum TCP bandwidth, allowing the tuning of various parameters and UDP characteristics. Iperf reports bandwidth, delay jitter and datagram loss. This software allows any host to play the client and server roles. In the experiment, it is used to obtain the bandwidth with a step of one second when executed in TCP mode and the loss rate when executed in UDP mode. The nodes in Layer 1 and 2 are configured as clients and the cloud node as server. We used Iperf with default TCP values to simplify the experiment: 576 octets, maximum segment size, TCP window size client 648 kB and TCP window size server 85.3 kB.

3. Ping [10]: It is a software used to test if a host on an Internet Protocol is reachable. It measures the round-trip time for messages sent from the originating host to a destination host. In the experiment, it is used to measure the latency delivery of a package over the Internet between the nodes in Layer 1 and 2 and the central node.

B. *PlanetLab network design*

The model of the ground stations network, the cloud and the end users accessing the web services provided was simplified to a set of interconnected nodes. The network interconnecting the nodes was divided into two layers connected by a central node representing the cloud servers:

Layer 1: it represents the connections between 12 nodes representing the ground stations and a central node representing the cloud servers. The nearest nodes to the real location of the ground stations were selected. For the central node, a PlanetLab node at INRIA (France) was chosen to represent BonFIRE. In table I the PlanetLab selected nodes for layer 1, 2 and the central node (represented by *CN*) are shown. The nodes are numbered in ascending order in function of the distance to the central node, i.e. the closest node is the number 0 and the furthest the 37.

Layer 2: it represents the connection between the central node representing the cloud servers and the end users. 31 different nodes were selected in PlanetLab in 31 different countries. This allowed us to have a representative sample of global users accessing the web services.

C. *PlanetLab experiment design*

The experiment is designed to measure the impairments of the network designed in the previous subsection. Those impairments are required parameters in Virtual Wall to deploy a topology network in such a testbed. Then, in this experiment we measured latency, loss-rate and bandwidth. The deployment of the experiment was done with NEPI, in which Iperf and Ping were implemented to measure the impairments.

The experiment consisted of establishing communications between any node in layer 1 or layer 2 with the central node and measuring the previously described impairments. 21600 trials were done during 6 hours of the experiment execution in steps of one second for each pair of nodes, i.e. a node from layer 1 or 2 and the central node.

Once all the data was obtained for each pair of nodes, the results were plotted and fitted to extract the most representative model for each impairment.

IV. EXPERIMENT RESULTS

During the execution of the experiment 21600 communications were established between every node representing ground stations and users and the central node representing the cloud. The bandwidth, latency and loss rate were measured. In Figure 2 the 21600 samples acquired in the communication between the node 22 and the central node during 6 hours of continuous execution are represented in a normalized histogram. The data

TABLE I. Impairments measured between any node and the central node

Country	**Selected Node**	#	**Layer**	**BW μ** [Mbps]	**BW σ** [Mbps]	**Latency μ** [ms]	**Latency σ** [ms]	**Loss Rate** %
France	ple6.ipv6.lip6.fr	CN	1,2	N/A	N/A	N/A	N/A	N/A
France	inriarennes2.irisa.fr	0	2	7.261104	2.147249	0.273073	0.301535	0.041
Switzerland	planetlab2.unineuchatel.ch	1	2	6.064255	2.003282	14.745501	4.261593	0.040
Belgium	rochefort.infonet.fundp.ac.be	2	2	2.930276	0.927951	31.728539	47.203988	0.018
Spain	dplanet2.uoc.edu	3	2	2.969305	1.037486	45.529232	4.288186	0.148
Netherlands	planetlab1.cs.vu.nl	4	2	6.304907	2.102949	20.186817	7.702484	0.062
Spain	Planetlab2.dit.upm.es	5	1	15.594752	2.135783	27.197632	1.418612	0.005
Germany	planetlab02.tkn.tu-berlin.de	6	2	3.551883	1.385088	48.594328	5.097654	0.041
Italy	planet-lab-node1.netgroup.uniroma2.it	7	2	3.769356	1.258299	32.414597	7.345108	0.002
Czech Republic	planetlab1.cesnet.cz	8	2	4.922084	1.529851	27.521367	4.136220	0.001
United Kingdom	planetlab-2.imperial.ac.uk	9	2	5.441677	1.220430	17.093975	5.070244	0.005
Ireland	planetlab-node-01.ucd.ie	10	2	5.598359	1.728834	21.461830	4.278779	0.019
Portugal	planet1.servers.ua.pt	11	2	3.378253	1.191509	44.628323	5.033462	0.024
Hungary	planet2.elte.hu	12	2	4.167417	1.324835	35.037211	4.226534	0.004
Poland	ple2.dmcs.p.lodz.pl	13	2	3.426796	1.234180	53.103548	4.204185	0.003
Norway	planetlab1.cs.uit.no	14	1,2	7.319547	1.902225	59.234261	1.382998	0.006
Greece	planetlab1.ionio.gr	15	2	3.503871	1.291074	54.617127	4.565056	15.68
Sweden	planetlab2.s3.kth.se	16	2	3.240286	1.120166	45.069598	27.110465	0.096
Finland	planetlab-1.research.netlab.hut.fi	17	2	1.120166	1.280860	46.972868	5.292955	0.002
Israel	planetlab2.tau.ac.il	18	2	1.162643	0.326491	115.761992	54.158721	0.042
Israel	planet1.cs.huji.ac.il	19	1	2.292386	0.767429	70.081679	4.243071	0.001
Russian Federation	plab1.cs.msu.ru	20	2	1.724467	0.679163	193.865830	4.743945	0.000
Canada	planetlab-2.usask.ca	21	1,2	3.393083	0.446765	166.633028	1.364346	0.008
USA	Planetlab1.eecs.ucf.edu	22	1	3.360441	0.456685	154.209601	1.314127	0.010
United States	planetlab-04.cs.princeton.edu	23	2	2.153858	0.895294	156.166992	4.195054	0.003
China	planetlab1.buaa.edu.cn	24	1	2.215692	0.725628	242.297943	4.664348	0.024
China	planetlab1.cqupt.edu.cn	25	2	1.155372	0.444665	281.606416	10.965620	0.048
Brazil	planetlab1.pop-pa.rnp.br	26	1,2	1.568929	0.202462	317.206839	1.226175	0.076
Korea, Republic of	netapp7.cs.kookmin.ac.kr	27	2	1.139138	0.409484	302.908380	4.257230	0.001
Reunion Island, France	lim-planetlab-1.univ-reunion.fr	28	1	2.293113	0.599198	207.366898	3.150162	0.010
Thailand	ple2.ait.ac.th	29	2	1.441929	0.559358	224.464973	5.175334	0.018
Hong Kong	planetlab1.ie.cuhk.edu.hk	30	2	0.919341	0.412962	265.410228	5.815682	0.135
Japan	planet1.pnl.nitech.ac.jp	31	2	1.202864	0.457197	271.900753	4.865709	0.045
Malaysia	planetlab1.comp.nus.edu.sg	32	1	2.229976	0.400011	201.515008	13.641897	0.063
Singapore	planetlab1.comp.nus.edu.sg	33	2	1.349700	0.557100	210.717257	15.094545	0.005
Argentina	planet-lab2.itba.edu.ar	34	1	0.215605	0.044660	302.688424	1.628971	0.240
Argentina	planet-lab2.uba.ar	35	2	0.207834	0.045172	304.554190	4.977954	0.519
Australia	pl1.eng.monash.edu.au	36	1,2	1.331592	0.336595	375.310920	2.353757	0.004
New Zealand	planetlab1.cs.otago.ac.nz	37	1,2	1.422580	0.270814	340.900785	2.509783	0.204

CN Central Node, BW Bandwidth, μ mean, σ standard deviation, # Number.

accurately fits to a gaussian distribution with mean $3.28\ Mbps$ and standard deviation $0.446\ Mbps$. In Figure 3 a normalized histogram of the measured latency is represented. It was fitted with a gaussian distribution with mean $154.210\ ms$ and standard deviation $1.314\ ms$. The loss rate between this node and the central node was obtained to be 0.0096%.

The previous procedure was followed for the rest of the nodes. In Table I, columns 5 and 6, the mean and the standard deviation for each node are depicted respectively. In the table it can be observed that in general, the bandwidth decreases when the distance between nodes increases. However the node 5 in Madrid presents a higher dispersion in the bandwidth value with respect to the rest of nodes. It has a bandwidth of $15.2\ Mbps$. The measurements were fitted with different functions by using the least squares optimization method. For each fitted function the R^2 coefficient of determination, which varies between 0 and 1, and indicates how well the statistical distribution is fitted. The highest the value of the R^2, the better the fitting. The following results were obtained: $Bandwidth = 4.655e^{-10^{-4}x}$, $R^2 = 0.5454$; $Bandwidth = -3 \cdot 10^{-4}x + 4.9444$, $R^2 = 0.3628$ and $Bandwidth = -1.519Ln(x) + 15.325$, $R^2 = 0.4539$, where x is the distance between any node and the central node in km. The bandwidth was obtained in $Mbps$. However, the hyperbolic function was the one that best fitted the distribution:

$$Bandwidth = 184.91x^{-0.547};\ R^2 = 0.582 \tag{1}$$

Columns 7 and 8 in Table I show the mean and standard deviation of the latency measured in all the nodes connecting the central node in France. In this case the fitting used was a linear function. It accurately fitted the data distribution. The equation that approximated the data is the following:

$$Latency = 0.0228x + 17.88;\ R^2 = 0.8927 \tag{2}$$

The latency is obtained in ms when the distance x is introduced in km.

Column 9 in Table I shows the loss rate between any node and the central node during the whole execution of the experiment. In most of the communications the loss rate was under 0.2%. Two cases are remarkable: on the one hand, between the node 20 in Russia and the central node 0% of loss rate was measured, which means that no packets were

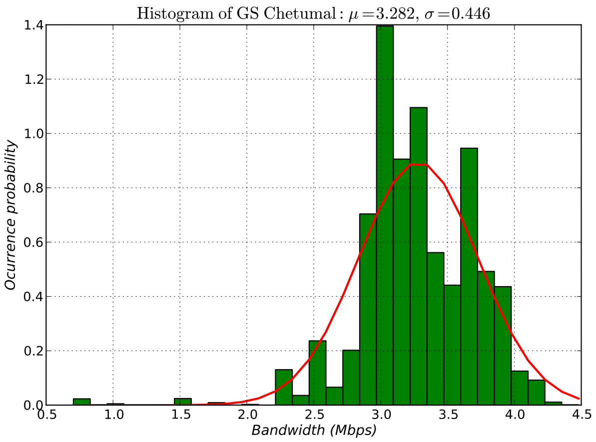

Fig. 2. Bandwidth of the node representing Chetumal ground station.

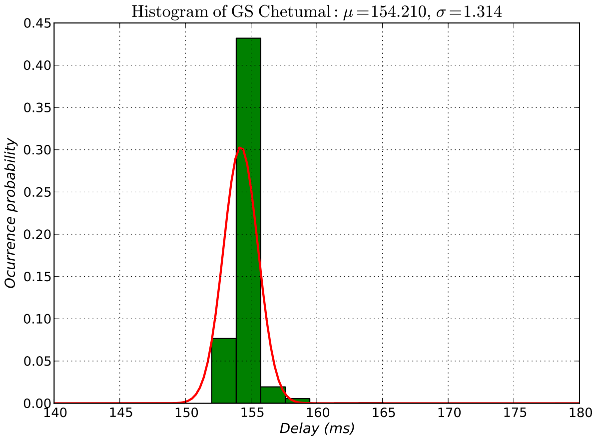

Fig. 3. Latency of the node representing Chetumal ground station.

lost; on the other hand, between Greece (node 15) and the central node, a loss rate of 15.68% was measured, maybe because of interruptions in the network, overload of the server in Greece or routed network fails. The mean of the loss rates between all the communications was 0.053% with a standard deviation of 0.097% without considering the node in Greece in the calculations.

V. CONCLUSIONS

This work presents the results of the experiment carried out in PlanetLab to use them in the GEO-Cloud experiment. At the time of writing this work the GEO-Cloud experiment was near the end of the implementation stage. It is then part of the future work to use the results of this work to configure the impairments of the networks deployed in GEO-Cloud to have a realistic behaviour. This will be done by tuning the impairments of the networks implemented in Virtual Wall so that the link between the nodes in Virtual Wall and BonFIRE will have a representative behaviour of the measured links in PlanetLab.

In this work, topology networks were created to simulate the communications between the ground stations and the cloud infrastructure and between this and the end users accessing the web services. The experiment consisted of measuring the real network impairments (bandwidth, latency and loss rate) to model them. NEPI, Iperf and Ping were used to measure the impairments. Our experience with those tools was positive, mainly with NEPI, which facilitated the implementation and automation of different processes very easily.

21600 trials during 6 hours continuous execution were carried out between any node and the central node. A normal distribution was adjusted to the bandwidth and the latency measured between each pair of nodes. The loss rate was obtained in percentage.

After obtaining the impairments for all the nodes, the bandwidth and the latency were fitted in function of the distance between nodes. The bandwidth best fitting was a hyperbolic function and that the latency linearly increased with the distance between nodes. In addition, the loss rate was obtained to be 0.053% in mean, with a standard deviation of 0.097%. The previous results will allow us to extrapolate the results to do load tests to the system implemented in GEO-Cloud. They will be done by simulating accesses from Virtual Wall to the web services offered from BonFIRE.

Finally, this experiment allowed us to use a globally distributed system (PlanetLab) very easily. We could observe the traffic between real nodes located in different parts of the world and how the network between them can be affected by impairments. However we found it difficult the execution of the experiment since many nodes were unreachable.

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