

Data Dissemination Techniques for Internet of Things Applications: Research Challenges and Opportunities

Halikul bin Lenando, Sanjay Charles Albert ^{*}, Mohamad Alrfaay [†]

Abstract. The escalating prevalence of Internet of Things (IoT) devices has necessitated efficient data dissemination methods to optimize the unprecedented volume of generated data. The rapid expansion of IoT devices and the resulting surge in data creation underscore the necessity for advanced data dissemination methods. A noticeable gap in existing literature prompts a critical review, specifically addressing challenges and opportunities in IoT data dissemination techniques. This paper aims to categorize and analyze existing data dissemination techniques, highlighting their strengths and limitations. Additionally, it explores emerging opportunities and innovations that can shape the future of IoT applications. Furthermore, the discussion addresses challenges in data dissemination and explores innovative solutions, including machine learning, AI-based strategies, edge, and fog computing, blockchain integration, and advanced 5G/6G networks. The hope is that this study sets the stage for innovative ideas contributing to the efficiency and robustness of IoT applications, informing future endeavours in this dynamic and evolving landscape.

Keywords: Internet of Things, data dissemination, challenges, opportunities, innovation

1. Introduction

The Internet of Things (IoT) has emerged as a transformative technological paradigm, facilitating the interconnection of various smart devices, objects, and systems through the Internet. According to the National Intelligence Council (NIC) of the United States, "by 2025, IoT may be embedded in everything, such as plants, food packets, vehicles, furniture, and so on" [19]. This notion is supported by Shahab's studies stating that the estimated number of IoT devices is expected to reach approximately 25.1 billion, enhancing machine

^{*} Department of Computer Systems and Communication Technologies, Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, 94300, Malaysia

[†] Institute of Mustaqbal University, Buraidah Al Qassim, Saudi Arabia

intelligence, processing, communication, and fostering productivity and interconnectivity [66]. The Internet of Things (IoT) connects physical and virtual objects through sensors, software, and other technologies, allowing for global data communication and sharing. It has become pervasive and interactive, modifying physical objects into smart ones, and creating an information-rich environment that is changing human living standards.

Efficient data dissemination plays a key role in IoT applications, significantly impacting decision-making, resource utilization, and operational efficiency [31]. The ubiquity of data sharing across IoT devices raises concerns, necessitating exploring the efficacy and challenges associated with such dissemination. In the realm of healthcare, the real-time dissemination of patient health data fosters collaboration and coordination among stakeholders, thereby promoting more effective and personalized treatment strategies [22][41]. Similarly, within the industrial sector, smart factories leverage data dissemination to optimize machinery and equipment usage, resulting in heightened productivity, safety, and security [6][33][78]. Nevertheless, addressing challenges such as scalability, data security, privacy, bandwidth utilization, and energy efficiency is imperative to ensure the effectiveness of data dissemination [15].

Data security and privacy stand as paramount concerns in the landscape of IoT applications, particularly when transmitting sensitive information between devices [15]. The vulnerability of such data to breaches underscores the need for robust safeguards and encryption protocols to ensure the integrity and confidentiality of information. As IoT ecosystems grow, the optimization of data dissemination gains prominence, emphasizing the judicious use of bandwidth to mitigate delays, prevent congestion, and uphold reliable communication standards [82]. Balancing the imperatives of efficient data flow with the imperative to protect against security threats becomes pivotal in shaping the sustainable and secure future of IoT technologies.

Effectively managing the scalability of data dissemination emerges as a critical imperative within IoT environments, especially with the burgeoning number of connected devices [67]. As the IoT ecosystem expands, the challenge lies in orchestrating a seamless data flow that accommodates the growing network of devices. Achieving efficient and adaptable data dissemination becomes essential, prompting the need for a nuanced exploration of strategies tailored to specific use cases. Innovations geared towards robust techniques play a pivotal role in addressing the scalability issue, ensuring IoT applications can handle the escalating demands imposed by an increasing array of interconnected devices.

This paper targets efficient and adaptable data dissemination in IoT applications. It investigates existing techniques, emphasizing potential innovations for further research. Presenting multiple studies on IoT data dissemination techniques, it addresses challenges and opportunities in the domain. The aim is to enhance the efficiency of data dissemination, offering a concise exploration of current techniques, challenges, and opportunities to propel innovative research and advance strategies for effective data dissemination in IoT applications.

The contributions of this paper include:

- Providing insights into the strengths and limitations of current data dissemination techniques for IoT applications through a thorough literature review.
- Highlighting key challenges and opportunities that shape data dissemination in IoT applications.
- Presenting novel techniques and emerging opportunities to advance efficient data dissemination in the IoT context.

The rest of this paper is organized as follows: we review the adaptation of data dissemination techniques in Internet of Things applications as described in Section 2. Addressing the challenges and opportunities faced in data dissemination is described in Section 3. Then, we explore the innovative techniques and emerging opportunities described in Section 4 and conclude this work in Section 5

2. Data dissemination techniques on the Internet of Things

Disseminating data effectively is crucial in IoT to manage and utilize immersive data. It also facilitates real-time monitoring, energy conservation, and decision-making by enabling efficient communication and data transmission between IoT devices. In addition, it ensures secure and effective data transmission while addressing connectivity, security, and privacy challenges in IoT networks. In this section, various data dissemination techniques currently employed in IoT applications are presented with general ideas, advantages, and examples of works that used the technique in IoT. The techniques that will be covered in this section include publish-subscribe, content-based, location-based, cluster-based, secure-based, and hybrid-based, as illustrated in Figure 1. We evaluated each technique by examining its strengths and limitations, as shown in Table 1.

Data Dissemination Techniques in Internet of Things					
Publish-Subscribe	Content-Based	Location-Based	Cluster-Based	Secure-Based	Hybrid-Based
1. Decentralized Lightweight Group Key Management architecture for Access Control (DLGKM-AC) 2. GeoBroker 3. Edge cloud pub/sub broker	1. Hierarchical Partitioning 2. Dynamic Behavior and Collaborative Prediction (DBCNPf) algorithm 3. Content dissemination technique for NDN-based cloud and mobile IoT nodes 4. Traffic priority-aware Medical Data Dissemination (TPMD2) scheme	1. Installation & data propagation mechanism using mobile-edge servers 2. NDN-based Geographic Interest Forwarding scheme (GIF) 3. Vehicular sensor networks using delay tolerant network 4. Fishbone forwarding (FiFo)	1. Cluster head rotation joint mobile vehicle data collection (CHR) scheme 2. Fixed-Parameter Tractable Approximation Clustering (FPTAC) protocol 3. Cluster-Based Routing Protocol with Static Hub (CRPSH) 4. Adaptive adjustment strategy based on capability weight for multi-layer clustering network 5. Power-efficient compressive data fusion and cluster-based multi-hop relay-assisted protocol (PECDF-CMRP)	1.Authentication-based Medium Access Control (A-MAC) protocol 2. Robust and Trusted scheme (RTS) 3. Lightweight and secure redactable signature scheme 4. Adaptive data dissemination scheme with trajectory privacy protection (ADDTp)	1. Merged routing strategy 2. Hybrid transmission scheme 3. ACO-AODV routing protocol 4. Routing based on the Tree and Geographic (RTG) protocol 5. Hybrid DTN routing protocol (HDRP)

Figure 1. Data dissemination techniques classifications

Table 1. Strengths and limitations of the proposed dissemination techniques

	Authors	Techniques	Strengths	Limitations
Publish-Subscribe Technique	Dammak et al.,2020	Decentralized Lightweight Group Key Management architecture for Access Control (DLGKM-AC)	Capable of handling the extensive scaling issue of large IoT devices and a larger number of subscribers.	IoT devices may possess constrained computational capabilities and memory space.
	Hasenburg & Bermbach,2020	GeoBroker	Boost packet delivery and throughput.	Maintaining the tree structure is difficult in highly mobile environments.
	Pham et al.,2020	Edge cloud pub/sub broker	Support large-scale data delivery for latency sensitive IoT applications.	The topic overlay network requires more resources when dealing with multiple topics and low topic similarities between pub/sub brokers.
Content-Based Technique	Kumar & Tiwari, 2023	Hierarchical Partitioning	Suitable for IoT systems with CCN for making optimal decisions on content placement.	Additional assessment requires to evaluate the scalability and adaptability of this technique.
	Yu et al.,2023	Dynamic Behavior and Collaborative Prediction (DBCPRF) algorithm	Uses of historical user behaviour and content attributes improve delay, overhead and delivery performances.	Further exploration is recommended to assess the algorithm's performance with diverse content types and attributes.
	Ayaz et al., 2022	Content dissemination technique for NDN-based cloud and mobile IoT nodes	Uses of data flow prioritization improves the processing time.	Additional assessment required for performance comparison with more than one benchmark.
	Anwar et al.,2022	Traffic priority-aware Medical Data Dissemination (TPMD2) scheme	Prioritizing data packets by sensitivity improves packet delivery, transmission delay, and energy efficiency.	Unassessed overhead rate.

Location-based technique	Shu et al.,2019	Installation & data propagation mechanism using mobile-edge servers	Uses both mechanisms have assure data object integrity and avoid transmission conflicts.	Significant amount of time is consumed when the mobile edge server' s travers before the
	Aboud et al.,2019	NDN-based Geographic Interest Forwarding scheme (GIF)	Supports push-based traffic and forwarding methods to balance network energy consumption.	Only suitable for dense networks with high-traffic network.
	Naseer et al.,2021	Vehicular sensor networks using delay tolerant network	Uses a Smart City Taxi Trajectory Coverage and Capacity Evaluation Model for data distribution.	Experimental dataset limited to Beijing.
	Seong et al.,2022	Fishbone forwarding (FiFo)	Improve forwarding efficiency in vast IoT networks, which can transmit emergency and disaster messages.	Only evaluates forwarding efficiency performances.
	Luo et al.,2019	Cluster head rotation joint mobile vehicle data collection (CHR) scheme	Collect data from decentralized WSNs with good energy usage and network lifetime.	Simulation performance with only four vehicles. In a smart city, the result may be altered by hectic transportation.
Cluster-based technique	Yarinezhad & Sabaei,2021	Fixed-Parameter Tractable Approximation Clustering (FPTAC) protocol	Uses clustering and an energy-aware routing technique to balance cluster head traffic.	Fixed-Parameter Tractable Approximation Clustering limit to approximation method.
	Lenka et al.,2022	Cluster-Based Routing Protocol with Static Hub (CRPSH)	Clustering and multipath minimize network load and improve data transmission.	Suffers from hotspot problems.
	X. Liu et al.,2022	Adaptive adjustment strategy based on capability weight for multi-layer clustering network	Node capability weight reduces energy usage, extends network longevity, and improves load balancing.	The proposed technique may work depending on network topology and node capabilities.
	Agbulu et al.,2022	Power-efficient compressive data fusion and cluster-based multi-hop relay-assisted protocol (PECDF-CMRP)	Uses wavelet-based data fusion and multi-hop relaying to minimize network traffic and boost energy-saving and delivery rates.	The proposed protocol may not work for all IoT sensor networks due to their varying requirements and limits.

Secure-based technique	N. Gupta et al.,2020	Authentication-based Medium Access Control (A-MAC) protocol	Communication, execution, storage, and overhead are reduced.	Further assessment in evaluating the scalability and applicability of the suggested protocol and framework in real-world contexts.
	Haseeb et al.,2020	Robust and Trusted scheme (RTS)	Improves data delivery ratios, network throughput, packet loss, latency, computational overhead, and energy efficiency.	Generates and distributes public-private keys between mesh devices, incurring network expenses.
	J. Liu et al.,2022	Lightweight and secure redactable signature scheme	Improves communication, computation, and security.	Scalability and interoperability issues.
	Xia et al.,2022	Adaptive data dissemination scheme with trajectory privacy protection (ADDTTP)	Leverages cooperative allocation of essential jobs and distance deviation to increase network connectivity, transmission delay, and average distance deviation.	Simulations determine evaluation, therefore real-world performance may vary.
Hybrid-based technique	C. M. Huang et al.,2019	Merged routing strategy	Boost packet delivery and throughput.	Maintenance of the tree structure is challenging in high mobility.
	J. Zhang et al.,2019	Hybrid transmission scheme	Improves energy consumption, latency, and reliability.	Further analysis needed to enhance energy consumption, delay, and reliability of specific parameter influences and relations.
	Safavat & Rawat,2021	ACO-AODV routing protocol	Uses modified ECC improves security and privacy.	Data distribution may be hampered in high-traffic circumstances if network congestion is not anticipated.
	Yarinezhad & Azizi,2021	Routing based on the Tree and Geographic (RTG) protocol	Uses combination methods boost dependability and energy efficiency.	In practice, network nodes may not generate data at uniform rates or utilize identical sensing energy.
	Tekouabou et al.,2021	Hybrid DTN routing protocol (HDRP)	Balancing energy usages.	The overhead rate increases with buffer size and TTL.

2.1 Publish-Subscribe technique

The Publish/Subscribe (PS) technique enables efficient data dissemination to facilitate communication and device coordination in IoT. The model operates on the principle of centralized communication with the broker, but some implementations try to decentralize the communication to avoid the overload of a single broker. It allows IoT devices to publish data and subscribe to specific topics, ensuring that they receive only necessary data or updated data, thereby reducing the amount of unnecessary information transmitted. With the support of scalability and flexible communication, it ensures that data is disseminated to the actual devices in a timely and reliable manner. In general, the PS model can be denoted as $\{(p,s) \mid p \in P, s \in S\}$ where the (p,s) represents that p is an element of the set of publishers P and s is an element of the set of subscribers S , implying that any publisher p can transmit data to any subscriber s , as illustrated in Figure 2.

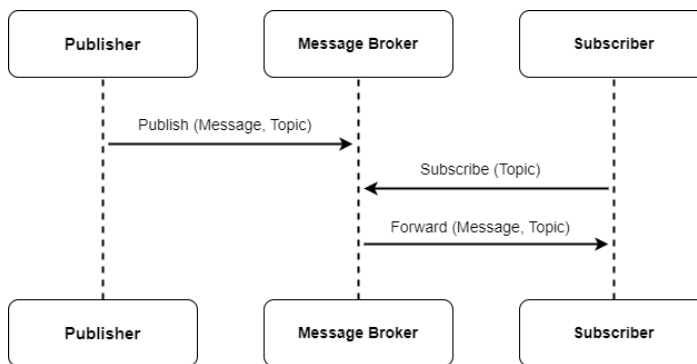


Figure 2. General model of Publish-Subscribe technique.

PS technique epitomizes flexibility in information distribution within IoT ecosystems. Publishers (P) employ a broadcast mechanism, delivering data to a diverse set of subscribers (S). This ensures timely and personalized information dissemination. The model optimizes information flow in the intricate network, fostering efficient communication. Thus, this optimization contributes to the advancement of green technology in IoT, emphasizing resource efficiency and sustainability. The PS model is also able to customize information delivery enhancing the overall functionality of IoT systems.

By delivering data exclusively to interested subscribers, the PS technique minimizes network congestion in the IoT ecosystem. This selective distribution enhances network efficiency, conserves bandwidth, and ensures that communication resources are utilized optimally, making it particularly advantageous in the context of the burgeoning IoT landscape. Moreover, prioritizing relevant recipients in PS not only alleviates congestion but also enhances overall system performance. This efficiency is crucial for supporting the growing number of devices connected to the Internet of Things ecosystem, facilitating better resource allocation and communication.

Examples of studies adopting publish and subscribe techniques:

Current access control schemes in IoT, primarily centralized and grounded in Group Key Management (GKM), grapple with the scalability challenge posed by the extensive scale of

IoT devices and the dynamic behavior of subscribers [18]. In response, the author introduces a groundbreaking Decentralized Lightweight Group Key Management architecture for Access Control in the IoT (DLGKM-AC), incorporating elements of publish/subscribe techniques. This hierarchical model, featuring a Key Distribution Center (KDC) and Sub Key Distribution Centers (SKDCs), optimizes subscriber group management, reducing rekeying overhead on the KDC. Simulation results demonstrate significant resource gains, spanning storage, computation, and communication overheads. From this study, it is shown that utilizing the PS concept promotes a scalable IoT architecture and addresses single points of failure in the IoT ecosystem.

Advancements in mobile technologies, and cyber-physical systems have exponentially increased data generation at the network edge. Existing data distribution services primarily concentrate on content, neglecting geo-context, leading to excess data dissemination in various IoT scenarios [26]. This results in unnecessary data dissemination in numerous IoT scenarios. To address this issue, Hasenburger and Bermbach utilized geo-context information to govern data distribution. They introduce GeoBroker, a data distribution service, that employs location-based controls, including geofences for messages and subscriptions, using publish and subscribe techniques. From the study, the result demonstrates a significant reduction in excess data dissemination. This innovation is based on a publish-subscribe technique able to optimize data distribution and creation of more green-based IoT applications.

The evolution of Internet-of-Things (IoT) technologies has facilitated diverse applications in agriculture, healthcare, transportation, industrial automation, and smart homes. Pham and colleagues introduce an innovative edge-cloud publisher and subscriber broker model for data dissemination in large-scale IoT projects [58]. In their proposed model, IoT devices equipped with publish and subscriber client applications periodically transmit hierarchically organized data to the nearest edge pub/sub-brokers. This approach achieves optimal data delivery latency, surpassing classical Cloud-based and Edge-Cloud pub/sub-schemes. The model empowers edge nodes to make prompt controlling decisions, responding to IoT devices or aggregating data for further delivery to interested edge or cloud brokers. For future enhancements, they aim to balance delivery latency, relay traffic ratio, and the number of connections in the broker overlay network. Moreover, considerations include applying artificial intelligence algorithms for more efficient clustering of brokers and routing of messages in publish and subscriber systems.

2.2 Content-based technique

The content-based technique in IoT data dissemination leverages network structure information and user interest profiles associated with messages. This approach tailors the distribution of data by considering the inherent structure of the network and the specific interests of users. By analyzing the content attributes and relevance to user profiles, the technique ensures that information is delivered selectively, aligning with user preferences and network characteristics. This personalized and context-aware strategy enhances the efficiency of data dissemination in the IoT, facilitating targeted communication and optimizing resource utilization within the interconnected environment. Let N be the set of nodes in the Network, U be the set of users with their corresponding interest profiles and M be the set of messages or content available for dissemination. The disseminated content can be represented as $(M \cap N \cap U) \times M$, where the data that has common attributes of the network

structure, N , and user interest profiles, U related to the available messages, M . Figure 3 shows the general flowchart of the content-based technique.

Leveraging the content-based technique in IoT enables personalized data dissemination, delivering information to users based on their interest profiles. This ensures relevance to user preferences and needs, optimizing resource utilization for enhanced efficiency. The tailored approach not only meets user expectations but also contributes to green technology by minimizing unnecessary data transmission, promoting a more environmentally sustainable IoT ecosystem. Recognized context-aware, the content-based technique in IoT considers both content attributes and network structure, optimizing data dissemination. Leveraging network structure information minimizes unnecessary broadcasts, conserves bandwidth, and ensures effective utilization of communication resources.

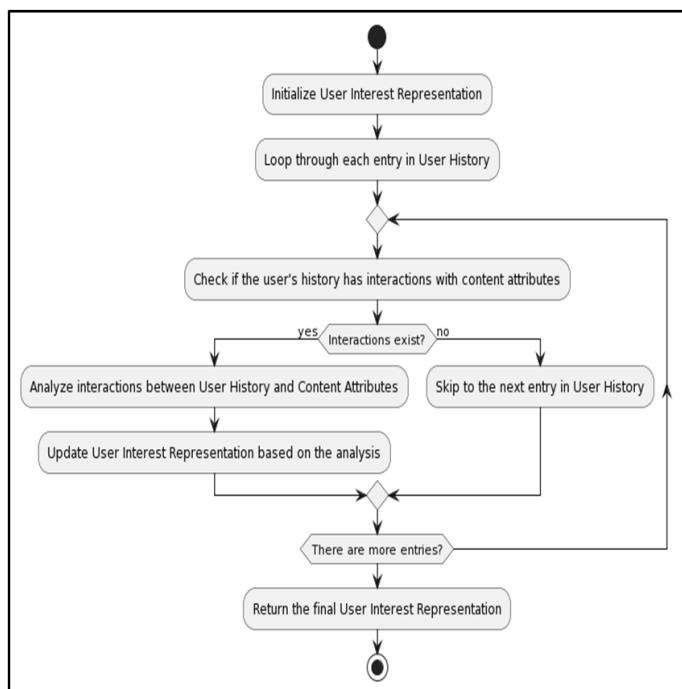


Figure 3. General flowchart of Content-based technique.

Examples of studies adopting Content-Based Techniques:

Optimizing the performance of disseminating data in IoT is crucial. Therefore, [35] introduces an approach based on Content-Centric Networking (CCN) to content caching in Internet of Things (IoT) systems. The primary aim is to improve content retrieval delays and optimize performance parameters such as cache hit ratio, hop count, delay, and network traffic. This can be achieved via utilizing the hierarchical partitioning in CCN-enabled IoT networks. Based on the results, the study effectively reduces content duplication and minimizes cache replacement operations. Not only that, but the approach also utilizes

normalized distance-based metrics and dynamic threshold heuristics to make caching decisions. However, it is important to conduct additional assessments to evaluate the scalability and adaptability of the proposed hierarchical partitioning method in real-world scenarios, as well as the effectiveness of the dynamic threshold heuristics in various IoT deployment scenarios.

The study introduces the Dynamic Behavior and Collaborative Prediction (DBCPNF) algorithm, designed for content sharing in the mobile Internet of Things (IoT) [88]. Leveraging user preferences and content attributes, DBCPNF identifies suitable recipients for content sharing by modeling user preferences through historical behavior analysis and cooperative user examination. The algorithm excels in content delivery ratio and overall network efficiency, optimizing the match between content attributes and user preferences for more effective data sharing in the IoT ecosystem. Further exploration is recommended to assess the algorithm's performance with diverse content types and attributes, highlighting the efficacy of content-based techniques in IoT applications.

Optimizing the dissemination of content for diverse network environments can be achieved with prioritization strategies. A priority-based approach is designed to improve the Quality of Service for NDN-based cloud and mobile IoT nodes in Vehicular Ad Hoc Networks [12]. Four types of prioritizations data flows are applied such as emergency, urgent, average, and least. The assigning of these data flows is based on the minimum deadline, size, and distance. This ensures that critical content with tight deadlines is disseminated promptly while less urgent data is prioritized accordingly. According to their experiment, emergency data flow performs minimum processing time as compared to the other data flow labels. However, the effectiveness of assigned priority values may vary depending on the VANET context and further investigation is needed.

Similarly, studies conducted by Anwar and colleagues in 2022 focused on effectively managing crucial patient health data in Wireless Body Area Sensor Networks (WBASNs) [11]. Leveraging the vital signs based on Sensitive Data and Non-sensitive Data to ensure that sensitive medical data packets are prioritized and routed efficiently to their designated destinations. The study effectively improves packet delivery, delay, and energy efficiency. This approach, grounded in the sensitivity of data traffic, possesses the capability to optimize the dissemination of data and elevate the efficiency of data management within healthcare applications.

2.3 Location-based technique

The location-based technique focuses on utilizing the geographical location of IoT devices to determine the efficient way to disseminate data [34][56]. By considering the proximity and location of devices, this technique minimizes latency and optimizes network resources by delivering data to nearby devices instead of routing it through distant nodes. Moreover, mobility is interconnected with this technique. It utilizes the movement patterns and behaviors of nodes or devices in a network to optimize communication, data dissemination, and resource management. This helps IoT devices effectively exchange data in real-time, especially in scenarios where devices are frequently moving or changing their location. With this combination, it enables optimizing resource utilization, improving delay sensitivity, energy consumption, and data propagation in IoT applications. Figure 4 illustrates the general flowchart of the location-based technique.

Examples of studies adopting location-based techniques:

Optimizing the dissemination of data in situations where nodes or IoT devices face limitations in network access or coverage constraints is of utmost importance. One of the alternative methods involves the implementation of a mobile node strategy that serves as an intermediary node. Prior to being distributed to the recipient node or IoT device, the generated data has been saved and transported. An edge-aided data dissemination system for wireless healthcare systems was proposed by [68]. The mobile edge servers play a pivotal role in efficiently disseminating data images to various network nodes. It incorporates an installation mechanism responsible for loading data into IoT nodes and a data propagation mechanism that reliably transmits complete data blocks to all IoT nodes. As a result, both mechanisms applied have improved the energy efficiency as compared to traditional dissemination approaches. However, obstacles arise in the propagation mechanism due to the significant amount of time that is consumed when the mobile edge server travels before the commencement of data exchange.

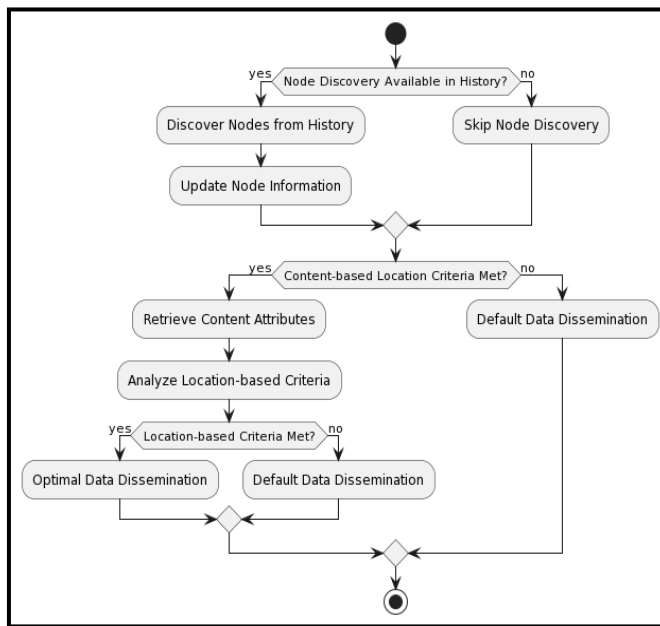


Figure 4. General flowchart of a location-based technique.

This differs from studies conducted by [54] whereby a smart vehicles network model was presented to enhance data dissemination and collection. It includes roadside units (RSUs) that are strategically placed at key locations and identified as the most visited in the area. A smart vehicle is used to collect and relay data from smart sensors in a smart city. This approach is designed to cater to delay-sensitive data forwarding and software updates. The author asserts that this suggested method is impervious to latency while possessing a substantial capacity for data offloading. For future enhancements, they recommend examining and identifying effective vehicles and RSU for data/code transmission. They aim to reduce data transmission time and improve data coverage by using the vehicle's historical information.

Other studies have evaluated this technique with transmission mode [1] and mobile communication system strategies [64]. A push-and-pull transmission mode is employed for data distribution and energy management enhancement through location awareness and forwarding techniques [1]. On the other hand, [64] uses location data from cellular systems to create forwarding paths and sub-axes, facilitating efficient data propagation in massive IoT networks.

2.4 Cluster-based technique

The cluster-based technique involves grouping IoT devices into clusters based on their proximity or similarity in characteristics. This approach allows for localized data dissemination within each cluster, minimizing the need for widespread data transmission and conserving network resources. Data processing and analysis can be performed collaboratively within a cluster, allowing devices to share resources and handle data more efficiently. Implementing this will improve the Quality of Service (QoS), leading to increased coverage, throughput, and service life. Algorithm 1 shows the general concept of cluster-based technique for IoT.

Algorithm1. Cluster-based technique

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1:      Initialize IoT Devices
2:      Determine Proximity or Similarity
3:      WHILE Devices Available for Clustering
4:          Select a Device
5:          Find Neighboring Devices
6:          Evaluate Proximity or Similarity
7:          IF Proximity or Similarity Met Threshold
8:              Add Device to Cluster
9:          ELSE
10:             Create a New Cluster with the Device
11:          ENDIF
12:      ENDWHILE
13:      WHILE Data Transmission Needed
14:          Perform Localized Data Dissemination within Cluster
15:          Collaborative Data Processing and Analysis
16:          Share Resources within Cluster
17:      ENDWHILE
18:      Improve Quality of Service (QoS)

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Examples of studies adopting cluster-based techniques:

A cost-effective approach to disseminating data is crucial in IoT. Research conducted by [48] presents a cluster head rotation that employs mobile vehicles to efficiently collect data from cluster heads (CH) and transmit it to a central data center via multi-hop communication. They implemented a single cluster head rotation (SCHR) scheme and a multiple cluster head rotation (MCHR) scheme to balance in-network energy consumption and prolong the network lifetime. In the SCHR scheme, it rotates the cluster head after a certain period to prevent the nodes near the cluster head from draining their energy quickly. Then, to balance the energy usage and extend the network lifetime, the MCHR scheme plays its role.

Therefore, both schemes are innovative strategies for gathering data that can establish a connection between a substantial amount of sensing devices within the context of the IoT.

On the other hand, the optimization strategy approach provides an impact on the dissemination of data in IoT applications. X. Liu and colleagues introduced an adaptive adjustment strategy for multi-layer clustering networks using weight capability [43]. The method entails randomly deploying sensor nodes in a designated region and leveraging data aggregation by cluster heads to gather and transmit it to a central station. Meanwhile, [37] presented a cluster-based Routing protocol with Static Hub that emphasizes peer discovery, cluster formation, data transfer, and re-clustering and rerouting in WSN-assisted IoT networks. The protocol uses adjacency matrices to create clusters and utilizes cluster heads to facilitate organized communication. Both studies have led to improved energy efficiency, data delivery, network longevity, and network performance.

Furthermore, the execution of a phased strategy also impacts the advancement of data dissemination in the IoT. In Wireless Sensor Network-based IoT (WSN) networks, a fixed-parameter tractable approximation clustering protocol has been introduced [87]. This study focuses on transmitting data packets from cluster heads (CHs) to a central sink based on four phases, bootstrapping, clustering, routing, and steady state. It aims to distribute the communication load of data packets among more nodes near the destination by proper segmentation of the area. Thus, [2] proposes a power-efficient compressive data fusion and cluster-based multi-hop relay-assisted protocol that addresses resource constraints in WSNs. This study focuses on clustering and cooperative data transmission. To improve delay and energy consumption, the authors introduced three phases which are network initialization and grouping, relay node allocation, data fusion, and cooperative transmission. Based on the result, delay, reception rate, and energy consumption have all been enhanced, leading to a longer lifespan.

2.5 Secure-based technique

The implementation of secure data dissemination strategies in IoT systems is essential due to the increasing number of Internet-connected devices. This technique aims to ensure the confidentiality, integrity, and availability of the transmitted data. Employing encryption techniques, access control mechanisms, and authentication protocols significantly protect the data from unauthorized access or tampering. By adopting this technique, IoT systems can mitigate the risks of data breaches and maintain the privacy of sensitive information. Figure 5 illustrates the general flowchart of secure-based technique for IoT.

Examples of studies adopting secure-based techniques:

Several studies have dealt with this technique with vehicular networks using trusted entity and trajectory privacy. Therefore, [23] proposes an authentication-based medium access control protocol that leverages Trusted Authorities (TAs) for authentication. This trusted entity uses sub-protocols to assign unique IDs, provision security keys, verify vehicle identities, and facilitate communication between vehicles. They aim to ensure that only authenticated vehicles are permitted to disseminate messages among each other in a distributed vehicle network. This differs from studies conducted by [81], whereby these authors propose an adaptive data dissemination scheme with trajectory privacy protection. This scheme optimizes key task distribution and leverages a vehicle's position deviation and pseudonym entropy to enhance the vehicle's trajectory privacy. They aim to improve the efficiency and security of data transmission in vehicular networks.

To improve routing reliability, data confidentiality, and integrity, [25] present a robust and trusted applied in IoT-based mobile mesh networks. The authors applied two main techniques to support this scheme. The first technique involves robust data routing among mobile mesh clients, routers, and gateways. The second technique is designed to provide secure and authentic data protection using a cryptography scheme. For future enhancement, the authors suggest incorporating machine learning-based optimization techniques. Meanwhile, securing the dissemination of healthcare data is critical. Therefore, [41] proposes a lightweight and secure redactable signature scheme with coarse-grained additional redaction control for cloud-assisted healthcare IoT systems. Utilizing threshold secret sharing and cloud-assisted processes allows controlled redaction while maintaining signature validity. They aim to ensure the confidentiality and integrity of healthcare data. They intend to enhance the security of schemes designed for cloud-assisted IoT systems for future improvements.

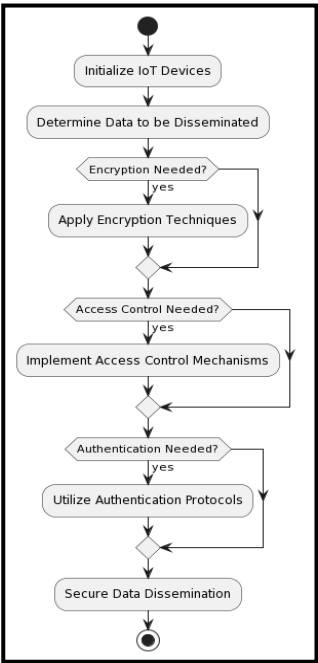


Figure 5. General flowchart of a secure-based technique.

2.6 Hybrid-based technique

Hybrid-based data dissemination employs various approaches to create more efficient and effective data dissemination. These solutions combine the strengths of various approaches to overcome the limits of a single technique. The combination of diverse methodologies creates

a flexible and adaptable data dissemination system to accommodate varied requirements and scenarios. This integration makes it possible to overcome the limitations and challenges associated with IoT applications. Algorithm 2 illustrates the general concept of hybrid-based technique for IoT.

Algorithm 2. Hybrid-Based Technique

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1:   Initialize IoT Devices
2:   Determine Data Dissemination Strategies
3:   IF Hybrid Technique Needed THEN
4:       Invoke AI Assistance
5:       IF AI Recommends Cluster-Based Technique THEN
6:           Apply Cluster-Based Approach
7:       ELSE IF AI Recommends Contents-Based Technique THEN
8:           Apply Content-Based Approach
9:       ELSE IF AI Recommends Publish-Based Technique THEN
10:          Apply Publish-Based Approach
11:      ELSE IF AI Recommends Secure-Based Technique THEN
12:          Apply Secure-Based Approach
13:      ELSE
14:          Fallback to Default Technique
15:      END IF
16:      Combine Various Approaches
17:      Create Flexible and Adaptable System
18:  END IF
19:  Efficient and Effective Data Dissemination

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Examples of studies adopting hybrid-based techniques:

Several studies have dealt with this technique using routing merging with different approaches [27][62][74][86]. Study conducted by Huang and colleagues, they implemented severalty and merged strategies to optimize data forwarding through node-disjoint paths, utilizing concepts like Non-member Stability Factor (NSF) and Dedicated Short-Range Communications (DSRC) links with multiple helpers [27]. They aim to address the challenges of limited bandwidth, high mobility, and frequent topology changes on the Internet of Vehicles (IoV). Besides, [62] employs Ant Colony Optimization (ACO) and Ad hoc On-demand Distance Vector (AODV) with Elliptic Curve Cryptography (ECC) to secure communication between vehicles with authentication, trust calculation, and optimal path selection applied. Their study focuses on preventing malicious or suspicious vehicles during message dissemination. However, the effectiveness of data dissemination may be compromised in high-traffic scenarios if network congestion is not considered.

On the other hand, [86] presents a combination of geographic routing and tree-based mechanisms to optimize data dissemination by considering node energy, distance, and sink location to adapt routing strategies. Based on the result, energy consumption and end-to-end delay have improved with the use of mobile sinks. They suggested that improving the proposed algorithm to support multiple mobile sinks could increase the applicability of the protocol. A hybrid DTN routing protocol was proposed by [74] and presented an effective bundle forwarding strategy by merging Flooding and Forwarding techniques. They aim to control the number of bundle replications to balance energy consumption on the network.

With that, the authors leverage the Prophet protocol metrics to enhance delivery rates and incorporate bundle replication for efficient forwarding to improve overall performance. For future enhancement, they plan to expand their schema by integrating an intelligent extension to forecast the delivery of a bundle.

Additionally, [90] suggests a hybrid transmission scheme for wireless sensor networks (WSNs) that combines Packet Reproduction (PR) and Hop-by-Hop (HBH) Automatic Repeat request (ARQ) to mitigate packet loss. The scheme divides the network into two parts: a load-light area (LLA) and a load-heavy area (LHA). Nodes in the LLA send multiple packet copies using PR, while nodes in the LHA use HBH ARQ to send or forward packets. The authors aim to enhance energy efficiency and decrease delay while ensuring reliability in the lossy Wireless Sensor Network (WSN). However, further analysis is needed to enhance energy consumption, delay, and reliability of specific parameter influences and relations.

3. Challenges and Opportunities

The Internet of Things (IoTs) is rapidly growing, which poses complex issues when it comes to the spread of IoT data. This presents both challenges and opportunities that impact the development of this technology. The increase in the number of connected devices makes it difficult to manage and transmit large amounts of data. However, it also creates new possibilities for innovation in various fields. In this section, we will highlight several challenges that impact data dissemination, including network congestion, communication overhead, security and privacy concerns, heterogeneity of IoT devices and protocols, mobility and dynamic topologies, and Quality of Service management, as illustrated in Figure 6.

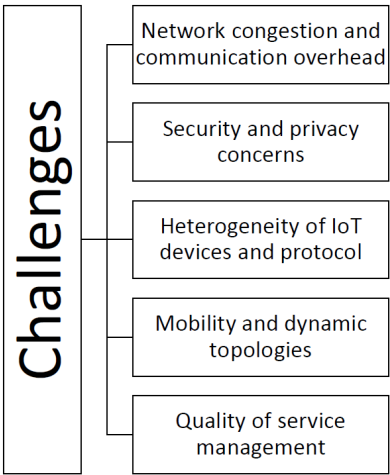


Figure 6. Data dissemination challenges for IoT applications.

3.1 Network congestion and communication overhead

The rapid expansion of IoT devices has raised concerns about network congestion and communication overhead, which can lead to data transmission delays, strain network resources, and reduce transmission rates [69][71]. As a result, the performance of IoT systems can be degraded when traffic load reaches its maximum capacity. Therefore, it is essential to control the transmission of traffic to alleviate network congestion. Several studies have been conducted to address this issue.

A cache replacement policy is employed to reduce cache size, minimize cache losses, and improve network traffic performance in NDN-based IoT networks [50]. Huang and colleagues have introduced a queuing delay utilization to minimize network traffic by routing services with similar attributes along the same path and consolidating them with other data along the route [28]. Utilization of a heterogeneous communication framework by considering the local and global real-time traffic information can reduce transmission network congestion, computational cost, and network overhead [38]. On the other hand, [9] proposed the use of Fog Cloud Computing (FCC) technology to enable local computing capabilities and real-time interactions through the Fog Management Area. They claim that this technology has the potential to reduce data transmission delays and improve access to traffic information for numerous vehicle nodes equipped with OBUs.

Furthermore, allowing multiple nodes to transmit data simultaneously on the same time-frequency resource block can reduce overhead and delay for Internet of Vehicle services [89]. A sustainable data dissemination system uses public buses as data carriers to reduce traffic and energy consumption in smart cities through neural network technology [52]. An offline algorithm for hybrid data dissemination for edge-assisted automated driving is used to minimize traffic on the edge by selectively injecting data into vehicles and leveraging the vehicle network to distribute the data [85].

However, these techniques may excel in specific scenarios but may not be universally applicable. We envision focusing on adaptability, real-time responsiveness, and efficient resource utilization aiming to create better robust, and versatile data dissemination solutions for IoT and networked environments.

3.2 Security and privacy concerns

Security and privacy concerns in data dissemination for IoT applications are of paramount importance due to the vulnerability of IoT devices to security breaches and the need to protect users' privacy. The volume of data collected and transmitted by IoT devices makes them vulnerable to security and privacy breaches due to the fragility and error-prone nature of IoT transmission mediums like radio frequency [24]. Moreover, the data transmitted by IoT applications frequently contains sensitive personal information, making it essential to safeguard users' privacy. Therefore, ensuring strong security measures and robust privacy protocols is crucial to mitigate the risks associated with data dissemination in IoT applications. Several studies have been conducted to overcome these issues.

In disseminating emergency messages, a Central Authority (CA) is employed to manage vehicle trust information based on feedback from Roadside Units (RSUs) and vehicles [46].

Similarly, a Trusted Authority (TA) is utilized for secure communication in Space-Air-Ground-Integrated Vehicular Networks (SAGIVNs) using a unique identifier, keys, and reputation management [45]. Besides, this author also employed a balancing approach for trust management and privacy preservation to defend against link attacks [44].

Furthermore, [40] proposed a two-phase system, consisting of registration and set-up, as well as data transmission, to enhance the reliability of Internet of Vehicles communication. Tan & Chung have proposed UAV-assisted solutions with certificateless cryptography and anonymity-preserving mechanisms [73]. In underwater acoustic sensor networks (UASNs), [42] employs an autonomous underwater vehicle (AUV)-aided message ferry approach (AMFA) used as a message ferry to disseminate data messages from the vulnerable anchored nodes being invaded by underwater spy robots.

From the communication perspective, an identity-based signature scheme is used as a cryptographic key to ensure authentication, data integrity, and privacy in network transactions [75]. On the other hand, a protocol for covert message-passing addresses privacy concerns by securely transmitting message fragments among IoT devices while preventing detection by unauthorized parties, emphasizing the importance of security and privacy in IoT communication [57].

However, numerous studies address IoT and network communication issues, but challenges persist such as complex trust management and privacy. We envision incorporating Blockchain-driven and Artificial Intelligence (AI)--driven adaptive security and privacy solutions for dynamic networks.

3.3 Heterogeneity of IoT devices and protocols

IoT devices come in various forms, with different capabilities, data formats, and communication protocols [8]. This heterogeneity makes it challenging to establish a standardized approach for data dissemination and interoperability among different IoT devices. Furthermore, the lack of standardized protocols can lead to compatibility issues and communication breakdowns between IoT devices. Therefore, it requires the development of protocols and technologies that can facilitate seamless communication and data dissemination among diverse IoT devices.

To address these issues, [51] introduced in-field collaborative network reprogramming as an innovative strategy for distributing code updates across diverse IoT Edge platform. Xu and colleagues have implemented edge-assisted reliable data transmission for coexisting heterogeneous sensor networks to address various applications and computational tasks [83]. On the other hand, [68] utilizing mobile edge servers and an adaptive protocol to distribute data fractions for heterogeneous IoT networks. [3] proposed a technique for sharing information among roadside units in Hybrid-VITS, a hybrid VANET intelligent transportation system. The system is designed to enable data exchange between different IoT devices, such as vehicles, VTSs, RSUs, and a 5G-based cellular base station (BS). Utilizing opportunistic routing based on a node parent set is employed to minimize overhead and conserves energy in disseminating data among heterogeneous devices [92].

However, these approaches are complex in managing and coordinating heterogeneous IoT. We envision developing a standardized and adaptive framework for IoT device heterogeneity, ensuring seamless data dissemination across various devices and protocols while addressing scalability and complexity concerns.

3.4 Mobility and dynamic topologies

The mobility of IoT devices and their dynamic topologies can make it difficult to disseminate data effectively [59]. Network topology changes due to device mobility can pose a challenge to maintaining consistent and reliable data dissemination. Additionally, IoT devices face challenges related to network connectivity and addressing. It is important for these devices to be able to connect and communicate with each other seamlessly, regardless of their location or movement. Therefore, it is necessary to develop efficient and scalable data dissemination that can handle the dynamic nature of IoT networks. Numerous studies have been carried out to address these issues.

In research conducted by [27], the authors employed a merging routing protocol using Vehicle Ad Hoc Networks (VANET) to address the issues on high mobility and frequent topology changes in a platoon of Internet of Vehicles (IoV). On the other hand, [91] uses of vehicles and UAVs to accelerate code dissemination for smart sensing devices (SSDs). Similarly, code mules' selection was used by [70] to disseminate data in smart cities based on maximum coverage ratio and reliable degree. Differ than study conducted by [30], it uses a potential vehicle to forward emergency messages from the source to the fixed or mobile destination through path-aware dissemination. A protocol for inter-UAV communication, utilizing multi-hop D2D communication and mobile users to disseminate data among UAVs, was proposed [32].

In disaster areas where disseminating data is challenging due to damage. Rajasekar and colleagues employed opportunistic density clustering routing to broadcast and forward stored data to the nearest node or endpoint even if nodes lose network access [61]. On the other hand, [79] introduced data selection and management mechanism focusing information dissemination on opportunistic social networks, where nodes are mostly mobile devices and have intermittent connections. Furthermore, [20] proposed a method to predict data transfer opportunities using predictive human mobility patterns and temporal contact of nodes.

However, these approaches involve complexity in implementing dynamic and mobile data dissemination, scalability challenges in diverse IoT environments and a potential high implementation cost. We envision incorporating Social-based and Artificial Intelligence (AI) solutions would create a dynamic and adaptive data dissemination framework to provide efficient, dependable, and user-centric data sharing in IoT and mobile networks.

3.5 QoS (Quality of Service) management

Quality of Service management is another key challenge in data dissemination for IoT applications. IoT applications often involve the transmission of enormous amounts of real-time data and ensuring timely and efficient delivery of this data is crucial for reliable operation. However, the diverse and distributed nature of IoT networks makes it difficult to guarantee consistent and reliable Quality of Service. Different IoT devices may have varying processing capabilities and network bandwidth, leading to network congestion and communication overhead. This can result in delays, packet loss, and degradation in the quality of service for data dissemination. Therefore, implementing effective QoS management mechanisms is essential to ensure reliable and timely delivery of IoT data.

Numerous studies have been conducted to tackle these concerns. From the energy optimization perspective, [21] utilized a UAV-assisted data dissemination system. A rotary-

wing UAV was used to disseminate data to multiple IoT device nodes on the ground. Besides, [5] utilized an optimization algorithm with Unmanned Aerial Vehicles (UAVs) to distribute files to IoT devices, which are interested in receiving a subset of the files. Furthermore, [17] investigate freshness of data in UAV-assisted IoT network. They optimize trajectory planning in multi-shot scenarios. In a post-disaster scenario, UAVs are utilized to transmit necessary data to IoT nodes on the ground where UAV charging facilities may be limited [84].

In optimizing service delivery and resource utilization, a weight-based neighbor discovery process is used to prioritize resource availability and accessibility over distance assisted by wireless sensor networks was proposed by [63]. Bello-Salau research introduced two discretized variants in optimizing the routing process for effective route discovery in VANETs [13].

However, these approaches involve complex algorithms, scalability concerns, limited energy budgets, and potential infrastructure limitations such as in disaster scenarios. We envision developing an integrated framework through approaches combination to optimize data dissemination efficiency, reliability, and energy consumption in IoT networks.

4. Innovative techniques and emerging opportunities

The rapid advancements in data dissemination and innovation play a crucial role in enhancing information delivery and operational efficiency across various domains. These advancements are driven by innovative technologies such as artificial intelligence (AI) and machine learning (ML), edge and fog computing, blockchain, and the integration of 5G/6G networks. The integration of these technologies is expected to revolutionize various fields, including computer sciences, telecommunications, and medicine. In this section, we will explore the potential benefits associated with these technologies in the context of data dissemination.

4.1 Artificial Intelligence (AI) and Machine Learning (ML)-based data dissemination

Artificial Intelligence (AI) and Machine Learning (ML)-based data dissemination used advanced algorithms to analyze large volumes of data and perform accurate predictions or recommendations [49]. These technologies are capable of simplifying and dynamically acquire data [72]. As noted by [10], the integration of reinforcement learning, deep learning, supervised learning, and unsupervised learning techniques has the potential to enhance the reliability, efficiency, and real-time distribution of data, see figure 7. By leveraging these advanced learning approaches, businesses and organizations may achieve more precise and reliable data analyses in real-time. This can lead to improved decision-making capabilities and enhance the overall performance of the organization.

The use of AI and ML has the potential to revolutionize communication systems and improve user experience. For instance, in the field of intelligent transportation systems, AI-assisted data dissemination methods enable to enhance the performance of vehicle-to-vehicle and vehicle-to-infrastructure communications [7]. Similarly, [52] employed machine learning techniques to accurately predict bus arrival time and allocate data onto buses.

An exemplary application of AI is demonstrated in the CogNet project, where the implementation of 5G networks is highlighted. This project outlines an architecture for an

autonomous self-managing network that augments Network Function Virtualization (NFV) management with a decision-making mechanism based on machine learning [65]. Sutikno and Thalmann claim that the real-time data acquired from IoT sensors that monitor industrial machinery can empower machine learning algorithms to predict future maintenance needs a pivotal process known as predictive maintenance and a paramount application of AI in the manufacturing realm [72]. On the other hand, [8] presents machine-learning-assisted data aggregation and offloading system which improves the response time and routing cost errors. With that, the integration of AI and ML technologies has the potential to improve service quality and enhance the dissemination of data within IoT applications.

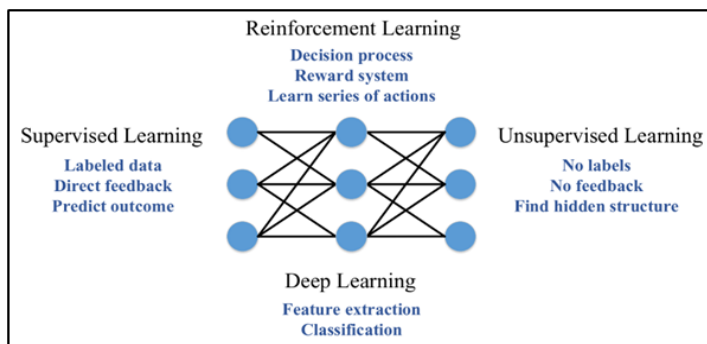


Figure 7. Various categories of ML algorithms and their key characteristics.

4.2 Edge and Fog computing for efficient data dissemination

Edge and Fog computing refers to the practice of analyzing and processing data at the edge of the network. This approach enables faster data processing and reduces the amount of data that needs to be transferred to the cloud or a central data center for analysis [14][55]. It leverages the capabilities of multiple computing resources to handle the processing and storage requirements of the data, such as edge devices and cloud servers [14]. Enabling faster response times, reducing network bandwidth and content retrieval latency, it is highly beneficial for real-time data processing and analysis [33][53].

Edge and Fog computing has been utilized in various applications to disseminate data effectively and efficiently. Camarinha-Matos and Katkoori highlighted the integration of AI with edge computing, which optimizes resource orchestration in IoT systems [16]. For example, edge devices can operate without batteries. Combining vehicles with fog computing can solve transportation delays and reliability issues due to the interruption problem [39]. Here, the public transportation facilities are used as fog nodes involving in distributed information exchange. Moreover, [80] proposes an integrated framework for platoon-based edge vehicular network to improve content precaching performance. With that, the integration of edge and fog computing has proven to be crucial in revolutionizing data processing and analysis by bringing cloud networking, computing, and storage capabilities down to the edge of the network. This addresses the real-time issue of IoT devices and provides secure and efficient IoT applications.

4.3 Blockchain technologies for secure data dissemination

Blockchain and distributed ledger technologies have the potential to revolutionize data dissemination by providing a transparent, secure, and decentralized platform for storing and sharing information. Lohstroh and colleagues supported that blockchain techniques surpass edge computing in their ability to decentralize critical functions which resulting in a fully distributed system [47]. In addition, these technologies enable trust and immutability, making them ideal for applications where data integrity and security are of utmost importance [4][60].

Blockchain technology has been utilized in various applications to disseminate data securely and efficiently. According to Wang research suggested that integrating this technology into contact tracing system is able to preserve privacy and ensuring precise contact tracing [77]. Additionally, this technology has expanded its capabilities into a decentralized model within the Industrial Internet of Things by providing certificates to IoT device owners [36]. This heightened security is crucial for safeguarding the communication between machines and the cloud, meeting the demand for secure and reliable IoT systems.

Huda and Moh proposed the use of blockchain technology in an unmanned aerial vehicle (UAV)-enabled offloading system [29]. The system involves an authentication process that verifies the security certification linked to an offloading task before it is executed. This integration ensures the security of the offloading process. The proliferation of growing technologies such as robotics and machine learning (ML) is facilitated by the seamless exchange and dissemination of medical data. On the other hand, Al-Blihed research emphasized the use of Blockchain technology to facilitate secure storage of medical data in a timely and protected manner [4]. It is evident that this technology plays a crucial role in revolutionizing data dissemination, particularly within the context of security and privacy.

4.4 Integration of 5G/6G networks for improved data delivery

The combination of 5G/6G networks involves the smooth coexistence and cooperation of 5G and 6G networks to enhance data delivery capabilities. This technology provides higher speeds, lower latency, and greater capacity compared to previous generations of cellular networks. This allows for faster and more reliable data dissemination, enabling real-time applications and services that were previously not possible. Furthermore, the ultra-reliable and low-latency communication capabilities of 5G/6G networks facilitate the efficient and seamless dissemination of data across various devices and edge nodes, improving the overall user experience [14]. Besides, the emergence of this technology underscores its significance for smaller resource-constrained devices and how they interact [55]. This technology has been utilized in various applications to disseminate data effectively and efficiently.

Benalia and Mellouk presents a 5G-IoV model to improve the dissemination of data with Quality of Service (QoS) and Quality of Experience (QoE) requirements for road safety and driver comfort [14]. They claim that this model can improve transportation by decreasing traffic congestion, accidents, and fuel consumption, resulting in potential economic advantages. In order to secure communication between smart vehicles, [62] suggested to integrate this technology with routing optimization which allow for a smart car to communicate with each other or with roadside infrastructure. In green communication, where energy is limited, managing the network's energy consumption is crucial. Verma and colleagues proposes cluster-based routing which dealing with 6G-enable IoT devices focuses

on minimizing energy consumption via clustering and routing management [76]. Furthermore, the development of an authentication-based secure data dissemination protocol represents a pioneering effort in the realm of 5G-enabled vehicular communications [23]. 5G/6G integration is a transformative step towards a seamless, high-speed data delivery future. By overcoming network limitations and enabling new applications, it will revolutionize various aspects of our lives.

5. Conclusion

The proliferation of Internet of Things (IoT) applications has led to an unprecedented amount of data being generated, necessitating the development of effective data transmission methods. In this paper, we have investigated various data dissemination techniques, analyzed their benefits and drawbacks, and determined their suitability for various IoT use cases. With the vast amount of data being produced and the increasing number of connected devices, it is crucial to have flexible and efficient data dissemination methods in IoT applications. To address these issues, it is essential to explore novel dissemination mechanisms such as artificial intelligence, edge, and fog computing, blockchain integration, advanced 5G/6G network integration, and other emerging technologies. These innovations have the potential to revolutionize the landscape of data dissemination in IoT environments, improving information delivery, boosting productivity, and fostering sustainability across various fields. It is critical for academics, developers, and stakeholders to remain up to date with these technological breakthroughs as we move forward in this era of connected devices. By harnessing the power of these disruptive technologies, we can overcome the data distribution issues in IoT and open new horizons for the ecosystem's efficiency, efficacy, and sustainability. As IoT applications continue to expand across various industries, from smart cities to healthcare and beyond, this research serves as a guiding beacon, leading us toward new frontiers of investigation and innovation.

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