IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.102 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 13, Issue 5, May 2024

DOI: 10.17148/IJARCCE.2024.13527

Guardians of the Cloud: A Survey on Cloud Monitoring Architectures

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Abstract: As cloud computing solidifies its place in modern technology, effective monitoring becomes paramount for optimizing performance and resource utilization. This paper conducts a comprehensive survey of cloud monitoring architectures, with a focus on Adaptive Monitoring Architecture (HSACMA), which has the capacity to balance monitoring capabilities and resource consumption across cloud layers. The exploration extends to Federated Architecture for Resource Management and Monitoring in Clouds (FEDARGOS-V1), offering a specialized approach to reconcile monitoring requirements in federated cloud infrastructures. Additionally, the survey takes into consideration the Cloud Monitor architecture, an innovative solution for independent cloud evaluations, showcasing its potential through preliminary results. The investigation culminates with a glance at the ElasticSearch, Logstash, and Kibana (ELK) stack, highlighting its versatility in log analysis for cloud environments. This survey illuminates the diverse landscape of cloud monitoring, resource management, and evaluation mechanisms, encapsulating both established paradigms and emerging trends.

Keywords: Cloud services, Monitoring, Log analysis, ELK stack

I. INTRODUCTION

In the realm of cloud computing, the widespread adoption of cloud services has significantly amplified the complexity and scale of cloud infrastructures. This paper undertakes a thorough exploration of cloud monitoring architectures and tools, focusing on the crucial tripartite process of data collection, analysis, and reporting/decision-making. The interplay between monitoring servers, led by either human cloud administrators or scalable monitoring systems, sets the stage for a nuanced examination of centralized and decentralized architectures. From small to medium-sized deployments, the paper navigates the intricacies of these monitoring stations. The analysis phase is dissected, showcasing a diverse array of tools, from simple graphing to trend analysis and stream processing, illuminating sophisticated methodologies [1]. The industry landscape is surveyed, acknowledging the burgeoning growth in cloud computing services alongside persistent challenges. The paper highlights pioneering efforts in cloud monitoring, emphasizing benchmarking and specialized evaluation mechanisms, exemplified by the embryonic stages of the Cloud Monitor architecture. The intersectionality of cloud monitoring and resource management is explored, with FEDARGOS-V1 emerging as an innovative solution for federated cloud infrastructures. A retrospective glance at the evolution of cloud computing underscores its transformative impact, seamlessly segueing into the indispensable role of cloud monitoring. The imperative for adaptive monitoring strategies is emphasized, and real-world validation, such as HSACMA in the CloudStack environment, further fortifies the credibility and applicability of these innovations.

II. LITERATURE REVIEW

The landscape of cloud computing demands effective monitoring strategies to ensure resource availability, performance, and quality of services. In response to the challenges faced by traditional monitoring systems, a study introduces HSACMA, a Hierarchical Scalable Adaptive Monitoring Architecture. HSACMA addresses the delicate balance between monitoring capability and resource consumption by monitoring physical and virtual infrastructure across layers and adapting intervals based on system states, demonstrating its effectiveness in a real production system on the CloudStack platform [2]. Resource management is identified as a critical element in ensuring quality cloud services, with monitoring standing out as a pivotal aspect. FEDARGOS-V1, a Federated Architecture for Resource Management and Monitoring in Clouds, is proposed to address the complexities of managing resources in a secure and scalable manner within federated cloud environments. This architecture, deployed in a real-time OpenStack-based FEDGEN cloud testbed, is evaluated against existing systems, emphasizing its potential for efficient and scalable resource monitoring [3]. Another facet of cloud monitoring involves the non-intrusive collection of monitoring data from the host OS, linking it with the cloud controller for efficient monitoring. This approach, demonstrated in a paper, offers an efficient, lightweight, and scalable

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cloud monitoring framework that incurs negligible overhead, showcasing its potential for practical implementation [4]. In the context of the unpredictable costs, unclear performance, and inconsistent security in cloud computing, a forward-looking approach presents an early-stage Cloud Monitor architecture. This architecture aims to integrate existing and new benchmarks in a flexible and extensible manner, allowing for independent evaluation of clouds under actual operating conditions. Preliminary results suggest that an independent monitoring solution could be a powerful enabler for next-generation cloud computing, providing benefits not only for consumers but potentially the entire ecosystem.

III. NEED FOR CLOUD MONITORING

Cloud computing offers significant advantages to businesses, ranging from small and medium-sized enterprises leveraging infrastructure and storage services to large enterprises modernizing applications for operational efficiency and flexibility [5]. The cloud allows enterprises to enhance customer service levels and reduce ownership costs. However, the distributed nature of physical and virtual resources across different geographical locations in the cloud necessitates proper monitoring. Without effective cloud monitoring, enterprises risk falling short of performance goals and may not realize the full benefits of their cloud investments, jeopardizing the targeted return on investment. Cloud monitoring, defined as the process of monitoring, evaluating, and managing cloud-based services, applications, and infrastructure, plays a crucial role in addressing various challenges and ensuring optimal cloud utilization. It is fundamental for capacity planning, enabling adjustments in resource allocation and planning based on real-time monitoring data. Continuous monitoring is essential for calculating resource usage, billing consumers accurately, identifying and addressing potential issues, troubleshooting, and adhering to service level agreements. Cloud monitoring also facilitates the delivery of detailed reports, in-depth graphs, and various metrics for performance management, optimization of cloud solutions and services, determination of resource status, control activities, secure migration, and achieving cloud-specific characteristics such as scalability, elasticity, and resource provisioning. In essence, cloud monitoring is indispensable for maximizing the efficiency, security, and performance of cloud-based operations.

Cloud monitoring involves three key stages: data collection, analysis, and reporting/decision-making. In the data collection stage, monitoring servers, managed by a cloud administrator or a scalable monitoring system, gather information about the status of resources in the cloud. The collection process varies based on the cloud's size, utilizing either a single monitoring server or a network of agents in larger deployments. The analysis stage employs techniques like graphing, threshold analysis, trend analysis, and stream processing to interpret the collected data. The decision-making stage involves actions such as reporting, alerting, or control actions based on the analysis. In smaller deployments, a single monitoring server is used, while in medium-sized deployments, multiple agents are tightly coupled with a centralized server forming a monitoring station. The system utilizes a master–slave model where agents, tied to specific resources, collect data and send it to the centralized server for analysis. The limitations of a centralized system include a single point of failure and poor scalability. Alternatively, decentralized monitoring architectures connect multiple monitoring systems in a peer-to-peer configuration, enhancing scalability and resilience. Each peer is equally important, and the failure of one does not impact others. Decentralized systems utilize distributed hash tables and epidemic-style communication for data collection, generating reports and taking actions based on the analyzed data. The analysis employs various tools, including simple graphing, threshold analysis, trend analysis, and stream processing. Simple graphing offers a holistic view of system-wide resource usage, while threshold analysis continuously checks values against predefined conditions to detect abnormal conditions. Trend analysis and stream processing handle large volumes of events, providing rich data analysis and detecting abnormal conditions. Decision-making is based on the analysis, with skilled personnel supervising and taking appropriate actions in complex situations.

IV. CHALLENGES IN CLOUD MONITORING

The integration of cloud computing into business operations is motivated by the promises of dynamic scalability, reduced capital and operational costs, and rapid resource provisioning. As enterprises migrate their workloads to the cloud [7], they manifest an increasing reliance on cloud service providers. However, despite the efficacy of the cloud in meeting service demands, the occurrence of cloud outages is on the rise, posing substantial economic costs and potential harm to customer relations.

To address these challenges, a variety of monitoring tools are utilized to continuously oversee and manage cloud operations. Nonetheless, several issues in cloud monitoring persist, hindering the attainment of comprehensive understandings into cloud services and processes.

1. Comprehensive Understandings: Current monitoring tools primarily provide metrics, lacking detailed information on resource consumption. For instance, CPU utilization metrics may lack specifics on the responsible process, resulting in limited visibility.

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2. Insights into Migration Life Cycles: As organizations migrate applications to the cloud, existing monitoring tools offer only restricted perspectives into migration processes. This limitation may hinder companies from achieving optimum service levels and maximum benefits.

3. Growing Complexity: The heterogeneity of multiple monitoring tools, a consequence of expanding cloud adoption, amplifies complexity. Cloud administrators spend considerable time and effort analyzing diverse metrics produced by these tools.

4. Challenges in Multi-Tenancy: Monitoring multi-tenancy requires a shift from merely observing application or resource status to focusing on Quality of Service (QoS) parameters specific to each tenant. Detecting key performance indicators (KPIs) for individual tenants becomes a daunting task [5].

5. Understanding End-User Response Time: Monitoring end-user response time in globally distributed cloud applications is intricate due to variations in user locations. Identifying the causes for these variations consumes considerable time.

V. COMPARITIVE ANALYSIS

The FEDARGOS-V1 architecture introduces a comprehensive approach to resource management in federated cloud environments. It addresses the challenges posed by multi-cloud tenants and various software stack levels by providing secure and scalable monitoring. The architecture focuses on resource discovery, selection, allocation, pricing, disaster management, and monitoring. With a specific emphasis on federated clouds, FEDARGOS-V1 aims to offer timely access to information for early identification of resource constraints, showcasing its potential for deployment in both private and public federated cloud infrastructures. The extended system, FEDARGOS-V1, incorporates three major engines - configuration, statistics, and query - to achieve comprehensive monitoring functionality. The configuration engine serves as the foundation for coordinating services, VM registration, configuration storage, and decision-making [2]. This architecture positions itself as a significant contribution to enhancing resource monitoring speed and scalability in federated cloud platforms.

CloudProcMon, addressing the growing importance of cloud monitoring, particularly emphasizes non-intrusive data collection from the host operating system. The paper highlights the challenges associated with collecting monitoring data non-intrusively and proposes a solution that efficiently utilizes Procfs of the host OS for data collection [3]. The CloudProcMon system leverages Procfs to obtain the current state of processes, providing a lightweight and scalable cloud monitoring framework with minimal overhead. By linking data from the host OS with the cloud controller, the proposed solution achieves effective monitoring while mitigating challenges related to process identity, VM mapping, and data linkage to the cloud controller.

In the realm of cloud monitoring challenges, HSACMA (Hierarchical Scalable Adaptive Monitoring Architecture) proposes a hierarchical and adaptive approach. HSACMA effectively monitors physical and virtual infrastructure, middleware, and application services through a hierarchical structure. Utilizing microservices, it achieves scalability and adaptively adjusts monitoring intervals and data transmission strategies based on the running state of the cloud computing system. The real-world deployment on the CloudStack platform validates HSACMA's efficacy in improving accuracy, real-time performance, and reducing resource consumption in cloud monitorinG [4]. The architecture introduces various monitoring services at different layers, emphasizing adaptability and scalability to address challenges related to cloud architecture and resource monitoring.

A comparative analysis of these architectures reveals nuanced strengths and weaknesses. FEDARGOS-V1 stands out for its specialization in federated cloud environments, providing a comprehensive solution for resource management challenges. CloudProcMon excels in non-intrusive data collection, ensuring efficiency and scalability. HSACMA, with its hierarchical and adaptive structure, addresses challenges in monitoring physical and virtual infrastructure. Each architecture demonstrates unique merits, offering valuable contributions to the evolving landscape of cloud monitoring. When considering deployment scenarios, FEDARGOS-V1 proves advantageous for federated clouds, CloudProcMon for non-intrusive data collection, and HSACMA for adaptability and scalability in monitoring diverse cloud layers. A holistic evaluation, incorporating factors such as scalability, adaptability, and real-world applicability, informs potential users and researchers in selecting the most suitable architecture for their specific cloud monitoring needs.

In comparing the deployment styles of the discussed cloud monitoring architectures, distinct methodologies emerge, each tailored to specific needs. The Cloud Monitor deployment relies on Terraform for management, Kubernetes for scaling and orchestration, and InfluxData suite for processing and storing results.

DOI: 10.17148/IJARCCE.2024.13527

Leveraging the Google Kubernetes Engine (GKE) in the europe-west4 region, this architecture demonstrates a robust infrastructure utilizing open-source tools [6] such as Kafka, Telegraf, and Packer for efficient monitoring. On the other hand, the section on VM deployment in the CloudProcMon study delves into the fundamental process of launching VMs in the cloud. This process highlights the client's interaction with the cloud controller for VM creation. The deployment is intricately explained, emphasizing the temporary profiling of VMs, cloud identifier assignment, and communication between the controller and compute nodes. This section provides a foundational understanding of VM deployment in the context of operating-system-based non-intrusive cloud monitoring. For FEDARGOS-V1, the deployment intricacies are visualized in a block diagram showcasing different components. The architecture utilizes FEDARGOS-V1 APIs for monitoring information access within federated cloud environments. The deployment involves REST APIs for interoperability with Web standards, addressing security and scalability concerns. The inclusion of a Web-based console enhances user interaction, providing a user-friendly display of monitored information. FEDARGOS-V1 ensures comprehensive monitoring of federated cloud deployments, encompassing performance, availability statistics, and applications like networking, storage, compute, image service, and telemetry.

In comparing these diverse studies on cloud monitoring architectures, each contributes a unique perspective to the evolving landscape of cloud management. FEDARGOS-V1 stands out for its focus on federated cloud infrastructure, extending the DARGOS reference and showcasing superior performance metrics in multi-tenancy scenarios. On the other hand, CloudProcMon emphasizes the efficiency of non-intrusive monitoring, demonstrating the lightweight and scalable nature of OS-based cloud monitoring, a method considered more efficient than intrusive alternatives. Meanwhile, the Cloud Monitor Architecture delves into the performance dynamics of different cloud providers, revealing variations in CPU performance and stability. Collectively, these studies underscore the significance of tailored monitoring solutions, addressing multi-faceted challenges in the dynamic cloud environment and providing valuable insights for both cloud users and providers.

VI. CHALLENGES IN CLOUD MONITORING

In the realm of cloud monitoring systems, future research trends and challenges are emerging, necessitating exploration to enhance efficiency, security, and performance. Advanced monitoring techniques are vital, requiring the development of new approaches for data collection, processing, and analysis, potentially leveraging machine learning and artificial intelligence for anomaly detection and resource optimization. Scalability and performance are key focuses, particularly in large-scale deployments, where optimizing monitoring tools and techniques is crucial to handle increased data volumes and resource constraints effectively. Multi-tenancy monitoring presents another challenge, necessitating effective methods to isolate and manage resource usage and performance for each tenant while maintaining scalability. Enhancing end-user response time monitoring in globally distributed cloud applications is essential, considering user locations and modern application architectures. Dynamic resourcing and virtualization demand exploration of new approaches to monitor and manage dynamic cloud resources continuously. Cloud security and compliance require investigation into methods to enhance encryption, authentication, and authorization mechanisms, along with monitoring for security breaches and compliance violations. Integration with emerging technologies like IoT, edge computing, and blockchain offers potential for creating more comprehensive monitoring solutions. Finally, the development of advanced real-time monitoring and analytics techniques is imperative for faster issue detection and response in cloud environments, reducing downtime and improving overall performance. Addressing these trends will enable ongoing innovation in cloud monitoring systems, benefiting both users and providers.

VII. CONCLUSION

Cloud monitoring systems play a crucial role in addressing various challenges and ensuring optimal cloud utilization. As cloud computing continues to evolve, monitoring systems must adapt to the changing landscape to maximize the efficiency, security, and performance of cloud-based operations. This paper has explored the stages of cloud monitoring, the challenges faced by these systems, and various monitoring architectures, highlighting their unique contributions to the evolving landscape of cloud management. The stages of cloud monitoring, as discussed in this paper, involve data collection, analysis, and reporting/decision-making. Data collection processes have evolved from single monitoring servers to decentralized architectures, enhancing scalability and resilience. The analysis stage employs various techniques to interpret the collected data, while the decision-making stage involves actions such as reporting, alerting, or control actions based on the analysis. Several challenges have been identified in cloud monitoring, including comprehensive understanding, insights into migration life cycles, growing complexity, challenges in multi-tenancy, understanding end-user response time, and dynamic resourcing. These challenges have been addressed by various monitoring architectures, each offering unique perspectives and solutions. The FEDARGOS-V1 architecture, for example, focuses on resource management in federated cloud environments, providing secure and scalable monitoring.

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The CloudProcMon system emphasizes non-intrusive data collection from the host operating system, demonstrating a lightweight and scalable cloud monitoring framework with minimal overhead. The HSACMA architecture proposes a hierarchical and adaptive approach to monitoring, effectively monitoring physical and virtual infrastructure, middleware, and application services through a hierarchical structure. When considering deployment scenarios, each architecture demonstrates unique merits, offering valuable contributions to the evolving landscape of cloud monitoring. FEDARGOS-V1 is advantageous for federated clouds, CloudProcMon for non-intrusive data collection, and HSACMA for adaptability and scalability in monitoring diverse cloud layers. This paper has provided a comprehensive overview of cloud monitoring systems, their stages, challenges, and various monitoring architectures. By understanding these aspects, researchers and developers can continue to innovate and improve cloud monitoring systems, addressing the challenges and complexities of the dynamic cloud environment and providing valuable insights for both cloud users and providers.

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