SECURITY AND PRIVACY ISSUES IN THE CLOUD COMPUTING AND BIG DATA

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ABSTRACT

Numerous organizations are seeking efficient methods to store and analyze vast quantities of data. Cloud computing offers scalable resources and economic advantages, including reduced operational expenses, serving as a key facilitator in this regard. However, this computing model introduces several security and privacy concerns that need careful consideration. Challenges such as multi-tenancy, a diminished sense of control, and issues of trust are prominent in cloud computing settings. This document examines current technologies and a broad spectrum of past and cutting-edge projects focused on securing cloud environments and safeguarding privacy. The research presented is organized around the layers of cloud reference architecture—orchestration, resource management, physical resources, and cloud service management—and includes an analysis of recent efforts to enhance security in Apache Hadoop, a widely used big data infrastructure. Additionally, it discusses emerging research on maintaining data privacy in data-intensive applications on the cloud, including models for privacy threats and solutions for enhancing privacy.

KEYWORDS

Cloud Security, Privacy, Trust, Big Data, Virtualization, Data Protection

1. INTRODUCTION

In recent years, there has been an exponential increase in the rate of data production [1, 11], leading organizations to seek out efficient methods for storing and analyzing this vast amount of data. This data, originating from diverse sources such as high throughput instruments, sensors, or IoT devices, can be effectively managed using big data technologies alongside cloud computing. The latter offers substantial advantages, including the on-demand availability of automated tools for assembling, connecting, and reconfiguring virtual resources. This capability significantly simplifies achieving organizational objectives, facilitating the swift deployment of cloud services.

However, the widespread adoption of cloud computing introduces critical security and privacy issues, particularly related to aspects like multi-tenancy, the establishment of trust, loss of control, and accountability. Platforms managing big data, especially those containing sensitive information, must implement both technical and organizational measures to prevent breaches that could lead to significant financial losses.

In the realm of cloud computing, sensitive information covers a broad spectrum of fields and disciplines. For instance, health data serves as a prime example of sensitive information managed within cloud environments, underscoring the universal demand for securing such personal health information. Consequently, as cloud technologies continue to expand, there has been a parallel evolution in privacy and data protection laws aimed at shielding individuals from unauthorized surveillance and data breaches. Notable legislations include the EU Data Protection Directive (DPD) and the US Health Insurance Portability and Accountability Act (HIPAA), both designed to ensure the privacy of personally identifiable information.

This document provides a summary of research into the security and privacy concerns associated with handling large volumes of sensitive data within cloud computing frameworks. It highlights recent advancements across various components of cloud infrastructure, including orchestration, resource management, physical hardware, and the management layers of cloud services. Additionally, this paper examines the latest in security measures for Apache Hadoop, as well as exploring methods for processing sensitive big data in the cloud with an emphasis on privacy threat identification and the implementation of privacy-enhancing techniques.

2. KEY CONCEPTS AND TECHNOLOGIES

Utilizing cloud computing for data-heavy applications is both efficient and cost-saving, yet it introduces security challenges when employing external systems instead of in-house solutions. To address these challenges and devise suitable solutions, it's essential to grasp several fundamental concepts and technologies frequently applied in data-rich cloud environments. These include big data frameworks, virtualization methods, various cloud service models, and container technologies.

2.1 Big Data

The digital universe is expanding rapidly, fueled by data from Internet of Things (IoT) devices, Next-Generation Sequencing (NGS) equipment, scientific simulations, and other significant data sources, necessitating robust systems to manage this influx of information. "Big Data" technologies such as the Google File System (GFS), MapReduce (MR), Apache Hadoop, and the Hadoop Distributed File System (HDFS) have been introduced, available both as commercial and open-source options.

Major IT companies, including IBM, Oracle, Microsoft, HP, Cisco, and SAP, initially adapted these big data solutions. At the outset, "Big Data" was met with various interpretations and considerable excitement. Over the recent years, the National Institute of Standards and Technology (NIST) established a big data working group as a collaborative effort among members from the industry, academia, and government. This group's mission was to agree on a unified definition, develop taxonomies, create secure reference architectures, and plot a technology roadmap. It characterizes big data by its massive and complex datasets that vary, encompassing structured, semi-structured, and unstructured data across numerous fields (variety), significant volumes of data (volume), high-speed data generation (velocity), and the evolution of data in terms of other properties (variability).

Table 1 summarizes the big data technologies from batch processing in 2000 to present with most significant stages and products.

Stage/Year	Characteristics	Examples

Batch Processing (2003-2008)	Large volumes of data are amassed, processed in batches, and outcomes are generated afterward. Utilizes Distributed File Systems (DFS) for resilience and scalability, with parallel computing models like MapReduce for data processing efficiency.	Google File System (GFS), MapReduce (MR), Hadoop Distributed File System (HDFS), Apache Hadoop
Ad-hoc (NoSQL) (2005 - 2010)	Facilitates random read/write capabilities to address the limitations of DFS suited for sequential access. NoSQL databases offer solutions through columnar stores or key-value stores, handling large, unstructured data sets like documents and graphs.	CouchDB, Redis, Amazon DynamoDB, Google BigTable, HBase, Cassandra, MongoDB
SQL-like (2008 - 2010)	Provides simple interfaces for data querying and access, resembling traditional data warehousing with functionalities for efficient data retrieval and manipulation.	Apache Hive/Pig, PrestoDB, HStore, Google F1 Query
Stream Processing (2010 - 2013)	Continuously ingests data streams for immediate processing before storage, accommodating unpredictable data flow patterns with fast, resilient, and always-available systems.	Hadoop Streaming, Google BigQuery, Google Dremel, Apache Drill, Samza, Apache Flume/HBase, Apache Kafka/Storm
Real-time Analytical Processing (2010 - 2015)	Enables automated decisions for data streams from machine-to-machine communications or live sources, applying real-time analysis and rules to incoming and existing data within a specific domain.	Apache Spark, Amazon Kinesis, Google Dataflow

Big data analytics offers significant solutions across various sectors, including manufacturing, education, telecommunications, insurance, government, energy, retail, transportation, and healthcare, facilitating problem-solving and efficiency improvements.

In recent times, leading IT corporations such as Amazon, Microsoft, and Google have made available virtual machines (VMs) through their cloud services, allowing users to lease them. These cloud platforms optimize the use of physical hardware resources, enabling features like the live migration of VMs, dynamic load balancing, and the ability to provision resources on demand. Consequently, enterprises adopting cloud-based VMs can substantially reduce their data center's physical server needs from thousands to merely a few hundred or even tens, significantly decreasing their hardware footprint.

2.2. Virtualization Mechanisms

A hypervisor, also known as a Virtual Machine Monitor (VMM), plays a crucial role in managing virtualized resources by sitting between virtual machines (VMs) and the physical hardware. It enables multiple isolated VMs to operate on a single physical server. Hypervisors fall into two main categories:

Type I Hypervisors: These operate directly on the host's hardware without an underlying operating system (OS), offering efficient performance by removing any middle layers. This model enhances security by isolating each VM; thus, a compromise in one VM does not impact the hypervisor or other VMs.

Type II Hypervisors: This variety functions atop a host OS, which then manages virtualization tasks like input/output (IO) operations and memory management. The hypervisor manages all VM activities, including IO requests, network actions, and system interrupts.

Xen (a Type I hypervisor) and Kernel Virtual Machine (KVM) (a Type II hypervisor) stand out as widely-used open-source hypervisors. Xen operates directly above the physical hardware, adding a virtualization layer underneath the VMs, allowing the operating systems within VMs to interact with virtual resources as though they were physical. KVM, integrated into the Linux kernel, enables the secure execution of guest VM code directly on the host's CPU.

2.3. Cloud Computing Characteristics

In the realm of cloud computing, it's crucial to grasp the spectrum of available services, their delivery mechanisms, and the diverse user base interacting with these services. Cloud computing encompasses the provision of computing software, platforms, and infrastructures as services following a pay-as-you-go model. These services manifest in forms such as Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS), facilitating on-demand access to computing power and storage. Recent years have seen an expansion of cloud service models into various domains under the "as-a-Service" umbrella, including Business Integration-as-a-Service, Cloud-Based Analytics-as-a-Service (CLAaaS), and Data-as-a-Service (DaaS). According to the features outlined by the NIST cloud service models, these services can be delivered through different cloud configurations—private, community, public, and hybrid—catering to a wide array of consumer needs.

Table 2, Categorization of Cloud Service Models and Features

Service Model	Function	Example
SaaS	Allows consumers to run applications by virtualizing hardware on cloud providers	Salesforce Customer Relationship Management (CRM)
PaaS	Provides the capability to deploy custom applications with their dependencies within an environment called a container	Google App Engine, Heroku
IaaS	Provides a hardware platform as a service such as virtual machines, processing, storage, networks and database services	Amazon Elastic Compute Cloud (EC2)7

The NIST cloud computing reference architecture identifies five key players in the cloud sector: consumers, providers, auditors, brokers, and carriers. These roles encompass individuals or organizations involved in cloud computing activities. Cloud consumers use services provided in a business context, whereas cloud providers offer these services. Auditors evaluate cloud services and security, brokers manage and optimize service use and delivery, and carriers facilitate the connection between providers and consumers through networks.

Cloud provider operations fall into several categories: service deployment, resource abstraction, physical resource management, service management, and security and privacy. Service deployment delivers cloud services according to models like SaaS, PaaS, and IaaS. Resource abstraction allows for interaction with computing resources, while physical resources involve the hardware and infrastructure used. Service management covers administrative functions, ensuring compatibility and interoperability with other services. Security and privacy are crucial, with providers implementing measures to protect service delivery and maintain a secure cloud environment.

Table 3, Security and Privacy Factors of the Cloud Providers

Security Context	Description
Authentication and Authorization	Authentication and authorization of cloud consumers using pre-defined identification schemes
Identity and Access Management	Cloud consumer provisioning and deprovisioning via heterogeneous cloud service providers

Confidentiality, Integrity, Availability (CIA)	Assuring the confidentiality of the data objects, authorizing data modifications and ensuring that resources are available when needed
Monitoring and Incident Response	Continuous monitoring of the cloud infrastructure to ensure compliance with consumer security policies and auditing requirements
Policy Management	Defining and enforcing rules to enforce certain actions such as auditing and proof of compliance
Privacy	Protect personally identifiable information (PII) within the cloud from adversarial attacks that aim to find out the identity of the person that the PII relates to

The majority of cloud computing infrastructures consist of reliable services delivered through data centers to achieve high availability through redundancy. A data center or computer center is a facility used to house computer systems and associated components, such as storage and network systems. It generally includes redundant or backup power units, redundant network connections, air conditioning, and fire safety controls.

3. SECURITY AND PRIVACY CHALLENGES

Cloud computing introduces several security challenges, such as data breaches, data loss, denial of service attacks, and threats from malicious insiders, largely stemming from multi-tenancy, data control loss, and trust issues. Notably, many cloud providers, including major ones like Amazon S3, Google Compute Engine, and Citrix Cloud Platform, often do not commit to specific security and privacy standards in their service level agreements (SLAs). This lack of guaranteed security and privacy standards highlights significant concerns for all stakeholders in the cloud computing ecosystem, necessitating careful consideration and discussion of these issues.

The tasks have been broken down into three subsections, each of which is explained in detail below:

3.1. Security Issues in Cloud Computing

In cloud computing, security concerns arise primarily from three areas: multi-tenancy, loss of control, and trust issues. Multi-tenancy, where multiple users share physical and virtual resources, increases the risk of an attacker accessing a target's data due to the shared infrastructure. Loss of control occurs when user data and resources are stored on the provider's premises, leading to potential data mining by providers and challenges in ensuring data deletion across all data centers. This loss of control makes it difficult for users to monitor their resources directly, treating the cloud provider as an opaque entity. Trust issues emerge as users must rely on cloud providers' assurances and trust mechanisms, due to the inability to directly manage their data and resources. Providers, therefore, aim to build customer confidence through compliance with standards and organizational safeguards.

3.2. Privacy Considerations of Processing Sensitive Data

Security issues in cloud computing give rise to significant privacy concerns, recognized globally as a fundamental human right. While security and privacy are distinct, the former is often essential for the latter's preservation. Privacy's complexity varies across different cultures and legal frameworks, with seminal work by Alan Westin in 1960 laying foundational concepts by defining privacy as an individual or group's right to control the dissemination of information about themselves. The International Association of Privacy Professionals (IAPP) views privacy as the appropriate use of information, contingent upon factors like individual preferences, legal context, and intended data use.

Privacy regulation differs notably between regions; the US focuses on "privacy" encompassing its laws and regulations, whereas the EU prefers "data protection" to describe its privacy laws. Complex legislation like the EU's Data Protection Directive (DPD) and HIPAA in the US outline stringent requirements for data handling. With the advent of cloud computing, these regulations emphasize the need for secure data management across borders, exemplified by agreements like the Safe Harbor Agreement (SHA) for transatlantic data transfer. However, evolving challenges such as cybercrime jurisdiction and international data transfer regulations necessitate continual adaptation. The EU's efforts to modernize its privacy framework with a comprehensive data protection regulation aim to enhance personal data protection and impose strict penalties for violations, highlighting the dynamic and intricate nature of privacy in the digital age.

3.3. Big Data Security Challenges

Apache Hadoop, widely used for big data infrastructures, often lacks stringent security measures, with few companies like Yahoo! implementing secure Hadoop environments. Hadoop operates in two modes: a default, non-secure mode with no authentication, where all users have equal access rights, posing risks of data breaches and unauthorized job manipulations, and a secure mode that introduces authentication and authorization mechanisms. In the secure mode, Kerberos is used for authentication, enhancing security by requiring credentials for access, and employs service-level authorization, including Web console authentication. This mode also supports group access permissions and secure data transmission via encrypted channels, contrasting with the default mode's lack of data confidentiality and key management. For organizations with specific security needs beyond Kerberos, alternative authentication systems may need to be established, highlighting the necessity for tailored security configurations in Hadoop deployments.

4. THE CLOUD SECURITY SOLUTIONS

4.1. Authentication and Authorization

This section reviews the research on security solutions such as authentication, authorization, and identity management that were identified in Table 3 as being necessary so that the activities of cloud providers are sufficiently secure.

Researchers have been working on making cloud computing safer by coming up with better ways to handle and protect user login information and permissions. They've figured out how to categorize and manage these login details more effectively, especially for services hosted on the internet, helping businesses choose the right security options. Some have proposed using more than one way to check who's logging in to make it harder for unauthorized users to gain access. There's also a neat tool called MiLAMob designed for people using their phones to access cloud services like storage on Amazon, making it safer and reducing internet data use.

Another approach taken by FermiCloud uses something called PKI X.509 certificates, a type of digital ID, for checking who's trying to access their system, ensuring only the right people can get in. This system is particularly useful for managing users through a web interface or command-line tools, and it's smart enough to link local user accounts with their cloud ID. There are also broader strategies being developed, like creating a service that handles permissions across different cloud services, making sure only authorized users can access certain data or features. This includes using modern methods to manage who has access to what, based on their role, and even allowing services to perform actions on a user's behalf without sharing sensitive login details.

4.2. Identity and Access Management

Identity management systems play a crucial role in making cloud computing services user-friendly and secure. For example, a system using Shibboleth, an open-source project, allows users to log in once but access many different cloud services securely without needing to re-enter their credentials. This kind of setup lets organizations rely on external clouds to manage who gets access to what, streamlining the authentication and authorization processes. Another concept, federated identity management, helps establish trust so users can safely access applications and resources across various cloud services. This approach often involves a mediator or proxy that processes user requests by communicating with a security token service, enhancing how SaaS and PaaS domains protect user interactions.

Efforts like Contrail aim to better connect different cloud services by creating a unified platform that simplifies how resources are managed and accessed, whether integrating services vertically within a single provider or horizontally across multiple providers. There are also projects focused on specific challenges, such as securely managing data sharing through role-based access control (RBAC) and using Web services to enforce identity checks. Moreover, initiatives like E-ID authentication offer solutions for using national e-ID cards for secure cloud storage access, blending traditional identification with modern cloud technology. The development of federated clouds, like the EGI federated cloud, showcases collaborative efforts to provide infrastructure-as-a-service (IaaS) and secure data sharing for research and education, highlighting the importance of robust identity management and access control in the expanding cloud ecosystem.

4.3. Confidentiality, Integrity, and Availability (CIA)

Terra designed to enhance cloud security, introducing the Trusted Cloud Computing Platform (TCCP). This platform treats the entire Infrastructure-as-a-Service (IaaS) as one system and uses a trusted virtual machine monitor to safeguard VMs, allowing users to check the security of cloud services before they start using them. With components like the external trusted entity (ETE) for monitoring VM security, TCCP relies on trusted platform module (TPM) chips for secure, verifiable cloud computing. Another innovative system, CloudProof by Popa et al., promises secure cloud storage by encrypting data with keys only known to the data owner, utilizing a unique attestation mechanism to verify the integrity and confidentiality of data stored in the cloud.

Further exploring cloud security, research has revealed vulnerabilities in popular open-source hypervisors like Xen and KVM, identifying the parts of these systems most susceptible to attacks that could compromise data security. The reports indicate that half of the observed vulnerabilities affect both Xen and KVM, highlighting the need for careful management of these systems to protect against breaches. On a different note, the "Swap and Play" method proposes a novel way to update hypervisors without downtime, ensuring high availability of cloud services, while Klein et al. introduce "brownout," a load-balancing technique that improves cloud service resilience during high-traffic periods or resource shortages.

In addition, efforts to streamline cloud service usage include new approaches to federated identity management and secure authorization, making it easier for users to access and share resources across different cloud platforms. These advancements aim to simplify the user experience while maintaining high levels of security and privacy, ensuring users can trust the cloud environments they depend on for storing and processing their data.

4.4. Security Monitoring and Incident Response

Security monitoring and incident response are essential practices in cloud computing to ensure that potential security threats are detected early and addressed promptly. Security monitoring involves continuously watching over the cloud environment to spot suspicious activities or vulnerabilities that might indicate a security breach. This could include unusual access patterns, an unexpected spike in data traffic, or attempts to exploit system weaknesses. Effective monitoring helps in identifying risks before they escalate into serious issues, allowing for immediate action to mitigate potential damage.

Incident response is the set of actions taken once a security threat is identified. It involves a coordinated effort to contain the threat, assess the extent of the damage, and restore any compromised services or data. This process requires a well-prepared plan that outlines how to react to different types of security incidents, who is responsible for each action, and how to communicate during the crisis. Quick and effective incident response is crucial to minimize the impact of security breaches, maintain trust with users, and ensure the continuous operation of cloud services. Together, security monitoring and incident response form a critical part of a cloud provider's security strategy, safeguarding data and infrastructure against potential threats.

4.5. Security Policy Management

Security policy management in cloud computing involves creating, implementing, and maintaining rules that govern how an organization's data and services are protected in the cloud. These policies are essentially a set of guidelines that dictate the do's and don'ts for employees, the technologies to be used for securing data, and the procedures for handling and responding to security incidents. The aim is to ensure that everyone knows their role in keeping the organization's data safe and that there are clear standards for what constitutes secure behavior online.

Developing an effective security policy requires understanding the specific risks associated with cloud services, including how data is stored, accessed, and shared. Once the policies are in place, they need to be regularly reviewed and updated to adapt to new threats or changes in the cloud computing environment. This ongoing process helps organizations stay one step ahead of potential security vulnerabilities and ensures that their cloud operations remain resilient against attacks. Effective security policy management is crucial for minimizing risks and protecting an organization’s assets in the cloud, making it a foundational element of any cloud security strategy.

5. BIG DATA SECURITY AND PRIVACY

This section outlines several efforts and projects on big data security and privacy including big data infrastructures and programming models. It focuses on the Apache Hadoop that is a widely- used infrastructure for big data projects such as HDFS and Hive, HBase, Flume, Pig, Kafka, and Storm. We also summarize the state-of-the-art for privacy-preserving data-insensitive solutions in cloud computing environments.

5.1. Big Data Infrastructures and Programming Models

Several initiatives aim to boost Hadoop's security, including projects like Apache Rhino, Apache Knox, Apache Ranger, and Apache Sentry. Apache Rhino, started by Intel in 2013, focuses on enhancing Hadoop's security by offering key management, authorization, single sign-on capabilities, and better audit logging. Apache Knox aims to secure Hadoop clusters with perimeter security, simplifying access through REST Web services and integrating easily with identity providers, alongside supporting various authentication methods. Apache Ranger provides a centralized way to manage security for Hadoop, enabling detailed access control and auditing for multi-tenant environments. Apache Sentry offers fine-grained access control within Hadoop clusters, using policy files to manage permissions.

Efforts to tackle big data's security and privacy challenges also come from academia, such as SEHadoop, which aims to increase isolation among Hadoop components and enforce minimal access privileges. Recent discussions, like those by Bertino, address big data security and privacy, emphasizing the need for integrity, data trustworthiness, and balancing security with privacy. These discussions also touch on the efficiency of cryptographic techniques in the context of big data’s scalability challenges, highlighting the need for a privacy-aware data lifecycle.

5.2. Privacy-Preserving Big Data Solutions in the Cloud

Privacy-preserving big data solutions in the cloud are designed to protect sensitive information while enabling the analysis and processing of large datasets. These solutions incorporate various techniques and technologies to ensure that data privacy is maintained without compromising the utility of the data for analysis purposes. One approach involves encrypting data before it's stored or processed in the cloud, ensuring that only authorized users can access the original data. Another method is anonymization, where identifying information is removed or obscured to prevent the data from being traced back to individuals.

Additionally, differential privacy techniques can be applied, adding random noise to the data or queries to protect individual data points while still providing accurate aggregate information. Federated learning is another privacy-centric approach, allowing models to be trained across multiple decentralized devices or servers holding local data samples, without exchanging them. These privacy-preserving techniques are crucial for maintaining trust and compliance with data protection regulations, such as GDPR, when dealing with big data in the cloud. By implementing these solutions, organizations can leverage the cloud's scalability and flexibility for big data analytics while ensuring that individual privacy is not compromised.

6. CONCLUSIONS

This paper reviewed several security and privacy issues on big data in the cloud. It described several big data and cloud computing key concepts such as virtualization, and containers. We also discussed several security challenges that are raised by existing or forthcoming privacy legislation, such as the EU DPD and the HIPAA.

The results that are presented in the area of cloud security and privacy are based on cloud provider activities, such as providing orchestration, resource abstraction, physical resource and cloud service management layers. Security and privacy factors that affect the activities of cloud providers in relation to the legal procession of consumer data were identified and a review of existing research was conducted to summarize the state-of-the-art in the field.

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Appendix A. Code Samples:

Github link :

https://github.com/keyur2303/Big-Data-Security-and-Privacy-in-NYC-Taxi-Trip-Data.git

Appendix B. Datasets

The dataset in question contains trip records for New York City taxis from the year 2013. It was made available to the public through the efforts of Chris Whong under the Freedom of Information Law (FOIL), a law that allows the public to request and obtain existing records from government agencies to promote transparency.

Dataset Overview:

Size: The dataset is provided in a compressed format (.bz2) that is 93 MB, which when uncompressed expands to 384 MB.

Format: It is available as a CSV file named taxi-data-sorted-small.csv.bz2, suggesting that it may be a subset or a processed version of a larger dataset, intended to be more manageable for analysis or demonstration purposes.

Contents: The dataset records various aspects of taxi trips, including:

- Medallion: A unique identifier for the taxi.
- Hack License: A license number for the taxi driver.
- Pickup and Dropoff Datetime: Timestamps for when a ride started and ended.
- Trip Time in Secs: Duration of the trip in seconds.
- Trip Distance: Distance of the trip in miles.
- Pickup and Dropoff Coordinates: Latitude and longitude coordinates for pickup and dropoff locations.
- Payment Type: Method of payment for the trip.
- Fare Amount: The charge for the trip before extras.
- Surcharge, MTA Tax, Tip Amount, Tolls Amount, Total Amount: Additional charges, taxes, tips, tolls, and the total amount charged for the trip.

Potential Uses:

This dataset offers a rich source of information for analysis, offering insights into patterns such as peak travel times, popular destinations, fare statistics, and the financial aspects of taxi usage in NYC. It can be utilized for various purposes, including urban and transport planning, economic analysis, and machine learning projects aimed at predicting fares or demand.

Access and Usage:

The dataset's availability through FOIL and individuals like Chris Whong highlights the importance of open data initiatives in fostering innovation and transparency. Researchers, data scientists, and enthusiasts are encouraged to explore and utilize this dataset while adhering to any usage guidelines or restrictions specified by the data provider.