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# Assessment of Regression-based Techniques for Data Location Verification at Country-Level

(Invited Paper)

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**Abstract**—Data storage in the Cloud became a very popular service. However, delegation of data management results in loss of control from user perspective, in particular regarding the real location where data are stored. Thus, data location verification in the Cloud is a challenging issue. Among the huge methods proposed to consider data location verification, this paper focuses on machine learning based methods, which use network Round Trip Times as main metric. In particular, it provides experimental results based on country-wide dataset collected through Grid’5000 platform. Results show the capacities of regression-based methods to support data location verification at specific accuracy depending on user requirements.

## I. INTRODUCTION

Nowadays companies, administrations, and individuals let data storage be handled by large-scale distributed storage systems, called Cloud services. Thus, they are relieved of management and maintenance of equipment used for data storage. Doing so, users have to trust their Cloud Service Provider (CSP) as they lose control over their data. To make Cloud services more widely accepted users can implement requirements in QoS clauses, including clauses about data location in the Service Level Agreement (SLA). Legal issues [10], privacy [13], and performance [8] are the main reasons for data location requirements.

Limitations about data location are often enforced by governments, which require some data to be stored in certified data centers with a location clause provided in the SLA [10], [11], [16]. That is why Cloud services users need to have means to verify their data location. However, Cloud infrastructure virtualization makes location verification a challenging issue, as data location cannot easily be known, even by the CSP in some cases. Moreover, even when SLA includes an initial clause about location and the clause is initially honored, the CSP is still able to change data location by moving them to another country to cut costs, by mistake or maliciously.

When a location clause exists in the SLA, the CSP agrees on it and should store the data at the specified location. Users can either trust the CSP and there is no data location verification problem, or assume that the CSP can be malicious and store data in an inappropriate location and they have to deploy mechanisms enabling data location verification at any time. Huge approaches addressing this problem were proposed in literature [12]. Three DLV (data location verification) approaches classes are commonly distinguished:

- Cloud framework-based DLV approaches [5], [15], [19] aim at installing a software framework on CSP. Such a framework is in charge of guaranteeing data location by forbidding data moves to unauthorized locations.
- Hardware-based DLV approaches [1], [3], [14] aim at providing a tamper-proof hardware root of trust. Such a hardware is physically connected to the CSP’s machines, thus guaranteeing its own location and the connected machines.
- Landmark-based DLV approaches [4], [6], [7], [8], [9], [13], [17], [18] aim at providing communication-based solutions. Such solutions allow users to estimate data location using landmarks, which are hosts connected to the Internet whose physical locations are known and that can interact with the user and with the CSP. Prior to launching the DLV process, landmarks are deployed by the user, in a way such that he/she tries to surround location in which data are supposed to be located. Then, landmarks interact with each other, building a model predicting distance, generally based on the Round-Trip Times (RTTs) measured during these interactions. Afterwards, when the user requests location verification, landmarks probe the CSP. Feeding CSP-related RTTs to built model of distance prediction allows to derive a geographic zone, reflecting the CSP estimated location according to the measured RTTs. Location agreed from the SLA should be included in the estimated zone, otherwise it is very likely that data were moved from the agreed location.

In the sequel, we address landmark-based DLV approaches and compare their location accuracy. For performance reasons, including data access delay and robustness, the data may be stored at different locations by the CSP and the users are aware of the distribution or duplication of their data. Without loss of generality, we assume that the entire data for which DLV is run are in a single location. Indeed, iterating the verification process described in the following sections would contribute to consider multi-location CSPs. The objective of the paper is to present results of experimentation based on a platform of data collection. DLV approaches are evaluated with the same dataset.

The rest of this paper is organized as follows. Section II presents the compared DLV approaches. In Section III, dataset collecting and preprocessing are described as well as assessment methodology. Section IV concludes the paper.

## II. OVERVIEW OF DLV APPROACHES

Most of the landmark-based DLV approaches are based on the same principle under the assumption that there is a relationship between RTT and distance. First, all the landmarks whose positions are known interact with each other, sending requests to each other and measure the RTTs of requests-responses. Hop count may also be collected. Using measurements, a machine learning model is built to estimate the distance according to measurements. After training phase, learning model can be evaluated by making measurements between landmarks and CSP to infer CSP location. Multilateration is used to calculate the zone of intersection where data is expected to be stored. In the sequel,  $N$  denotes the number of measures used in training and  $r_{l,k}^i$  and  $d_{l,k}^i$  the  $i^{\text{th}}$  training RTT measure from landmark  $l$  to another landmark  $k$  and the associated distance, respectively. The distinctive feature between DLV approaches is the distance model they use. A distance is associated to RTT value. Among the proposed DLV approaches, we select three, which are representative in the field of data location verification [12].

### A. Bestline-based approach

Distance models used in Fotouhi et al. [8] and Gondre and Peterson [9] approaches are based on bestline. The latter is the highest linear function lower than all points in the Distance-RTT graph. Bestline-based model results in distance overestimate; depending on the dataset coverage, the returned area should include the real location. Each landmark builds its own function to describe the bestline, which represents distance in function of RTT, as follows:

$$\widehat{d}_{\text{best}_l} = a_{\text{best}_l} \times r + b_{\text{best}_l}$$

where variable  $r$  is associated with RTT value; slope  $a_l$  and intercept  $b_l$  of  $l$  landmark's bestline are calculated according to bestline definition.

### B. Linear regression-based approach

Watson et al. [18] and Benson et al. [4] used a linear function obtained through linear regression as distance model. The slope  $a_l$  and intercept  $b_l$ , associated with any landmark  $l$ , are computed using linear regression. Consequently, inaccuracy in the result grows according to the spread of RTT values for a given distance.

$$\widehat{d}_{\text{linreg}_l} = a_{\text{linreg}_l} \times r + b_{\text{linreg}_l}$$

### C. Polynomial regression-based approach

Eskandari et al. [7] proposed to use a polynomial function to estimate the distance in function of RTT. It should be noticed that, in Eskandari's approach, all landmarks use the same coefficients. Assuming  $M$  is the degree of the polynomial function, distance estimation model is:

$$\widehat{d}_{\text{polyreg}} = \sum_{j=1}^M a_{\text{polyreg}_j} \times r^j + b_{\text{polyreg}}$$

$a_j$  coefficients and  $b$  are obtained through polynomial regression. As mentioned for previous approach, when regression is used, uncertainty in the result grows according to the spread of RTTs for a given distance. In machine learning practice, degree  $M$  is selected depending on the shape of measurements. In our experimentation, polynomial degree is increased until no improvement in results is observed.

## III. METHODOLOGY AND EXPERIMENTATION SETUP

### A. Dataset collection

Authors of DLV approaches provided some simulation or experimentation results, which were obtained through specific real or simulated environments and hypotheses, to emphasize the performance of their approaches. Unfortunately, the diversity of simulation/experimentation environments makes comparison between results either infeasible or unfair. Our first contribution is to design and implement a distributed framework to collect credible and representative dataset at country level, France in our work. Then, the same data is used to evaluate all three DLV approaches we selected. Our data collection was run over a long period (in month), while many authors evaluate their solutions using data collected online during a short period of simulation (in second).

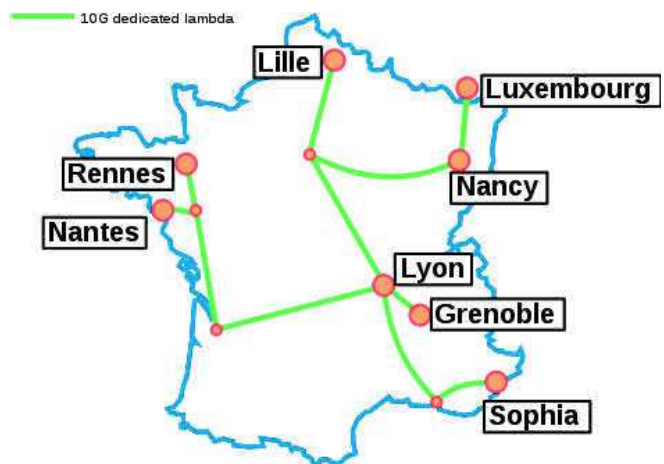


Fig. 1: Grid'5000 Map and nodes connection

To collect the dataset, we used Grid'5000 platform [2]. The latter is a french distributed infrastructure composed of nodes located at main french cities including Grenoble, Lille, Lyon, Nancy, Nantes, Rennes, and Sophia and one site in Luxembourg. Grid'5000 nodes are connected through 10 Gigabits dedicated links as shown on Figure 1.

On each node, a script was activated to send requests to all the other nodes each 5 minutes from May 22<sup>nd</sup> 2018 to June 22<sup>nd</sup> 2018. We collected a total of 614,244 samples between all Grid'5000 nodes. A sample consists of a timestamp, an RTT, and a hop count obtained with *traceroute* command.

Statistics (mean, standard deviation, and dataset size) regarding collected data are shown on Table I. Overall, collected data were quasi-symmetrical, i.e. measures from node  $A$  to

TABLE I: Statistics summary of raw RTTs collected in Grid’5000

		Destination											
		Grenoble			Lille			Luxembourg			Lyon		
		$\mu$	$\sigma$	size	$\mu$	$\sigma$	size	$\mu$	$\sigma$	size	$\mu$	$\sigma$	size
Origin	Grenoble	0.02	0.01	9627	13.42	3.17	9629	17.63	3.63	9628	4.30	3.88	9629
	Lille	14.12	3.72	10813	0.04	0.08	10813	12.05	1.76	10813	11.53	3.71	10813
	Luxembourg	18.47	8.10	10839	12.04	6.88	10839	0.04	0.02	10839	15.79	7.93	10839
	Lyon	3.95	0.60	7228	10.36	2.69	7227	14.51	3.07	7227	0.06	0.03	7228
	Nancy	16.65	4.14	7258	9.66	0.81	7258	2.67	0.99	7258	14.06	4.08	7258
	Nantes	16.65	0.67	10838	24.12	3.86	10837	28.41	4.33	10837	14.03	0.64	10837
	Rennes	17.97	1.28	9337	25.75	4.00	9340	30.16	8.94	9338	15.34	0.97	9339
Sophia	10.29	0.63	10839	17.72	3.89	10839	22.01	4.56	10840	7.68	0.60	10839	

		Destination											
		Nancy			Nantes			Rennes			Sophia		
		$\mu$	$\sigma$	size	$\mu$	$\sigma$	size	$\mu$	$\sigma$	size	$\mu$	$\sigma$	size
Origin	Grenoble	15.91	5.75	9629	16.72	0.91	9628	18.18	1.39	9629	10.26	0.97	9628
	Lille	10.29	3.71	10813	24.20	4.22	10813	25.53	4.36	10813	17.75	4.21	10813
	Luxembourg	3.35	4.66	10839	28.51	8.19	10839	29.84	8.16	10839	22.07	8.20	10839
	Lyon	12.98	4.44	7226	13.91	0.42	7229	15.28	1.08	7228	7.45	0.89	7226
	Nancy	0.02	0.01	7258	26.72	4.30	7258	28.03	4.44	7258	20.35	4.27	7258
	Nantes	26.27	4.13	10838	0.03	0.01	10837	1.94	1.42	10837	20.22	0.43	10837
	Rennes	27.90	4.49	9339	1.97	1.72	9339	0.06	0.04	9337	21.53	0.90	9338
	Sophia	20.08	4.56	10839	20.30	0.50	10839	21.65	0.80	10839	0.03	0.02	10839

another node  $B$  are similar to those from node  $B$  to node  $A$  as it can be seen on Table I. Also, we did not consider collected hop counts in location verification, because their values are static due to dedicated connections established through Grid’5000 platform: hop count is either 1 when a front-end server interact with itself or 3 when it interacts with another node.

### B. Dataset preprocessing

Being a free public research platform, some frontend nodes on which our scripts were running could be rebooted without any warning. Consequently, some measures were missing leading to different sizes in subsets associated with different couples of nodes as shown on Table I. To provide the same conditions for evaluated VDL approaches, we first discarded measures for some nodes (Lyon and Nancy nodes, because the ratio of missing measures is high; see Table I). Then, we discarded outliers, like those samples with hop count greater than 3 or RTT values higher than 100 ms, which result in abnormal routing in Grid’5000. Finally, we synchronized the remaining measures for each originating city. Synchronization is based on sample timestamps, with a certain error margin due to the scripts being distributed. Measures are kept when they are sampled in the same time interval for all the city nodes. After preprocessing, the dataset included 172,392 samples.

### C. Learning algorithms comparison

Supervised machine learning is based on two steps: training to build a model and prediction to provide results to user. DLV approaches mainly differ in their learning process. The prediction is similar for approaches we considered, it consists in feeding data—i.e. collected RTTs without location, i.e.

without labels—to built model and let it return a result, i.e. a predicted location.

Training in bestline-based and linear regression-based approaches consists in building the distance prediction functions using bestline and linear regression functions, respectively. One function is produced per node, using all requests issued by such a node to probe other nodes.

In the polynomial-based approach, a single prediction function is needed; it is obtained by polynomial regression on the entire dataset, as done in [7].

In prediction step, distance estimate model is applied to new samples collected from known origins. Returned estimate distance is mapped to a circle for each node, which collected test data. Circle centers are location coordinates of nodes.

Then, approximation of circles as polygons of 10,000 points are derived and intersections of all polygons are calculated. The final result is a polygon representing a geographic zone in which the data are expected to be located. When multilateration result is perfect, all circles intersect at a single point, which is the location of CSP. However, due to fluctuations in collected RTTs, we address estimated distances as a maximum boundary, thus the intersection is a zone.

To use DLV methods, one has to specify the zone where data are accepted to be located, which is called *accepted zone*. There are different ways to describe accepted zone including names (of cities, countries, states...), geometric forms, geographic points... To apply multilateration in our context, we associate a circle to each node in Grid’5000 platform; circle centers are coordinates of buildings hosting Grid’5000 nodes in considered cities.

In order to give smart output, we use Google Maps to

TABLE II: Statistics summary of preprocessed RTTs (Dataset with 172,392 samples)

		Destination					
		Grenoble		Lille		Luxembourg	
		$\mu$	$\sigma$	$\mu$	$\sigma$	$\mu$	$\sigma$
Origin	Grenoble	0.02	0.01	13.54	3.16	17.73	3.19
	Lille	13.51	3.20	0.04	0.03	11.93	0.33
	Luxembourg	17.58	3.22	11.80	0.28	0.04	0.02
	Nantes	16.63	0.28	23.44	3.18	27.67	3.21
	Rennes	17.93	0.20	24.79	3.19	28.94	3.21
	Sophia	10.24	0.34	17.05	3.26	21.23	3.29

		Destination					
		Nantes		Rennes		Sophia	
		$\mu$	$\sigma$	$\mu$	$\sigma$	$\mu$	$\sigma$
Origin	Grenoble	16.73	0.25	18.10	0.36	10.27	0.37
	Lille	23.54	3.22	24.87	3.20	17.09	3.30
	Luxembourg	27.63	3.23	28.97	3.23	21.16	3.31
	Nantes	0.03	0.01	1.88	0.19	20.20	0.39
	Rennes	1.91	1.09	0.06	0.04	21.47	0.42
	Sophia	20.26	0.34	21.61	0.32	0.03	0.01

display multilateration result as shown on Figures 2, 3, and 4. In blue is estimate zone, in red is accepted zone, and in green is the intersection of both zones.

To assess estimate results, we use three scores:

- *Verification consensus score*, a verification consensus score  $vcs_i$  is associated with each prediction test  $i$ ; it equals the ratio of the maximum of number of intersecting estimated zones to the total number of landmarks participating in the verification.  $vcs_i$  equals 0 means that landmarks failed to have any consensus on common estimated zone. Then, an average success score, denoted **VCS**, is computed for all tests for each DLV approach;  $Nt$  is the number of tests:

$$vcs_i = \frac{\text{Maximum number of intersecting estimated zones}}{\text{Number of landmarks participating in verification}}$$

$$VCS = \frac{1}{Nt} \sum_{i=1}^{Nt} vcs_i$$

- *Inclusion ratio score*, denoted **IRS**, is ratio of the intersection between predicted and accepted zones to accepted zone. **IRS** indicates the proportion of accepted zone covered by estimated zone.

$$IRS = \frac{\text{Accepted zone} \cap \text{Estimated zone}}{\text{Accepted zone}}$$

- *Estimate accuracy score*, denoted **EAS**, is the ratio of the intersection between predicted and accepted zones to predicted zone. **EAS** indicates the proportion of estimated zone covered by accepted zone.

$$EAS = \frac{\text{Accepted zone} \cap \text{Estimated zone}}{\text{Estimated zone}}$$

**VCS**, **IRS**, and **EAS** together provide useful details to assess DLV algorithms. **VCS** alone reflects the percentage of landmarks, which agreed on a common zone. Unfortunately, they

may agree on a zone without intersection with the expected zone. **IRS** alone is not enough. Let us take an example. Imagine that accepted zone is a 1km-radius-circle entirely included in an estimated zone covered by a 10km-radius-circle. In this case, **IRS** equals 1.00. However, as the size of estimated zone is 100 times the one of accepted zone, the data could be located out of the accepted zone. **EAS** is 1%, which means that the location verification accuracy is very low. **EAS** alone also is not enough. Let us take the following scenarios: i) estimated and accepted zones are 100 km<sup>2</sup> and intersect at 50%, resulting in a zone of 50 km<sup>2</sup> of unauthorized zone where the data may be located, ii) if both zone sizes are heightened with a factor  $F$ , **EAS** remains 50%, but the unauthorized zone is heightened with the same factor. Consequently, in addition to scores, the size of estimated zone is useful to user to assess the verification result. User derives the estimated zone from **IRS**, **EAS**, and accepted zone.

#### D. Experimentation scenarios

To provide significant results to assess DLV approaches, we carried out multiple scenarios designed as follows:

- Varying ratio between training and test sets: three alternatives for splitting the dataset into training and test sets are considered: 0.8/0.2, 0.5/0.5, and 0.2/0.8.
- Varying accepted zone scale: four alternatives of accepted zone size are considered: 10 km (city scale), 50 km (metropolis-and-surroundings scale), 200 km (region scale), and 500 km (country scale).
- Varying the degree in polynomial regression until no result improvement is observed.

Experimentation results for 0.5/0.5 train/test ratio are summarized in Figure 5. Notice that histograms are associated with **VCS** with unanimity (i.e. all estimated zones intersect in a common non-empty zone).

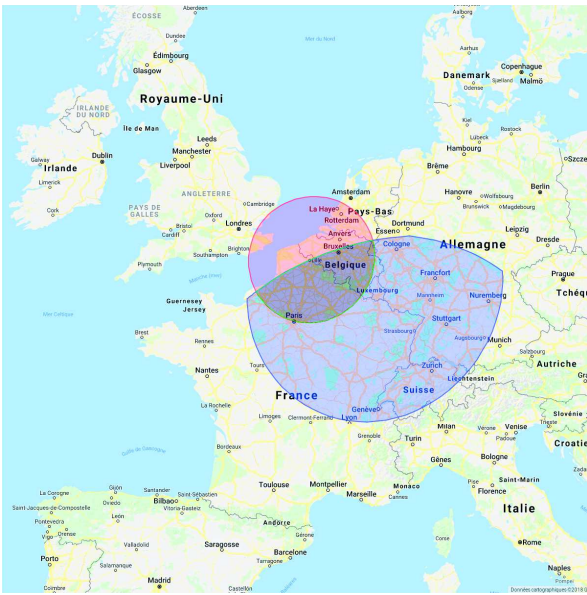


Fig. 2: Example of output for bestline-based DLV. The green polygon is the intersection between the predicted zone us in blue, and the accepted zone around Lille in red.

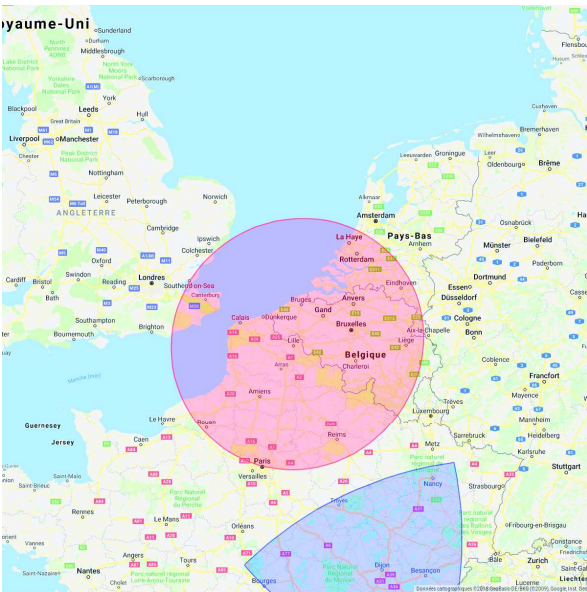


Fig. 3: Example of output for linear regression based DLV. The blue zone is the predicted one. In this case it did not succeed in predicting location (Lille)

#### IV. CONCLUSION

In this paper, we report on an experimentation of data location verification approaches based on regression and bestline. Experimentation is based on Grid5000, which is a national communication infrastructure connecting the main cities in France. During a month, measurements of RTTs have been collected by landmarks located at different cities. Then, three verification approaches (bestline, linear regression, and poly-

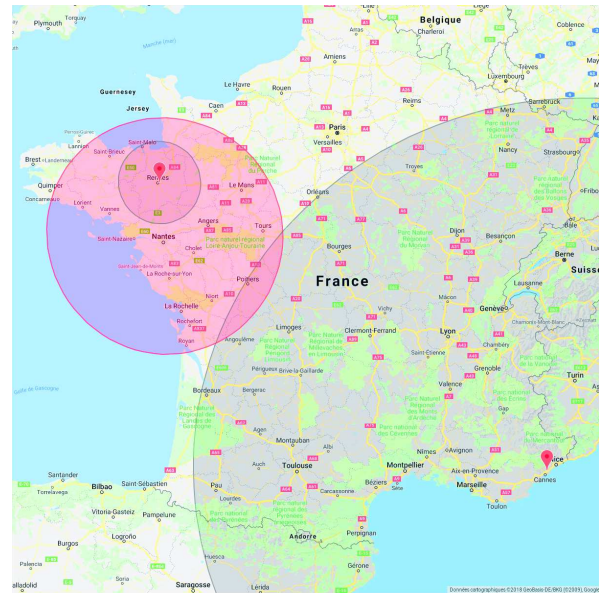


Fig. 4: Example of output for polynomial regression based DLV. There is no resulting zone because circles do not intersect. Circles are denoted in grey with a location marker at their centers, there is one in Sophia (the big one) and one in Rennes. As there is no resulting zone, it fails to prediction location (Nantes)

nomial regression) have been assessed. Hopeful results have been observed, meaning that landmark-based verification approaches are credible solutions to locate data at country-scale. Bestline-based approach has a high Verification consensus score (because it overestimates distance) but a low accuracy, because of the size of estimated zone. Linear regression-based approach outperforms polynomial regression-based approach when all landmarks use the same polynomial. Whenever each landmark uses its own polynomial the reverse performance is observed. Regression-based approaches tend to optimize the distance estimate model, which, unfortunately, results in smaller estimated zones, which are unlikely to intersect in a common zone. Even when the expected zone is large, the localization success may be low.

In our current work, we are analyzing the compromise between accuracy of distance model of individual landmarks and the size of expected zone for which the localization success would be high. For future work, we are extending our analysis by collecting and experimenting a worldwide dataset. We would also like to include classification-based approaches in our performance analysis.

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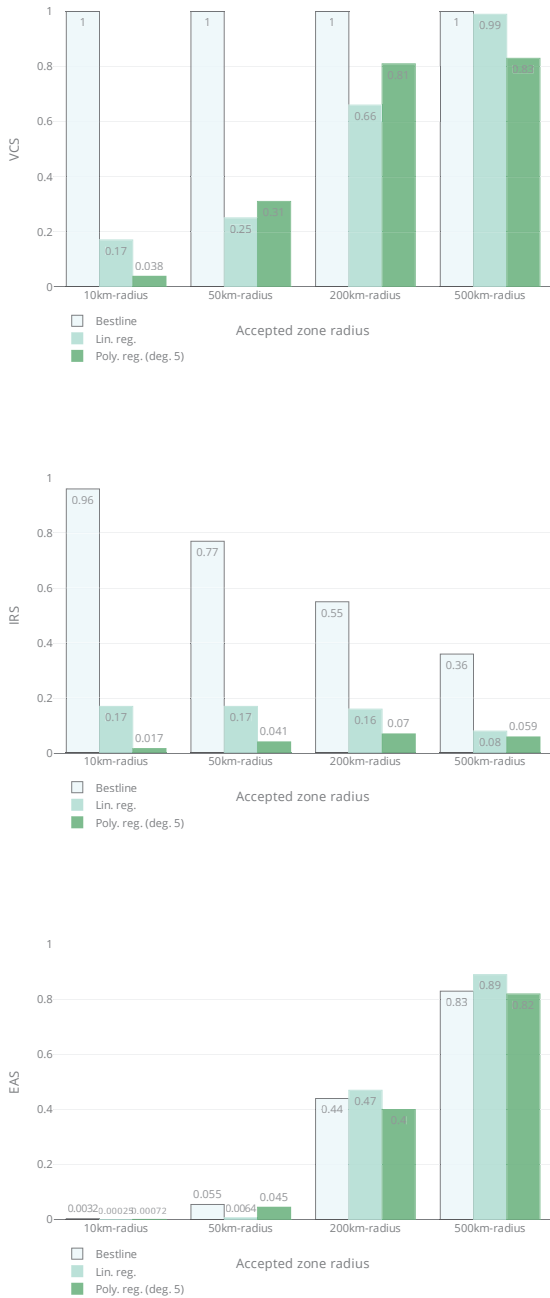


Fig. 5: Scores for a 0.5/0.5 train/test ratio with 10km, 50km, 200km and 500km-radii accepted zone scales. (VCS is increased only when all estimated zones intersect)

virtualization capabilities to the Grid'5000 testbed. In Ivan I. Ivanov, Marten van Sinderen, Frank Leymann, and Tony Shan, editors, *Cloud Computing and Services Science*, volume 367 of *Communications in Computer and Information Science*, pages 3–20. Springer International Publishing, 2013.

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