CONTEMPORARY DEVOPS STRATEGIES FOR AUGMENTING SCALABLE AND RESILIENT APPLICATION DEPLOYMENT ACROSS MULTI-CLOUD ENVIRONMENTS

[1]Chaitanya Kanth Tummalachervu
[1]RingCental Inc, Denver, Colorado, United States
[1]Tummalachervu@gmail.com

Abstract: Containerization in a multi-cloud environment facilitates workload portability and optimized resource uti-lization. Containerization in multi-cloud environments has received significant attention in recent years both from academic research and industrial development perspectives. However, there exists no effort to systematically investigate the state of research on this topic. The aim of this research is to systematically identify and categorize the multiple aspects of containerization in multi-cloud environment. We conducted the Systematic Mapping Study (SMS) on the literature published between January 2013 and March 2023. Eighty-six studies were finally selected and the key results are: (1) Four leading themes on cloud computing and network systems research were identified: 'Scalability and High Availability', 'Performance and Optimization', 'Security and Privacy', and 'Multi-Cloud Container Monitoring and Adaptation'. (2) Seventy-four patterns and strategies for containerization in multi-cloud environment were classified across 10 subcategories and 4 categories. (3) Ten quality attributes considered were identified with 47 associated tactics. (4) Four frameworks were introduced from the analysis of identified challenges and solutions: security, automation, deployment, and monitoring challenge-solution frameworks. The results of this SMS will assist researchers and practitioners in pursuing further studies on containerization in multi-cloud environment and developing specialized solutions for containerization applications in multi-cloud environment.

Key words: Containerization, Multi-Cloud Environment, Systematic Mapping Study and Cloud Computing

Introduction:

The use of containers in multi-cloud environment has been widespread in the industry for

Corresponding Author: *Chaitanya Kanth Tummalachervu*
RingCentral Inc, Denver, Colorado, United States
Mail: tummalachervu@gmail.com

many years [96]. Containers are standalone and executable packages of software that include everything needed to run an application, such as code, system tools, libraries, and settings [90]. Containers allow the packaging of an application along with its required dependencies, which makes it easy to move the application across different environments with little or no modification [47]. On the other hand, multi-cloud environment is the distribution of cloud assets [109]. Using containers in multi-cloud environment allows organizations to achieve flexibility, agility, and cost efficiency. Developers can build applications in a consistent environment and easily move them between multiple cloud platforms, thereby leveraging the unique strengths (e.g., extensive infrastructure, seamless integration, advanced data analytic) of each platform.Containerization in multi-cloud is illustrated in Figure 1. This figure provides an overview of applications deployed within various cloud configurations including public, private, and hybrid models. Each cloud hosts multiple applications encapsulated in containers, and completes different types of tasks with their required binaries and libraries, emphasizing the portability and isolation that containerization offers. A container platform layer, which could be exemplified by systems like Kubernetes or Docker, manages and orchestrates these containers across the different cloud environments. This architecture enables a flexible and scalable approach, allowing efficient application deployment and operations in a multi-cloud setting, while maintaining consistency and resilience across platforms.

METHODOLOGY:

We conducted a Systematic Mapping Study (SMS) by following the guidelines in [111] and augmenting them with SLR strategies [81]. Our SMS consists of three phases: specifying research questions and search string, conducting the literature search, and performing data analysis and documentation. Figure 2 illustrates the SMS execution process.

Snowballing:

In Phase 2, we utilized the snowballing technique, as described in [152], to examine references within primary studies for identifying additional relevant studies. This strategy was augmented by forward snowballing, where we gathered studies that cited the selected studies, and backward snowballing, which involved using references within the selected studies. Notably, we encountered several dozen studies during the forward and backward snowballing that had been excluded in primary search. This phase resulted in the addition of 8 more studies, bringing the final count to 86.

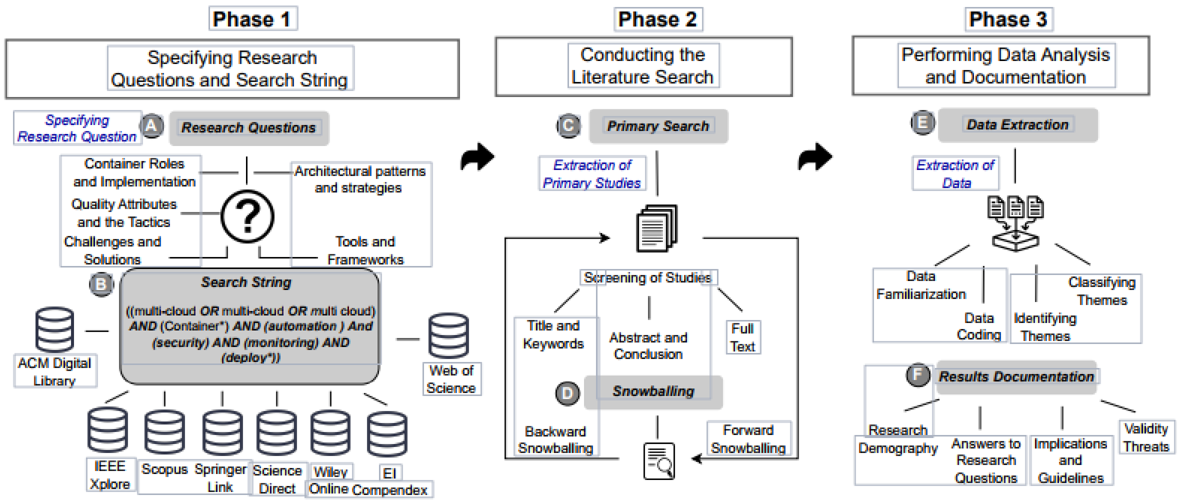

Fig.1. Research methodology implementation:

Data Extraction and Analysis:

The data extraction form was designed based on predefined data items (see Table 5) that were formulated to address the RQs specified in Table 1. To ensure the reliability of the extracted data items, the pilot data extraction was conducted on ten studies by the first author, and all the other authors assessed the extracted data. Subsequently, the first author employed a revised set of data items (e.g., D11, D12, D16), determined after evaluating the extracted data items, for the formal data extraction from the selected studies. To mitigate the personal bias and ambiguity, all authors engaged in discussions regarding the extracted data. The data items labeled as D1 to D11 present a summary of the demographics of the primary studies selected, while D12 to D26 are specifically employed to address RQ1 to RQ6. A concise description of each data item is also presented in Table 5. Finally, Google Sheets were used to record and further analysis of the extracted data.

Data Analysis:

We employed a descriptive statistics to analyze the quantitative data from data items D1, D5, D7, D8, and D9. For the remainder of the data, which primarily consist of qualitative free-text descriptions (e.g., study aim, roles of containers, challenges, and solutions), we conducted a thematic analysis in accordance with the guidelines outlined in [26]. Our thematic analysis process consists of the following steps:

(1) Data Familiarization: We conducted a thorough review of the selected studies by repeatedly reading through them and meticulously noting key points related to study aims (D7), contributions (D8), roles of containers (D9), implementation strategies (D10), architectural patterns (D11), quality attributes (D12), tactics (D13), motivations (D14), and challenges and

solutions (D15-D21) in automation, deployment, monitoring, and security challenges and solutions, as well as the tools, languages, and frameworks (D22) employed.

(2) Generation of Initial Codes: After developing a thorough understanding of the data, we created an initial set of codes derived from the information extracted concerning the data items identified in the previous step.

(3) Identification of Types and Emerging Themes: In this step, we conducted a two-tiered analysis. Initially, we examined the codes to ascertain their types. Subsequently, we developed subcategories based on these types, and then formulated overarching categories that encompass the related subcategories.

(4) Critical Evaluation of Types, Subcategories, and Categories: All authors actively participated in rigorously reviewing and refining the coded data, including types, subcategories, and categories. During this collaborative process, we redefined, merged, or dropped certain themes based on collective input and discussion.

(5) Defining and Naming Categories: At this point, we provided explicit definitions for each of the identified themes and further refined them, ensuring that the terminology used for the categories was precise and unambiguous. The process of obtaining research themes executed in this SMS is shown in Figure 2. Two researchers participated in the process in order to reduce personal bias. The most important activity of this process is brainstorming sessions that were mainly conducted while reviewing, defining, and naming the research themes. In these sessions, both researchers discussed and validated the research themes found.

Concerning data item D9 (testing approaches) and D10 (testing challenges), we used the open coding and constant comparison techniques from Grounded Theory [62] to analyze the qualitative data extracted from the selected studies. Finally, we provided a replication package [149] containing the results of each phase of the study selection process (e.g., Phase 1, Phase 2) and detailed results (e.g., Contributions, Patterns, QAs, Challenges, Solutions) for verification and validation purposes of this SMS.

Conclusions:

The findings of this SMS will benefit researchers who are interested in understanding the state of research on containerized applications in multi-cloud environment and conducting further in-vestigations to address the open research issues highlighted in Section 4. Additionally, the insights gained from this SMS will support knowledge transfer to practitioners by providing insights into the challenges, solutions, and methods for monitoring, securing, and optimizing containerized applications in multi-cloud environment. We emphasize the importance for practitioners to develop targeted solutions that effectively tackle monitoring, security, and performance degradation concerns within multi-cloud environment deployment. As a future endeavor, we intend to enhance our SMS by conducting industrial case studies with companies, thereby obtaining practical insights and perspectives from practitioners on the effectiveness and applicability of our proposed frameworks in real-world scenarios. This approach will allow us to bridge the gap between research and practical implementations concerning containerized applications in multi-cloud environment and contribute to the advancement of both academic and industry understanding in this domain.

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