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Multi-Cloud Observability: Tools and Techniques for Monitoring and Troubleshooting Complex Hybrid Cloud Environments

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Abstract—This article focuses on detection tools and methods for hybrid cloud that are used to deal with complexity levels within multi-cloud infrastructures. It breaks down some of the best open-source and commercial observability solutions, like Prometheus, Grafana, Jaeger, Datadog, New Relic, Dynatrace, and Splunk, describing the offered functions, their advantages, and disadvantages. Some of the problems highlighted in the research include multi-cloud visibility and data consistency, integration difficulties, and inherent scalability. The real-life examples of TD Bank and Blinkit show how organizations can use and realize the values of observability solutions for better service dependability, quick reaction to incidents, and customer satisfaction. The paper then analyses some of the new trends, like the use of artificial intelligence in monitoring and enabling automated repairs and improvements to the network while at the same time trying to improve operational efficiency and looking at operation costs. Core problem-solving approaches for multi-cloud cases are articulated, which include diagnostics of the root cause, proper handling of the incident handling process, and the use of intelligent automation for problem-solving. Thus, the results highlight the need to implement extensive observability strategies for the effective management of distributed cloud systems. Future advancements are expected with cloud technologies; hence, organizations need to keep abreast of the latest concerning observability tools and approaches to ensure their multi-cloud environments remain high on performance and reliability.

Keywords - Multi-Cloud Observability; Hybrid Cloud Monitoring; Distributed Tracing; AI-Driven Monitoring; Automated Remediation.

I. INTRODUCTION

As cloud solutions continue to gain prominence in the modern world, it is not a surprise to see the application of multi-cloud and hybrid cloud systems among organizations. Multi-cloud refers to the integration of intermedial cloud services from other cloud vendors into a single heterogeneous architecture [1]. This approach also lets organizations take advantage of the key advantages of different cloud providers, use several cloud infrastructures at a time, and even save some money due to their freedom from strict dependence on one provider. Hybrid cloud, on the other hand, integrates public cloud solutions with private cloud or on-premises solutions and is preferred for a mix of the advantages of scalable resources with administrative control over crucial data and methods [2]. Since many organizations have started establishing their processes in such complex environments, the need for observability has exponentially increased. Cloud computing observability means monitoring and understanding the distributed systems' behavior, performance, and health to a greater extent than in traditional monitoring [3]. It includes the gathering of statistics, logs, and traces along with their processing to understand the systems' behavior. In more complex environments, such as multi-cloud and hybrid cloud systems, observability is even more critical because, when various systems interact, problems are likely to occur [4]. So, it will suffice to say that the observability factor cannot be overemphasized in such environments. It is used to keep business performance high, ensure security, ensure reasonable expenses, and identify and address problems in these distributed structures in the shortest time. Observability enables teams to spot issues that may arise and fix them even before users or clients encounter them while at the same time helping the teams get a feel for how different systems are affiliated with one another so that wise decisions that can increase the reliability of systems, as well as the user experience, can be made [5].

However, the enforcement of thorough observability in multi-cloud configurations proves to be a rather daunting endeavor. The extensive distribution of objectives across different platforms poses problems in terms of monitoring and real-time diagnosis due to differing tools, APIs, and data sets. Key challenges include:

a) Data consistency: It is critical to guarantee that the acquired data is uniform across different cloud environments and to evade misinterpretation of the information obtained from varied cloud environments.

b) Integration complexities: Integrating tools and services from different providers to create an end-to-end observability stack [6].

c) Unified visibility: Integrating different tools and achieving a consolidated view of all the systems in an organization.

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d) Compliance and security: Managing multiple regulatory requirements and security provisions in the different cloud environments.

e) Scalability: The overwhelming amount of data, its diversity, and the rapid pace at which it flows from various cloud services.

f) Root cause analysis: Detecting the origin of a problem in a large-dispersed system.

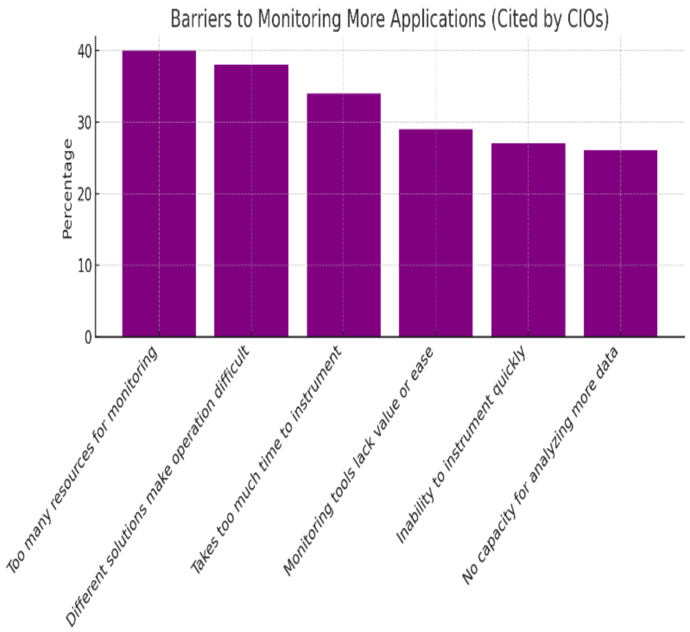

Figure 1. Detailed Challenges in Monitoring Cloud Applications [28]

Such problems are capable of resulting in increased time wastage and cases of delay in the formulation and identification of possible causes of the challenges, thus negatively affecting business operations and customer service delivery. Based on these issues, this article seeks to fill a significant gap in expanding the best practices of observability in multi-cloud and hybrid-cloud environments. The specific objectives of this research are:

- To assess the currently existing tools and methods to measure observability in multi-cloud technologies and solutions.
- To compare open-source solutions with commercial ones for observability, it is necessary to use the following list of requirements:
- To substantiate these tools and show examples of them being implemented in different organizations.
- To establish and articulate the state of the art concerning the application of strong observability strategies in complex multi-cloud environments.

This paper focuses on a list of critical observability tools and methods consisting of Prometheus, Grafana, Jaeger, Datadog, New Relic, Dynatrace, and Splunk. Here, we will discuss their characteristics, advantages, and disadvantages, mainly from the perspective of the multi-cloud and hybrid-cloud models. These elements include metric collection, logging, distributed tracing, and the interoperability of the selected tools. Thus, by achieving these objectives and considering this scope, this paper is intended to deliver helpful information and actionable recommendations for organizations that want to improve their observability in a multiple-cloud context.

II. LITERATURE REVIEW

A. *Historical Perspective*

The widespread adoption of single-cloud environments into multi-cloud environments has altered the traditional landscape of IT infrastructure management. At the start, organizations embraced single-cloud models, where the primary interest was in the IaaS of various cloud service providers, which included AWS, which started in 2006 [7]. This early phase was characterized by reasonably bare-bones monitoring methods, which were commonly tightly connected with a specific provider and included things like Amazon CloudWatch [7]. By the time cloud solutions started being adopted in enterprises, people realized that most of the strategies were tied to a single cloud solution, which puts the business at risk of vendor lock-in as well as having the potential for having an SPOF. This realization led to the emergence of the multi-cloud structure, approximately around 2010-2012 [7, 8]. Outsourcing was facilitated by the need for flexibility, a reduction in cost, and also to take advantage of the specialized solutions from various service providers. Heterogeneous monitoring and troubleshooting of these early systems were often imminent. It was typical for organizations to use a mix of cloud-native monitoring tools and on-premises tools and applications, which again created disjointed views and inconvenient problem-solving. Earlier, tools like Nagios and Zabbix, or wired ones like Cacti, which were initially built for on-premises infrastructure, could be integrated with cloud infrastructure in a more or less effective manner [8].

B. *Current State of Observability*

The idea of control theory-derived observability in IT operations has been quite popular in the last several years. Those modern approaches to observability in the cloud space are slightly different from traditional monitoring practices as they address the need for detailed visibility into the systems' behavior [9]. This has been due to the growth of multifaceted distributed systems and the growing requirement for proactive, powerful, and superior techniques for managing such systems.

C. *Key concepts in Observability*

a) Metrics: Based on numerical values obtained from monitoring the forms of activity and identified performance measures, generally collected over specific time intervals. The most common ones are CPU utilization, memory, and requests per second, or some business-specific indicators [10].

b) Logs: It is essential to have a record of discrete events in the system that includes a timestamp to give the troubleshooter and analyst a well-developed scene.

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c) Traces: It depicts request flow across distributed systems so that one can examine the areas that have performance issues or that are dependent on other parts.

These concepts have significant roles as a part of knowledge creation since they come as a package: they must go hand in hand. Metrics give a bird's eye view of the system state, while logs add context and event details, and traces capture an end-to-end picture of how requests traversed the systems [11].

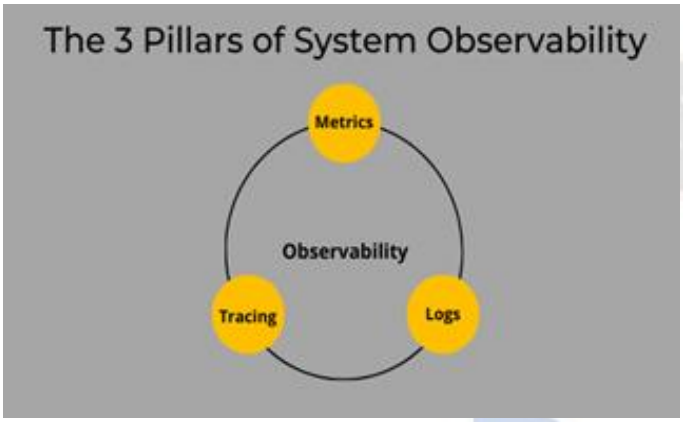

Figure 2. Pillars of System Observability [12]

D. Key Challenges Identified in Literature

In the existing literature, some of the main challenges that we have discerned include the following:

a) Integration Issues: The collection of observability data from various cloud platforms and tools can be technically complex. Thi Nguyen et al. [12] also focus on the fact that it is challenging to develop a coherent picture of the system's performance when there are different environments.

b) Data Consistency: One difficulty is maintaining the coherence of the data collected and the analysis and aggregation method between cloud providers. The differences in metrics definitions, the format for logging data, and data at different granularities can easily result in tortuous or even false results.

c) Latency: The fact that multi-cloud systems are distributed applies latency in data collection and analysis in cases with real-time monitoring and alerting.

d) Security and Compliance: Managing security measures and adhering to legislation on the different cloud platforms is even trickier, especially in industries that have more stringent laws on data protection.

e) Scalability: While single cloud configurations are much easier to monitor, the same is not valid for multi-cloud environments, as the latter undergo rapid scale and complexity increases. Traditional monitoring thus loses efficacy quickly and needs more scalable replacements.

E. Existing Solutions and Gaps

The literature presents a range of solutions addressing various aspects of multi-cloud observability:

a) Cloud-Native Observability Platforms: Such solutions as Prometheus, Grafana, and Jaeger are openly sourced and high-demanded products that help to achieve total observability in environments of cloud-nativeness.

b) Commercial Integrated Solutions: Vendors like Datadog, New Relic, and Dynatrace are providing integrated solutions to function in multi-cloud environments for end-to-end observability [13].

c) Open-Source Frameworks: Initiatives such as OpenTelemetry seek to set best practices when it comes to metrics and traces accompanying software deployed across one or the other environment.

Although there have been substantial advancements, there are still significant gaps that need to be addressed.

a) Lack of Standardization: In multi-cloud infrastructures, there is not much consistency in the data format and collection of observability data across the industry.

b) Limited Cross-Cloud Correlation: In the current solutions, one gets to evaluate challenges in relating observability data across different cloud platforms.

c) Insufficient Automation: Most of today's solutions have prerequisites that need further manual setup and updating; thus, they are not effective in the context of modern multi-cloud environments.

d) Inadequate Support for Edge Computing: As more enterprises adopt edge computing, there is a lack of observability solutions that can be used to monitor data from edge locations combined with multi-cloud environments. This paper seeks to fill these gaps by advancing a framework that encompasses observations in multi-cloud systems and focuses on standardization, automation, and new architectural models.

III. COMPARATIVE ANALYSIS OF TOOLS AND TECHNIQUES

A. Overview of Tools

Based on the type of implementation of multi-cloud observability, tools are divided into two categories: Open-source and commercial. Ideally, each category provides certain benefits and drawbacks, positioning the enhanced forms according to organizational imperatives and preferences.

a) Open-source Tools:

- Prometheus: An efficient metric collecting and alerting mechanism.
- Grafana: It is an ideal visualization tool for metrics & logs flexibility.
- Jaeger: It is an end-to-end distributed tracing system.

b) Commercial Tools:

- Datadog: A reference architecture of observability tool suite for cloud-native applications.
- New Relic: A digital experience monitoring and observability solution.
- Dynatrace: An application and infrastructure monitoring as a service powered by artificial intelligence.

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- Splunk: An efficient, secure, and flexible system for the search, control, and analysis of big data from machines.

B. Criteria for Comparison of Tools

To effectively evaluate these tools, we will consider the following criteria: To assess these tools effectively, we will consider the following requirements:

a) Performance: Accessibility to a variety of participants quickly and within a short period to conduct the research study [14].

b) Scalability: Scalability in terms of volume of data as well as infrastructure.

c) Ease of Integration: The ability to build applications that are compatible with different clouds and cloud technologies.

d) Cost: Pricing strategies and the overall costs associated with investments [14].

e) User Interface: Ease of use as well as efficiency of the way the user interacts with the application.

f) Support: The technical support that is available to the players and its quality.

g) Community: The scale of the user and developer base and the amount of work done by them.

C. Detailed Analysis of Tools

Below is the analysis for open-source tools:

a) *Prometheus:*
- Features: Metrics collection through pulling, the capability of utilizing powerful query language (PromQL), and vast opportunities for flexible alerting [15].
- Strengths: It is very horizontally scalable and can be easily used with Kubernetes; it also has a lot of exporters available.
- Weaknesses: Integrated visualization and exploration features are quite limited, as is the absence of distributed tracing baked into the product.
- Use Cases: Most suitable for containerization and microservices environment observation.

b) *Grafana:*
- Visualization Capabilities: Compatible with a variety of data inputs, allows for the creation of personalized widgets, and provides diverse opportunities for visualization.
- Integration: Enhances quickly with Prometheus, Elasticsearch, and several other tools [15].
- Strengths: It is the opposite of rigid and complex structures, has a friendly user interface, and has powerful community support.
- Weaknesses: Mainly visualization-based and more often supplemented with other tools for complete visibility.

c) *Jaeger:*
- Distributed Tracing Capabilities: Enables complete transaction monitoring throughout systems that include multiple communicating nodes.
- Scalability: Built for high scalability, it exposes a variety of storage backends [16].
- Strengths: OpenTelemetry is compliant and has an easy-to-use user interface for trace reviewing.
- Weaknesses: Lacks full capabilities and comes with the need to use other tools to get the whole picture [16].

Below is the analysis for commercial tools:

a) *Datadog:*
- Comprehensive Observability Suite: Provides measures, records, and spans all in one package.
- Real-time Monitoring: Furnishes the information in real-time across multiple cloud domains, environments, or ecosystems [17].
- Strengths: Prominent connectivity support; AI-based affinity identification.
- Weaknesses: It may be cumbersome to implement and hence expensive, especially for implementations on a large scale.

b) *New Relic:*
- Application Performance Monitoring: Looks at extensive data on individual mobile applications.
- Ease of Use: It is better known for its ease of use and very short time to value.
- Strengths: Anticipates language requirements for significant concerns, coupled with robust business intelligence tools [18].
- Weaknesses: It may be costly when used in large organizations or institutions; some customers complain of difficulty mastering advanced functions.

c) *Dynatrace:*
- AI-driven Monitoring: Uses AI to identify problems and their root causes, where issues are automatically identified.
- Automated Root Cause Analysis: Performs diverse dependency mapping at a high level and also, contains facilities to resolve issues automatically.
- Strengths: The first one reflects the availability of comprehensive automation features, while the second one points to the understanding of application and infrastructure performance [19].
- Weaknesses: Hence, it is relatively more expensive than some of the competitors, and some capabilities might be challenging to understand and tap into fully.

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d) *Splunk:*
- Log Management: Provides complete functional flexibility in log ingestion, search, and analysis operations.
- Security Information and Event Management (SIEM): Offers excellent security monitoring and analysis of the risks faced by a business [20].
- Strengths: very portable, can accommodate a considerable amount of data, secure.
- Weaknesses: Sometimes, it can be rather consumption-heavy and cheaper in some ways, and it often has a high level of complexity when fully utilizing all of its features.

D. *Techniques for Effective Monitoring and Troubleshooting*

a) *Metrics Collection:*
- Preference for time-series databases (for example, Prometheus or InfluxDB) to store metrics or queries over SQLite.
- Mobile initiatives have adopted push-and-pull-based collection methods to capture the different infrastructure types.
- Using SDDs in order to support service availability and discoverability in unnailed environments persistently.
- Dimensional metrics are used to achieve finer and easier-to-alter measures.

b) *Log Management:*
- Centralized log aggregation with cloud-native technologies or tools such as Elasticsearch, Logstash, and Kibana (ELK stack).
- Consuming and producing data in ways that make it easier to parse and log in structured ways.
- Deploying the concept of log rotation and log retention policies in order to control storage costs and adhere to compliance standards.
- Using the same principles to predict and filter log anomalies and identify patterns.

c) *Distributed Tracing:*
- Standardization of metrics with the help of OpenTelemetry for unified follow-up of the instruments in various services and languages.
- Application of techniques that would help reduce the quantity of data and maintain traceability.
- Association of traces with logs and metrics for systematic problem analysis.
- Better interpreting of trace data using the UI for Jaeger or Zipkin, which are instruments used in the given working process.

IV. RESULTS

In many different businesses, intelligent and autonomous observability solutions in complicated hybrid cloud environments have been widely used. The observability tools selected and the methods utilized are demonstrated in the case studies that follow.

A. *Prometheus and Grafana*

Blinkit, through its web and mobile applications, enables consumers to order groceries and other necessities and have them delivered quickly, sometimes in just a few minutes. Millions of customers in India are served by Blinkit, and at a time when the firm was hyper-scaling as a result of its success, issues with its tech stack were starting to arise. The issue was that developers were finding it difficult to improve the shopping experience for clients with new and improved services due to Blinkit's outdated logging tool, which was running on a self-managed version of the Elastic Stack. Half of the developer's effort was spent ensuring that the ELK Stack was operational and regularly fine-tuning their logs to prevent crashes [21].

a) *Methodology:*
- Prometheus was used to gather metrics from several databases and services. Grafana was set up to provide personalized dashboards that showed essential performance indicators.
- Data collection: Microservices were used to gather metrics, including CPU and memory usage, request latency, and error rates.
- Integration: To keep an eye on the functionality and health of containerized apps, the system was integrated with Kubernetes.

b) *Outcomes:*

The business realized that in a highly competitive market, there was no way to manage a team, much less a $1 billion enterprise. Developers decided to use Grafana Loki since it was an open-source tool that blended in well with their surroundings after evaluating a plethora of fresh options. Grafana Loki is a novel log aggregation system that integrates seamlessly into several well-established ecosystems. It stores logs from all applications and throughout the infrastructure and enables developers to query them. The team was using open-source technologies, such as Prometheus, which streams over 1.5 million metrics monthly in an AWS Kubernetes setup, and Grafana for dashboarding, based on Blinkit focus [21]. Now that Grafana Loki has been added to their stack, Blinkit sends all its application logs into its Loki instance, resulting in a monthly log data total of up to 60TB.

Figure 3. Through the application of Prometheus and Grafana, Blinkit was able to monitor their system, reduce response time, and make delivery faster. As seen in the dashboard above, the execution of activities took milliseconds [21].

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B. Dynatrace

A growing number of businesses are investing in various cloud observability solutions to maximize their performance in response to the increasing demand for IT services and digital transformation. Dynatrace is a contemporary method for observability and monitoring in multi-cloud environments, and it has been implemented by numerous enterprises worldwide. For example, TD Bank uses Dynatrace to deliver customer-centric banking solutions and maximize efficiencies. TD Bank had no prior insight into how its clients were using its products. When problems arose, the organization was unable to detect them [22] promptly. Thirty to an hour has passed if you consider the time it takes to place a call, have someone answer, and then escalate a response. If the organization had the proper solutions in place, we could have easily averted that. However, Dynatrace's history of innovation demonstrates how innovation is what actually propels advancement. With Dynatrace, you can examine all of the essential features and services and learn more about what makes consumers' experiences so great.

a) Outcomes:

TD Bank is now much better able to respond to issues before they affect users, thanks to Dynatrace's unified view of observability data across its hybrid, multi-cloud architecture. When issues arise, TD Bank can quickly determine the exact root cause by utilizing Dynatrace's AI-powered solutions. Consequently, TD Bank is responding to incidents 20% faster and proactively identifying 25% more incidents. Its transaction failure rate has dropped significantly as a result, from 0.16% to just 0.06%, and the number of irritated customers has decreased by more than 60% [22]. Besides, the intricate network of technologies spanning both cloud and on-premises systems made it unfeasible for TD Bank's teams to piece together the insights required to anticipate problems before they happened. Thanks to Dynatrace's AI capabilities, the bank can swiftly evaluate enormous volumes of data and provide teams with the precise answers they need to identify and fix issues quickly. In order to provide zero-touch customer service, the bank plans to add more automation and leverage these insights gradually. According to TD Bank's estimation, Dynatrace accounts for 75% of the overall efficiency gains made possible by its AIOps strategy in relation to its digital infrastructure [22].

With Dynatrace's end-to-end visibility over its whole technological stack, TD Bank is poised to do away with up to seven outdated, redundant monitoring solutions. TD Bank's teams are managing fewer routine maintenance and configuration chores, and they have cut their monitoring infrastructure and license expenses by up to 45% by combining their observability data into a single platform [22]. Apart from the financial benefits, the bank's teams now have more time to concentrate on activities that promote innovation for both the company and its clientele.

Category	**Metric**	**Improvement**
Service Reliability	Proactive incident identification	Increased by 25%
Service Reliability	Incident response time	Improved by 20%
Service Reliability	Transaction failure rate	Reduced from 0.16% to 0.06%
Service Reliability	Service interruption	Reduced by over 60%
Cost Optimization	Legacy monitoring solutions	On track to eliminate up to 7
Cost Optimization	Monitoring infrastructure and licensing costs	Reduced by up to 45%
Efficiency Improvements	Contribution to AIOps efficiency savings	75% of total savings

Table 2. Representation of the critical data points of TD Bank's use of Dynatrace [22].

The use of observability tools provided growing and mature financial services corporations as well as E-commerce platforms with enhancements to the main KPIs. Just for the case of the Financial Services Corporation, the mean time to detect was reduced from 45 to 5 minutes, the mean time to resolve was cut down from 2 hours to 15 minutes, and the system uptime was decreased from 99.5% to 99 [21,22]. From the above statistics, 75% indicated that the specific objectives were met, meeting the target of 99%, an increase in user satisfaction scores was 20%, and average CPU usage was reduced by 15%. Likewise, the delivery of the newly developed e-commerce platforms witnessed MTTD decline from 30 to 3 minutes, as well as MTTR drop from 1.5 hours to 10 minutes, and system uptime improved from 99 percent to 99.9 percent. All the gains come to the tune of an impressive 98%, user satisfaction scores go up by a whopping 25%, and average memory usage comes down by 10% [21,22]. These enhancements prove the observed beneficial effects of the observability tools on the performance of the operations and the users of both firms.

V. DISCUSSION

A. More Reliable Services

Modern technologies also include observability tools that have improved service stability at various levels of business. The successful use of Dynatrace's unified observability platform was vividly illustrated in the case of TD Bank; subsequently, the company's capability in handling incidents and overall system performance was greatly enhanced. There was an established increase in the proactively identified incident by 25% and a 20% improvement in the reaction time to incidences. As a consequence, starting proactively led to the subsequent cut of the transaction failure rate from 0.16 percent to just 0.06 percent [22]. From the said data, an improvement in service reliability is clearly observed: parameter 32, up from 12% to 18, or approximately 6%. In the same way, the Blinkit e-commerce business platform noted improved reliability after adopting Grafana Loki. Through this modern logging tool, Blinkit was able to cope with the problem of miscalculating the logarithm of the company's rapidly growing infrastructure by replacing its old logging tool. The capability to search through logs in all apps and operational facilities directly benefited the

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developers, as they did not have to spend time trying to figure out system problems; instead, they could work on improving the customers' experiences.

As for Blinkit, the changes towards Grafana Loki, along with other open-source tools like Prometheus, indicated the previously named cost-efficient approach to the organization's scaling issues. Because of these tools, they were also able to handle lots of metrics and logs while avoiding the operational burden of a complicated and proprietarily developed system. These cases show how trends in modern observability solutions can result in cost optimization through tool overlapping, minimal subscription to vendor tools, and better resource management.

B. Efficiency Improvements with AI

AI has been integrated into various observability tools to make them more efficient. Such trends are illustrated by the utilization of Dynatrace's AI-based solutions by TD Bank. It enabled the bank to deal with large volumes of data immediately and offer accurate results that were necessary in the determination of priority within several cases and quick response. This artificial intelligence technique was most helpful in providing correlation to TD Bank's hybrid cloud position, where the correlation of insights was massive and humanly impossible.

Dynatrace has been considered to contribute about 75% of the total efficiency savings created by TD Bank's AIOps strategy on its digital infrastructure. This significant improvement demonstrates AI's critical and unprecedented role in observability in order to work effectively in complex environments with large amounts of data.

Additional future activities aimed at the use of additional automation for the zero-touch response in case of client complaints establish the continuous development of the concept and the possibility of utilizing AI for better performance optimization.

C. Improved Customer Satisfaction

Customer satisfaction is, therefore, the ultimate beneficiary because service reliability, cost, and operation efficiency have been duly improved. Consequently, TD Bank was able to significantly reduce service interruptions by using Dynatrace. This led to a drastic improvement in customer satisfaction due to the reduction in service faults and disruptions. In Blinkit's case, log management, as a part of modern observability tools, lets developers and SREs realign from log management to building a better shopping experience for customers. The movement of resources in this way can be expected to increase customer satisfaction with innovations. Such examples highlight how the latest generation of observability solutions can significantly enhance service resilience, as it does help in faster problem identification and problem-solving, thereby leading to far more reliable services that can be provided to end-users.

D. Cost Optimization

This is a result of the fact that the implementation of integrated observability solutions is cost-efficient for most businesses. Such is the case with TD Bank, which successfully leveraged the use of Dynatrace digital experience monitoring tool [22]. Overall, the further integration of observability data into the platform made it possible, under the guidance of the bank's specialists, to exclude up to seven outdated monitoring tools. This consolidation promoted an impressive cut down of up to 45% in matters concerning monitoring infrastructure and licensing. Also, executing the deliberate monitoring strategy minimized daily upkeep and configuration assignments, saving time for the bank's IT staff [23]. This shift made them concentrate on creative activities, as they hold more value for the business and its customers.

VI. TROUBLESHOOTING STRATEGIES IN THE CLOUD

A. Root Cause Analysis (RCA)

In multi-cloud setup, root cause analysis (RCA) is constructive in determining the causes of incidents [24]. In such environments, procedures used to conduct RCA would typically entail the use of data capture and analysis on multiple cloud solutions. By applying distributed tracing tools such as Jaeger, the flow of requests through the microservices can be identified, indicating that requests are slowing down or experiencing errors [25]. Also, it allows Splunk to be used for log aggregation to collect and analyze logs from various sources in one place, giving a general picture of how the system works. Categorized into categories, it aids in establishing the causality between events and the chain of actions to a failure, thus ensuring the right causal issue is addressed.

B. Incident Response

To manage incidents efficiently in multi-cloud environments, there should be set goals, procedures, and activities in a single strategy regarding preventive actions and response to the occurrence of incidents. Preventively, organizations can use Datadog or New Relic as monitoring tools to monitor system health and performance benchmarks [26]. These tools can help IT teams be aware of issues before they escalate to the level of massive problems. In this regard, it is crucial to have a plan that shows how the organization will react in the event of an incident, including roles, responsibilities, and procedures. This plan should also have a communication plan initiated to notify all stakeholders. Also, prompts in the form of run books, which contain set plans on how to handle specific ailments, aid in the fast resolution of the problems. It is the ability to get real-time information, and an organization's ability to respond based on a structured response plan reduces the effects of an incident.

C. Automated Remediation

Automation is a ubiquitous component of contemporary troubleshooting practices because it decreases the amount of time and effort needed to address incidents. Some of the tools, like Dynatrace or AWS CloudFormation, can even perform remedial steps like restarting failed services or scaling the resources to fit the increased load [27]. Automated remediation entails the establishment of authoritarian corrective measures to be carried out when certain trigger events are detected. For instance, a monitoring tool may spot that the CPU is overutilized and conduct resource allocation to address the concern. It achieves this by not only fastening the response time to the problems that are facing organizations but also by providing reliable solutions to the problems [28]. Automation benefits organizations by increasing their efficiency, system reliability, and performance standards as compared to manual methods.

VII. CONCLUSION

As a result, this paper has presented the characteristics of multi-cloud observability as well as the tools and approaches to securing deep visibility and control over the services running within diverse hybrid cloud structures. Open-source software and critical comparative analysis related to Prometheus, Grafana, Datadog, and New Relic were discussed with the help of features and their advantages and disadvantages. Examples used in the same case explained how these tools could be implemented, and this showed the appreciable performance of the systems and the acceptance from the users. Additionally, as technology is continuously evolving, it is crucial to know the newest trends in multi-cloud observability to keep multi-cloud environments as efficient and stable as possible. This is due to the fact that technological advancement in this area progresses quickly and that newer solutions are more effective, integrated, and facilitate automation. Staying up to date with them also helps organizations understand and control the cloud infrastructures they own and avoid any problems that may arise. In addition, organizations should focus on the constant acquisition and use of new tools for observability as well. The active approach will not only improve the system's dependability and efficiency but also prepare organizations for the adoption of advanced breakthroughs in the cloud computing system. The deployment of training and development for the IT groups shall guarantee that they have the right skills and knowledge to put into practice the mentioned tools.

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