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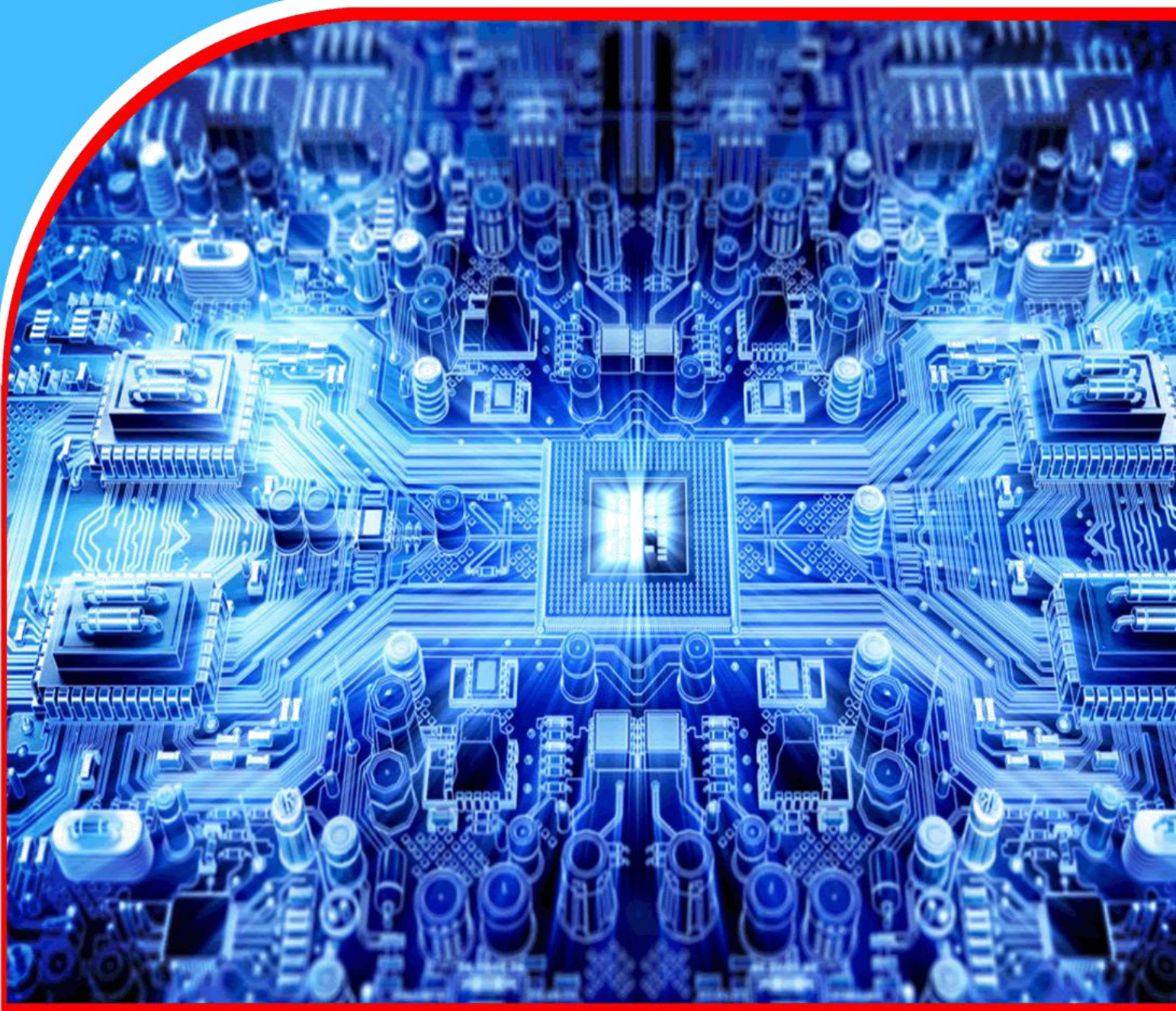

Cloud Data-Center Network Verification: Approaches, Algorithms and Toolchains

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Cloud Data-Center Network Verification: Approaches, Algorithms and Toolchains

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Abstract

The Cloud data center networks are the foundation of the modern cloud computing since they allow access to distributed virtualized resources on demand, at scale, and at reasonable costs. With the rapidly rising cloud services, however, new serious concerns have arisen that were associated with energy consumption, security, correctness, and reliability of the large-scale networked infrastructures. This paper gives a detailed analysis of verification methods in cloud data center networks, including static, dynamic and runtime verification methods. The techniques that can be used to identify configuration errors and policy errors before implementation are discussed as static techniques like header space analysis, SMT/SAT-based verification, and graph-based analysis. It is examined using dynamic and runtime methods, such as telemetry-based verification, invariant mining and misconfiguration detection methods to handle dynamic network behaviors and security threats over operational settings. The paper also covers the theoretical base of these techniques, and focus on SMT solvers, symbolic execution, and logical attestation to enforce correctness and access control. Moreover, the achieved tools chains and real-life applications of academic literature, industry cloud vendors, and open-source SDN environments are examined to reflect their strengths and weaknesses.

Keywords: *Cloud Computing, Cloud Data-Center Networks, Computing Networks, Dynamic and Runtime Approaches, Network Verification*

INTRODUCTION

Nowadays, cloud computing is among the most talked-about fundamental technological subjects. Newly formed, it has far-reaching implications for data storage, software engineering, software engineering, and information technology. Among the most noticeable changes is an improvement in their capacity [1]. The expenditure on hardware, software, and personnel training, among other things, should not rise in tandem with this enhanced capability [2]. According to the National Information Systems Technology Institute, " Cloud computing is a model that allows for the easy delivery of various forms of service provider contact together with convenient, omnipresent, on-demand access to pooled resources" [3]. Many information technology settings have adopted cloud computing because of its accessibility and efficiency [4]. Security components including authentication, confidentiality, integrity, access control, and integrity have also been the centre of debate when it comes to cloud privacy and security.

These days, data centers use a lot more intelligent monitoring than in the past. Every part of the data centre's infrastructure has to do its job properly, including providing enough energy support without using too much power, so that data may be kept available at all times. Modern data centers have made energy saving a top priority, and the issue has only gotten more complicated [5]. All parts of the data centre's architecture must work together as intended to prevent data centre outages that would necessitate additional energy resources in order to keep data availability high [5]. Included in the technical infrastructure are power supplies, technological coolers, and technical security, all of which are essential components of any IT system. The value of physical infrastructure downtime is negligible compared to the impact on IT service performance [6].

Network monitoring helps operators understand how a network is currently behaving. For accurate cyber threat intelligence and real-time performance analysis, dependable network monitoring is essential for every organization's network and infrastructure. The devices, apps, and services in the network can be quickly and proactively identified in this way. If this capability were lacking, data analysis would be a major pain point for the NOC and SOC [7]. Cybersecurity and network experts are consequently forced to use out-of-date data about networks or to haphazardly apply new measures, both of which increase the risk that the suggested remedy is inappropriate. Cybersecurity, network scalability, and company operations all rely on network analysis technologies. A network monitoring tool's primary function is to gather metrics and events from a company's network through the use of SNMP polling or syslog collection from a wide variety of distributed devices. For instance, older IT infrastructure may have expanded beyond the capabilities of system monitoring teams to manually handle, which is one reason why scaling issues are becoming more apparent in still-used, older solutions. In the end, this causes problems because the observed and real network states are unlikely to match.

A. Structure of the Paper

The paper is organized is as follows: Section II presents an overview of verification approaches in cloud data center networks, Section III talks about the algorithms and theoretical basis of cloud verification, Section IV examines the toolchain, systems and practical applications of the same by academia as well as industry and open-source, In Section V, the report comes to a close and provides suggestions for further research.

II. Verification Approaches in Cloud Data Center Networks

The capacity to access data from any location at any time is a key feature of cloud computing (CC). Instead of storing and organizing data on a single computer or server, it makes advantage of a distributed network of servers throughout the internet. The user has access to a virtual resource through the Cloud's services and apps, which operate on a distributed network. Common networking and Internet protocols could access these resources. But there are a

number of problems that arise from relying more and more on cloud computing, the most significant of which is the problem of energy consumption. Although cloud computing can be considered cheap in most cases, the fast growth of digital services and data storage has added to the escalation of energy requirements of data centres and telecommunications networks.

A. Static Verification Techniques

The techniques of Static verification concentrate on analysis of the configuration of the data-Center network, the network topology and forwarding state prior to deployment of the system or without involving live traffic. The methods construct abstract models of routing tables, forwarding policies and intent policies and proceed to systematically test them to the properties of correctness including reachability, lack of loops, isolation, load-balancing and security compliance. Since analysis is done offline, scale does not adversely affect the performance of statically verified large cloud environments and can also aid in detecting misconfigurations early, when they have not spread to the production network. Methods like header space analysis, constraint solving and extraction of configuration graphs can be used to ensure that any verification tool in use can exhaustively search all possible combinations of packet routes, revealing subtle bugs that would not necessarily be revealed by pure runtime monitoring. Subsequently, the issues of the verification of statistics offer a layer of confidence in cloud data-centers networks, facilitating a safe update, policy uniformity, and sound intent execution.

1) Header Space Analysis

The entire packet header is treated as a random mix of bits by HSA, rather than the fields in the protocol header being treated as first-class entities [8]. In a space where L is the maximum length of a packet header, each packet is a point between zero and one plus L. Depending on the network device, packets can be "multicast" (moved) from one location to another.

2) SMT/SAT-Based Verification

SMT solvers integrate cutting-edge SAT problem solver techniques with the capacity to resolve first-order theories via the use of methodologies proposed by Nelson and Oppen for cooperative decision procedures. While the majority of simple solvers can instantiate quantifiers using heuristics taught on the non-SAT-based prover Simplify, their main objective is to resolve problems without quantifiers. Common concepts handled by SMT solvers include equality, datatypes such as arrays, bitvectors, and records, and linear arithmetic over integers and rationals [9]. The use of SMT solvers makes these theories appropriate for automated proof in VCs where they are prevalent. To prove a VC, one uses an SMT solver to check if the VC's assumption hypothesis and negation of its conclusion are mutually incompatible.

3) Graph-Based Analysis

The traceroute data can be used to generate a directed graph, an undirected graph, or a version of the undirected graph. The undirected graph is the most hopeful model of computer science connectivity because it uses every edge for arbitrary traffic forwarding in both directions, towards any node and any part of the network that is related with them. By assuming that CSPs and ISOs are as flexible as possible, the undirected graph model can reorganize internal and Internet routing to make use of any node; this way, backup channels can be established in the event that regular communication paths fail. A directed graph is one in which every edge has a direction, meaning it enters at one vertex and exits at another. In Figure 1, shows a sample of a potential undirected IP graph in which two nodes are associated with a cloud provider.

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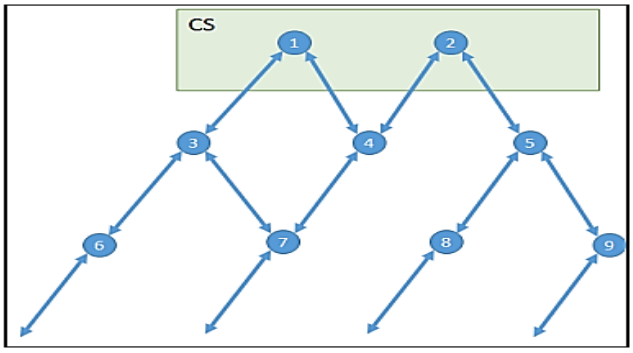

Fig. 1. Example Section of the IP-Level Graph

B. *Dynamic* And Runtime Verification

Data stored in the cloud must be protected at all costs in this digital age; no compromise to data security or privacy tolerated. There has been an explosion in the storing of digital information, particularly in the wake of the COVID-19 epidemic. Secure data storage is not enough; a hostile user must be unable to alter the stored data in any way. The data owners incurred overhead due to the data integrity check they conducted.

1) *Telemetry-Driven Verification*

New telemetry models are allowing for more precise insights to be provided. This new version has a P4 programmable data plane, in-band network telemetry, and high bandwidth monitoring engines. Telemetry on both a packet and a flow level, as well as real-time feedback between data plane and AI controllers, are all features of these technologies. In the beginning, SNMP, NetFlow, and sFlow were used for coarse-grained monitoring, often every few seconds to minutes. On a nanosecond time scale, none of these methods can identify micro-congestion, packet jitter, or queuing. But for AI applications to work in near real-time, fabric-level indications like flow drop rates, channel utilization, queue depths, ECN markings, and end-to-end packet delays are necessary.

2) *Invariant Mined Verification*

Invariants can be mined on training data, or those revealed on-the-fly. A number of tasks, including as capacity planning and the identification of failures, anomalies, and SLA breaches, can be aided by the mining techniques developed by invariants, according to scientific research. On the other hand, operation engineers still face difficulties when putting them into practice. Geographically replicated database systems [10] are frequently available and have minimal latency, and they use weak models of consistency. The failure to impose invariants on all of the replicas is one of the major weaknesses that make such databases impossible to deploy in a medium number of applications.

3) *Misconfiguration Detection Verification*

System configuration errors, also known as misconfigurations, are a leading source of catastrophic system failures that impact cloud-scale services and hundreds of millions of end users today. Consistency in configuration settings is problematic in large-scale cloud datacentres due to the numerous configuration parameters utilized by different components, including hostnames, languages, and time zones. When this happens, service failures could be caused by incorrectly specified parameters. Automatically determining potential misconfigurations, misconfiguration detection methods use statistical decision tree analysis to find the relations existing among the majority of parameters [11]. The second most common reason for service interruptions at one of Google's primary services is misconfigurations.

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III. Algorithms and Theoretical Foundations

Public, private and hybrid cloud data centers enable the unprecedented flexibility in the provision of virtual machines (VMs). Nevertheless, the acquisition, use as well as maintenance of the underlying physical amenities is expensive and polluting in terms of money and the environment. Cloud providers must constantly strike a balance between the competing demands for performance and operational expenses [12] in order to maximize the utilization of physical resources through the careful distribution of VMs to hosts. This crucial optimization issue has seen multiple algorithm proposals in the last several years. Regrettably, due to minor variations in the problem models utilized, the suggested methods are scarcely equivalent.

A. *Smt Solver in Symbolic Execution*

Symbolic execution constitutes a collection of program analysis techniques that are extensively employed in both dynamic and static analysis. Propositional satisfiability (Sat) problems and first-order theories based on Nelson and Oppen's work on collaborating decision procedures are both used by Smt (Sat Modulo Theories) solvers. Although most of the basic solvers can also instantiate quantifiers in a heuristic manner meant to function with the non-Sat-based prover, they primarily operate on problems that do not require quantifiers. Make easy.

1) *Path-Sensitive Static Analysis*

Static analysis of source code must take into account the fact that the control-flow graph's path determines the likelihood of various faults. Some of them may not even have a path that may be considered plausible, meaning they have no effect on execution and are thus not faults at all. Use of a path-sensitive analysis is one strategy to lessen the occurrence of false alarms without sacrificing the transmission of valid alerts. Figure 2 shows a portion of the CFG that can be analyzed in this way.

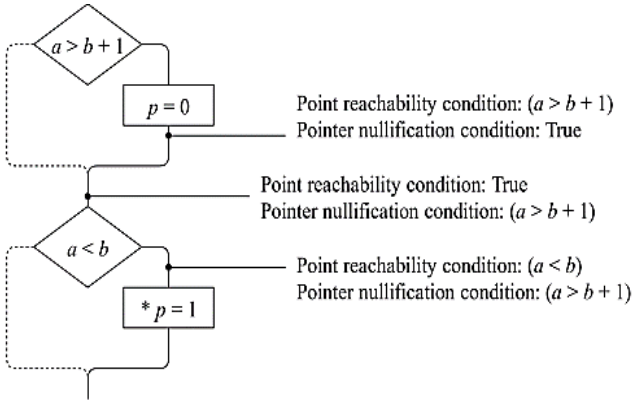

Fig. 2. An Example for Path-Sensitive Analysis

2) *Dynamic Symbolic Execution*

The purpose of DSE is to generate fresh execution routes by changing a small number of branch conditions in the previously generated path restrictions. The suggested execution path's feasibility is determined by newly developed conditions. Thus, SMT solvers are employed in contemporary DSE tools for this purpose.

B. Logical *Attestation*

The foundation of logical attestation is the creation, dissemination, and application of formulas representing attributable properties. It expands upon credentials-based authorization, a body of work that relies on logical inference for authorization [13]. The main point of the credentials-based authorization is that every request has credentials with it that can be asserted about the principals. there is a guard that guarantees accesses to resources that follow a resource-specific authorization policy.

1) *Logic Labels and NAL*

Labels are used to make all authorization choices in logical attestation. A label is an orderly list of things. P says S, which means that a statement S is linked to a principal P. This is written in Nexus Authorization Logic (NAL). The logic's design is talked about in more depth elsewhere. Here, outlines why NAL can be used in an OS environment.

2) *Label Creation*

The labels are made in Nexus by calling the say system call. An NAL statement code is passed as a string input to this system call. The words and predicates used in a statement are not constrained in any way by Nexus in terms of their semantics. In the case of the label "isTypeSafe(PGM)" from Type Checker, for instance, the principal is believed to know the meaning of the predicate "isType Safe" as it is defined by Type Checker.

IV. Toolchains, Systems, and Practical Implementations

Recent years have seen cloud computing's meteoric rise to the top of the IT infrastructure computing model. This approach allows for on-demand, ubiquitous, flexible, and inexpensive access to a vast pool of shared resources. A large trend toward moving on-premises services and apps to the cloud has emerged in response to the meteoric rise of cloud computing. With the introduction of "cloudified" versions of these environments, software development environments have grown even more popular, making them an essential application area. The growing dependence on cloud computing for mission-critical services and applications has highlighted the need for more efficient software development processes [14]. Ideas and technologies related to the cloud lay the groundwork for software development environments that are "in the cloud, for the cloud." These environments can readily supply a vast array of computing resources for coding and testing, and they can also facilitate developer collaboration through code repositories.

A. *Academic Verification Tools*

Verification is the process of making sure that something is true, correct, or valid. An example of this would be checking official papers. Falsifying their educational qualifications is a common practice among applicants. Plus, according to professionals in the field, academic dishonesty is the most typical kind of resume fabrication. The biggest threat to organization comes from this. People who apply for jobs with false information have made this happen faster. Greater recruiting and replacement costs, compromised corporate performance, diminished market value, lost customers and revenue, increased employee turnover, potential civil and criminal liability are all outcomes that could result from failing to verify applicants.

1) *VeriFlow*

If on the controller side new rules are initialized then the Veri Flow investigate the system. This is the primary role for the Veri Flow. To provide security between the switches and the controller. Veri Flow between the switch and controller it can check the system and look for any newly introduced rules. If found then it can start validation to ensure everything goes smoothly [15]. Veri Flow works based on different sub-classes. In case of a new rule, such subclasses are updated. Eventually, it starts the validation process again. All the sending graphs are overseen by the Veri Flow.

2) *NetPlumber*

A runtime network monitor, Net Plumber keeps an eye on network events and checks network policies to prevent or detect issues. Discussed at length are ways to build cloud monitoring services around security SLAs [16]. There are a number of further papers that focus on auditing cloud data storage and location, as well as audits of infrastructure changes.

3) *Minesweeper*

Minesweeper works with a lot of different protocols, features, and topologies, so it has a wide range of network design covering. Another benefit is its high data plane coverage, which is achieved by thoroughly testing numerous attributes for each data plane that could originate from the control plane. The dense logical constraints on its nodes and edges comprise its graph-based design, which encodes all possible interactions of route messages [17]. It encodes the network's stable states using an acceptable assignment to an SMT formula.

B. *Industrial and Cloud Provider Solutions*

New computing technologies are appearing for these kinds of uses, and one of them is the "cloud of things" (CoT). CoT is an amalgam of the latest developments in CC and the IoT. Because CC serves as the foundation for Internet of Things (IoT) technologies, their rise in industrial automation has rendered them extremely dependent on one another. This helps with things like security compliances, data storage, analytics, processing, and the creation, implementation, and use of commercial applications. With the integration of cloud and IoT technologies, utilities are becoming smarter, more service-oriented, and more secure, which is great news for the long-term viability of manufacturing processes. Cyberattacks have skyrocketed in tandem with the pandemic's expansion of remote access to computing facilities.

1) *AWS and Zelkova*

The use of cloud computing, specifically AWS, has become increasingly common among organizations and their capacities. One of the most well-known public cloud platforms today, AWS offers hundreds of services. The reporting of security problems affecting AWS services is, nevertheless, regular. A number of security services are offered by WS as well, including Inspector for EC2 security and vulnerability evaluations. An additional set of evaluations grounded in formal methodologies are offered by AWS. Zelkova analyzes policy configurations, and TIROS checks network reachability [18]. The fact that security incidents continue to happen despite the extensive range of services and solutions offered by AWS indicates that the platform is not without its flaws.

2) *Microsoft Azure*

A CC service, Microsoft Azure offers over a hundred distinct services, ranging from basic storage and virtual machines to artificial intelligence (AI) capabilities and IoT services. To put it simply, Azure's pay-as-you-go model lets pay for services only when really use them. If know estimated consumption in advance, and also can find deals with a one- or three-year reservation that are more affordable. There is a global location (like "Sweden Central") linked to every Azure resource.

3) *Google's Espresso*

Espresso is a software-defined networking (SDN) model for Google's Internet peering edge routing architecture. This concept was created to address the need for application-aware routing at the peering size of the Internet and for exponential, cost-effective scaling at the perimeter of the Internet. Espresso creates a new capability for fine-grained traffic engineering by utilizing commodity switches and host-based routing/packet processing [19]. Taken as a whole, Espresso gives Google a leg up when it comes to flexible and scalable peering that can handle international traffic. Also, with Espresso, and able to rapidly deploy new networking features to the peering edge. Espresso, which has been running for two years, serves about 22% of Google's total web traffic.

C. *Open-Source and Programmable Data-Plane Tools*

A great deal of research, including surveys and reviews, has focused on SDN in recent years. The application, control, and data planes are the three distinct parts of a SDN. Execution of network applications occurs on the application plane, rule regulation for the entire network occurs on the control plane in response to requests from the application plane, and the controller

configures the data plane switches in accordance with the established rules [20]. According to the controller's instructions, the data plane switch's only job is to forward packets. A review of the literature on software-defined networking reveals that the data plane has received inadequate attention from the start of the field.

1) ***Batfish***

Batfish verifies that existing or proposed network configurations are correct and detects mistakes. Without worrying about disruptions or security breaches, it enables the network to evolve quickly and safely. Researchers from Microsoft Research, UCLA, and USC originally developed batfish. Intentioned subsequently improved and maintained it. Ever since the Intentioned team became an AWS customer, the project has been administered by AWS and is open source under the Apache 2.0 license. The project has received contributions from many others.

2) ***Assert P4***

Metadata, parsers, actions, tables, control blocks, and extern objects are all part of a P4 program's collection of domain-specific components. Packet in and packet out are two of the basic data types defined by P4 that are used to represent and manipulate packets [21]. Examples of causes that can lead to P4 software bugs include incorrect assignments, flawed logic, and control misconfiguration.

3) ***CI/CD Pipeline***

Digital systems becoming the key factor in the everyday business activity, the concept of security being incorporated into the software development has gained the priority. The DevSecOps methodology satisfies this need by establishing security best practices into the CI/CD pipeline. However, there is currently no structured approach to include security testing into continuous integration and continuous delivery procedures.

LITERATURE REVIEW

This literature review is the summary of the recent development in cloud computing and virtualization with special focus on VM scheduling, resource allocation, simulation platforms, network function virtualization and cost effective cloud service models. The works are aimed at the enhancement of the resource utilization, performance, scale, and economical efficiency and concern the issues like the complexity of algorithms, multi-objective optimization and the realistic assessment of cloud systems.

Toka, Gema and Sonkoly (2019) This study presents a matching theoretical model that formally states the well-studied cloud scheduling problem. The model translates the mapping of virtual machines to physical servers into a stable matching problem. Their search for the optimal scheduling scheme is based on a sophisticated algorithm developed in the field of matching theory. They use numerical models of cloud environments to test different algorithms, but the algorithm's complexity gets in the way. Following the heuristic algorithm's validation, they showcase the suggested method's execution as an OpenStack-specific compute scheduler [22].

Dai, Zhou and Wang (2018) This paper first plans and builds WebCloudSim, a cloud data center network experiment system that can help with testing in both the real world and a simulation setting. The study next tests and evaluates the results after implementing three standard techniques for virtual machine deployment based on WebCloudSim. Experimental results demonstrate that WebCloudSim is a useful tool for evaluating the efficiency of virtual machine placement algorithms [23].

Jakaria and Rahman (2017) Modern computer networks depend a lot on expensive, proprietary gear that is set up in fixed places. By bringing elasticity to the deployment of new network functions and flexibility to the network architecture, network functions virtualization (NFV) alleviates the constraints of vendor-specific hardware. With the help of service providers' virtual

network functions as a service (VNFaaS) offering, customers can have access to cloud-based, software-defined networking applications. With NFV, virtual network services may be dynamically and flexibly implemented in core cloud infrastructure and in virtual machines running on COTS servers located in different regions [24].

Malik et al. (2017) The most cutting-edge cloud simulators available today lack realistic network communication models, have limited features, and do not provide a powerful graphical user interface (GUI) for researchers and developers to manipulate the cloud's behavior. To enable the simulation of cloud environments, present CloudNetSim++, an all-inclusive packet-level simulator. A large variety of cloud components can be tested with CloudNetSim++, including processor elements, storage, networking, SLA, scheduling algorithms, energy usage at finer granularities, and virtual machine consolidation techniques [25].

Al Noor et al. (2016) The authors provided an in-depth analysis of the costs associated with setting up a cloud service as compared to an opaque cloud service. Litigo service providers can use their empirical methodology to study the business model and carve out a specific niche in the market. For Litigo, they conducted thorough analyses with the use of simulated model verification. At a fair price, the suggested model provides clients with an opaque cloud as a service by optimizing the use of cloud service providers' resources and revenue [26].

Ma and Zhang (2015) Cloud data centre virtual machine (VM) management is a significant issue that has not been adequately resolved. Improving data centre resource utilization and power consumption efficiency has been the focus of much research into physical-to-virtual resource mapping management. But these competing managerial goals are incompatible. Not every goal can be optimally met by a single solution. Cloud data centre virtual machine (VM) resource mapping is addressed in this work using a multi-objective optimization strategy [27].

Table I briefly summarizes some of the prominent studies in CC and virtualization with a focus on the research, methods, tools, contributions, as well as limitations. Despite the reported improvement in VM scheduling, resource utilization, performance, and cost efficiency, there are still challenges in the complexity of the algorithms, multi-objective trade-offs, and realistic evaluation. The future work is directed towards more flexible, scalable, and feasible resource management solutions.

Table 1: Recent Studies Review of Cloud-Data Center Network and Verification

Reference	Research Focus / Problem	Approach	Platform Used	Key Contributions	Gaps
Toka, Gema & Sonkoly (2019)	Cloud scheduling and VM-to-physical server mapping	Matching theory–based stable matching model; heuristic evaluation via simulations	OpenStack (custom compute scheduler)	Formalized cloud scheduling as a stable matching problem; proposed and implemented a practical heuristic scheduler	High algorithmic complexity; relies on heuristics rather than optimal solutions
Dai, Zhou & Wang (2018)	Performance evaluation of VM deployment algorithms	Design of experimental framework; implementation and comparison of classic VM placement algorithms	WebCloudSim	Introduced WebCloudSim supporting hybrid real–simulation experiments; validated VM placement algorithms	Limited to classic algorithms; does not explore advanced optimization techniques
Jakaria & Rahman (2017)	Network Functions Virtualization (NFV) and VNF-as-a-Service	Conceptual and architectural analysis of NFV deployment in cloud environments	NFV framework on COTS servers	Highlighted flexibility, scalability, and elasticity benefits of NFV and VNFaaS	Lacks experimental validation and performance evaluation
Malik et al. (2017)	Cloud simulation with detailed networking and energy modeling	Packet-level simulation model with GUI support	CloudNetSim++	Proposed a comprehensive cloud simulator supporting networking, SLA, energy, and VM consolidation	Simulation-based only; no real-world deployment validation
Al Noor et al. (2016)	Cost and profit modeling for opaque cloud services	Empirical cost model with simulated verification	Simulated cloud model (Litigo framework)	Developed a pricing and profit model maximizing resource utilization and provider revenue	Focused on economic modeling; limited discussion on scheduling or performance metrics
Ma & Zhang (2015)	VM management and resource mapping optimization	Multi-objective optimization for VM-to-physical resource mapping	Simulation-based evaluation	Addressed conflicting objectives such as energy efficiency and resource utilization	Does not provide a single optimal solution; computational complexity not fully addressed

CONCLUSION AND RECOMMENDATIONS

Conclusion

Cloud computing and virtualization that goes with it have become the most important designs in modern computer design. Performance evaluation of cloud computing is very important because of the growth and popularity of CC in many companies. This helps computer designers prepare for the capacity of the system. The work has provided an in-depth discussion of verification practice of cloud data center networks, posing the required importance of rightness, protection and dependability to the large-scale cloud frameworks. Through a discussion of the mechanisms of the methods of static verification, dynamic and runtime monitors and the theoretical background of these approaches, the research shows how formal models, telemetry-based, and logical reasoning can be useful to detect misconfigurations, policy breaches, and performance deviations. The discussion of the scholarly resources, commercial applications, and other open-source programmable data-plane models also demonstrates the practical feasibility and the existing constraints of the current verification systems. As much as great gains have been accrued, it is still difficult to have scalable, real-time, and energy conscious verification that can match the ever growing and dynamic cloud environments. The next research step should be directed at making verification more intertwined with automation, artificial intelligence-based analytics, and DevSecOps pipelines to provide resilient, efficient, and reliable cloud data centre operations.

Recommendations

The future directions will be to create scalable, energy-conscious verification systems that combine both the analysis of statistics with AI-based automation. It will be stressed that in order to provide an adaptable, cost-effective, and secure verification of highly dynamic network of cloud data centres at large-scale deployments real-time telemetry, programmable data plane, and DevSecOps integration will be emphasized.

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