Review of Fog Computing: Architectures, Applications With Cloud Challenge

Archana Daravai
Btech Scholar
TIT & Science, Bhopal.

Akanksha Meshram
Btech Scholar
TIT & Science, Bhopal.

Arun Kumar
Btech Scholar
TIT & Science, Bhopal.

Kumar Satyam
Btech Scholar
TIT & Science, Bhopal.

Abstract— Cloud services for smart objects face challenges with latency and sporadic connectivity. Positioned between the cloud and smart devices, fog devices alleviate these issues. Their high-speed Internet connection to the cloud and proximity to users enable real-time applications, location-based services, and mobility support. Cisco has championed fog computing in domains like smart grids, connected vehicles, and wireless sensor networks. This survey explores extending fog computing to decentralized smart building control, recognizing cloudlets as part of this paradigm and linking it to SDN scenarios. Literature review findings indicate a limited number of articles on this topic. The study delves into demand response management in smart grids, cooperative data scheduling, and adaptive traffic light challenges in vehicular networks. However, security, privacy, trust issues, and network control regulations remain underexplored in fog computing.

Keyword: Fog Computing, Cloud Computing

I. INTRODUCTION

The advent of computer networks in the 1970s ushered in the era of distributed systems (Andrews, 1999). A distributed system comprises separate computers that present themselves to users as a unified entity, offering a singular system view (Tanenbaum & Steen, 2006). Among the array of distributed systems technologies, peer-to-peer (P2P) networks stand out as one of the most common forms, facilitating coordinated aggregation of distributed computers for extensive accessibility. Concurrently, distributed computing systems, a vital subset employed for high-performance computing tasks, gained prominence (Tanenbaum & Steen, 2006).

Cluster computing gained traction due to the proliferation of cost-effective, potent personal computers, and high-speed networks (Hajibaba, 2014). Grid computing and Cloud computing emerged in the mid-1990s and 2007, respectively, coinciding with the internet's expansion. Cloud computing swiftly rose to prominence, becoming the dominant technology (Qian et al., 2009). However, as per Gartner's Hype Cycle for Emerging Technologies, Cloud computing transitioned from the "peak of inflated expectations" to the "trough of disillusionment," with an estimated two to five years until maturity (Gartner, Inc., 2013). Consequently, novel computing paradigms are gaining favor in distributed systems.

Jungle computing emerged as a novel approach to enhancing performance by integrating disparate and highly heterogeneous distributed computing systems (Seinstra et al., 2011; Kahanwal & Singh, 2012). In 2012, Fog computing extended the Cloud computing paradigm to the network's periphery, enabling new application and service possibilities (Bonomi et al., 2012). A taxonomy of distributed computing paradigms is illustrated in Figure [1]

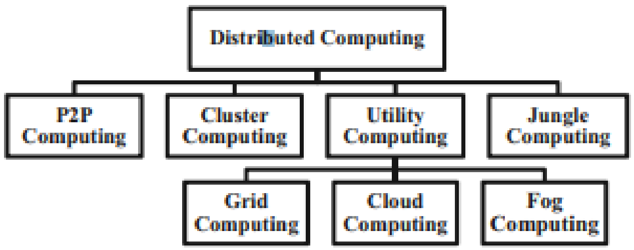

Figure 1. Taxonomy of distributed computing.

The discussion encompasses two emerging distributed computing paradigms: Jungle computing and Fog computing, along with Cloud computing, which shares connections with both. Collectively, these three paradigms constitute modern distributed computing paradigms. A thorough review of these models and their attributes could enhance understanding of the similarities and distinctions among contemporary distributed computing concepts (Gorgin, 2014).

II. LITERATURE REVIEW

QINGLIN Q et al. (2019) explored "A Smart Manufacturing Service System Based on Edge Computing, Fog Computing, and Cloud Computing." In this system, smart manufacturing operates across multiple layers. Smart devices form the foundational layer, serving as data sources and supporting edge computing. The data transmission network, acting as the intermediary layer, facilitates fog computing. At the apex is the cloud, where big data is stored and analyzed. Edge computing and fog computing, empowered by the computational, storage, and networking capabilities of nearby nodes, minimize data transmission to the cloud and reduce the risk of service downtime, thereby ensuring the resilience of the smart manufacturing system. The synergy among edge computing, fog computing, and cloud computing optimally caters to the demands of smart manufacturing applications [1].

In contrast, Vishal Kumar et al. (2019) conducted a comparative study titled "Comparison of Fog Computing & Cloud Computing." This analysis sheds light on the disparities between fog and cloud computing. While cloud computing has reached an advanced stage, offering a plethora of development tools for architecting cloud-based solutions, fog computing is still in its nascent phase. Prototype models and development tools for fog computing are in the early stages of development. However, the researchers foresee fog computing as the future of modern computing technology, evolving rapidly and leveraging device edges for computational resources. Tables provided in the paper outline the advantages of fog computing over cloud computing. They predict that fog computing will emerge as a promising business model for service providers in the future [2].

Mohammed Al Yami et al. (2019) explored "Fog Computing as a Complementary Approach to Cloud Computing." In both industry and government sectors, fog computing plays a pivotal role in facilitating big data applications. It serves as a crucial element in cutting-edge products and services such as smart cars, smart manufacturing facilities, digital healthcare systems, and smart transportation systems that are rapidly proliferating worldwide. Despite its numerous advantages, Cloud Computing environments encounter various challenges, including data security, service latency, network congestion, and bandwidth limitations. However, integrating Cloud and Fog Computing can help enterprises unlock new potentials in information-driven industries while addressing existing challenges. Integration offers several benefits to businesses, including the establishment of robust disaster recovery systems, enhanced organizational agility, risk mitigation, improved data security, and the generation of new revenue streams. Consequently, fog and cloud computing emerge as indispensable components for many enterprises, suggesting a need for more widespread adoption to bolster revenue generation and data security [3].

Sourav Kunal et al. (2019) provided an in-depth examination titled "An overview of cloud-fog computing: Architectures, applications with security challenges." Within the realm of fog devices, various designs cater to specific application domains such as Energy Lattices, MediFog, UXFog, and Connected Parking System, among others. Each design addresses security concerns at every level of the architecture to thwart unauthorized access or tampering of data. The discussion extends to encompass authentication, integrity maintenance, secure storage, key management, and intrusion detection systems (IDS) pertinent to both fog devices and cloud computing. The overarching objective is to establish a secure and reliable framework capable of securely and swiftly acquiring relevant data across various facets of human life as and when required [4].

Amandeep Singh Sohal et al. presented a study titled "A Cybersecurity Framework to Identify Malicious Edge Device in Fog Computing and Cloud-of-Things Environments" [5]. They highlighted the potential threat posed by edge device attacks in hindering the successful deployment of fog computing environments [55]–[57]. The research demonstrated the efficacy of their proposed cybersecurity framework in detecting malicious edge devices within a distributed fog computing setting. To achieve early detection of both malicious and legitimate edge devices, the suggested cybersecurity architecture leverages a two-stage Markov model. Experimental findings validate the effectiveness and efficiency of the system, supported by test results. Notably, the framework includes a crucial feature enabling the recovery of genuine edge devices from the Virtual Hard Disk (VHD) in case of accidental mishaps. Additionally, the framework introduces and rigorously tests an Intrusion Detection System (IDS) with adaptive capabilities, alongside a false alarm controller [5].

Tian Wang et al. (2018) explored "Coupling resource management based on fog computing in smart city systems." The integration of Cyber-Physical Systems (CPS) with cloud computing has garnered significant attention within the smart city research landscape. To address the challenge of coupling resource management, a fog computing-based technique is devised. This system ensures near-optimal resource allocation. Positioned as an intermediary tier between the cloud and the upper and lower layers of CPS, the fog computing layer plays a pivotal role. Furthermore, the Enhanced Hierarchical Grid-Based (EHGB) approach integrates a buffer queue into the fog computing layer to mitigate computational coupling. In scenarios involving malicious nodes and user requests, the fog layer can cache data from conflicting nodes, thereby averting system conflicts. Theoretical analysis coupled with experimental evidence suggests that this strategy effectively resolves the coupling resource management issue, fostering the development of a sustainable smart city system [6].

Shanhe Yi et al. (2015) conducted a comprehensive examination titled "A Survey of Fog Computing: Concepts, Applications and Issues." This survey delves into the nuances of fog computing by juxtaposing its definitions with related concepts, illustrating representative applications, and addressing various challenges encountered during the design and implementation of fog computing systems. Key topics explored include Quality of Service (QoS), interface specifications, resource management, security, and privacy concerns. Additionally, the survey discusses emerging opportunities and hurdles within the realm of fog computing vis-à-vis related methodologies. The authors anticipate that with the rapid advancements in underlying technologies such as the Internet of Things (IoT), edge devices, radio access techniques, Software-Defined Networking (SDN), Network Function Virtualization (NFV), Virtual Machines (VM), and Mobile Cloud, fog computing will continue to evolve. They posit that while fog computing holds significant promise, concerted efforts across various underlying approaches are necessary to elevate it to its full potential [7].

Ivan Stojmenovic et al. (2014) explored "Fog computing: A cloud to the ground support for smart things and machine-to-machine networks." They highlighted the prevalent issues of latency and sporadic connectivity in cloud services for smart objects. Positioned between the cloud and smart devices, fog devices alleviate these challenges. Leveraging their high-speed Internet connection to the cloud and proximity to users, fog devices enable real-time applications, location-based services, and mobility support. Notably, Cisco has endorsed the concept of fog computing, particularly in domains such as smart grid, connected vehicles, and wireless sensor and actuator networks. This survey extends the application of fog computing to decentralized smart building control, identifying cloudlets as a subset of fog computing and linking it to Software-Defined Networking (SDN) scenarios. Although the literature review yielded a limited number of articles, the study delves into various aspects, including demand response management in smart grids, cooperative data scheduling, and adaptive traffic light challenges in SDN-based vehicular networks. However, the exploration of security, privacy, trust concerns, control information overhead, and network control policies appears to be lacking in the fog computing concept [8].

III. METHODOLOGY

A systematic methodology, as illustrated in Fig. 2, was employed for this study. The initial phase aimed to identify relevant publications, a task compounded by two challenges: (i) the dispersion of fog computing articles across a wide array of journals and conferences, and (ii) the absence of a standardized nomenclature for fog computing, hindering straightforward keyword searches. To overcome these obstacles, we adopted a combination of three search strategies:

Manual search: Five specific conferences focusing on fog computing were identified:

The IEEE International Conference on Fog and Mobile Edge Computing (FMEC), held annually since 2016.

The IEEE International Conference on Fog and Edge Computing (ICFEC), conducted over 100 times since 2017.

The IEEE International Conference on Edge Computing (EDGE), established since 2017.

Edge Computing Symposium (ACM/IEEE) (SEC), commenced since 2016.

The IEEE Fog World Congress (FWC), convened biennially since 2017.

Each paper presented at these conferences was manually scrutinized for relevance to our study, adhering to predefined inclusion and exclusion criteria.

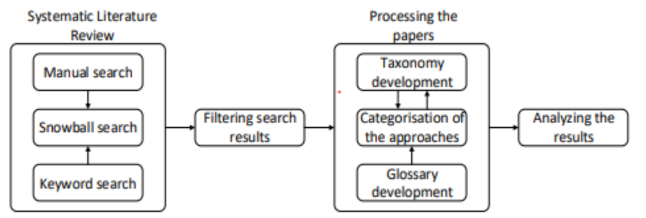

Figure 2: Overview of the used survey methodology

- Keyword search: We devised a search string based on the relevant documents identified. Beginning with [5]'s basic search string, we refined it through iterations until it matched at least 85 percent of the 105 manually identified documents (the original search string only matched around 20 percent). The refined search string is as follows:

  ((TITLE-ABS-KEY("edge computing" OR "fog computing" OR cloudlet)) OR (TITLE-ABS-KEY(offload*) AND TITLE-ABS-KEY(cloud)) AND (TITLE-ABS-KEY(optim* OR minimize OR maximize OR "objective function"))) AND (TITLE-ABS-KEY(optim* OR minimize OR maximize OR "objective function"))
- Snowball searching: We explored papers cited by or citing each identified document to uncover an additional 110 relevant papers. This search was conducted with a deadline of November 1st, 2018. The combined approach yielded a pool of potentially relevant papers, subsequently filtered using the following criteria:
- Only articles specifically addressing optimization challenges in fog computing were considered. Papers unrelated to fog computing, such as those focusing on task offloading from end devices to cloud services rather than fog nodes, were excluded. Additionally, papers lacking a specified optimization problem were eliminated, including those discussing technology and architecture issues in fog computing.
- Non-English papers and short papers (less than 4 pages in double-column format) lacking sufficient information were excluded from consideration. Initially, 285 papers were reviewed manually, from which 9 were deemed relevant for this study. Subsequently, starting from these 9 papers, an additional 40 papers were identified through snowball searching. These 49 papers formed the basis for defining the search string. By our cutoff date, the keyword search yielded approximately 1,700 papers, of which over 1,420 were deemed irrelevant. Notably, many papers containing relevant keywords did not describe optimization problems and were consequently discarded.
- In total, 280 relevant publications were identified. Subsequently, these publications were scrutinized to extract crucial information regarding the optimization challenges they addressed. A taxonomy of primary optimization difficulties was developed based on the collected data. Simultaneously, each paper was categorized using this taxonomy. This process was iterative, starting from open coding and progressing towards the development of a comprehensive taxonomy. As the number of classified publications increased, adjustments to the taxonomy were made, necessitating the re-categorization of previously processed papers. Additionally, alongside the taxonomy of optimization problem variants, a glossary of different metrics utilized in the papers was created. This glossary was also employed for tagging the papers.

In the final step, the analysis was conducted on the detailed categorization of the papers to extract insights into the primary focuses of existing research.

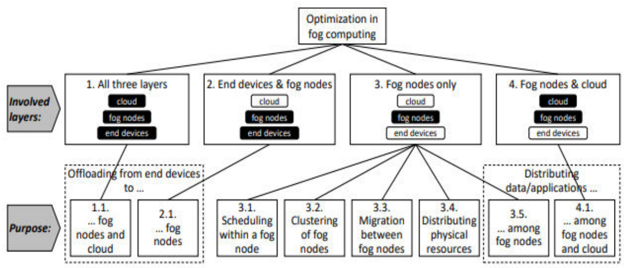

Figure 3: Taxonomy of optimization problems in fog computing

IV. CONCLUSION

Fog computing, a burgeoning technology, has emerged as a solution to address the challenges of executing Big Data IoT applications at the edge, where continuously generated data needs to be processed. While still in its nascent stages, this computing paradigm shows significant promise. However, numerous concerns require thorough examination. This study evaluates various existing Fog computing architectures to pinpoint research concerns related to executing Big Data applications using the Fog paradigm. A high-level Fog computing design is proposed, alongside an exploration of additional Fog computing architectures, highlighting their respective benefits. The limitations of cloud computing in executing Big Data applications, particularly in the IoT environment, are discussed, followed by an examination of the challenges associated with executing Big Data applications on Fog. Recent research endeavors focusing on executing Big Data applications on Fog are also reviewed. Additionally, the characteristics of current commercial Fog-related platforms and devices are examined. Finally, several open research issues are identified, intended to guide future research endeavors among both industry experts and academia.

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