CLOUD SOLUTIONS FOR GIS AND CLOUD-BASED TESTING OF WEB-BASED GIS APPLICATIONS

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Abstract: *This paper is focused on the role of cloud computing technologies in the presentation and availability of the spatial data via internet and cloud-based testing of web-based GIS applications. The article has two main aims. The first one is the survey of published results attained by the synergy of two research fields – web-based GIS applications and cloud computing in the context of usability. The second one is the performance evaluation of selected web-based GIS applications in the Czech Republic, which will be mostly focused on the response time of the application.*

Keywords: *Cloud computing, GIS, Web-based GIS, Cloud-based testing, Usability.*

JEL Classification: *L86, M15, O30.*

Introduction

A Geographic Information System (GIS) is a collection of computer hardware, software, methods, people and geographic data used for capturing, storing, updating, manipulating, analysing, and displaying all forms of geographically referenced information. The term describes any information system that integrates stores, edits, analyses, shares, and displays geographic information for informing decision making. As the new platform for real-time data, GIS utilizes high-resolution satellite imagery, light intensity detection and ranging, GPS data, computer-aided design files, and enterprise database management systems for complex analysis. Users can also cross-reference these geographic data sources in a GIS and create impressive geographic displays catered to an area of interest and to individual or specific applications. All these new approaches need more computing resources to meet users' requirements. [7]

Web-based GIS applications are online services over the internet that provide maps and various spatial analysis and spatial processing to the users and help them to search and browse spatial data like locating different places and routes. A web-based GIS application is an application that is accessible through a browser. It makes it possible for the users to access GIS with its basic functionalities like searching locations, getting directions, zooming and panning and printing maps via web browsers. In other words, web-based GIS means that spatial data can be published, searched, analysed and displayed over the internet. [17]

Cloud computing can be viewed as a collection of services, which can be presented as a layered cloud computing architecture. The services offered through cloud usually include services referred as to Software-as-a-Service (SaaS), which enable users to run applications remotely from the cloud. Infrastructure-as-a-service (IaaS) then refers to computing resources as a service. This includes virtualized computers with guaranteed processing power and reserved bandwidth for storage and internet access. Platform -as-a-Service (PaaS) is similar to IaaS, but also includes operating systems and required services. PaaS is IaaS with a custom software stack for the given application. [6]

Functions and services of web-based GIS applications that operate on spatial data are geographically and logically distributed due to the source of data, location of computing facilities and organizations. The spatial analysis on large amount of data is complex and computationally intensive. In order to share and work with these data as well as the computation results among geographically dispersed users, a scalable and low cost cloud computing platform is a good solution for not only web-based, but also all GIS applications. Cloud solutions also enable many users from different parts of the world to interact together, exchanging and collaborating with data etc. Cloud-based testing helps to better understanding of the behaviour of web-based GIS applications, especially to identify performance characteristics, e.g. peak demands through the day, response times or other load issues of the application. The concept of this research paper is focused on the resources and the performance of IaaS layer for GIS.

1 Problem formulation

The recent developments of GIS applications have ranged from the standalone desktop to distributed enterprise GIS architectures and further towards large scale cloud architectures. Two main trends can be now identified in the area of using cloud computing technologies for GIS. The first one is focused on the cloud infrastructure and delivering of highly available and flexible services for enterprise GIS applications – e.g. ArcGIS for server cloud solutions offered by Esri, more details in [12]. The second one deals with web-based GIS applications, which can utilise any of a number of current technologies and database or storage platforms. However, the choice of which can impact on the performance of these applications. Both these problems need to be described, especially advantages and disadvantages of these approaches. As the methods the analysis and the comparison was used.

Solving of the first problem is presented by a review of literature, limited mainly to academic articles and recent books. This area will be mostly dedicated to spatial cloud computing, managing spatial data and the role of usability. The second part extends the results of previous studies of usability evaluation of web-based GIS – e.g. in [11]. Improvements in usability through improved user interfaces also account for the increased popularity of visualisation techniques and GIS in general. More popularity means more users and more users mean increasing demands on the performance of the web-based GIS application. An important consideration in software selection is speed of response as users may expect the result of GIS analysis to be produced in real time. Cloud-based testing can helps to discover bottlenecks in the application performance, so the second part is focused on techniques and tools of cloud-based testing and the comparison of selected web-based GIS in the Czech Republic.

2 Cloud computing infrastructures and spatial cloud computing

With the growing popularity of the cloud computing paradigm, many applications are moving to the cloud. The elastic nature of resources and the pay as you go model have broken the infrastructure barrier for new applications which can be easily tested out without the need for huge upfront investments. The sporadic load and performance characteristics of these applications, coupled with increasing demand for data storage and varying degrees of consistency requirements pose new challenges for data testing and management in the cloud. Virtualization, automation and standards are the pillars of the foundation of all good cloud computing infrastructures. [2], [6] Cloud computing provides opportunities and advantages for GIS to become more cost-effective, productive, and flexible in order to rapidly deliver new capabilities with lower total cost of ownership, increased availability, faster application delivery etc. [12]. Cloud providers also deliver large space for storing spatial data, virtual machines are hosted in cloud hardware that are constantly upgraded by the service provider as well as software, it offers dynamic configuration global access (collaboration between GIS researchers) etc. [16]. The main research problems and studies solved in recent years are: performance measurement, evaluating the suitability of cloud provider for hosting GIS services, comparison of services, low cost solutions for the deployment in the public sector, open source solutions based on Apache Hadoop, etc.

Spatial Cloud Computing (SC2) adds geography to the cloud computing paradigm and also provides dynamically scalable geo-information technology, spatial data, and geo-applications as a web service. It can be represented with a framework including physical computing cloud infrastructure, computing resources distributed at multiple locations, and a spatial cloud computing virtual server that manages the resources to support cloud services for end users. Because the geo-technology infrastructure, the services and the data are provided, there is no large initial investment in time and cost, or ongoing maintenance. By providing the GIS functionality and data as a web service, SC2 eliminates the need for in-house GIS capability. And for organizations with in-house GIS, SC2 frees them up from responding to basic mapping requests, and lets them deal with more complex and specialized tasks and services such as cartography, spatial data maintenance, and spatial analysis. [14], [20]

3 Web-based GIS applications

GIS web applications are defined as web-based applications having characteristics of desktop GIS applications and are delivered by way of a standard web browser [1]. Web-based GIS applications can be as simple as presenting a simple map of the world to front-ending complex spatial analyses of spatial distributions and processes. These types of applications are focused on end users, mostly on casually working people who may have only a very limited knowledge of GIS. [1], [11]

Architecture of web-based GIS applications is usually based on the n-tier client / server architecture. Two-tier architectures retain the user interface and functional part of the web application on the first tier and deploy the database and data storage functions on the second tier. However, a more efficient architecture is a 3-tier architecture in which the user interface and functional parts are separated on different tiers. This architecture significantly supports scalability, maintainability, central data management and protection. The following layers should be recognized: presentation layer (user interface), web server (communication between browser and application), application layer (application logic) and data layer (data storage and access). [1], [11]

3.1 Role of usability for web-based GIS applications

Usability is important factor concerning the web and if any web-based application has problems like file downloading takes time, no clear navigations and not oriented towards the needs of the users, then users get frustrated and they will probably not use this application in future. Usability aspects give benefits to the users accessing this services which contain easy to use and attractive exploring functions. The interface of the application then must be so simple that users who may have only a very limited knowledge of GIS can easily use it and fulfill their requirements with it. The users are satisfied when they can achieve their goals in a successful and efficient way. [10]

For a web-based GIS application that attracts thousands of visitors each week, usability is an important ingredient to success. The performance of the web-based GIS application is one of the main parts connected with usability. User will probably visit an application less often if it is slower than a close competitor. The main indicator for the user is mostly load time (response time) of the application, which is the total time it takes from when a user makes a request until user receive a response. Research has shown that the optimal load time is between 2 and 4 seconds – e.g. in [18].

3.2 Web-based GIS applications and their performance

Also increase of web technologies and new models has leads to an improvement of the geographical information utilization and availability. The important factor for the application users is the flexibility it provided them for accessing the GIS application service. While this improvement provides new opportunities for public domain as well as commercial use of spatial data, new problems arise. One of them is the performance problem of transferring data efficiently from server to client, as these datasets need to migrate, as fast as possible, from server to client tiers. Spatial data are generally very large, though it depends on the situation and the way of delivering, and this process may demand too much time. [9]

The database is an important part of web applications. In the case of web-based GIS applications, it becomes more important because of the storage requirements of geographically referenced data, which can be especially in the cloud computing environment stored and accessed from different servers. It can sometimes cause long answering times for GIS applications while the necessary data is being compiled and returned to the user interface. Thus the performance of a database has a direct impact upon the performance of the web application which needs to be tested. Database performance indicates the response time of the database management system for retrieving / storing records, it also represents how efficiently database handles multiple read / write requests to different database tables. When relying on an internet service, there is always a question of availability and the peak load capacity that the provider can carry. The limitation of web-based GIS applications is also the problem of bandwidth. If the internet speed is slow then response time will be high. [1], [14]

4 Cloud-based testing and its techniques

Cloud-based testing refers to testing and measurement activities on a cloud based environment and infrastructure by leveraging cloud technologies and solutions. It is a form of software testing in which web applications and services use cloud computing technologies to simulate testing environment with real world user traffic as a means of load testing and stress testing web sites. The ability and costs to simulate web traffic for software testing purposes has been an inhibitor to overall web reliability. [3]

Cloud-based software testing (cloud testing) basically uses the concept of cloud and SaaS or PaaS. It provides the ability to test by leveraging the cloud. These systems are designed based on cloud platform and service oriented concepts for continuous testing without procuring licenses for programs and testing tools and installing them. Service providers give testers environment with tools, which offer access to scalable and virtual labs with a library of operating systems, test management and execution tools, middleware and storage necessary for creating a test environment that closely mirrors the real environment. Users can save the cost of complicated maintenance and upgrade effort and providers can upgrade their services without impact on the end-users. [21]

There are also three types of cloud test environments [8]: a cloud-based enterprise test environment, in which application vendors deploy web-based applications in a cloud to validate their quality; a private / public cloud test environment, in which vendors deploy SaaS applications SaaS in a private (or public) cloud to validate their quality; a hybrid cloud test environment, in which vendors deploy cloud-based applications on a hybrid cloud infrastructure to check their quality. Most cloud testing today is being performed via automated services, but there are software packages that offer a variety of options in pricing, performance, and feature set. More details can be found in [3], [8], [13], [15] or [21].

The different types of testing of web applications are performed [3], [8], [15]:

- Stress testing is defined as the process of determining the stability or capabilities of the application under extreme conditions,
- performance testing done to measure the application's ability such as speed to value, flexibility, cost, more mobility, scalability, easy implementation to support various applications,
- compatibility testing is one which is used to cloud environment under different operating systems, the main advantage is to verify whether the cloud environment is able to support all operating systems,
- cross browser testing – different web browsers are used to run tested applications to check the compatibility of these web browsers,
- load testing (load simulation) is performed to identify the application's behaviour under normal and extreme conditions in conducting more efficient and more realistic large-scale tests.
- latency testing is used to measure the difference between action and response time of an application.

The cloud testing tools can be distinguished in three categories [13]:

- Browser based tools (accessible through a web browser), which are free available without registration – e.g. Cloud Assault or Load Impact,
- browser based tools available after registration, which usually allows the user to try out all the essential functions of this testing tool for one week to one month – The JMeter Cloud, Test Perspective 3.0, PractiTest or LoadStorm,
- tools, that have to be installed on the client side, registration is required – e.g. SilkPerformer CloudBurst, HP LoadRunner, NeoLoad Cloud Testing or TestMaker.

5 Cloud-based testing of selected web-based GIS applications

This case study is focused on the cloud-based testing of selected web-based GIS applications in the Czech Republic. More precisely, all 14 applications of the Czech regional authorities were selected for testing because they are focused on the same type of users, have same features like navigation and get directions, but with different legends, colours and design. They are run by the same type of public administration authority

– on the each level of NUTS 3. These applications were tested together with Mapy.cz and aMapy.cz, which are an example of commercial web-based GIS focusing on the same type of end-users. The list of them is shown in the Tab. 1.

Tab. 1: List of the selected web-based GIS applications in the Czech Republic

No.	Name of provider of web-based GIS	URL of the tested web-based GIS application (available in the first half of 2013)
1.	**Central Bohemia Region**	http://mapy.kr-stredocesky.cz/dmu25_ortofoto.htm
2.	**Hradec Králové Region**	http://mapy.kr-kralovehradecky.cz/gis/isapi.dll?MU=INTERNET&LANG=CS-CZ&MAP=spravni_cleneni
3.	**Karlovy Vary Region**	http://arcgis.kr-karlovarsky.cz/Spravni_hranice/
4.	**Liberec Region**	http://twist.kraj-lbc.cz/tms/geografie/index.php
5.	**Moravia-Silesia Region**	http://mapy.kr-moravskoslezsky.cz/tms/admin_clen/index.php
6.	**Olomouc Region**	http://mapy.kr-olomoucky.cz/
7.	**Pardubice Region**	http://195.113.178.19/html/bez_km.dll?gen=map&map=spravni
8.	**Plzeň Region**	http://mapy.kr-plzensky.cz/arcims/cleneni/viewer.htm
9.	**Region of the Capital City of Prague**	http://mpp.praha.eu/DMP/default.aspx
10.	**South Bohemia Region**	http://gis.kraj-jihocesky.cz/mapy/obce/mapa.jsp
11.	**South Moravia Region**	http://up.kr-jihomoravsky.cz/ITC/
12.	**Ústí nad Labem Region**	http://gis.kr-ustecky.cz/administrace/
13.	**Vysočina Region**	http://geoportal.kr-vysocina.cz/web/Map
14.	**Zlín Region**	http://vms4.kr-zlinsky.cz/kmp/
15.	**Seznam.cz**	http://mapy.cz/
16.	**Centrum.cz**	http://amapy.centrum.cz/

Source: Authors

The following aims were stated for the planned testing:

- The main aim is to measure load (response) times of selected applications and identify the performance problems of tested applications, which could affect the response time and also usability for end-users.
- The second goal is to identify the approximate peak load of each application during the working day.
- The last goal is to compare applications from the public and private sector.

Based on [13] the best cloud-based testing tool for web-based GIS applications, which is for free or trial, is Load Impact, which offers client-side load testing. This tool offers more real time measurements and characteristics, even interactive charts, but these are not suitable for web-based GIS applications.

The selected web-based GIS were tested simultaneously at 9.00, 12.00, 15.00 and 18.00 (during the working day), because of different web traffic during the day. Every test used 50 virtual users, which were accessing the application concurrently for 5 minutes. These performance characteristics (metrics) were selected for measurement: average user load time in seconds (for all 50 virtual users concurrently), data received (total number of bytes received during test) in MB, and total number of received requests. Results of all selected metrics are shown in Tab. 2.

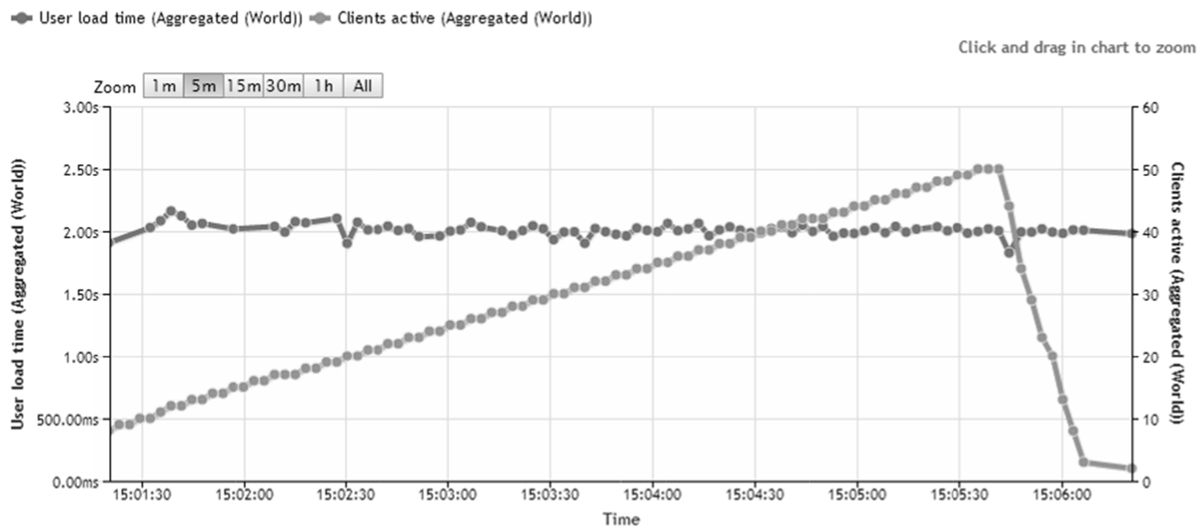
Tab. 2: Results of cloud-based testing of the selected web-based GIS applications

No. / time	9.00			12.00		
	user load time [s]	data received [MB]	requests	user load time [s]	data received [MB]	requests
1.	1,45	1,60	1615	2,13	1,72	1740
2.	2,51	66,23	1008	2,85	88,32	1341
3.	32,37	57,77	4748	34,58	57,47	3840
4.	37,82	25,87	6298	38,16	19,71	4629
5.	11,45	36,63	7180	12,40	41,04	8054
6.	2,48	20,66	1023	2,56	21,92	1084
7.	2,97	83,81	1274	5,65	79,86	1217
8.	2,31	4,98	556	2,56	4,98	556
9.	67,42	89,43	7481	72,15	68,27	5460
10.	9,86	10,05	2952	10,05	9,38	2744
11.	51,40	256,76	5722	83,72	178,39	3714
12.	6,28	165,67	1112	6,42	144,22	968
13.	7,82	167,58	5571	7,57	138,04	4567
14.	8,80	390,07	897	9,11	379,69	879
15.	1,46	86,27	1217	2,02	115,66	1643
16.	11,25	40,90	649	14,89	38,21	604
No. / time	**15.00**			**18.00**		
	user load time [s]	data received [MB]	requests	user load time [s]	data received [MB]	requests
1.	2,37	1,63	1643	1,95	1,68	1704
2.	5,36	81,41	1240	4,71	77,78	1184
3.	71,56	56,82	3641	81,75	60,26	4750
4.	32,48	20,57	5013	27,74	21,63	5266
5.	19,98	35,41	6953	4,74	51,68	10175
6.	2,44	21,79	1079	2,25	21,56	1068
7.	2,07	73,14	1073	2,78	87,11	1323
8.	1,96	5,00	558	1,82	5,14	574
9.	78,51	83,17	6466	91,32	73,65	6679
10.	15,65	8,68	2538	9,54	9,63	2826
11.	85,57	185,22	3211	98,67	187,71	4001
12.	4,30	150,85	1019	2,79	168,06	1128
13.	7,84	139,61	4564	3,25	160,98	5358
14.	9,40	383,09	880	12,66	383,10	881
15.	1,65	118,61	1684	1,74	114,11	1623
16.	15,27	41,24	715	13,12	47,03	729

Source: Authors

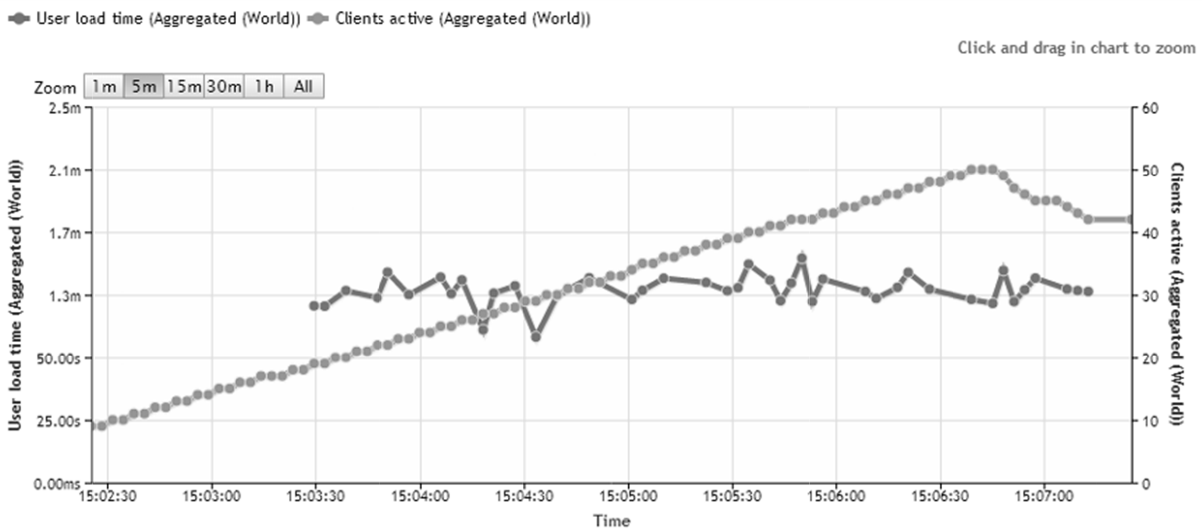
On the Fig. 1 is shown the process of throughout the load test for the web-based GIS application with the shortest average user load time, which is not commercial (Plzeň Region). On the Fig. 2 is then shown the process of throughout the load test for the web-based GIS application with the highest average user load time – also is not commercial (South Moravia Region), which varies during the testing from 60 to 90 seconds and the virtual user has to wait more than 1 minute to load the web-based GIS.

Fig. 1: The process of throughout the load test for the application of Plzeň Region



Source: Authors

Fig. 2: The process of throughout the load test for the application of South Moravia Region



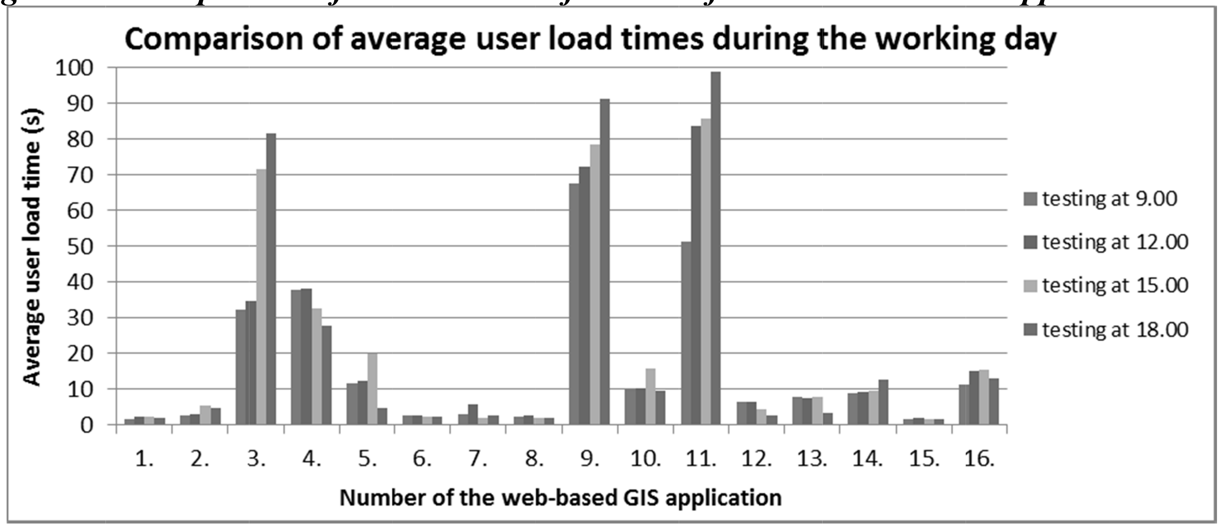
Source: Authors

6 Results and discussion

The collected data were then statistically analysed using Microsoft Excel 2010. The most important metric is user load time, which is connected with the size of received data, which means, how much of the data had to be transferred from the database of web-based GIS application to the virtual user. Thus, the type and size of spatial data on the providers' side is important, because it directly affects the response time. The ratio between data received and user load time should be maximized for a single user. It is an indicator of the performance of the database on the providers' side. Load Impact also offers other characteristics of tested web-based GIS – e.g. URL content type distribution and URL content type load time distribution, which shows how much of the total load time was a certain type of resource responsible for. Thus, there have been found other factors, those have an influence to the performance of web-based GIS applications. These are: use of java, javascripts files and Cascading Style Sheets (CSS).

The comparison of average user load times during the day is shown on the below Fig. 3. The web-based GIS application with the shortest user load time is Mapy.cz, which is the commercial product and is also more popular than the other commercial product aMapy.cz, which has user load time more than 10 seconds. The figure also shows, that values usually increase during the day (peak load is mostly at 15.00), except Karlovy Vary Region, Zlín Region, South Moravia Region and Region of the Capital City of Prague. According to results, these 4 applications are also java-based applications. Most data were received from Zlín Region. In addition, none of peak loads, in the meaning of stress testing which affects the stability of application, weren't able to measure, because for testing were used only 50 virtual users concurrently.

Fig. 3: The comparison of user load time for each of the web-based GIS application



Source: Authors

The user load time could be also influenced by hardware configuration (bandwidth, servers, databases), which is unknown for us, and software configuration of the web-based GIS application, which can be only partly described by this study (use of java, images etc.). User load time is also connected with the other aspects like availability, capability, latency, error rates, etc. However, in this case study were measured only: load time for a single user, data received and total number of received requests. No further functions of web-based GIS or use of external Web Map Services (WMS) were measured or compared for their performance requirements.

Although using cloud-based testing is, in many cases, more realistic than testing in the lab, simply using this kind of testing is not enough to ensure the most realistic tests. Real users often have access to less bandwidth and slower connection than a load generator of the cloud-based testing tool in a cloud data centre, so they will have to wait longer than the load generator to download all the data needed for a web-based GIS application. Results of this comparison could be also different by the use of another cloud-based testing tool and probably by users' knowledge of using selected web-based GIS application.

Conclusion

For each of the web-based GIS application, average user load time was measured, however differences were relatively large, especially for application of the region of the Capital City of Prague, Karlovy Vary Region and South Moravia region, where is average response time for a single user more than 1 minute, and also the peak load is at 18.00.

However, user will be probably more patient waiting for a map to load than for a search result, thus the optimal user load time should be definitely under 10 seconds. Bottlenecks and problems in the application performance are usually affected by the use of a lot of java, javascripts and CSS. Commercial web-based GIS applications are also better than applications of public administration authorities, especially Mapy.cz.

Results of this study may help the regional authorities to improve their web-based GIS applications from the performance point of view and also the better use of their computing resources, as well as cost effectiveness. Cloud computing technologies and services have a great potential for GIS and testing of web-based GIS applications. Most of works already discussed GIS and spatial data in the cloud environment. They are focused on deployment of GIS – e.g. implementing a web map service on Google App Engine in [4] or spatial data managing e.g. a framework for retrieving, indexing and accessing of spatial data in the cloud environment in [19]. However, security and privacy are mostly mentioned as two main risks in cloud. Typical security and privacy examples include data storage and data transfer protection, vulnerability management and remediation, personnel and physical security, application security, data privacy and identity management [12]. Information security in the cloud environment is also discussed in [5] and it's focused on the security of the data from the physical point of view.

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