A Backup-as-a-Service (BaaS) Software Solution

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Abstract: Backup is a replica of any data that can be used to restore its original form. However, the total amount of digital data created worldwide more than doubles every two years and is expected to reach 44 trillions of gigabytes in 2020, bringing constant new challenges to backup processes. Enterprise backup is one of the oldest and most performed tasks by infrastructure and operations professionals. Still, most backup systems have been designed and optimized for outdated environments and use cases. That fact, generates frustration over currently backup challenges and leads to a greater willingness to modernize and to consider new technologies. Traditional backup and archive solutions are no longer able to meet users current needs. The ideal modern backup and recovery software should not only provide features to attend a traditional data center, but also allow the integration and exploration of the growing Cloud, including "backup client as a service" and "backup storage as a service". The present study proposed and deploys a Backup as a Service software solution. For that, the cloud/backup parameters, cloud backup challenges, researched architectures and Backup-as-a-Service (BaaS) system requirements are specified. Then, a selected set of BaaS desired features are developed, resulting in the first truly cloud REST API based Backup-as-a-Service interface, namely "bcloud". Finally, this work conducts an on-line usability poll with a significant number of users. The analysis of results in an overall average objective zero to ten questions evaluation was 8.29%, indicating a very satisfactory user perception of the bcloud BaaS interface prototype.

1 INTRODUCTION

In the words of (Guise, 2008), backup is the replica of any data that can be used to restore its original form. In other words, backup is a valid copy of data, files, applications or operating systems that can serve for the recovery purpose. That is why, customarily, backup is often stored to lower cost of high capacity removable media, such as magnetic tapes, normally stored in fireproof safes or another protected physical environment.

Conforming to the International Data Corporation (IDC, 2014), the total amount of digital data created worldwide more than doubles every two years. It will grow from 4.4 zettabytes in 2013 to 44 zettabytes by 2020. For example, one zettabyte is equal to 1 trillion gigabytes. According to (Russell et al., 2016), enterprise backup is among the oldest most-performed tasks for infrastructure and operations professionals. Still, most backup systems have been designed and optimized for outdated environments and use cases. As stated by (Silva, 2014), traditional backup and archive solutions are no longer able to meet users current needs.

In line with (Kaiser et al., 2016), the massive increase in data generation and processing in industry and academia has dramatically increased the pressure on backup environments. Data itself has become a very valuable asset, and its protection requires the use of reliable backup systems.

In the vision of (Russell et al., 2016), the ideal modern currently backup and recovery software products should not only provide features to attend a traditional data center, e.g.: backup to conventional random-access or sequential media (hard disk, solid-state, tape drives), data reduction techniques (compression, deduplication or single instancing) and systems interoperability. However, this software must also allow the integration and exploration of the growing Cloud, including "backup client as a service" and "backup storage as a service".

Moreover, even many currently solutions are sold as BaaS, some of them do not meet the new market requirements for data center backup and recovery software (Russell et al., 2016). Backup software for a homogeneous environment is also excluded, such as native tools from Microsoft or VMware for their specific platforms.

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This work in this paper aims to propose and deploy a BaaS solution, under the Remote Backup to the Cloud architecture. For that, we determined the cloud/backup parameters, cloud backup challenges, researched architectures and BaaS system requirements. Then, a set of features were selected, developed and implemented to attend the architecture. Finally, we applied a user-poll technique with a significant amount of users to validate the developed features and analyzed their answers.

The paper is organized as follows : in Section 2 we present the related work of this research. In Section 3, we present the Proposal of the BAAS Solution, in which we used as a starting point some previous work of the authors (Bacula The Open Source Backup Software (book) (Faria, 2016). Storage Growing Forecast with Bacula Backup Software Catalog Data Mining (Faria et al., 2017a). Backup Storage Block Level Deduplication with DDUMBFS and BACULA (Faria et al., 2017b), A Hadoop Open Source Backup Solution (Faria, 2018)). . In Section 4 shows the Evaluation Methodology and Results. Section 5 draws some conclusions and future work

2 RELATED WORK

In correspondence with (Armbrust et al., 2010; Buyya et al., 2011), cloud computing is a long-held idea of computing as a general utility. It promises to shift data and computational services from individual devices to distributed architectures. As reported by (Columbus, 2017; Ried et al., 2011; Arean, 2013), cloud computing services global total market revenues value is expected to grow from U$ 67 billion by 2015 to U$ 241 billion by the end of 2020. Still in 2013, near to 61% of United Kingdom businesses were relying on some cloud services. Cloud computing is becoming more popular (Khoshkholghi et al., 2014) in large-scale computing because of its ability to share globally distributed resources.

Pursuant to (Khoshkholghi et al., 2014), Disaster Recovery (DR) is a persistent problem in Information Technology (IT) platforms, and even more crucial in cloud computing. A Cloud Service Provider (CSP) must find ways to provide services to their customers even if the data center is down (v.g.: due to a disaster). Disasters can lead to expensive service disruption (Khoshkholghi et al., 2014), regardless of the nature of their causes. A CSP can adopt two different DR models: traditional and cloud-based service models. The use of the traditional model can happen as either a dedicated infrastructure or shared approach.

Nevertheless, as claimed by IBM (Raju et al., 2012) the weather causes only 50% of disasters in its cloud, and the rest because of miscellaneous causes (e.g., cut power lines, server hardware failures, and exploitation of security vulnerabilities). In this way, disaster recovery is not only a mechanism to deal with natural events but also for all severe disruptions that may also happen with the modern cloud environment services.

Along with (Khoshkholghi et al., 2014), there are three defined DR levels:

Data Level. The security of application data.

System Level. Reducing system recovery time as short as possible.

Application Level. Application continuity.

As stated by (Alhazmi and Malaiya, 2013), Recovery Point Objective (RPO) and Recovery Time Objective (RTO) there are two main parameters that all recovery mechanisms should observe. If RPO and RTO values are lower, the systems can achieve higher business continuity. RPO might be interpreted as the amount of lost data a disaster. RTO consists on the time frame between disruption and restoration of service. As demonstrated by equation 1, the Recovery Point Objective value is inversely proportional to the frequency of backups terminated along the time, where FB represents the *Frequency of Backup*.

$$RPO \quad \propto \quad \frac{1}{FB} \tag{1}$$

On the other hand, as exhibited by equation 2, Recovery Time Objective formula usually includes a fraction of RPO, the readiness of the backup and five failover steps delays, depending on backup capabilities.

$$\text{RTO = fraction of RPO+jmin+S1+S2+S3+S4+S5} \tag{2}$$

Each variable used in the equation 2 has the following description:

fraction of RPO. Computation time lost since the last backup.

jmin. Depends on service readiness of the backup.

S1. Hardware setup time.

S2. Operating System initiation time.

S3. Application initiation time.

S4. Data or process state restoration time.

S5. Internet Protocol (IP) address switching time.

Therefore, as alleged by (Wood et al., 2010), DR mechanisms must have five requirements for an efficient performance:

- Minimum RPO and RTO.
- Minimal impact on the normal system operation.
- Should be geographically separated.
- The application shall be restored to a consistent state.
- DR solution must guarantee integrity, privacy, and confidentiality.

These general requirements are technology independent and can also affect the Cloud-Based Disaster Recovery Models.

In (Khoshkholghi et al., 2014), a disaster is defined as an unexpected event in the lifetime of a system. It may consist (1) of natural causes, such as tsunami or earthquake; (2) software or hardware failures; (3) human error or sabotage. As claimed by (Kashiwazaki, 2012), it can lead to significant financial or human lives loss. However, only approximately 2% to 4% of the IT infrastructure budget in huge companies are annually destinated to DR solutions (Prakash et al., 2012).

As maintained by (Khoshkholghi et al., 2014), *cloud-based DR solution is an increasing trend because of its ability to tolerate disasters and to achieve the reliability and availability.*

As shown in Figures 1, 2, 3 and 4, different architectures were proposed to overcome the cloud-related DR challenges: Remote Backup to the Cloud (Camacho et al., 2014), Local Backup from the Cloud (Ismail et al., 2013; Javaraiah, 2011), Cloud Geographical Redundancy and Backup (GRB, (Pokharel et al., 2010)), Inter-private Cloud Storage (IPCS, (Jian-hua and Nan, 2011)) and Secure-Distributed Data Backup (SDDB, (Ueno et al., 2010)).

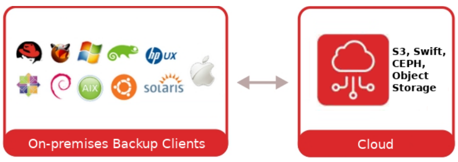

Figure 1: Remote Backup to the Cloud.

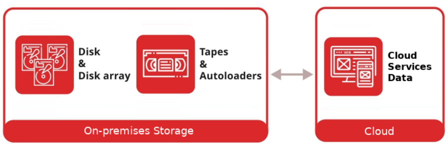

Figure 2: Local Backup from the Cloud.

According to (Ismail et al., 2013) and under the verified cloud backup architectures, the backup solution must support different backup data, since different layers of operation originate them. Still, to offer backup as an Anything-as-a-Service model, it must inherit the cloud characteristics such as self-service, on demand and ease-of-use.

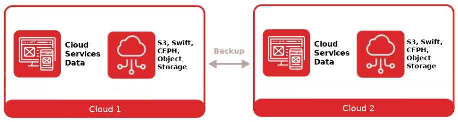

Figure 3: Cloud Geographical Redundancy and Backup.

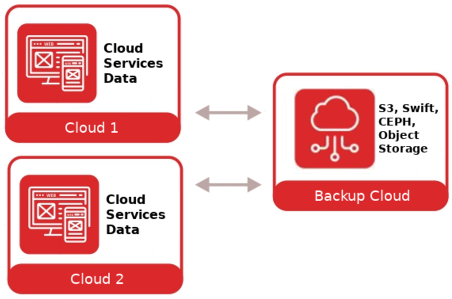

Figure 4: GRB and IPCS Cloud Backup Architectures.

3 PROPOSAL OF THE BaaS SOLUTION

There are currently on-premise self-hosted data center backup solutions that can evolve with some development support towards a BaaS delivery solution for CSPs, but other relevant open source based solutions other than the Gartner Magic Quadrant (Russell et al., 2016) are also considered.

The primary criteria to choose one of the solutions would be the integration with cloud storage; the variety of plug-ins for specific application backup; standard cloud industry interfaces such as REST API and open backup catalog format for more natural BaaS development and the licensing costs. The commercial versions of Arcserve, Bacula Enterprise, Bareos, EMC solutions, IBM Spectrum Protect, Veeam and Veritas Netbackup were evaluated. Due to the exclusive REST API availability at the time, broad Cloud S3 Object backup storage support, open catalog format, one of the widest range of applications backup plug-ins, reasonable pricing and developer availability to help on the BaaS interface development, Bacula Enterprise was considered the most suitable backup software to deploy a minimum BaaS product in a short time frame.

This work focused on one of the reviewed Cloud backup architectures. According to (Heslin, 2014), self-owned data centers and collocation are still the most common IT infrastructure model used by the companies. Therefore, the proposed solution aims to prototype a BaaS solution for the *Remote Backup to the Cloud*, since it would serve to the majority of enterprises. In this scenario and considering Cloud is user-centric, the most notable and critical requirements are interface related, such as a multi-tenant user-friendly operation. Now the backup Clients are deployed and configured by the ordinary Cloud User instead of the old backup administrator specialist. The traditional backup software is not multi-tenant, and as observed by (Amvrosiadis and Bhadkamkar, 2015) they are too complicated even for specialized users since the majority of them uses stock backup software configurations for schedules and backup retentions.

A list of 17 requirements were defined for an ideal BaaS interface, but only the four more critical were prioritized and evaluated. They were: reconfiguration, personalization and customization capabilities; multi-tenancy; easy new tenants creation; and user-centered design. The prototype development stage had four months of duration until the interface Alpha version release, which involved the web interface development and backup client wizards to ease and automate their deploy.

As shown in Figure 5, bcloud topology relies on the Bacula REST API that enables control of Bacula with high-level HTTPS/REST calls.

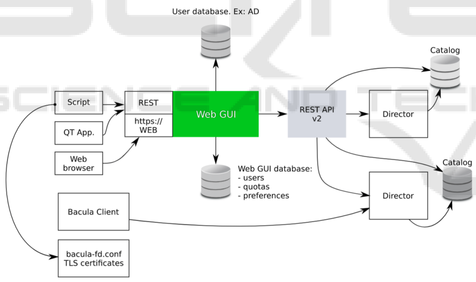

Figure 5: bcloud topology.

The REST API plays a crucial role on the BaaS interface development, creating an abstraction layer for Bacula operation, granting a faster programming and making unnecessary to know or to change Bacula source code.

We selected the Smarty PHP framework for development. The use of a popular PHP framework will allow the screens to be customized, and will also allow future addition of custom modules.

The Tray Monitor is a multi-platform QT program that enables to monitor the Client (File Daemon) and start backup jobs, especially when behind inaccessible firewalls or NATed networks. The end user will be able to use the Tray Monitor program to start client initiated backup jobs or to perform other Bacula related actions.

The bcloud offers a PHP module (class and templates) that will list a local server directory and the sub-directories for self-service backup clients download.

As displayed in Figure 6, the user will access the Download Center to fetch multi-platform backup client installation packages and configuration wizards, to automatically attach its machines to the backup system.

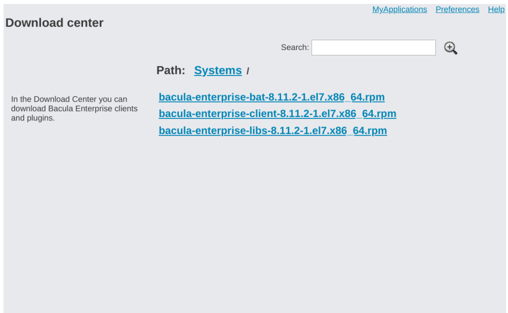

Figure 6: Client Download Center.

As exhibited in Figure 7, the backup client Registration Wizard can run in operating systems with and without graphical interfaces. That is important especially for servers that usually doesn't have a GUI and are the principal Bacula service object.

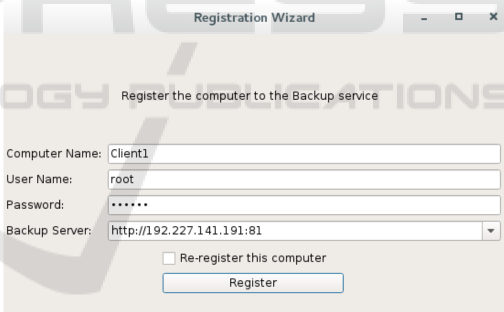

Figure 7: Configuration Wizard.

The interface saves all the backup server configuration in a temporary area (named work set). The Client is configured with the server information (Name, Password and TLS certificate). The Client's local daemon is started. The registration program must be executed on the Client with the necessary permissions to edit the daemon configuration file, the Tray Monitor configuration file and control the backup service (root on Unix and Administrator on Windows).

By default, the CSP administrator will be notified about the registration request and can commit, modify or discard the request.

All Bacula Clients that are attached to a Director will be located on networks that may be protected by firewalls or behind routers. A direct connection from the Director to the File Daemon using the TCP port 9102 may not be possible without a VPN configuration.

Once installed, configured, and approved by the Cloud Administrator, the backup clients will appear at the "My Data" bcloud screen. From this moment, as shown in Figure 8, the user can proceed with backup job configuration steps, such as choosing what folders, files or applications will be backed up, and scheduling. Ad hoc queuing is also supported.

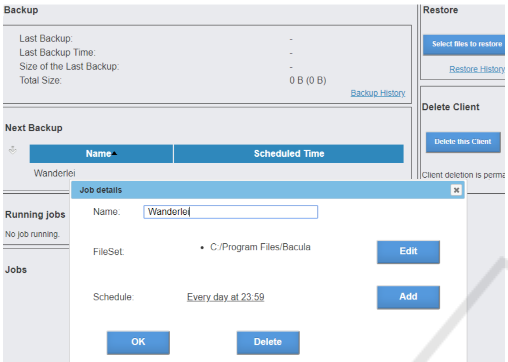

Figure 8: Job Configuration.

As presented in Figure 9, a dashboard shows all terminated and on-going jobs. It displays information such as backup duration, number of files, size, transfer rate, start and termination time. The user can filter listed jobs by level, status, client, and time frame, using the same tab options.

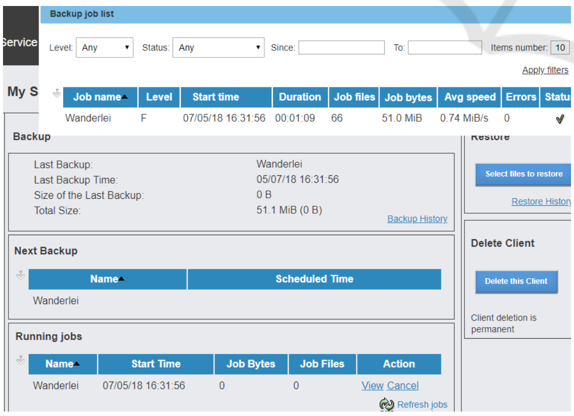

Figure 9: Job Terminated Jobs Overview.

Finally, as displayed in Figure 10, the Cloud User can select one or more terminated backup jobs, generally according to their termination time, and proceed with file browsing and data restore. Differential and incremental backups can be selected, manually or automatically, together with last full and other necessary jobs to provide a complete restore to a given time.

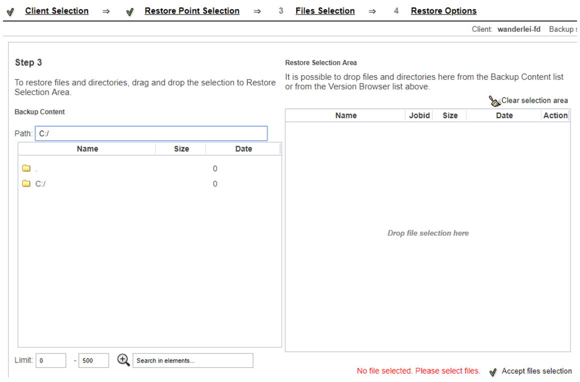

Figure 10: Restore Job File Browsing.

4 EVALUATION METHODOLOGY AND RESULTS

The case study presents two basic bcloud roles: Cloud Service Administrator and the Cloud User. The first is the backup-as-a-service provider, that access bcloud to perform administrative tasks or another Bacula CLI, GUI or other web-based interfaces. The second one is the backup-as-a-service costumer, who receives a tenant and executes the steps to set up the backup of its data.

To validate the developed features, we set up a small environment for user tests over the Internet. The initial requirements are similar to a Bacula backup server since bcloud is just one more hosted interface. We used a machine with 64 bits virtualized CentOS operating systems with 100 GB of disk space, and 16 GB of RAM. Also, a 512 GB direct-attached solid-state drive was set up to host the global deduplication backup engine since it requires faster random access for on-the-fly processing. The backup server local network traffic relies on gigabit Ethernet connections, but the client backup traffic data goes through the Internet. This capacity considers a small workload, estimated to support up to 100 backup clients, 50 simultaneous bcloud web interface users and 50 TB of backups.

Since Cloud services are user-centric, focused on user-experience and accessed by a large number of customers with different profiles and technical levels, we chose the individual inquiry technique for the bcloud evaluation in this study.

The user inquiry was performed using documentation, prototype user access, and an online questionnaire that contained six objective zero to ten evaluation questions. That scale was chosen for being practical and for providing a granular perception of the evaluated features. Nevertheless, a general user-feedback open question was made available, and the variety of answers were categorized and presented. A total of 278 fillings were considered, corresponding to a population of 1000 users, with an error margin of 5% and a confidence level of 95%. We used the Normal (Gaussian or Gauss or Laplace–Gauss) continuous probability distribution, to represent real-valued random variables whose distributions are not known. The random variables observations sample averages drawn from independent distributions converge to the normal, in other words, they become normally distributed when the number of observations is sufficiently large.

The statistical population is higher than most small and medium company staff sizes, in a hypothetical and extreme scenario where every employee becomes a Backup-as-a-Service user. Worldwide users were invited to test the bcloud interface, follow the Cloud User and Cloud Administrator workflow suggestion, and provide feedback via questionnaires. The users received a research description, the interface user manual and the credentials to access the prototype. The poll sought heterogeneous user-profiles, with different technical background and seniority levels. Invites were sent to infrastructure, cloud, operating system, backup and even Bacula user groups.

We monitored the bcloud web engine logs to make sure each invited customer was able to access the solution, perform the defined user roles and start a backup. We evaluated the BaaS solution according to the four cloud requirements that we chose earlier. The "Interface Reconfiguration Capabilities", "Multi-Tenancy Support", and "Easy New Tenants Creation" criteria had one question each. The "User-Centered Design" was divided into three questions: "Reduced User Operation Errors", "Improved User Acceptance and Satisfaction", "and Improved Productivity". We present the questions as follows.

4.1 Analysis of Results

In this section, we present the average questionnaire evaluation for the first three questions as follows:

1. Reconfiguration, personalization and customization of the BaaS interface
2. Bacula single instance of the object code and database supports multiple customers
3. Easy new tenants creation

As shown in Figure 11, the average replies about the investigated features deploy ranged from roughly 8 to an 8.5 score. The "Interface Reconfiguration Capabilities" was the worse evaluated criteria and the "Multi-Tenant Deploy" was the best.

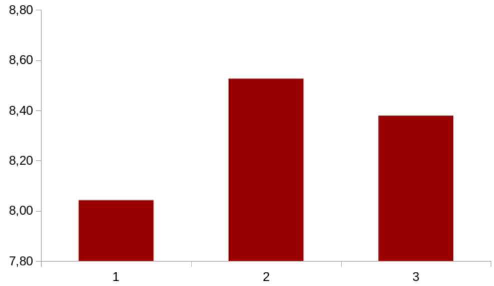

Figure 11: Questions 1, 2 and 3 average evaluations.

We present the Design User-centered design question results as follows:

1. Reduced backup operation error capacities
2. Improved user acceptance and satisfaction
3. Improved productivity

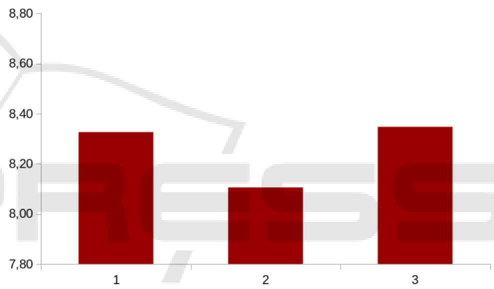

Figure 12: Questions 4, 5 and 6 average evaluations.

As shown in Figure 12, the average replies ranged from 8.1 to an 8.35 score. The "Improved User Acceptance and Satisfaction" interface quality was the worse evaluated, and the "Reduced Backup Operation Error Capabilities" was the best-evaluated criteria. The user-feedback open question (7) received a high number of different themes, and they were summarized as follows:

1. Usability and user technical level concerns
2. Safety and performance considerations
3. More User experience work is needed
4. Innovative solution
5. Useful software
6. Adherent to the cloud trend

The three first topics were considered more detrimental to the user interface perception and will be taken into consideration for the future prototype improvement. The last three are more positive replies which reaffirm the importance of the Backup-as-a-Service solution development. The overall average objective questions mark was 8.29%, what indicates a very satisfactory perception of the bcloud BaaS interface prototype in such a short time-frame. We present and comment each one of the objective user-inquiry answers result from highest to the lowest as follows.

Multi-Tenancy Support - 8.52. This result is a little bit surprising, because there are no gray shades of multi-tenancy on the prototype deployment. By default, each user only sees and manages its own backup clients and jobs, even though bcloud has multi-party capabilities. We report the score not being perfect to the user lack of knowledge about multi-tenancy, and to a fail in explain that to the inquired subjects.

Easy New Tenants Creation - 8.4. We chose not to create an "add user" feature directly on the bcloud interface, because it would elevate the complexity considerably.

Improved Productivity - 8.37. As mentioned on the literature review, many backup administrators just want to use the backup software defaults. We associate that fact to the good grade achieved in this question, and automated features such as the backup clients configuration must have contributed.

Reduced Backup Operation Error Capacities - 8.32. The bcloud interface abstracts many of the complexities of current data center backup software ones. The users can select and download only the backup clients and plug-ins that the administrator provides, and the installation wizard makes much easier to install the new clients. The user-experience focused design abstracts complicated backup elements such as storage capacity, type, pools and volumes. Users of virtually any level can operate bcloud.

Improved User Acceptance and Satisfaction - 8.07. This result was a little disappointing, but it can be explained on the lack of demonstrations, any "help" content or built-in tutorial, due to the lack of time.

Interface Reconfiguration Capabilities - 8.04. We report this lower result to the fact there was no mention on the bcloud user manual on how to customize the bcloud interface, even though it is CSS based.

Despite of not being into the scope of the formal analysis, the user submitted globally deduplicated backups average transfer rate was 1.41 MB/s. The deduplication is a fundamental technique for cloud backups to use the minimum possible Internet link bandwidth, so in this case lower values are better. Even though, small links are still a bottleneck for data that was never backed up (e.g., first machine full backup) since there are no similar blocks in the deduplication engine to avoid the transfer.

5 CONCLUSIONS AND FUTURE WORK

The present study developed and prototyped a BaaS solution, under the "Remote Backup to the Cloud" architecture. The cloud/backup parameters, cloud backup challenges, researched architectures and BaaS system requirements were determined. A set of features were selected to be developed and implemented to attend the chosen architecture. We surveyed the backup software alternatives according to consultancy indicated leaders and the most popular solutions. According to the BaaS macro-requirements and cost, we chose Bacula's Enterprise version for the BaaS Interface prototype deployment. The already existing REST API feature, open catalog format, cloud backup storage capabilities, a variety of specific applications backup plug-ins and reasonable cost were the main reasons for this decision. We defined a list of 17 requirements for an ideal BaaS interface, we prioritized and evaluated the four feasible within the limited time frame. They were: reconfiguration personalization and customization capabilities; multi-tenancy support; easy new tenants creation; and user-centered design. Considering these features, we developed a new web interface named bcloud. As the result of this work, the users received a research description, the interface user manual and the credentials to access the prototype interface. A sample was determined to attend to most Small and Medium Business in an extreme scenario where every corporate user would be a BaaS user, rendering a total of 278 fillings. That corresponds to a thousand users, with an error margin of 5% and a confidence level of 95%. The overall average objective zero to ten questions mark was 8.29%, indicating a very satisfactory perception of the bcloud BaaS interface prototype. The "Multi-Tenancy Support" and "Easy new tenants creation" were the best evaluated criteria according to the user feedback. The "Improved User Acceptance and Satisfaction" quality and the "Interface Reconfiguration Capabilities" were the worse evaluated topics, and we are going to improve the interface according to these feedbacks.

As an improvement to the prototype deployment, we are going to add interface help content and demonstrations, so even most unexperienced user will be able to use the interface. That might improve the end-user acceptance and satisfaction perception. Still, we plan to incorporate a CSS code editor to the bcloud administrator interface, so it will be easier for the administrator to perform design configuration changes. We are going to assist, study and evaluate a bcloud production deployment, and will conduct another inquiry to verify the product evolution.

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