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http://www.elysiumtechnologies.com, info@elysiumtechnologies.com

227-230 Church Road, Anna Nagar, Madurai – 625020.
0452-4390702, 4392702, + 91-9944793398.
info@elysiumtechnologies.com, elysiumtechnologies@gmail.com

Branch Office: Chennai
S.P.Towers, No.81 Valluvar Kottam High Road, Nungambakkam,
Chennai - 600034. 044-42072702, +91-9600354638,
chennai@elysiumtechnologies.com

Branch Office: Trichy
15, III Floor, SI Towers, Melapudur main Road, Trichy – 620001.
0431-4002234, + 91-9790464324.
trichy@elysiumtechnologies.com

Branch Office: Coimbatore
577/4, DB Road, RS Puram, Opp to KFC, Coimbatore – 641002
0422- 4377758, +91-9677751577.
coimbatore@elysiumtechnologies.com
Branch Office: Ramnad
1st Floor, A.R.IT Park, Rasi Color Scan Building, Ramanathapuram - 623501. 04567-223225, +919677704922.ramnad@elysiumtechnologies.com

Branch Office: Tirunelveli
Flat S3, II Floor, Magnum Suraksa Building, Near Muthamil Hospital, Ibaco upstairs. Trivandrum road, Palayamkottai - 627002
0462-2582104, +919677733255.tirunelveli@elysiumtechnologies.com

Branch Office: Erode
74, 2nd floor, K.V.K Complex,Upstairs Krishna Sweets, Mettur Road, Opp. Bus stand, Erode-638 011. 0424-4030055, +91-9677748477 eroie@elysiumtechnologies.com

Branch Office: Pondicherry
No: 88, First Floor, S.V.Patel Salai, Pondicherry – 605 001. 0413-4200640 +91-9677704822
pondy@elysiumtechnologies.com

Branch Office: Salem
salem@elysiumtechnologies.com
When a single Cloud service (i.e., a software image and a virtual machine), on its own, cannot satisfy all the user requirements, a composition of Cloud services is required. Cloud service composition, which includes several tasks such as discovery, compatibility checking, selection, and deployment, is a complex process and users find it difficult to select the best one among the hundreds, if not thousands, of possible compositions available. Service composition in Cloud raises even new challenges caused by diversity of users with different expertise requiring their applications to be deployed across different geographical locations with distinct legal constraints. The main difficulty lies in selecting a combination of virtual appliances (software images) and infrastructure services that are compatible and satisfy a user with vague preferences. Therefore, we present a framework and algorithms which simplify Cloud service composition for unskilled users. We develop an ontology-based approach to analyze Cloud service compatibility by applying reasoning on the expert knowledge. In addition, to minimize effort of users in expressing their preferences, we apply combination of evolutionary algorithms and fuzzy logic for composition optimization. This lets users express their needs in linguistics terms which brings a great comfort to them compared to systems that force users to assign exact weights for all preferences.
Data centers consume tremendous amounts of energy in terms of power distribution and cooling. Dynamic capacity provisioning is a promising approach for reducing energy consumption by dynamically adjusting the number of active machines to match resource demands. However, despite extensive studies of the problem, existing solutions have not fully considered the heterogeneity of both workload and machine hardware found in production environments. In particular, production data centers often comprise heterogeneous machines with different capacities and energy consumption characteristics. Meanwhile, the production cloud workloads typically consist of diverse applications with different priorities, performance and resource requirements. Failure to consider the heterogeneity of both machines and workloads will lead to both sub-optimal energy-savings and long scheduling delays, due to incompatibility between workload requirements and the resources offered by the provisioned machines. To address this limitation, we present Harmony, a Heterogeneity-Aware dynamic capacity provisioning scheme for cloud data centers. Specifically, we first use the K-means clustering algorithm to divide workload into distinct task classes with similar characteristics in terms of resource and performance requirements. Then we present a technique that dynamically adjusting the number of machines to minimize total energy consumption and scheduling delay. Simulations using traces from a Google's compute cluster demonstrate Harmony can reduce energy by 28 percent compared to heterogeneity-oblivious solutions.

Scheduling multiple large-scale parallel workflow applications on heterogeneous computing systems like hybrid clouds is a fundamental NP-complete problem that is critical to meeting various types of QoS (Quality of Service) requirements. This paper addresses the scheduling problem of large-scale applications inspired from real-world, characterized by a huge number of homogeneous and concurrent bags-of-tasks that are the main sources of bottlenecks but open great potential for optimization. The scheduling problem is formulated as a new sequential cooperative game and propose a communication and storage-aware multi-objective algorithm that optimizes two user objectives (execution time and economic cost) while fulfilling two constraints (network bandwidth and storage requirements). We present comprehensive experiments using both simulation and real-world applications that demonstrate the efficiency and effectiveness of our approach in terms of algorithm complexity, makespan, cost, system-level efficiency, fairness, and other aspects compared with other related algorithms.
With cloud data services, it is commonplace for data to be not only stored in the cloud, but also shared across multiple users. Unfortunately, the integrity of cloud data is subject to skepticism due to the existence of hardware/software failures and human errors. Several mechanisms have been designed to allow both data owners and public verifiers to efficiently audit cloud data integrity without retrieving the entire data from the cloud server. However, public auditing on the integrity of shared data with these existing mechanisms will inevitably reveal confidential information-identity privacy-to public verifiers. In this paper, we propose a novel privacy-preserving mechanism that supports public auditing on shared data stored in the cloud. In particular, we exploit ring signatures to compute verification metadata needed to audit the correctness of shared data. With our mechanism, the identity of the signer on each block in shared data is kept private from public verifiers, who are able to efficiently verify shared data integrity without retrieving the entire file. In addition, our mechanism is able to perform multiple auditing tasks simultaneously instead of verifying them one by one. Our experimental results demonstrate the effectiveness and efficiency of our mechanism when auditing shared data integrity.

In a large Infrastructure-as-a-Service (IaaS) cloud, component failures are quite common. Such failures may lead to occasional system downtime and eventual violation of Service Level Agreements (SLAs) on the cloud service availability. The availability analysis of the underlying infrastructure is useful to the service provider to design a system capable of providing a defined SLA, as well as to evaluate the capabilities of an existing one. This paper presents a scalable, stochastic model-driven approach to quantify the availability of a large-scale IaaS cloud, where failures are typically dealt with through migration of physical machines among three pools: hot (running), warm (turned on, but not ready), and cold (turned off). Since monolithic models do not scale for large systems, we use an interacting Markov chain based approach to demonstrate the reduction in the complexity of analysis and the solution time. The three pools are modeled by interacting sub-models. Dependencies among them are resolved using fixed-point iteration, for which existence of a solution is proved. The analytic-numeric solutions obtained from the proposed approach and from the monolithic model are compared. We show that the errors introduced by interacting sub-models are insignificant and that our approach can handle very large size IaaS clouds. The simulative solution is also considered for the proposed model, and solution time of the methods are compared.
ETPL CLD - 006

Thermal-Aware Scheduling of Batch Jobs in Geographically Distributed Data Centers

Decreasing the soaring energy cost is imperative in large data centers. Meanwhile, limited computational resources need to be fairly allocated among different organizations. Latency is another major concern for resource management. Nevertheless, energy cost, resource allocation fairness, and latency are important but often contradicting metrics on scheduling data center workloads. Moreover, with the ever-increasing power density, data center operation must be judiciously optimized to prevent server overheating. In this paper, we explore the benefit of electricity price variations across time and locations. We study the problem of scheduling batch jobs to multiple geographically-distributed data centers. We propose a provably-efficient online scheduling algorithm - GreFar - which optimizes the energy cost and fairness among different organizations subject to queueing delay constraints, while satisfying the maximum server inlet temperature constraints. GreFar does not require any statistical information of workload arrivals or electricity prices. We prove that it can minimize the cost arbitrarily close to that of the optimal offline algorithm with future information. Moreover, we compare the performance of GreFar with ones of a similar algorithm, referred to as T-unaware, that is not able to consider the server inlet temperature in the scheduling process. We prove that GreFar is able to save up to 16 percent of energy-fairness cost with respect to T-unaware.

ETPL CLD - 007

Transformation-Based Monetary Cost Optimizations for Workflows in the Cloud.

Recently, performance and monetary cost optimizations for workflows from various applications in the cloud have become a hot research topic. However, we find that most existing studies adopt ad hoc optimization strategies, which fail to capture the key optimization opportunities for different workloads and cloud offerings (e.g., virtual machines with different prices). This paper proposes ToF, a general transformation-based optimization framework for workflows in the cloud. Specifically, ToF formulates six basic workflow transformation operations. An arbitrary performance and cost optimization process can be represented as a transformation plan (i.e., a sequence of basic transformation operations). All transformations form a huge optimization space. We further develop a cost model guided planner to efficiently find the optimized transformation for a predefined goal (e.g., minimizing the monetary cost with a given performance requirement). We develop ToF on real cloud environments including Amazon EC2 and Rackspace. Our experimental results demonstrate the effectiveness of ToF in optimizing the performance and cost in comparison with other existing approaches.
### A Scientometric Analysis of Cloud Computing Literature

The popularity and rapid development of cloud computing in recent years has led to a huge amount of publications containing the achieved knowledge of this area of research. Due to the interdisciplinary nature and high relevance of cloud computing research, it becomes increasingly difficult or even impossible to understand the overall structure and development of this field without analytical approaches. While evaluating science has a long tradition in many fields, we identify a lack of a comprehensive scientometric study in the area of cloud computing. Based on a large bibliographic data base, this study applies scientometric means to empirically study the evolution and state of cloud computing research with a view from above the clouds. By this, we provide extensive insights into publication patterns, research impact and research productivity. Furthermore, we explore the interplay of related subtopics by analyzing keyword clusters. The results of this study provide a better understanding of patterns, trends and other important factors as a basis for directing research activities, sharing knowledge and collaborating in the area of cloud computing research.

### A Self-Scalable and Auto-Regulated Request Injection Benchmarking Tool for Automatic Saturation Detection

Software applications providers have always been required to perform load testing prior to launching new applications. This crucial test phase is expensive in human and hardware terms, and the solutions generally used would benefit from further development. In particular, designing an appropriate load profile to stress an application is difficult and must be done carefully to avoid skewed testing. In addition, static testing platforms are exceedingly complex to set up. New opportunities to ease load testing solutions are becoming available thanks to cloud computing. This paper describes a Benchmark-as-a-Service platform based on: (i) intelligent generation of traffic to the benched application without inducing thrashing (avoiding predefined load profiles), (ii) a virtualized and self-scalable load injection system. The platform developed was experimented using two use cases based on the reference JEE benchmark RUBiS. This involved detecting bottleneck tiers, and tuning servers to improve performance. This platform was found to reduce the cost of testing by 50% compared to more commonly used solutions.
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<th>ETPL CLD - 010</th>
<th>An Autonomic Approach to Risk-Aware Data Center Overbooking</th>
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Elasticity is a key characteristic of cloud computing that increases the flexibility for cloud consumers, allowing them to adapt the amount of physical resources associated to their services over time in an on-demand basis. However, elasticity creates problems for cloud providers as it may lead to poor resource utilization, specially in combination with other factors, such as user overestimations and pre-defined VM sizes. Admission control mechanisms are thus needed to increase the number of services accepted, raising the utilization without affecting services performance. This work focuses on implementing an autonomic risk-aware overbooking architecture capable of increasing the resource utilization of cloud data centers by accepting more virtual machines than physical available resources. Fuzzy logic functions are used to estimate the associated risk to each overbooking decision. By using a distributed PID controller approach, the system is capable of self-adapting over time – changing the acceptable level of risk – depending on the current status of the cloud data center. The suggested approach is extensively evaluated using a combination of simulations and experiments executing real cloud applications with real-life available workloads. Our results show a 50% increment at both resource utilization and capacity allocated with acceptable performance degradation and more stable resource utilization over time.
ETPL CLD - 011  Performance and cost evaluation of an adaptive encryption architecture for cloud database services

The cloud database as a service is a novel paradigm that can support several Internet-based applications, but its adoption requires the solution of information confidentiality problems. We propose a novel architecture for adaptive encryption of public cloud databases that offers an interesting alternative to the trade-off between the required data confidentiality level and the flexibility of the cloud database structures at design time. We demonstrate the feasibility and performance of the proposed solution through a software prototype. Moreover, we propose an original cost model that is oriented to the evaluation of cloud database services in plain and encrypted instances and that takes into account the variability of cloud prices and tenant workload during a medium-term period.

ETPL CLD - 012  Budget-Driven Scheduling Algorithms for Batches of MapReduce Jobs in Heterogeneous Clouds

In this paper, we consider task-level scheduling algorithms with respect to budget and deadline constraints for a batch of MapReduce jobs on a set of provisioned heterogeneous (virtual) machines in cloud platforms. The heterogeneity is manifested in the popular “pay-as-you-go” charging model where the service machines with different performance would have different service rates. We organize the batch of jobs as a -stage workflow and study two related optimization problems, depending on whether the constraints are on monetary budget or on scheduling length of the workflow. First, given a total monetary budget B, by combining an in-stage local greedy algorithm (whose optimality is also proven) and dynamic programming (DP) techniques, we propose a global optimal scheduling algorithm to achieve minimum scheduling length of the workflow within O(B2). Although the optimal algorithm is efficient when B is polynomially bounded by the number of tasks in the MapReduce jobs, the quadratic time complexity is still high. To improve the efficiency, we further develop two greedy algorithms, called Global Greedy Budget (GGB) and Gradual Refinement (GR), each adopting different greedy strategies. In GGB we extend the idea of the local greedy algorithm to the efficient global distribution of the budget with minimum scheduling length as a goal whilst in GR we iteratively apply the DP algorithm to the distribution of exponentially reduced budget so that the solutions are gradually refined.

Second, we consider the optimization problem of minimizing cost when the (time) deadline of the computation D is fixed. We convert this problem into the standard Multiple-Choice Knapsack Problem via a parallel transformation. Our empirical studies verify the proposed optimal algorithms and show the efficiencies of the greedy algorithms in cost-effectiveness to distribute the budget for performance optimizations of the MapReduce workflows.
| ETPL CLD - 013 | A Novel Model for Competition and Cooperation Among Cloud Providers |

Having received significant attention in the industry, the cloud market is nowadays fiercely competitive with many cloud providers. On one hand, cloud providers compete against each other for both existing and new cloud users. To keep existing users and attract newcomers, it is crucial for each provider to offer an optimal price policy which maximizes the final revenue and improves the competitive advantage. The competition among providers leads to the evolution of the market and dynamic resource prices over time. On the other hand, cloud providers may cooperate with each other to improve their final revenue. Based on a Service Level Agreement, a provider can outsource its users’ resource requests to its partner to reduce the operation cost and thereby improve the final revenue. This leads to the problem of determining the cooperating parties in a cooperative environment. This paper tackles these two issues of the current cloud market. First, we solve the problem of competition among providers and propose a dynamic price policy. We employ a discrete choice model to describe the user’s choice behavior based on his obtained benefit value. The choice model is used to derive the probability of a user choosing to be served by a certain provider. The competition among providers is formulated as a non-cooperative stochastic game where the players are providers who act by proposing the price policy simultaneously. The game is modelled as a Markov Decision Process whose solution is a Markov Perfect Equilibrium. Then, we address the cooperation among providers by presenting a novel algorithm for determining a cooperation strategy that tells providers whether to satisfy users’ resource requests locally or outsource them to a certain provider. The algorithm yields the optimal cooperation structure from which no provider unilaterally deviates to gain more revenue. Numerical simulations are carried out to evaluate the performance of the proposed models.
Energy conservation is a major concern in cloud computing systems because it can bring several important benefits such as reducing operating costs, increasing system reliability, and prompting environmental protection. Meanwhile, power-aware scheduling approach is a promising way to achieve that goal. At the same time, many real-time applications, e.g., signal processing, scientific computing have been deployed in clouds. Unfortunately, existing energy-aware scheduling algorithms developed for clouds are not real-time task oriented, thus lacking the ability of guaranteeing system schedulability. To address this issue, we firstly propose in this paper a novel rolling-horizon scheduling architecture for real-time task scheduling in virtualized clouds. Then a task-oriented energy consumption model is given and analyzed. Based on our scheduling architecture, we develop a novel energy-aware scheduling algorithm named EARH for real-time, aperiodic, independent tasks. The EARH employs a rolling-horizon optimization policy and can also be extended to integrate other energy-aware scheduling algorithms. Furthermore, we propose two strategies in terms of resource scaling up and scaling down to make a good trade-off between task’s schedulability and energy conservation. Extensive simulation experiments injecting random synthetic tasks as well as tasks following the last version of the Google cloud tracelogs are conducted to validate the superiority of our EARH by comparing it with some baselines. The experimental results show that EARH significantly improves the scheduling quality of others and it is suitable for real-time task scheduling in virtualized clouds.
### Analysis, Modeling and Simulation of Workload Patterns in a Large-Scale Utility Cloud

Understanding the characteristics and patterns of workloads within a Cloud computing environment is critical in order to improve resource management and operational conditions while Quality of Service guarantees are maintained. Simulation models based on realistic parameters are also urgently needed for investigating the impact of these workload characteristics on new system designs and operation policies. Unfortunately there is a lack of analyses to support the development of workload models that capture the inherent diversity of users and tasks, largely due to the limited availability of Cloud tracelogs as well as the complexity in analyzing such systems. In this paper we present a comprehensive analysis of the workload characteristics derived from a production Cloud datacenter that features over 900 users submitting approximately 25 million tasks over a time period of a month. Our analysis focuses on exposing and quantifying the diversity of behavioral patterns for users and tasks, as well as identifying model parameters and their values for the simulation of the workload created by such components. Our derived model is implemented by extending the capabilities of the CloudSim framework and is further validated through empirical comparison and statistical hypothesis tests. We illustrate several examples of this work's practical applicability in the domain of resource management and energy-efficiency.

### Deadline based Resource Provisioning and Scheduling Algorithm for Scientific Workflows on Clouds

Cloud computing is the latest distributed computing paradigm and it offers tremendous opportunities to solve largescale scientific problems. However, it presents various challenges that need to be addressed in order to be efficiently utilized for workflow applications. Although the workflow scheduling problem has been widely studied, there are very few initiatives tailored for Cloud environments. Furthermore, the existing works fail to either meet the user’s Quality of Service (QoS) requirements or to incorporate some basic principles of Cloud computing such as the elasticity and heterogeneity of the computing resources. This paper proposes a resource provisioning and scheduling strategy for scientific workflows on Infrastructure as a Service (IaaS) Clouds. We present an algorithm based on the meta-heuristic optimization technique, Particle Swarm Optimization (PSO), which aims to minimize the overall workflow execution cost while meeting deadline constraints. Our heuristic is evaluated using CloudSim and various well-known scientific workflows of different sizes. The results show that our approach performs better than the current state-of-the-art algorithms.
Today, batch processing frameworks like Hadoop MapReduce are difficult to scale to multiple clouds due to latencies involved in inter-cloud data transfer and synchronization overheads during shuffle-phase. This inhibits the MapReduce framework from guaranteeing performance at variable load surges without over-provisioning in the internal cloud (IC). We propose BStream, a cloud bursting framework that couples stream-processing in the external cloud (EC) with Hadoop in the internal cloud (IC) to realize inter-cloud MapReduce. Stream processing in EC enables pipelined uploading, processing and downloading of data to minimize network latencies. We use this framework to guarantee service-level objective (SLO) of meeting job deadlines. BStream uses an analytical model to minimize the usage of EC and burst only when necessary. We propose different checkpointing strategies to overlap output transfer with input transfer/processing while simultaneously reducing the computation involved in merging the results from EC and IC. Checkpointing further reduces the job completion time. We experimentally compare BStream with other related works and illustrate the benefits of using stream processing and checkpointing strategies in EC. Lastly, we characterize the operational regime of BStream.
Network I/O virtualization plays an important role in cloud computing. This paper addresses the system-wide virtualization issues of TCP/IP Offload Engine (TOE) and presents the architectural designs. We identify three critical factors that affect the performance of a TOE: I/O virtualization architectures, quality of service (QoS), and virtual machine monitor (VMM) scheduler. In our device emulation based TOE, the VMM manages the socket connections in the TOE directly and thus can eliminate packet copy and demultiplexing overheads as appeared in the virtualization of a layer 2 network card. To further reduce hypervisor intervention, the direct I/O access architecture provides the per VM-based physical control interface that helps removing most of the VMM interventions. The direct I/O access architecture out-performs the device emulation architecture as large as 30%, or achieves 80% of the native 10 Gbit/s TOE system. To continue serving the TOE commands for a VM, no matter the VM is idle or switched out by the VMM, we decouple the TOE I/O command dispatcher from the VMM scheduler. We found that a VMM scheduler with preemptive I/O scheduling and a programmable I/O command dispatcher with deficit weighted round robin (DWRR) policy are able to ensure service fairness and at the same time maximize the TOE utilization.
ETPL CLD - 020 Workload-Aware Credit Scheduler for Improving Network I/O Performance in Virtualization Environment

SR-IOV (Single-Root I/O virtualization) has become the de facto standard of network virtualization in cloud infrastructure. Owing to the high interrupt frequency and heavy cost per interrupt in high-speed network virtualization, the performance of network virtualization is closely correlated to the computing resource allocation policy in Virtual Machine Manager (VMM). Therefore, more sophisticated methods are needed to process irregularity and the high frequency of network interrupts in high-speed network virtualization environment. However, the I/O-intensive and CPU-intensive applications in virtual machines are treated in the same manner since application attributes are transparent to the scheduler in hypervisor, and this unawareness of workload makes virtual systems unable to take full advantage of high performance networks. In this paper, we discuss the SR-IOV networking solution and show by experiment that the current credit scheduler in Xen does not utilize high performance networks efficiently. Hence we propose a novel workload-aware scheduling model with two optimizations to eliminate the bottleneck caused by scheduler. In this model, guest domains are divided into I/O-intensive domains and CPU-intensive domains according to their monitored behaviour. I/O-intensive domains can obtain extra credits that CPU-intensive domains are willing to share. In addition, the total number of credits available is adjusted to accelerate the I/O responsiveness. Our experimental evaluations show that the new scheduling models improve bandwidth and reduce response time, by keeping the fairness between I/O-intensive and CPU-intensive domains. This enables virtualization infrastructure to provide cloud computing services more efficiently and predictably.

ETPL CLD - 021 Decreasing Impact of SLA Violations: A Proactive Resource Allocation Approach for Cloud Computing Environments

User satisfaction as a significant antecedent to user loyalty has been highlighted by many researchers in market based literatures. SLA violation as an important factor can decrease users’ satisfaction level. The amount of this decrease depends on user’s characteristics. Some of these characteristics are related to QoS requirements and announced to service provider through SLAs. But some of them are unknown for service provider and selfish users are not interested to reveal them truly. Most the works in literature ignore considering such characteristics and treat users just based on SLA parameters. So, two users with different characteristics but similar SLAs have equal importance for the service provider. In this paper, we use two user’s hidden characteristics, named willingness to pay for service and willingness to pay for certainty, to present a new proactive resource allocation approach with aim of decreasing impact of SLA violations. New methods based on learning automaton for estimation of these characteristics are provided as well. To validate our approach we conducted some numerical simulations in critical situations. The results confirm that our approach has ability to improve users’ satisfaction level that cause to gain in profitability.
**ETPL CLD - 022**

**Swiper: Exploiting Virtual Machine Vulnerability in Third-Party Clouds with Competition for I/O Resources**

The emerging paradigm of cloud computing, e.g., Amazon Elastic Compute Cloud (EC2), promises a highly flexible yet robust environment for large-scale applications. Ideally, while multiple virtual machines (VM) share the same physical resources (e.g., CPUs, caches, DRAM, and I/O devices), each application should be allocated to an independently managed VM and isolated from one another. Unfortunately, the absence of physical isolation inevitably opens doors to a number of security threats. In this paper, we demonstrate in EC2 a new type of security vulnerability caused by competition between virtual I/O workloads - i.e., by leveraging the competition for shared resources, an adversary could intentionally slow down the execution of a targeted application in a VM that shares the same hardware. In particular, we focus on I/O resources such as hard-drive throughput and/or network bandwidth - which are critical for data-intensive applications. We design and implement Swiper, a framework which uses a carefully designed workload to incur significant delays on the targeted application and VM with minimum cost (i.e., resource consumption). We conduct a comprehensive set of experiments in EC2, which clearly demonstrates that Swiper is capable of significantly slowing down various server applications while consuming a small amount of resources.

**ETPL CLD - 023**

**Identity-Based Distributed Provable Data Possession in Multi-Cloud Storage**

Remote data integrity checking is of crucial importance in cloud storage. It can make the clients verify whether their outsourced data is kept intact without downloading the whole data. In some application scenarios, the clients have to store their data on multi-cloud servers. At the same time, the integrity checking protocol must be efficient in order to save the verifier’s cost. From the two points, we propose a novel remote data integrity checking model: ID-DPDP (identity-based distributed provable data possession) in multi-cloud storage. The formal system model and security model are given. Based on the bilinear pairings, a concrete ID-DPDP protocol is designed. The proposed ID-DPDP protocol is provably secure under the hardness assumption of the standard CDH (computational Diffie-Hellman) problem. In addition to the structural advantage of elimination of certificate management, our ID-DPDP protocol is also efficient and flexible. Based on the client’s authorization, the proposed ID-DPDP protocol can realize private verification, delegated verification and public verification.
Thank You!