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SURVEY

Cloud Continuum: The Definition

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ABSTRACT The cloud continuum concept has drawn increasing attention from practitioners, academics, and funding agencies and been adopted progressively. However, the concept remains mired in various definitions with different studies providing contrasting descriptions. Therefore, to understand the concept of cloud continuum and to provide its definition, in this work we conduct a systematic mapping study of the literature investigating the different definitions, how they evolved, and where does the cloud continue. The main outcome of this work is a complete definition that merges all the common aspects of cloud continuum, which enables practitioners and researchers to better understand what cloud continuum is.

INDEX TERMS Cloud continuum, edge, Fog.

I. INTRODUCTION

The adoption of service-oriented architecture in cloud computing has profoundly changed the way how software, especially large-scale distributed systems, are built [24]. The cloud is often viewed as an endless pool of resources, on which we build and scale applications for various purposes. Modern cloud systems, however, are inherently complex spanning public cloud to private cloud, possibly co-located across different regions, and may also include components and compute resources at the edge of the network.

Cloud continuum is one of the most recent hypes in the cloud computing domain and has raised interests of funding agencies of EU and US [1], [2], [3]. However, while the hype is increasing, its definition is still not clear, and various papers are describing the concept of cloud continuum inconsistently.

In order to understand the differences between the disparate definitions of cloud continuum, we propose a systematic mapping study of the literature.

In this work, we investigate the existing definitions and common characteristics of "cloud continuum" as well as their evolution through the time.

We formulate three main Research Questions (RQs) as follows.

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- ***RQ1:*** *What are the definitions of cloud continuum?*
  With this RQ we aim at understanding whether there are different definitions of cloud continuum.
- ***RQ2:*** *How has the definition of cloud continuum evolved?*
  Via the comparison amongst the different definitions, we shall observe the changes from the earliest to the latest. In this way, we shall identify what are the new aspects taken into account regarding "cloud continuum".
- ***RQ3:*** *Where does the cloud continue?*
  As cloud is "continued" into other infrastructures, we expect to find cloud-to-* extensions, where * could be on premise servers, but also edge, or other infrastructures. In this RQ we aim at understanding which are these extensions, so as to clarify where the cloud could be continued.

The remainder of this paper is structured as follows. Section 2 presents related reviews. Section 3 describes the research method adopted. Section 4 presents the results answering the RQs. Section 5 discusses the results while Section 6 draws the conclusion and highlights future works.

II. BACKGROUND AND RELATED WORK

A. CLOUD, FOG, EDGE, AND MORE

Cloud computing builds on the promise of economies of scale in leveraging scalability and reliability. Scaling up is made possible by creating multiple compute instances and distributing them. Containers have long been the basis for implementing microservices based architectures but recent advancement towards serverless and Functions as a Service further emphasize the role of the cloud as a platform abstracting underlying infrastructure resources [6], [18].

Fog computing can be simplified as the cloud brought closer to the use case applications. Fog nodes minimize load on the cloud and are able to host some services from the cloud, and thus respond faster and also reduce networking to the cloud [9]. Chiange et al. [10] define that "fog is inclusive of cloud, core, metro, edge, clients, and things," and "fog seeks to realize a seamless continuum of computing services from the cloud to the things" instead of independent application resource pools.

Edge computing takes place at the edge of the network close to IoT devices, however, not necessarily on the IoT devices themselves but as close as one hop to them [25]. Edge computing has been pushed heavily by the telecommunication industry but it has also emerged from the need to perform computation closer the applications or with independence from cloud computing. Edge computing is characterised by short latency in contrast to cloud computing where transmission of data, allocation of resources typically includes delays.

For applications where large amounts of data needs to be processed both fog and edge computing can introduce benefits as cost savings in transfer, storage and processing. This includes, for example, data from thousands of sensors, audio and video streams, and emerging machine learning (ML) based solutions. In Virtual Reality (VR) and Augmented Reality (AR) edge computing together with low latency communication is claimed to enable cutting the cord, and it has been shown to achieve minimum gains of up to 30% reduction in end-to-end delay and even more for most parts of the communication [11].

B. RELATED WORK

Over the last few years, more and more researchers have been focusing on the cloud continuum paradigm. Therefore, some surveys/reviews on the subject have already been presented. In the following, we report an overview of the most relevant works available in the literature and discuss the differences with our work.

Al-Sharafi et al. [4] presented a literature review on the adoption of cloud computing services at the organizational level, with a focus on the elements that contribute to long-term adoption.

Pahl et al. [19] performed a literature review to identify, catalog, and compare the corpus of existing research on containers, their orchestration, and particularly the use of this technology in the cloud.

Bittencourt et al. [8] presented a literature review on IoT-Fog-Cloud continuum with the aim of understanding (i) what are the best types of infrastructures to deploy the entire ecosystem, (ii) what are the required mechanisms to allow orchestration, data exchange, and resource management, and (iii) what are the types of applications that can benefit most from this ecosystem.

Nguyen et al. [17] surveyed the current landscape of the existing approaches and tools that attempt to cope with this edge and cloud heterogeneity, scalability and dynamicity.

Bendechache et al. [7] surveyed the list of suitable methods, algorithms, and simulation approaches for resource management in cloud-to-thing continuum.

Ramanathan et al. [21] conducted a survey to retrieve all the resource allocation techniques that have been developed for the cloud continuum.

Svorobej et al. [23] reviewed the orchestration mechanisms along the cloud-to-thing continuum with a focus on container-based orchestration and orchestration architectures tailored for fog.

Asim et al. [5] provided a summary of research issues in Cloud computing and Edge computing, as well as current developments in resolving them with CI approaches.

Ghobaei-Arani et al. [13] provided a literature analysis aiming to identify the state-of-the-art mechanisms on resource management approaches in the fog computing environments.

Kampars et al. [14] reviewed application layer protocols that can be used for the communication between the IoT, edge and cloud layers.

Spataru [22] surveyed the applications of Blockchain or Smart Contracts for computing resources management, data storage, and services operation in the context of Cloud continuum.

Kansal et al. [15] presented a systematic literature review of the resource management approaches in fog/edge paradigm.

Compared to our work, the previous literature reviews spent a noticeable effort in understanding technical and managerial aspects of the cloud continuum (Table 1). Instead, our work focuses on identifying the definition of the cloud continuum, how it evolved, and where the cloud continues.

III. RESEARCH METHODOLOGY

In this study, we conducted a systematic mapping study of the literature, by taking into account the guidelines proposed by Petersen et al. [20]. The main aim was to systematically and impartially summarize and classify the collected information regarding the research questions. Specifically herein, we aimed to not only characterize all the existing definitions of the "cloud continuum" and other relevant concepts, but also to investigate the evolution of such definitions through time.

The process of the study included four main steps. Firstly, we established the research questions. Secondly, we defined the search strategy. Thirdly, we defined the data extraction strategy. Fourthly, we synthesized and visualized the obtained results.

TABLE 1. Summary of the related literature reviews.

Source	Target	Year
Al-Sharafi et al. [4]	Adoption of cloud computing services at the organizational level	2017
Pahl et al. [19]	Containers orchestration and usage in the Cloud	2017
Bittencourt et al. [8]	IoT-Fog-Cloud continuum infrastructures, orchestration, data exchange, and resource management	2018
Nguyen et al. [17]	Existing approaches and tools supporting edge and cloud development	2019
Bendechache et al. [7]	Resource management in cloud-to-thing continuum	2020
Ramanathan et al. [21]	Resource allocation techniques for the Cloud continuum	2020
Svorobej et al. [23]	Orchestration mechanisms along the cloud-to-thing continuum	2020
Asim et al. [5]	Research issues in Cloud computing and Edge computing	2020
ghobaei2020resource	Resource management approaches in the fog computing environments	2020
Kampars et al. [14]	Communication protocols between the IoT, edge and cloud layers	2021
Spartaru [22]	Blockchain usage in Cloud continuum	2021
Kansal et al. [15]	Resource management in fog/edge paradigm	2022
Our study	Definition of Cloud continuum	2022

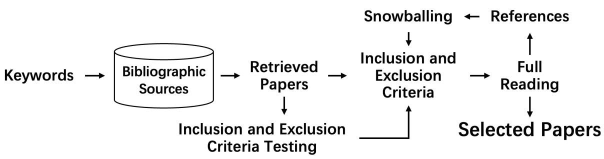

FIGURE 1. The Search and Selection Process.

TABLE 2. Initial search results by sources.

Library	Scopus	IEEE	ACM	WoS	Non-Duplicates
Count	271	148	61	102	378

A. SEARCH STRATEGY

The aim as well as the challenge for a systematic mapping study was to define the search query that enables the retrieval of a complete set of studies that contain the definitions [16]. For such a purpose, the search strategy encompassed a set of steps, namely, defining search string, identifying key sources, selecting primary studies, extracting data and synthesizing the results.

The search strategy involved the outline of the most relevant bibliographic sources and search terms, the definition of the inclusion and exclusion criteria, and the selection process relevant for the inclusion decision. Our search strategy can be depicted in Fig. 1.

As for the search terms, we included cloud concepts, Fog, Edge, and Continuum:

*(**cloud** AND (**edge** OR **fog**) AND **continuum**)*

We searched for scientific literature in four bibliographic sources: Scopus,[1] IEEEXplore Digital Library,[2] the ACM Digital Library,[3] and Web of Science.[4] The adoption of four databases ensured the completeness of the search results.

We conducted our search on March 1st 2022, retrieving 378 non-duplicated papers from the four sources. The number of papers retrieved for each source is reported in Table 2.

B. PRIMARY STUDIES SELECTION

In order to select the primary studies from the preliminary search results, we defined the inclusion and exclusion criteria shown in Table 3. We included the research papers published in journals or conferences, defining Cloud Continuum. On the other hand, we excluded the research papers that are not in English, duplicated, not discussing the topic connected to the defined research questions. Furthermore, we also excluded the papers that are not peer-reviewed, as well as the work plans or roadmap, posters and vision papers.

With the inclusion and exclusion criteria defined, we selected the primary studies via two steps. Firstly, two of the authors read the title and abstract of each paper separately to determine whether it should be excluded or be read fully. Whenever there was disagreement between them, a third person assert the decision by the inclusion and exclusion. Out of 378 papers screened, we had 93 disagreement with a Cohen's kappa coefficient of 0.51, indicating a moderate agreement [12]. As a result, we identified 181 papers that need to be considered for the next step.

We then ran a snowballing process including all the papers referenced by the 181 papers. We then followed the same process by applying inclusion and exclusion criteria to their titles and abstracts. As a result, we included two more papers: one peer-reviewed, and one grey literature [SP1]. The reason for including this specific non-peer-reviewed work [SP1] is due to its large amount of citations; especially when many of our selected papers referred to it as the first definition of cloud continuum. Though belonging to the gray literature, this study represents an important milestone for the definition of cloud continuum that has evolved over time with the addition/removal of other keywords. It is also important to notice that no other grey literature works are mentioned by the selected studies.

Each of the 183 papers (181 from the initial search, and 2 from snowballing), was fully read by one of the authors independently and evaluated by the inclusion and exclusion criteria. As a result, we selected 36 papers.

[1] Scopus, https://www.scopus.com
[2] IEEEXplore Digital Library https://ieeexplore.ieee.org/
[3] ACM Digital Library: https://dl.acm.org
[4] Web of Science database: https://www.webofscience.com/

TABLE 3. Inclusion/Exclusion criteria.

Inc./Exc.	Criteria
Inclusion	Papers defining the concept of cloud continuum
Exclusion	Not in English Duplicated (post summarizing other websites) Out of topic (using the terms for other purposes) Non-peer-reviewed papers Work plans, roadmaps, vision papers, posters

C. DATA EXTRACTION STRATEGY

From the 36 Selected Papers (SP), we extracted the data that answers our research questions. Importantly, we extract the definitions on ''continuum'', the year of the publication, and the information on where the cloud is ''continued''. In addition to the key data mentioned above, we also extracted the type of publication (e.g. conference paper, or journal article).

TABLE 4. The information extracted from the selected papers.

RQ	Information Extracted	Motivation
RQ1	Definition of Continuum	
RQ2	Publication Year	To understand the chronological evolution of the definition.
RQ3	Cloud-to-* continuum	Identify the possible extensions of the cloud (*) mentioned in the SPs

The description of the information extracted, together with their motivation and the mapping to the RQs, is reported in Table 3.

D. KEYWORDING

The different definitions were written in natural language. Therefore, we needed to run a qualitative analysis among the authors, to identify similar definitions and different ones.

For this purpose, we applied a collective coding process to answer our RQs:

The manual identification of the aforementioned information was extracted collaboratively. From each paper, we first extracted the definition and print it to a post-it note (**RQ1**). Then, one author attached it to a whiteboard, and the other authors read all the other definitions proposed by the papers. All the authors discussed one by one the similarities and differences of each of the definitions, so as to decide whether to group them into a single definition or to create a new one.

Finally, the authors re-position the post-it notes reporting groups of similar definitions, and their key differences. For each definition, all the authors follow the same process to identify common aspects.

Last, authors highlighted with different colors the continuum extension to the cloud (**RQ3**)

IV. RESULTS

As expected, publications on Cloud Continuum are continuously growing in the recent years. The first definitions of cloud continuum were presented in [SP1] and [SP2] in 2016. For the following three years only four papers are identified

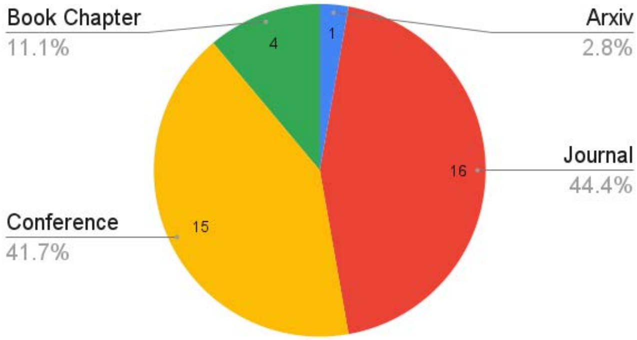

FIGURE 2. Selected papers by types.

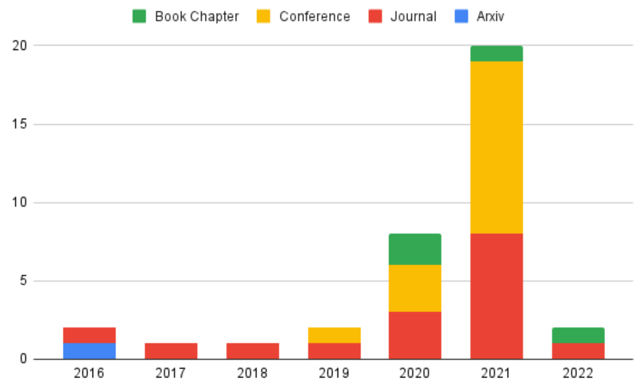

FIGURE 3. Selected Papers by Years.

as related to the definition of cloud continuum. The interest in the topic started to grow in 2020. As depicted in Fig. 3 the majority of paper identified are from 2021. In the remainder of this Section, we answer our RQs.

A. THE DEFINITIONS OF CLOUD CONTINUUM (RQ1)

The first definitions of Cloud Continuum were both presented in 2016. Gupta et al. [SP1] defined cloud continuum as ''a continuum of resources available from the network edge to the cloud/datacenter'' while Chiang et al. [SP2] defined cloud continuum explicitly mentioning computational-related aspects, for instance, where and how the computation is performed.

We identify three main groups of definitions, with respect to their main aspects. Each group is represented by a block of a different colour in Fig. 4. The first and larger group contains all those sources defining cloud continuum as an aggregation/combination of different elements such as IoT devices, fog and edge nodes. In this case, cloud continuum only refers to the continuum of resources, but not of the computation. The second block contains all the sources defining cloud continuum with a particular focus on the processing/computation. Finally, we group together all those sources that do not belong to these two blocks.

Fig. 4 also shows that the definition of cloud continuum has two different origins. Both of the papers which gave origin to the definition, as presented previously, have been

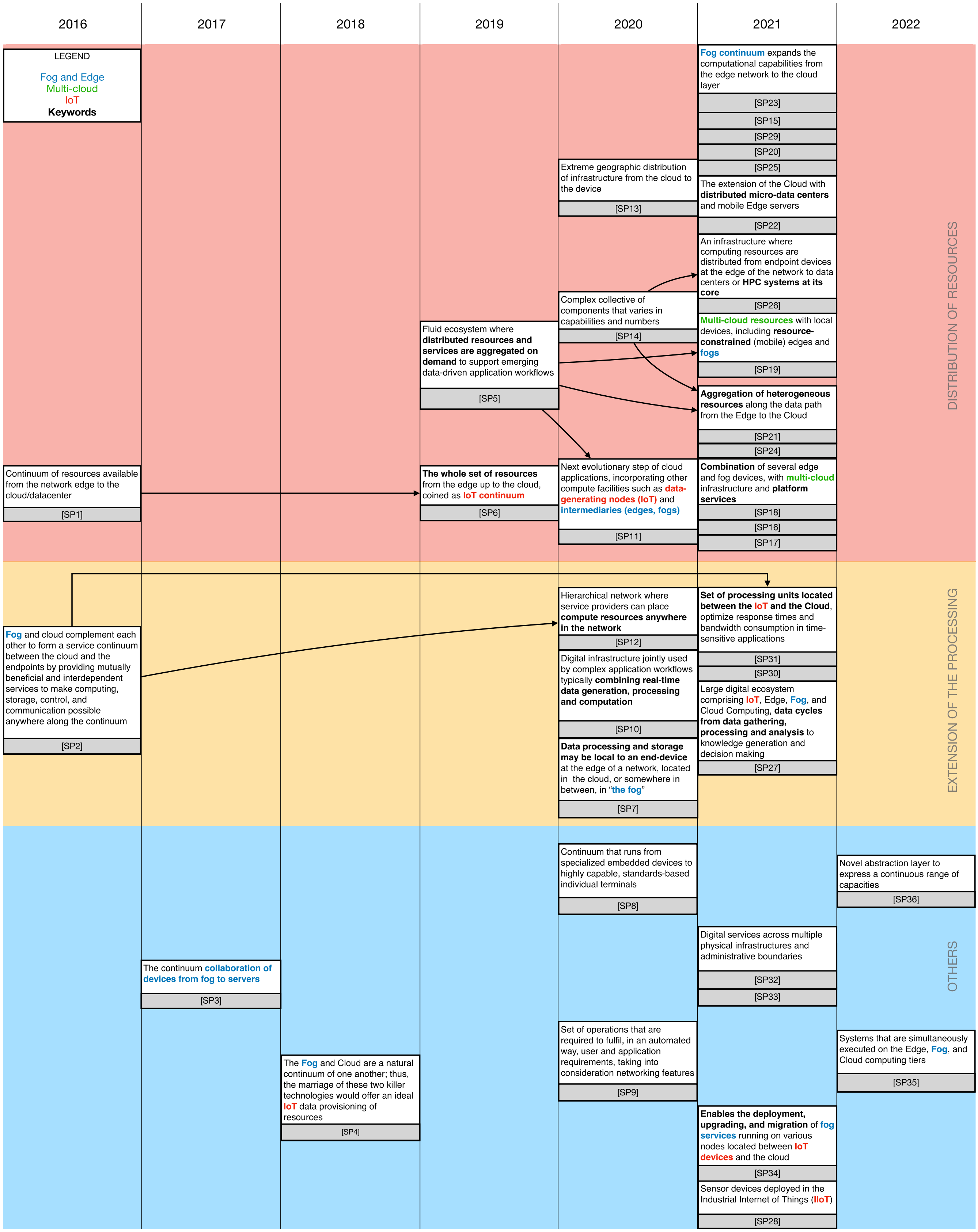

FIGURE 4. Definitions of cloud computing grouped by year and concepts. Each column represent a different year while the coloured blocks represents different aspects. Arrows between two blocks indicate that there is a direct citation to the definition.

published in 2016 but each of these focused on a different aspect. While the definition in [SP1] focused on the elements composing the system, the one proposed in [SP2] was centered around the concept of ''where happens what''.

The definition provided in [SP1] has been extended in 2019 from Kahvazadeh et al. [SP6] where the continuum of resources has been extended to 'the whole set of resources from the edge up to the cloud'. In parallel to this, Balouek-Thomert et al. [SP5], centered their definition on the concept of ''distributed resources services on demand''.

Within these groups we can identify some clusters. Each cluster combine multiple work within the same year defying the concept of cloud continuum in the same fashion. It is important to notice that each cluster is year-based as the definition evolved during the years (even when the author is the same). The highest amount of cluster can be found in the first group of work, those related to the distribution of resources.

Within this group we can find 3 different clusters. The first one includes 5 different work agreeing on the same definition which puts the concept of continuum strictly related to the concept of fog. The second cluster is composed of 3 works which stress the importance of having a combination of multiple edge and fog devices. The third cluster defines the cloud continuum as an aggregation of heterogeneous resources from the Edge to the cloud. The latter even tho it is composed of only two works, has a definition that focuses on the data path with a bottom-up design.

The other two clusters can be found one per each group. The first one, in the group ''extension of the processing'', includes two works defying cloud continuum as a Set of processing units located between the IoT and the Cloud. The other one, also including two works, focuses on the different services across multiple infrastructures.

B. THE EVOLUTION OF THE CLOUD CONTINUUM DEFINITION (RQ2)

In order to answer RQ2, we firstly extract the commonly adopted keywords of the cloud continuum definitions of the selected papers. Herein, based on the opinions of two domain experts, we extract six different keywords that delineate the characteristics (i.e., how, when and where) of cloud continuum and specify the entities (i.e., what) it connects. The keywords include:

- **Multi-Cloud:** definitions referring to multiple cloud entities;
- **Fog:** definitions explicitly referring to Fog;
- **IoT:** definitions referring to internet of things, IoT, things;
- **Anywhere:** definitions explicitly reporting that the computation can be executed everywhere;
- **Micro Datacenters:** definitions explicitly reporting the use of micro datacenters to the goal of providing low-latency access to data processing and data storage.
- **Simultaneous:** definitions explicitly reporting that the computation can be simultaneously executed on multiple nodes.

Therefore, by summarizing the adoptions of these keywords by the selected papers in chronological order (reported in TABLE 5), we can observe the evolution of the cloud continuum definition.

The two earliest definitions, [SP1] and [SP2] in 2016, both anchored the concept of fog between cloud and edge, where the term ''continuum'' was firstly used by its literal meaning in this context. Specially, Chiang and Zhang [SP2] emphasized that within such continuum, services like computing, storage, control and communication could be provided anywhere between cloud and edge. From 2017 to 2018, the two studies, [SP3] and [SP4] continued adopting the term ''continuum'' describing the combination of fog and cloud, when Peng et al. [SP4] indicated that the continuum of fog and cloud could provide ideal IoT data provisioning. In 2019, Balouek-Thomert et al. [SP5] also mentioned ''computing continuum'' as a fluid ecosystem with aggregated resources and services but didn't emphasized its positioning between cloud and edge. Meanwhile, also in 2019, Kahvazadeh et al. [SP6] proposed the term ''IoT continuum'' but similarly coined the definition as a whole set of resources between edge and cloud.

Since 2020, the number of studies that provided definitions to cloud continuum has been growing sharply. In 2020, eight studies mentioned the concept of ''continuum'' and similarly placed the concept as the services between cloud and the end-devices (i.e., edge). However, though five studies, [SP7], [SP8], [SP11], [SP12], and [SP14], mentioned ''fog'' when defining continuum, none of the studies have clearly distinguish them; when some studies, e.g., [SP8], [SP12], indicate continuum is between cloud and fog. Meanwhile, four studies mentioned IoT when defining continuum [SP11]-[SP14]; however, the relation between continuum and IoT is not clearly delineate either. On the other hand, Kassir et al. [SP12] also indicate that compute resources can be placed anywhere in the network when citing [SP2]. Furthermore, Spillner et al. [SP11] emphasize that continuum is more than simply a ''multi-cloud'' but incorporating other compute facilities, e.g., mobile devices, IoT sensor nodes, edges and fogs, which is the first time continuum is connected with the notion of ''multi-cloud''.

In 2021, nine studies mentioned ''fog'' as a critical entity in the definition of continuum. Different from previously, many of these studies, e.g., [SP18]-[SP20], [SP22], [SP23], have anchored the continuum concept as the combination or aggregation of several fog, edge, IoT devices or services, or the extension of the cloud. Meanwhile, four studies [SP16]-[SP19] also indicate that cloud continuum is a ''multi-cloud'' infrastructure. On the other hand, eight studies indicate that IoT is a crucial part of the cloud continuum concept when, however, the interpretation of the term differs slightly. For example, Xhafa and Krause [SP27] define cloud continuum as a large digital ecosystem comprising IoT, Edge, Fog, and

TABLE 5. Initial search results by sources.

Reference	Year	Architecture				Performance	
		Multi-Cloud	Fog	IoT	Micro Datacenters	Anywhere	Simultaneous
[SP1]	2016		✓				
[SP2]	2016		✓			✓	
[SP3]	2017		✓				
[SP4]	2018		✓	✓			
[SP5]	2019						
[SP6]	2019			✓			
[SP7]	2020		✓				
[SP8]	2020		✓				
[SP9]	2020						
[SP10]	2020						
[SP11]	2020	✓	✓	✓			
[SP12]	2020		✓	✓		✓	
[SP13]	2020			✓			
[SP14]	2020		✓	✓			
[SP15]	2021						
[SP16]	2021	✓					
[SP17]	2021	✓					✓
[SP18]	2021	✓	✓				
[SP19]	2021	✓	✓				
[SP20]	2021		✓				
[SP21]	2021						
[SP22]	2021		✓		✓		
[SP23]	2021		✓				
[SP24]	2021						
[SP25]	2021						
[SP26]	2021						
[SP27]	2021		✓	✓			
[SP28]	2021			✓			
[SP29]	2021			✓			
[SP30]	2021		✓	✓			
[SP31]	2021		✓	✓			
[SP32]	2021			✓			
[SP33]	2021			✓			
[SP34]	2021		✓	✓			
[SP35]	2022		✓				✓
[SP36]	2022						

etc., where IoT is the individual entity/device providing services; Zeiner and Unterberger [SP28] defines edge-to-cloud continuum as *a data-driven Internet of Things combines the physical world with the world of information*, where IoT is referred to as the assembly instead of the individual. Specially, Mehran et al. [SP22] define cloud continuum as the extension of the cloud with distributed micro-datacenters and mobile edge servers, which is the first and only time when micro-datacenter is used.

Until February 2022, two studies also provided definitions to cloud continuum. Dustdar et al. [SP35] define it by emphasizing it is the system that is "simultanously" executed on the edge, fog, and cloud computing tiers. Similarly, in 2021, Risco et al. [SP17] also mentioned the term "simultanously" by indicating cloud continuum "*simultaneously involves both on-premises and public Cloud platforms to process data captured at the edge*". The other definition given by Spillner et al. did not specify the entities that cloud continuum aggregating but emphasize it is an "*novel abstraction layer to express a continuous range of capacities*".

C. WHERE DOES THE CLOUD CONTINUE (RQ3)

Among the 36 SPs, nine of them mention the continuum as "cloud-to-thing(s) continuum". Therein, these studies indicate that cloud continuum connects or is placed between cloud(s) and the IoT-connected devices (i.e., things). Specially, Kassir et al. [SP12] state that "cloud-to-thing(s) continuum" is equivalent to "Fog-to-Cloud continuum". Meanwhile, two studies, [SP22] and [SP23], use "Cloud-fog continuum" or "fog continuum" indicating the continuum extends the cloud towards fog, which could either refer to fog nodes (i.e., also things) or fog in general.

On the other hand, seven papers amongst the 36 SPs use the term "Edge-to-Cloud continuum" (or Cloud-edge continuum, or edge/cloud continuum) indicating the cloud "continues" towards edge nodes. Kahvazadeh et al. [SP6] use the term "IoT continuum" but describe the same connection between cloud and edge. Three studies use directly the term "cloud continuum" but also define it as combination of cloud and edge.

Furthermore, ten studies use "Computing Continuum" to emphasize the computing capability instead of the connection of entities. Within these definitions, the "continuum" can be used connecting any entities, e.g., edge, fog, local devices (i.e., IoT or things), data centers, etc. Specially, Balouek-Thomert et al. [SP5] do not describe the specific nodes being connected by continuum but defines "computing continuum" as "a digital infrastructure jointly used by complex application workflows". Beckman et al. [SP14] provide a similar definition as "a collective of components with various capabilities and numbers in aggregate". Spillner et al. [SP36] provide a high-level abstracted definition of computing

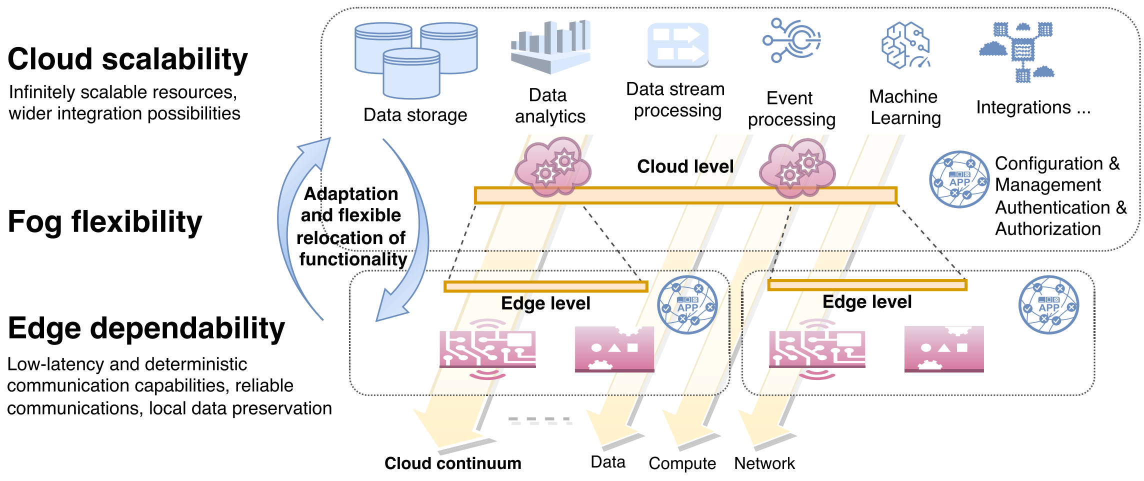

FIGURE 5. Architecture of Cloud Continuum.

continuum as "novel abstraction layer to express a continuous range of capacities"

Comparatively, early studies, e.g., [SP1] and [SP2], did not try to provide distinguishable terms but only use the term "continuum" literally trying to describe the conceptual idea. Similarly, these two studies also place the "continuum" between cloud to edge or cloud to fog.

V. DISCUSSION

Several definitions of Cloud Continuum have been proposed in the last six years. However, only few have been used or extended.

It is interesting to notice the two main types of definitions, one considering the continuum as distribution of resources in different network elements, including IoT, Fog, Edge, but also HPC, while the other definition considering the continuum as an extension of the processing power to different nodes, often mentioning the possibility of executing also AI.

The investigation of the different cloud continuum concepts allowed us to draw an overall architecture of the cloud continuum (Figure 5)

Based on the analysis conducted in this work, we can propose a new definition of cloud continuum, combining the most frequently mentioned aspects.

> **Cloud Continuum** is an extension of the traditional Cloud towards multiple entities (e.g., Edge, Fog, IoT) that provide analysis, processing, storage, and data generation capabilities.

A. FUTURE CHALLENGES

The results of this work enabled us to distill a set of challenges for the cloud continuum. Therein, the majority of the SPs point out the challenges concerning the **dynamic allocation of the computation**([SP31], [SP22]), and in particular of the execution of the AI, and the related resource orchestration, network partitioning ([SP30]) and support for context-awareness ([SP9]).

As part of the resource orchestration, **job scheduling** is also identified as one of the most common challenges that need to be addressed in the future ([SP4], [SP13], [SP14], [SP16], [SP24]). Tools such as Kafka-ML ([SP30]) and network virtualization ([SP1]) are proposed towards such an end. Furthermore, other techniques, e.g., adopting APIs ([SP16]) and game theory ([SP20]), are proposed as promising solutions for application deployment and orchestration.

The **robustness** of the cloud continuum is also considered a critical aspect for the future. For example, [SP11] highlights the complexity of the awareness of application deployment towards the adaptation for higher resilience. [SP23] and [SP15] also indicate that tolerant IoT services and **self-healing** components shall serve for the future steps towards structural and behavioral optimization of cloud continuum system.

Furthermore, **security** of the cloud continuum systems ([SP2], [SP4]) is also a key aspect when specific techniques, e.g., Information-Centric Network integration ([SP9]), and Hybrid key distribution ([SP6]) are seen as future works.

Other **performance** characteristics, e.g., scalability ([SP28]), mobility ([SP23]) and consistency ([SP2]), together with the corresponding ways of acquisition ([SP11]), comparison ([SP29]) and benchmark ([SP26]) are also mentioned as the challenges.

Meanwhile, other future challenges include high-level abstraction models and architectural trade-off ([SP2], [SP10]), [SP14]), interfaces and user experience ([SP1], [SP2]), positioning and localization, ([SP4]) and the Incentives of device participation ([SP2]). The researchers shall consider contributing to the solutions to the above challenges in order to enrich the domain knowledge of cloud continuum research.

B. THREATS TO VALIDITY

We are aware that our work is subject to threats to validity. The terms Cloud, Fog, IoT, and Edge are sufficiently stable to be used as search strings. In order to assure the retrieval of all papers on the selected topic, we searched broadly in general publication databases, which index most well-reputed publications. To improve the reliability of this work, we defined search terms and applied procedures that can be replicated by others. Since this is a mapping study and no systematic review, the inclusion/exclusion criteria are only related to whether the topic of Cloud Continuum is present in a paper or not, as suggested by [20]. As for the analysis procedure, since our analysis only uses descriptive statistics, the threats are minimal. However, we are aware that the synthesis of the definition might be subjective. To mitigate this threat, the analysis was done collaboratively, using a collecting coding methods, and discussing with all the authors about inconsistencies. The Kohen K index about our disagreement also confirms the quality of the qualitative analysis performed.

VI. CONCLUSION

In this work, we proposed a systematic mapping study on the definition of Cloud Continuum to obtain an overview of its existing definitions and how the concept has been evolved.

We identified 36 studies which proposed definitions to Cloud Continuum dated from 2016. All these definitions are summarized in Figure 4. We organized all the 36 existing definitions in chronological order.

In conclusion, we propose to complement existing definitions into a common one that merges explicitly two aspects: the continuum as **extension of the resources**, and as **extension of computational capabilities**.

As a result, we formulated the definition of cloud continuum as ''**an extension of the traditional Cloud towards multiple entities (e.g., Edge, Fog, IoT) that provide analysis, processing, storage, and data generation capabilities.**''

The new definition enables both practitioners and researchers to better understand the concept of cloud continuum and to gain insights into the potential advance in service-oriented computing.

As regards future work, we are planning to extend this work in the context of cognitive continuum.

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