A SURVEY OF DDS IMPLEMENTATION IN EDGE AND FOG COMPUTING

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Abstract – This survey investigates the application of the Data Distribution Service (DDS) within the domains of edge and fog computing architectures. DDS, a middleware architecture conceived by the Object Management Group (OMG), offers robust publish-subscribe functionalities characterized by low latency, high reliability, and scalability attributes, rendering it particularly suitable for real-time data dissemination in distributed systems. The paradigms of edge and fog computing, recognized for their capability to process data in proximity to its origin, leverage the functionalities of DDS to tackle issues such as latency minimization, bandwidth enhancement, and resource efficiency. The research meticulously evaluates the significance of DDS in facilitating scalable and reliable communication for applications spanning industrial automation, healthcare, and smart urban environments. It delineates pivotal implementation obstacles, including resource limitations, interoperability challenges, and security concerns within decentralized frameworks. Mitigation strategies such as lightweight DDS protocols, adaptive Quality of Service (QoS) policies, and artificial intelligence-driven optimizations are underscored to address these constraints. Employing PRISMA guidelines, a total of 16 peer-reviewed studies were scrutinized to respond to research inquiries centered on the role of DDS in edge and fog computing, associated technical hurdles, implications for QoS, and emergent trends. The results underscore the capacity of DDS to converge with cutting-edge tech-nologies such as 5G, blockchain, and digital twins, thereby influencing the evolution of intelligent distributed systems. This survey enhances the existing comprehension of DDS's transformative capabilities within contemporary computing architectures, offering valuable insights into best practices and prospective avenues for the optimization of edge and fog computing environments.

Keywords – Survey, DDS, edge computing, fog computing

I. INTRODUCTION

The DDS is a crucial middleware framework for edge and fog computing applications. It is a peer-to-peer and decentralized archi-tecture used for real-time data distribution. Because of its excellency DDS is suited for dynamic applications in asynchronous publish and subscribe communication. And offers a strong and powerful support for Quality-of-Service standards, in-cluding low latency, dependable communication, and data priorities. If the connec-tivity varies in some situations the DDS guarantees the effectiveness of scalable communication between distributed nodes in the context of fog and edge computing [1][2].

Edge computing is a paradigm shift that process data at the "edge" of the network close to end devices and users, instead of totally depending on the centralized cloud services. This method greatly lowers bandwidth and latency needs, which makes it especially useful for time-sensitive, real-time applications like smart grids and smart transportation. By dividing out computers and storage activities across edge nodes, edge computing reduces the computational and network strain on centralized systems and guarantees quicker reaction times and better Quality of Service (QoS) [3]. It also improves energy efficiency by shifting resource-intensive operations from de-vices with limited power to edge nodes with more capabilities. Typically, edge computing systems consist of a far-end with centralized cloud resources for jobs requiring a lot of processing power, a front-end with end devices, and a near-end with gateways or edge servers for data processing [4][5].

Fog computing allows for localized data processing using distributed and dis-persed fog nodes, in contrast to typical cloud computing, which entails sending enormous amounts of data to be centralized servers for analysis. By processing data closer to the source at the network edge, fog computing, an outgrowth of cloud computing, gets around the drawbacks of centralized architectures. If a quick reaction is needed and effective resource use since it minimizes latency, supports real-time applications and lowers energy consumption, this paradigm is appropriate for the situations [3][6].

Additionally, the study clarifies and emphasises how real-time data processing and distribution are made possible by the Object Management Group's Data Distribution Service, which greatly improves industrial performance when combined with edge and fog computing. DDS offers a strong publish and subscribe middleware that facilitates dependable and low-latency connectivity for the applications that are sensitive to latency and data. By using DDS in edge and fog environments, businesses can use local computing resources to process data closer to its source. This lowers the bandwidth and latency usage that come with transferring data to centralized cloud services. In addition to enabling quicker decision-making, this architecture enhances system scalability and dependability, meeting the intricate requirements of contemporary industrial applications in a variety of industries, including manufacturing, healthcare, and transportation [7].

The increasing demand for low-latency and effective data transfer in distributed systems is the driving force behind the survey on the use of DDS in fog and edge computing. Strong and powerful middleware solutions like DDS that can enable dependable data exchange among heterogeneous computers and devices are required because of the increased volume of generated data and the need for real-time processing. To improve system performance, scalability and in-teroperability, and ultimately help in the more efficient deployment of intelligent applications in resource-constrained environments [8][9].

According to the research, this survey will analyze DDS in the context of fog and edge computing to identify best practices, opportunities and Obstacles. Additionally, the DDS implementation survey for fog and edge computing aims to point out the important issues raised by these environments' decentralized structure, where conventional cloud-centric models might not be enough. This survey intends to point out and highlight methods for improving and enhancing latency, bandwidth efficiency, and fault tolerance by investigating how DDS can maximize data sharing and communication among computers and other devices at the edge. Furthermore, to advancing knowledge of DDS's function in contemporary computer architectures, this survey and investigation encourages creativity in creating robust and flexible systems that can satisfy the changing needs of a range of appli-cations, including industrial automation and smart cities.

II. SIGNIFICANCE OF THE STUDY

A. Literature Review

1. Data Distribution Service Overview

The DDS, as delineated by the Object Management Group (OMG), represents a middleware protocol that facilitates data-centric, publish-subscribe communication paradigms [12]. Conceived to support immediate communication within large-scale system infrastructures, DDS has grown into an essential technology for a multitude of notable distributed systems, covering sectors like industrial Internet of Things (IoT) and autonomous driving applications. Its architectural framework emphasizes the tenets of reliable communication, scalability, efficiency, and interoperability, thereby rendering it exceptionally competent for complex, distributed operational contexts [13].

DDS is meticulously structured to maintain stable communication within real-time domains, encompassing, but not limited to, IoT, smart grid configurations, and cyber-physical systems. It enables scalable, efficient, and location-independent interactions among multiple publishers and subscribers, thereby facilitating fluid data exchange mechanisms. Moreover, DDS enhances network interoperability among interconnected devices, enterprise systems, and mobile platforms, thus augmenting its relevance across a multitude of IoT scenarios [13].

A notable attribute of DDS is its provision for a comprehensive range of Quality of Service (QoS) policies, which are crucial for ensuring reliable and effective data distribution procedures. These policies span various dimensions, including security, prioritization, durability, and reliability, thereby permitting the development of tailored communication strategies [13]. DDS employs advanced discovery mechanisms that support the identification of network topologies and the establishment of connections directly between peers, thus obviating the need for a central server. A data-centric approach underpins its framework, fostering a universal data ecosystem that facilitates seamless machine-to-machine communication devoid of intermediaries. Additionally, DDS affords universal access to information across diverse hardware and software architectures and networks, illustrating its adaptability to dynamic environmental conditions.

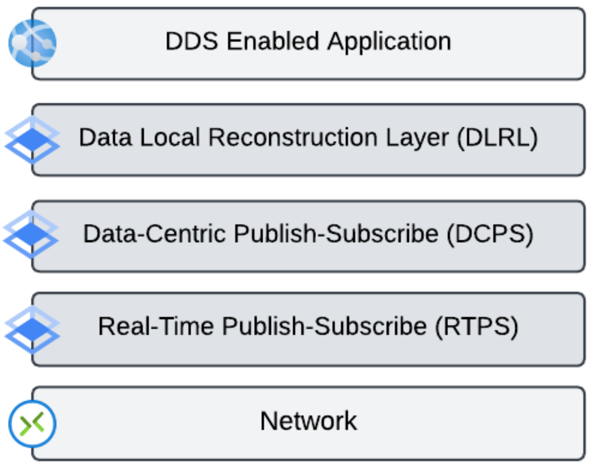

Figure 1 Distinction of layer in DDS Model

The OMG articulates the architecture of DDS as comprising three distinct layers. Figure 1 illustrates the layers of DDS [14]:

1. Data Local Reconstruction Layer (DLRL)
   This optional upper layer specifies the manner in which applications ought to interact with the Data-Centric Publish-Subscribe (DCPS) layer. It provides an object-oriented abstraction, enabling developers to engage with data as localized objects, thereby optimizing the application development process.
2. Data-Centric Publish-Subscribe (DCPS)
   As the foundational and mandatory layer of DDS, DCPS facilitates communication among DDS entities. It orchestrates the efficient transmission of data from publishers to subscribers, ensuring that relevant information reaches the appropriate recipients within a specified temporal framework.
3. Real-Time Publish-Subscribe (RTPS)
   Positioned beneath DCPS, RTPS serves as the wire protocol that enables interoperability across various DDS implementations. It ensures that products from different DDS vendors can communicate seamlessly, thereby promoting a standardized approach to data exchange within real-time systems.

In the DCPS paradigm, communication is systematically structured around data domains, which delineate the parameters for data interchange between publishers and subscribers. The principal entities encompassed within this framework include [14]:

1. Domain Participant: Functions as the application's conduit to a particular data domain and operates as a repository for all pertinent DCPS entities.
2. Data Writer: Facilitates an application's capability to disseminate data by interfacing with the publisher.
3. Publisher: Oversees the distribution of data and may be associated with multiple data writers as delineated by the application's requirements.
4. Data Reader: Empowers an application to retrieve subscribed data through its interaction with the subscriber.
5. Subscriber: Manages the acquisition of data from publishers and may be linked to numerous data readers as designated by the application's specifications.
6. Topic: Characterizes a data object by its nomenclature and type. Effective communication necessitates that the topics utilized by both publishers and subscribers are congruent. A singular topic may be associated with multiple publishers and subscribers.
7. QoS Policy: Functions as the essential component for delineating Quality of Service parameters to govern various dimensions of DDS behavior. DDS proffers 22 distinct QoS policies to promote dependable communication.

The DDS represents a multifaceted middleware protocol that enables real-time data interchange across diverse domains [15][16][17][18]. Its applications encompass:

1. Industrial IoT: It is widely employed within industrial environments to ensure reliable and efficient data communication.
2. Autonomous Systems: DDS accommodates extensively distributed applications, including autonomous vehicular systems and smart city infrastructures.
3. Mission-Critical Systems: Its capabilities for universal accessibility and prioritized data transmission render DDS appropriate for mission-critical systems.
4. Edge and Fog Computing: DDS integrates with fog computing architectures to facilitate near-sensor analytics and decentralized data processing, thereby augmenting performance in edge computing contexts.

2. Edge and Fog Computing Overview

Edge computing facilitates the proximity of data processing and storage to the data sources, typically situated at the periphery of the network—such as gateways, routers, or end-user devices [19]. By strategically positioning nodes in close proximity to sensors, edge computing significantly reduces bandwidth consumption and minimizes data transmission durations. This strategy promotes minimal delay, as handling data locally lessens the common hold-ups seen in cloud services, which makes it particularly advantageous for instant applications like intelligent health care frameworks and autonomous driving systems. Moreover, edge computing fosters mobility and dynamic location-based services, which are especially advantageous for mobile devices and applications.

Edge computing finds extensive application across various domains. In the area of progressive urban planning, it provides live traffic oversight, refined energy distribution systems, and upgraded public safety protocols [20]. Within the healthcare sector, it enables the instantaneous processing of critical patient data imperative for urgent diagnostics [21]. In parallel, in the area of industrial Internet of Things (IoT), it maintains a significant role in the instant supervision and regulation of manufacturing tasks [22]. Notwithstanding its benefits, edge computing encounters challenges including the necessity for compatibility among diverse devices, the imperative of safeguarding security and privacy for sensitive data, and the efficient management of resources and tasks [23].

Fog computing expands upon the foundational concepts of edge computing by establishing a connection between edge devices and the cloud, introducing intermediary layers that enhance data processing and analytical capabilities. Fog computing features a distributed design, in which fog nodes engage in processing activities near data origins, all while preserving a connection to the cloud [24]. This paradigm ensures scalability by accommodating a broad spectrum of devices and applications, ranging from local sensors to global networks, while bolstering security by diminishing exposure to external threats through localized processing.

Fog computing is also employed across an array of sectors. In smart homes, it enhances automation through the facilitation of localized decision-making processes. Regarding self-navigating cars, it strengthens the dialogue among vehicles, ultimately aiding in achieving safer driving results [24]. In the agricultural sector, it supports precision farming initiatives through real-time analytics of soil and meteorological data [25]. However, fog computing struggles with difficulties including ensuring energy efficiency in resource-limited devices, the unavailability of common protocols for the combination of fog and edge devices, and the vital necessity for seamless teamwork among cloud, fog, and edge layers [24].

While both paradigms aim to enhance IoT performance by reducing reliance on centralized cloud systems, they have distinct characteristics as described in table I.

TABLE I COMPARISON OF EDGE AND FOG COMPUTING

Aspect	**Edge Computing**	**Fog Computing**
Architecture	Decentralized, near data sources	Hierarchical, between edge and cloud
Scalability	Limited to local devices	Highly scalable through distributed nodes
Security	Enhanced through local data handling	Strong with intermediate layers and localized processing
Latency	Very Low	Moderate

B. Methodology

This survey used Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a set of guidelines to enhance the report of systematic reviews and meta-analyses [10]. PRISMA guidelines are pervasively utilized to reduce potential bias and improve the rigor and cutability of systematic reviews and meta-analyses.

Specific keywords related to Data Distribution Service, fog computing, and edge computing were sent via a literature search in the databases Scopus and Web of Science (WoS). The search terms used were "Data distribution service," "DDS," "fog computing," and "Edge computing," applied to the TITLE-ABS-KEY fields. The query, structured with Boolean operators, was TITLE-ABS-KEY ("Data distribution service") OR TITLE-ABS-KEY("DDS") AND TITLE-ABS-KEY ("fog computing") OR TITLE-ABS-KEY ("Edge computing"). This query obtained a total of 65 records (42 from Scopus and 23 from WoS), without records from other registers. After removing 12 duplicate records, 53 unique records were assessed at the screening stage.

In the next step, we set specific inclusion and exclusion criteria to ensure the selected literature was relevant, reliable, and focused. These criteria were established to aid the selection process by eliminating studies that do not substantially contribute to understanding DDS's role in edge computing within the scope of the research goals. To define the papers to be added to this survey, we followed the inclusion items shown in Table II [11]. To be included in the survey pool, a publication had to meet all of these criteria. The Attribute column names the properties considered for inclusion, and the Description column explains what it means for an attribute to be included.

The exclusion criteria, therefore, excluded studies meeting one or more of these conditions, as summarized in Table III [11]. The Serial Number column provides a concise reference, the Attribute column specifies the attributes associated with exclusion, the Description column describes the conditions that may prevent a study from being eligible, and the last column shows how many papers were excluded due to each given criterion.

TABLE II INCLUTION CRITERIA

SN	Attribute	Description
1	Relevance	Papers should be directly oriented towards DDS, middleware technologies, frameworks, or their application areas within the edge and fog computing context.
2	Focus	All papers should focus on or discuss the use of DDS in edge computing, including their challenges, opportunities, and impacts
3	Publication Type	Include peer-reviewed journal articles, conference papers, and technical reports that provide substantial technical insights into DDS and edge computing.
4	Recency	Preferably include papers from the last decade to ensure the data represents up-to-date research directions in DDS and edge computing.
5	Diversity	Consider articles from different geographic areas and viewpoints to provide a holistic picture of DDS use in diverse edge computing models.

TABLE III EXCLUSION CRITERIA

SN	Attribute	Criteria›	# Excluded
1	Focus	Exclude papers focusing on DDS applications outside edge and fog computing, such as traditional cloud computing or enterprise-only environments.	3
2	Language	Exclude papers published in languages other than English due to accessibility and consistency in interpretation.	1
3	Sources	Exclude non-peer-reviewed sources like blogs, opinion pieces, and non-technical reports to maintain academic rigor.	3
4	Duplicates	Remove duplicate publications or similar studies with substantial overlap in content to ensure a diverse range of studies.	12
5	Type	Exclude non-technical papers or those lacking significant detail on DDS architecture or implementation within edge and fog computing contexts.	0

As the screening process got underway, a preliminary evaluation of titles and abstracts led to the rejection of four records, deemed unrelated to the study's aims. The remaining 49 reports underwent scrutiny for full-text retrieval; however, access to two of these reports was not attainable. Consequently, 47 reports were subjected to a comprehensive eligibility assessment predicated on both inclusion and exclusion criteria, with particular emphasis on the pertinence of DDS, its association with fog or edge computing, and the methodological rigour exhibited. In this evaluative phase, 31 reports were excluded: two based on their titles, 21 based on abstracts, and eight subsequent to a thorough full-text review. Ultimately, 16 studies satisfied all eligibility criteria and were thus incorporated into the final analysis. Figure 2 presents a PRISMA flow diagram that encapsulates this screening process, elucidating each stage along with the rationale for exclusions. This methodological framework provides a transparent, systematic, and replicable strategy for identifying high-quality studies pertinent to DDS within the contexts of fog and edge computing environments.

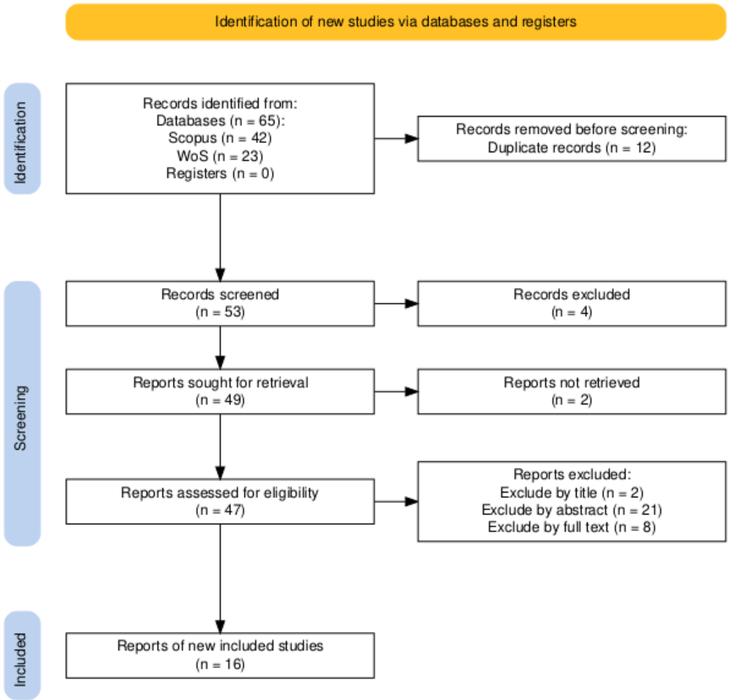

Figure 2. PRISMA data flow diagram for this survey

To facilitate a thorough examination of the literature, we employed an extraction table meticulously constructed in alignment with the research questions delineated in Table IV. This table served the purpose of systematically collating and categorizing pertinent information from each study, concentrating on the specific dimensions of DDS applications within edge and fog computing as delineated by the research inquiries.

For RQ1, we gathered data concerning the multifaceted applications and functions of DDS in edge and fog architectures, encompassing both practical implementations and research prototypes. For RQ2, the emphasis was placed on discerning critical technical and operational challenges encountered during the implementation of DDS in these environments, alongside the strategies employed to mitigate these challenges. RQ3 directed the extraction of information regarding Quality of Service (QoS) policies, examining their implications for data distribution performance, latency, and reliability within distributed systems. Finally, RQ4 facilitated the collection of insights pertaining to emerging trends and prospective trajectories, including advancements in security, scalability, and interoperability that may shape the future evolution of DDS in edge and fog computing. This methodical approach enabled a comprehensive synthesis of the extant literature, yielding a lucid and concentrated understanding of the current landscape and prospective developments of DDS in distributed computing environments.

TABLE IV RESEARCH QUESTIONS

SN	Research Question	Remarks
1	What is the role of Data Distribution Service (DDS) within the frameworks of edge and fog computing architectures?	What is the role of Data Distribution Service (DDS) within the frameworks of edge and fog computing architectures?
2	What significant hurdles and limitations are encountered during the deployment of DDS in edge and fog computing, and which approaches are presently being utilized to tackle these hurdles?	To elucidate the fundamental technical and operational impediments to DDS deployment in edge environments, along with the strategies currently in place for their mitigation.
3	In what ways do Quality of Service (QoS) policies in DDS affect the performance and	To conduct an analysis of how varying QoS configurations impact data transmission efficiency,

	reliability of data distribution within edge and fog computing environments?	latency, and reliability in DDS-driven edge computing scenarios.
4	What are the emerging trends and prospective trajectories for DDS in edge and fog computing, particularly concerning advancements in security, scalability, and interoperability?	To investigate recent advancements and identify potential avenues for future research and enhancements in the application of DDS within edge and fog computing contexts.

III. RESULT AND DISCUSSION

A. DDS Implementation in Edge and Fog Computing

In edge and fog computing architectures, the DDS is a vital communication enabler that makes it possible for data to be dispersed across distributed systems in an effective, real-time, and scalable manner. Devices at the edge and fog nodes can exchange data with low latency and great throughput thanks to DDS's widespread use in these situations for real-time data transfer [8]. DDS, for example, is frequently used in Internet of Things applications to manage sensor data streams, facilitating quick decision-making near the data source. DDS links devices and sensors into fog nodes for industrial automation, facilitating operational effectiveness and predictive maintenance. In a similar vein, DDS ensures smooth operation in autonomous systems by facilitating communication between sensors, actuators, and control systems [8].

Additionally, DDS has crucial features that make it ideal for fog and edge computing. By transmitting data only when events occur, its publish/subscribe architecture minimizes communication overhead and maximizes bandwidth use in contexts with limited resources. By providing fine-grained control over communication factors including data priority, latency, and reliability, DDS's QoS policies guarantee that a variety of application needs are satisfied [7]. Additionally, DDS improves distributed systems' scalability and stability by functioning decentralised, doing away with the necessity for a central broker. DDS guarantees smooth integration across diverse devices and systems by facilitating dynamic discovery and interoperability using defined protocols such as DDS-RTPS. Along with these features, DDS is useful for transportation and smart city applications, facilitating real-time data sharing between fog nodes and edge sensors for environmental monitoring and traffic control. Like this, DDS is utilized in the healthcare industry to aggregate and analyze data from medical equipment in real-time, offering crucial fog layer insights. DDS is a key element of edge and fog computing architectures, fostering creativity and efficiency in contemporary distributed systems with its scalability, resilience to faults, and capacity to manage dynamic situations.

B. Challenges and Limitations of Implementing DDS in Edge and Fog Computing

The scattered nature of edge and fog computing systems, resource limitations, and a variety of application requirements make it difficult to implement DDS in these architectures. The resource limitations of edge and fog devices, which frequently have constrained CPU, memory, and power, are one important drawback. This may make it more difficult to implement DDS, especially for applications that require a lot of resources. Lightweight DDS im-plementations, such as Micro XRCE-DDS, have been created in response to this issue, allowing DDS to function well on devices with limitations [26]. Resource consumption can also be decreased by optimizing DDS configurations by utilizing just necessary features and customized QoS settings.
Another major issue is scalability, since controlling communication among numerous nodes in edge and fog environments can result in resource contention and excessive network traffic [27]. By filtering and prioritizing data flows through its peer-to-peer architecture and partitioning techniques, DDS lessens this. Additionally, dynamic discovery techniques are being improved for big de-ployments in order to reduce overhead and improve scalability. Similar to this, network lag and device malfunctions can make it challenging to support real-time limitations. In order to achieve

strict latency requirements, DDS uses improved transport protocols like the RTP in addition to QoS parameters including latency budget, deadline, and priority settings. Interoperability issues arise from the heterogeneity of systems and devices in edge and fog environments. With the OMG DDS-RTPS protocol, which guarantees cross-platform compatibility, DDS gets around this. Non-DDS systems are also integrated via protocol converters and middleware bridging solutions. Another significant drawback is security and privacy issues, since DDS must manage private information safely in decentralized settings vulnerable to hackers [28]. Strong security features like authentication, encryption, access control, and secure data logging are all included of DDS to mitigate these threats. Lightweight encryption designed for devices with limited resources is also included.

Consistent communication is further complicated in dynamic and unstable contexts where nodes join or depart the network regularly. With characteristics like durability, liveliness monitoring, and transient data persistence, as well as adaptive QoS setups to manage changes in network conditions, DDS guarantees resilience. However, because it necessitates meticulous adjustment of QoS settings and network configurations, setting up and maintaining DDS can be challenging, especially for large-scale implementations. This process is made simpler by tools like the RTI Admin Console and automatic QoS tuning systems, and new AI-driven solutions are being investigated to make dynamic predictions about the best setups. Lastly, the price of commercial DDS deployments may be a deterrent, especially for large-scale deployments or smaller enterprises. Open-source substitutes that follow DDS standards, including Cyclone DDS and Fast DDS, offer affordable solutions. DDS is becoming more useful and potent for edge and fog computing applications as a result of ongoing research on edge-optimised DDS protocols, AI-driven network optimization, hybrid architectures, and improved interoperability standards.

C. QoS of DDS in Edge and Fog Computing

In edge and fog computing settings, the DDS's QoS regulations play a key role in maximizing the performance and dependability of data distribution. By providing fine-grained control over data transmission across dispersed nodes, these policies guarantee that the system's latency, dependability, and resource efficiency needs are satisfied. For instance, QoS policies like Latency Budget enable developers to define acceptable time limits for data delivery in latency-sensitive applications like industrial automation or driverless cars, guaranteeing timely replies even in the face of constraints [29]. In edge and fog architectures, where effective data flow frequently determines real-time decision-making, this degree of control is essential.

Another crucial component of DDS QoS regulations is reliability, especially in dynamic and resource-constrained settings. The Reliability QoS policy has two modes: Reliable, which guarantees delivery and is perfect for mission-critical applications like healthcare monitoring or fault detection in industrial systems, and Best Effort, which is appropriate for non-critical data where occasional loss is acceptable. Furthermore, by keeping messages for late-joining nodes, the Durability QoS policy guarantees data permanence and supports robustness in situations where nodes connect and disengage often, as is typical in edge and fog networks[29]. In DDS implementations, QoS regulations also improve resource efficiency and scalability. By limiting memory use when only the most recent data is required or allowing for more thorough analysis by keeping longer histories, the History policy, for example, controls how much data is saved for subscribers. In a similar vein, the Partition QoS policy permits logical data stream segmentation, reducing superfluous traffic and guaranteeing that only pertinent nodes receive certain data [29]. These characteristics are especially helpful in settings with limited bandwidth, such as edge and fog computing, where resource efficiency is crucial. In edge and fog computing, DDS offers a dependable and adaptable architecture for data delivery by customizing communication characteristics via QoS regulations. By balancing trade-offs between latency, dependability, and resource consumption, it guarantees that system performance complies with application-specific criteria. Because of its versatility, DDS is a strong option for meeting the many needs of contemporary distributed systems.

D. Trends and Future Direction of DDS

With developments in security, scalability, and interoperability influencing its future, the Data Distribution Service (DDS) is set to undergo a substantial transformation in edge and fog computing. Security continues to be a primary concern as these infrastructures get more complicated. Adaptive security frameworks designed for edge devices with limited resources and the incorporation of lightweight encryption techniques are examples of emerging concepts. To protect sensitive data in decentralized systems, improved support for role-based access control, dynamic trust management, and end-to-end encryption is being developed [1]. Post-quantum cryptography is one of the innovations being investigated to future-proof DDS against new cybersecurity threats. DDS is developing in terms of scalability to accommodate the exponential expansion of fog and edge devices. To handle the increased burden of large-scale systems, improved partitioning techniques, peer-to-peer communication, and dynamic discovery protocols are being developed [1]. Furthermore, edge-native DDS implementations are becoming more popular; these are made especially to function well on limited devices without sacrificing scalability. Another exciting area is integration with AI-driven network optimization, in which machine learning models forecast and modify DDS setups to dynamically balance resource usage and performance.

As edge and fog systems incorporate a wide variety of devices, platforms, and protocols, interoperability is becoming more and more important. Future advancements in DDS will concentrate on improving interoperability with other communication protocols, such as MQTT, CoAP, and AMQP, in order to expand support for heterogeneous ecosystems. In order to facilitate smooth cross-domain integration, standardization initiatives are also growing to encompass more extensive IoT and industrial automation protocols. In order to promote a single foundation for communication, middleware solutions are being improved to serve as links between DDS and non-DDS systems. The adoption of hybrid architectures, which integrate DDS with other technologies to meet certain use cases in edge and fog computing, is another new trend. For instance, DDS might be merged with 5G and beyond to take advantage of ultra-low-latency connectivity, or it could be combined with blockchain for safe data provenance. Furthermore, because DDS enables real-time data synchronization for virtual clones of physical systems in edge and fog environments, developments in digital twins are propelling its use [30][31]. Energy-efficient algorithms are anticipated to be incorporated into DDS in the future to correspond with the increasing focus on sustainability in computing. DDS will continue to develop as a pillar of dependable and scalable communication in edge and fog computing by utilizing AI, edge-specific protocols, and optimum QoS setups, opening the door for next-generation applications across a variety of industries.

IV. CONCLUSIONS

This research has taken a systematic look at the role of DDS within the edge and fog computing states and their characteristics. It clearly demonstrates how DDS can also enable us to achieve low-latency, reliable and scalable communications. Results emphasize on how critical DDS is for optimal utilization of resources, improvement of QoS and the ability to make decisions on the fly in a changing environment DDSS implemented at the edge of the network has been in the recent years getting focus for many services because it's able to alleviate issues of latency, bandwidth, fault tolerance and heterogeneity But there are signs of weakness Adoption is fraught with issues such as the constraints of resources availability on edge devices, security issues and the need to translate DDS to commercial deployments.

Innovations such as lightweight DDS, adaptive QoS methods or AI together with 5G show a bright future of DDS in these systems. One of the critical areas of research and development will be e-commerce and content delivery. Future opportunities will help DDS Further research is required in these areas, as research stops there are no commercial deployments – while working with DL, many extreme learning machine-based algorithms can solve various problems based on image recognition including: feature extraction and pattern recognition for real-time smart systems using fog computing architectures in smart cities. Although fog computing-based smart cities is a virtually untouched area for industrial development, these systems mark an important evolutionary step in many domains, including the computing paradigm, algorithms, and structures frequently used in computing systems.

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