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Fog Computing Platform to Handle Internet of Things Data Heterogeneity

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Abstract. Internet of Things (loT) sensors produce a huge amount of data every second. This unexpected data volume needs great effort to manage, structure, save, and process to produce effective information and best utilize it. Extracting valuable knowledge from this heterogonous data is a high demanding need. Making accurate decisions based on this data was a dream in the near past. Data management and handling data heterogeneity locally on sensor boards and regionally on local servers using Fog and centrally on Cloud acts as an enabler for giving IoT a great value even if it faces many complexities and challenges, as discussed in this paper. As previously said, data management in IoT is a serious issue due to communication among billions of devices, which generate massive datasets. Data analysis on such a big volume of data is a difficult undertaking due to the lack of any standard. A definition of loT-based data should be established in order to determine what is available and how it can be used. A study like this also points to the need for new approaches to deal with such problems. It's a great difficulty to cope with such a range of data as IoT delivers processing nodes in the form of smart nodes due to the heterogeneity of linked nodes, varied data rates, and formats. It provides a solid foundation for big data research. Finally, we briefly outline current open issues of edge computing platforms based on our literature survey.

Keywords: Internet of things, industrial loT, edge computing, fog computing, cloud computing, data management, data heterogeneity, big data, artificial intelligence, machine learning, deep learning

1. Introduction

IoT has been defined in (Gazis, V 2017) as "a world where computers would relieve humans of the Sisyphean burden of data entry by automatically recording, storing, and processing in a proper manner all the relevant information about the things involved in human activities.” (Gazis, V. 2017; Karpf, B. A. 2017). The industrial IT approach is marked in publications such as a 2015 report (Macaulay, J. et al., 2015) by DHL and Cisco titled "Internet of Things in Logistics" that combines the commerce, manufacturing, retail, transportation, healthcare, and infrastructure domains all under the concept of industrial IT (IIoT) (Karpf, B. A. 2017; Macaulay, J. et al., 2015). This trend also arises through technical standardization groups such as one Machine to Machine (M2M) that split standardization activities between consumer IT technologies and industrial IT technologies (Karpf, B. A. 2017; Park, H. et al., 2016). M2M connectivity, Big Data (BD), IoT, Cloud Computing (CC), and real-time data processing from interconnected sensor devices are all part of the Industrial IoT (Hossain, M. S. et al., 2016; Chen, M. et al., 2014).

M2M communications, Wireless Sensor Networks (WSNs), Radio-Frequency Identification (RFID), and supervisory control and data collection (SCADA) are the four essential pillars of IoT (Razzaque, M. A. et al., 2016). The IoT paradigm is transforming the current Internet into a fully integrated future Internet, as shown in Fig. 1 (Botta, A. et al., 2015; Stergiou, C. et al., 2018; Ji, B. et al., 2020). While the Internet's evolution resulted in a previously unheard-of connectedness of people, the current tendency is to connect items to create a smart environment (Botta, A. et al., 2015; Gubbi, J. et al., 2013; Ullah, A. et al., 2020). In this context, identifying things with unique addresses is crucial for the success and sustainability of IoT. This facilitates addressing many devices uniquely and connecting and monitoring them over the Internet (Botta, A. et al., 2015; Gubbi, J. et al., 2013).

Scalability, durability, uniqueness, and reliability are all important characteristics to consider while creating a unique addressing schema (Botta, A. et al., 2015; Khodkari H. et al., 2016). In the IPv4 environment, unique identification challenges may arise to some extent (typically, a group of cohabiting sensor devices may be detected and recognized regionally, but not individually). With its Internet Mobility characteristics, IPv6 can overcome some of the device identification issues and is predicted to contribute a lot of value to this industry. IoT is a network paradigm in which physical, digital, and virtual items are equipped with sensing, identification, processing, and networking functions so that they may communicate with one another and with other devices and services on the Internet to complete tasks (Diène, B. et al., 2020; Atzori, L. et al., 2017; Mashal, I. et al., 2014).

In the context of the 4th industrial revolution, Industry 4.0 extends recent digital technologies to a more comprehensive scope, which principally includes Cyber-Physical Systems (CPS), IoT, and CC (Sonntag, M. et al., 2021). Many IoT applications are designed to make human life easier and more comfortable Diène, B.

et al., 2020. The use of loT technologies in the automobile industry, for example, spawned the concept of the Industrial Internet of Things (IIoT), which encouraged the use of CPS, in which humans and machines communicate (Diène, B. et al., 2020)

Traditional database management systems are not the ideal fit for IoT data because of its diversity, heterogeneity, and enormous volume provided by these sensors Diène, B. et al., 2020. The design of IoT data management systems should take into account a number of special concepts Diène, B. et al., 2020. Several approaches to loT data management, such as middleware or architecture-oriented solutions that facilitate the integration of generated data, or other solutions that provide efficient storage and indexing structured and unstructured data, as well as support for the NoSQL language, are based on these distinct principles (Diène, B. et al., 2020; Huacarpuma, R. C. et al., 2017; Celesti, A. 2019)

Thus, this paper focuses on the most important concepts in data management in loT, reviews currently proposed solutions for loT data heterogeneity, discusses most promising ones, and clarifies relevant open research issues on the topic, highlights fog computing and its role in IoT data management, proposes the Fog of Things platform, discusses the main contribution of this platform in IoT data management in general and data heterogeneity and data privacy in specific, focuses on how this platform handles IoT data heterogeneity challenges, and finally provides guidelines for further contribution and frameworks implementation in IoT data management especially data heterogeneity and data privacy.

2. Integration of IoT and Cloud Computing

CC can be defined as "a set of network-enabled services, providing scalable, Quality of Service guaranteed, normally personalized, inexpensive computing infrastructures on demand, which could be accessed in a simple and pervasive way" (Kar, A. K. et al., 2014; Campos, J. 2014; Al Bajjari, F. 2014; Khadka, J. 2021; Yu, Z. et al., 2017). CC involves both the applications which can be provided as services over the Internet and the hardware and software systems in the data centers that deliver those services (Armbrust, M. et al., 2010).

A loT plays a critical role and is extensively delivered with the aid of many heterogeneous devices that result in seriously huge information (Sharma, R. et al., 2020; Lee, C. K. M. et al., 2015). Large storage is strongly needed for the amount of data generated through numerous IoT sensors (Sharma, R. et al., 2020; Rizwan, P. et al., 2017). Moreover, processing this data requires large memory spaces, which represents a big challenge (Sharma, R. et al., 2020; Rizwan, P. et al., 2017). This directs to being computationally wasteful to store, process, or even analyze such huge amount of data (Rizwan, P. et al., 2017). This massive amount of easily available raw data has been growing at an exponential rate (Sharma, R. et al., 2020). One of the most important aspects of loT is the continuing or near-constant communication of facts about "connected matters" (Rizwan, P. et al., 2017). The four guidelines of IoT are: (a) a large amount of data, (b) a high rate of data exchange, information exchange (online Transaction Processing [OLTP]), and data preparation (online Analytical Processing [OLAP], examination), (c) a variety of structured and unstructured data, (d) a variety of information structures and query dialects, a variety of data sources, and veracity (Sharma, R. et al., 2020).

BD and loT are extensively operated in many applications globally (Sharma, R. et al., 2020; Rizwan, P. et al., 2017). Many researchers are working day and night to enhance the services of BD and IoT (Sharma, R. et al., 2020). There are many challenges in both technologies: security, privacy, and heterogeneity (Sharma, R. et al., 2020; Rizwan, P. et al., 2017). The common reason is that BD and IoT access the Cloud extensively (Sharma, R. et al., 2020). Moreover, the data stored in Cloud is confidential, heterogeneous, and missing some security standards (Rizwan, P. et al., 2017). As a result, it is necessary to treat these technologies carefully from a security standpoint (Sharma, R. et al., 2020). Some researchers are also combining RFID and IoT in their studies (Razzaque, M. A. et al., 2016; Sharma, R. et al., 2020; Zhou, H. 2013; Perera, C. et al., 2014). Most drivers to the Integration of loT and CC come in three categories: computation communication and storage, while a few others are more basic (Botta, A. et al., 2017).

The two worlds of Cloud and IoT have evolved at a rapid and self-contained pace (Botta, A. et al., 2017). These worlds are vastly distinct, and, even better, their characteristics are frequently complementary, as highlighted in Table 1 (Botta, A. et al., 2017). Many academics have projected onto their integration because of this complementarity, with the goal of obtaining benefits in certain business application scenarios (Botta, A. et al., 2017; Alhakbani, N. et al., 2014).

Many applications have relied on Database Management Systems (DBMS) for a long time to store and handle data. As the number of connected devices grows, the number of users and data generated by IoT has expanded dramatically in recent years and will continue to do so in the future (Díaz, M. et al., 2016). Meanwhile, the excessive growth in users, data, and sensors reflects that a large DBMS is not suitable anymore. As a result, a platform that can meet these requirements in terms of scalability, processing, and even storage is required (Díaz, M. et al., 2016).

Many platforms recently arose for storing, processing, and accessing large amounts of heterogeneity data known as BD (Díaz, M. et al., 2016). These platforms are batch processing, distributed database, real-time processing, and distributed queues (Díaz, M. et al., 2016). Each of these platforms has its management, monitoring, and deployment tools, techniques, and mechanisms to be followed.

As clarified in Figure 2 and Table 2, all the mentioned challenges for IoT are still hot and need more work to cover except data aggregation (Botta, A. et al., 2017; Abbasi, M. A. et al., 2017). Data aggregation in IoT has covered a lot of research in the last decade, even it is still hot in correlation with other challenges, especially security and privacy (Botta, A. et al., 2017).

IoT data heterogeneity is currently pertaining to a big range of fields and businesses like public security via video surveillance, healthcare, smart homes, smart cities, Mobility, logistics, environment, etc., as mentioned in Table 2 (Botta, A. et al., 2017). Many models and frameworks were developed to manage data heterogeneity in loT like: Service-Oriented- Data-Management-Framework and Policy-Based Coordination Architecture, which is described in detail with a set of other IoT challenges frameworks and Models in Table 3 (Abbasi, M. A. et al., 2017).

Table 2 shows the results. Although the integration of the loT and CC can achieve the aims of storing, representing, and processing huge amounts of data in loT domains, there are still outstanding issues such as analyzing, normalizing, verifying, and filtering loT data (Botta, A. et al., 2017; Abbasi, M. A. et al., 2017). Because of the lack of open standards, the wide range of technologies associated with the Internet of Things, and the vast volume of data generated, strategies to improve and optimise such integration challenges are required (Díaz, M. et al., 2016). Fig 2 focuses on IoT challenges and highlights the volume of effort done in these challenges using current data management models, frameworks, and platforms (Abbasi, M. A. et al., 2017).

Even though CC can assist overcome some of the restrictions of IoT, there are other situations that must be addressed, such as mobility support, geo-distribution, location awareness, and low latency, and CC shortages make it difficult to do so (Díaz, M. et al., 2016; Gharaibeh, A. et al., 2017). A new platform, called Fog Computing (FC), wants to provide networking, computing, services, and storage between CC and end devices (Díaz, M. et al., 2016). It's called "Fog" since fog is a low-lying cloud, and its primary goal is to extend CC to get it closer to loT devices. (Díaz, M. et al., 2016; Gharaibeh, A. et al., 2017). In other cases, data may not need to be stored in the cloud or must be handled with extremely low latency and mobility. Through a distributed and combined platform in partnership with loT devices, FC can supply the necessary requirements in IoT (Díaz, M. et al., 2016).

Notwithstanding, due to loT limited restrictions, FC cannot provide functions such as data access to large numbers of users, storing historical data, and complex analysis complemented with CC (Díaz, M. et al., 2016). Under FC, most data processing functionalities are done out from the Cloud. An efficient and reliable communication system is required to get a robust, cost-effective power supply through Smart Grids (SGs). The FC model can meet computational requirements for SG applications (Naranjo, P. G. V. et al., 2016).

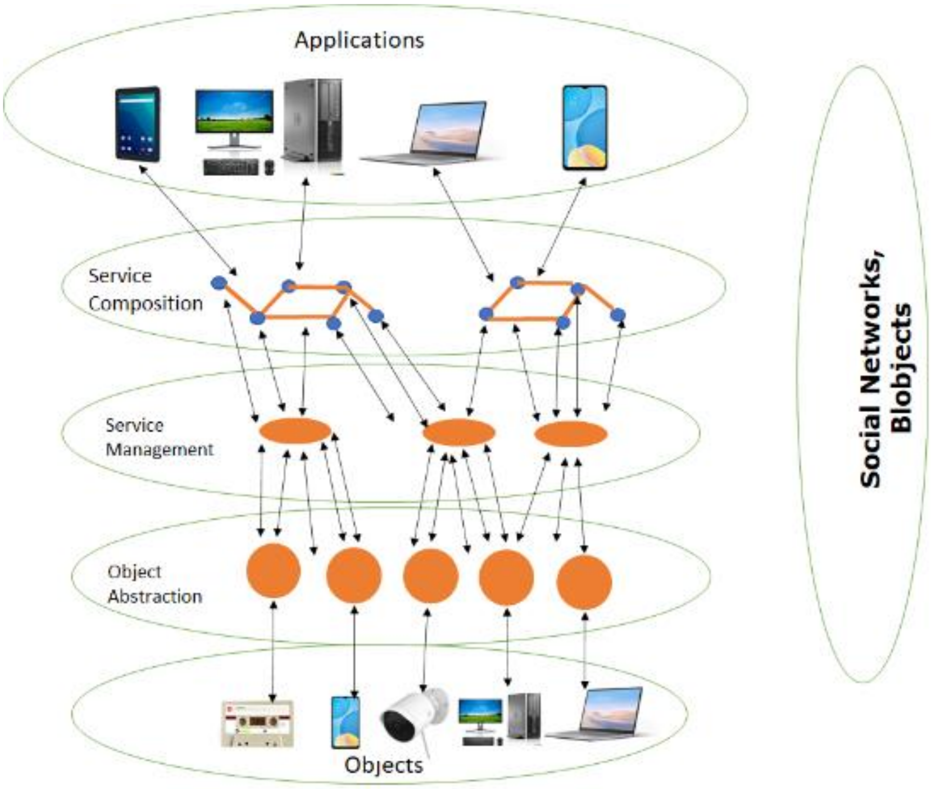


Fig. 1: IoT paradigms (Botta, A. et al., 2015; Kosmatos, E. A. et al., 2011)

Table 1: Complementary Aspects of CC and IoT (Botta, A. et al., 2015)

Item	Cloud	IoT
Displacement Centralization	Centralized	Spreading widely
Reachability	Everywhere	Limited
Components	Virtual recourses over physical Hardware	Devices/Sensors
Physical Computational capabilities	Huge but limited	Limited
Physical Storage	Huge but limited	Limited or not exists
Role of the Intranet	Service Delivery Means	Point of convergence
Role for Big Data	Data Management Means	Data-Source
Virtual Components	Virtual recourses	None
Virtual Computational capabilities	Virtually unlimited	None
Virtual Storage	Virtually unlimited	None

Table 2: Challenges pertaining to cloud-IoT Data and Applications (Botta, A. et al., 2015)

		Heterogeneity	Privacy	Legal & Social Aspects	Large Scale	Security	Reliability	Performance
Applications	Smart Home	✓	✘	✘	✘	✘	✓	✓
	Video Surveillance	✓	✘	✘	✘	✓	✓	✓
	Healthcare	✓	✓	✓	✓	✓	✓	✓
	Smart cities	✓	✓	✓	✘	✓	✓	✓
	Smart Energy	✓	✓	✓	✘	✓	✓	✓
	Automotive	✓	✘	✘	✘	✓	✓	✓
	Smart Logistics	✓	✘	✓	✓	✘	✓	✘
	Smart Metering	✓	✘	✘	✘	✘	✓	✓
	Smart Communities	✓	✓	✓	✘	✓	✓	✓
	Smart Grid	✓	✓	✓	✘	✓	✓	✓
	Smart Mobility	✓	✘	✘	✘	✓	✓	✓
	Environmental Monitoring	✓	✘	✘	✓	✓	✓	✓

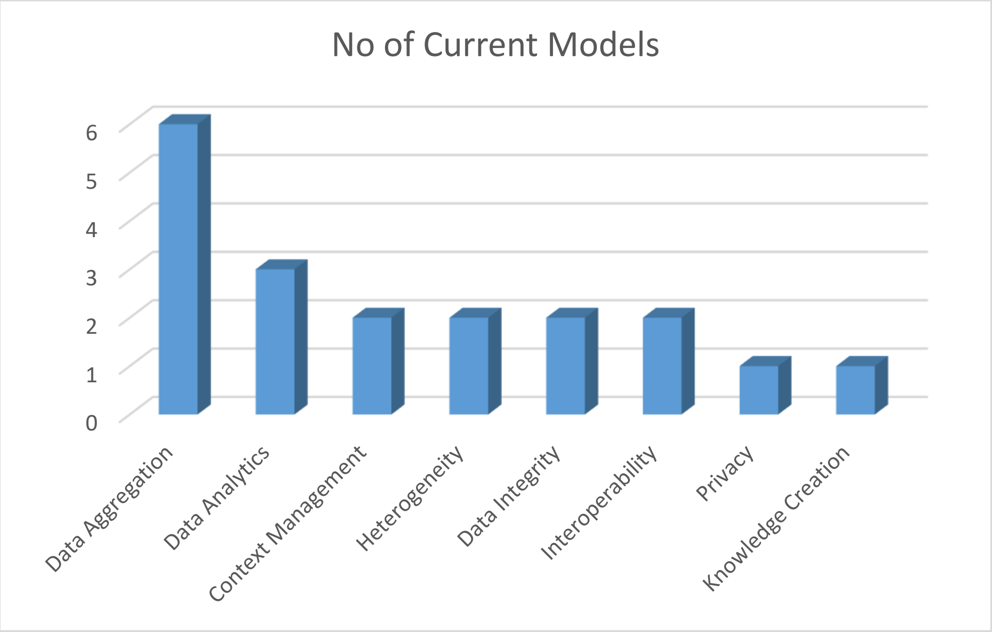


Fig. 2: IoT data management challenges [34]

Table 3: IoT Data Management Challenges for Available Frameworks Or Systems (Abbasi, M. A. et al., 2017)

Framework Model	Data Aggregation	Data Analytics	Context Management	Hetero-geneity	Data Integrity	Inter-operability	Privacy	Knowledge creation
(Mishra, N. et al., 2015)	✓	✓	✘	✘	✘	✘	✘	✓
(Fan, T. et al., 2010)	✓	✘	✘	✓	✘	✓	✘	✘
(Fonseca, J. et al., 2016)	✘	✘	✓	✘	✘	✓	✘	✘
(Khodadadi, F. et al., 2015)	✓	✘	✓	✓	✘	✘	✘	✘
(Quanqing, X. et al., 2016)	✓	✓	✘	✘	✓	✘	✘	✘
(Ma, S. et al., 2014)	✓	✓	✘	✘	✘	✘	✘	✘
(Valera, A. J. J. et al., 2010)	✓	✘	✘	✘	✓	✘	✓	✘

3. IoT data heterogeneity

Thousands of small chips, gadgets, and items comprise systems and subsystems in a typical IoT ecosystem, generating massive amounts of data and information (Ahad, M. A. et al., 2020). The data from these devices interact to provide services to the users (Ahad, M. A. et al., 2020). As previously mentioned, multiple research have presented data heterogeneity management systems and frameworks based on several architectures involving EC, FC, and CC (Atlam, H. F. 2018; Mahmud, R. et al., 2018; Alreshidi, E. J. et al., 2022; Chiang, M. et al., 2016). Data heterogeneity has to be handled all over these dimensions concurrently, geographically, and semantically. This will focus on the proposed framework in the Fog of Things platform section below.

4. Fog computing

4.1. Why fog computing?

Since data centers of the cloud are geographically centralized, they are not usually able to deal with billions of geo-distributed loT devices (Díaz, M. et al., 2016; Wang,

T. et al., 2019). As a result, overloaded networks, excessive service delivery latency, and poor Quality of Service (QoS) are common. (Wang, T. et al., 2019; Islam, T. 2018; Mirzavand, E. et al., 2018).

FC has enough storage and processing power to store collected video streams, transcode, and process video frames for activities like object recognition, data mining, and object tracking (Yi, S. et al., 2015). We can then simply deliver notifications, events, descriptions, or video summaries to end-users, central servers, or databases. (Yi, S. et al., 2015). We can eventually achieve processing and feedback of high-volume video streaming, as well as service scalability on low-bandwidth output data, with Fog support (Yi, S. et al., 2015). To alleviate the risk of personal privacy leaks in public surveillance systems, privacy-preserving measures can also be used on the fog side (Yi, S. et al., 2015).

4.2. What is fog computing?

FC is a distributed computing paradigm that serves as a bridge between IoT devices and cloud data centers. centers (Mahmud, R. et al., 2018; Islam, T. 20185). It has several features, like as computation, storage, and networking, that allow Cloud-based services to be brought closer to IoT devices (Mahmud, R. et al., 2018; Yi, S. et al., 2015). The concept of FC was first presented by Cisco in 2012 to tackle the issues of loT applications in traditional CC (Macaulay, J. et al., 2015; Macaulay, J. et al., 2015). With real-time and latency-sensitive service requirements, IoT devices are widely dispersed at the network's edge (Macaulay, J. et al., 2015; Macaulay, J. et al., 2015).

Low latency and location awareness, wide-spread geographical distribution, Mobility, a large number of nodes, the leading role of wireless access, a substantial presence of streaming and real-time applications, and ultimately heterogeneity are all features that define the Fog (Bonomi, F. et al., 2012). Fog is a natural extension of Cloud: Fog and Cloud collaborate to build a mutually beneficial and interdependent service continuity between the Cloud and endpoints, allowing communication, storage, computation, and control to take place anywhere (Chiang, M. et al., 2015). To address the technological gaps in IoT support, a new computing and networking architecture, such as Fog, will be required, which will bring processing, control, storage, and networking functions closer to end-user devices. Fog outperforms the Cloud in the following three categories: perform considerable data networking and communication at or near the end-user, perform significant data storage at or near the end-user, and perform significant control and computation at or near the end-user (Atlam, H. F. 2018; Alreshidi, E. J. et al., 2022; Chiang, M. et al., 2016; Ribeiro, F. M. et al., 2021; Bukhari, M. M. et al., 2022; Kamruzzaman, M. M. et al., 2022; Hewa, T. et al., 2022; Jain, S. et al., 2021).

To monitor and control the Fog, cloud services may be deployed (Atlam, H. F. 2018; Chiang, M. et al., 2016; Gill, S. S. 2022). Fog can operate as a proxy for the

Cloud in delivering Cloud services to IoT devices and for IoT devices in interacting with the Cloud (Atlam, H. F. 2018; Ahlmeyer, M. et al., 2016). Some functions are better performed in the fog, whereas others are better performed in the cloud. (Atlam, H. F. 2018; Alreshidi, E. J. et al., 2022; Chiang, M. et al., 2016). The primary problems of fog research and innovation will be determining which functionalities that is recommended to operate in the fog and what are the recommendations of how interaction can be done between the fog and the Cloud (Atlam, H. F. 2018; Mahmud, R. et al., 2018; Yi, S. et al., 2015).

4.3. Fog computing architecture

CC is made up of mainly homogeneous physical resources that are installed and maintained centrally (Bonomi, F. et al., 2014; Pang, J. et al., 2021). Fog extends the Cloud to the edge and IoT devices, complementing and outspreading it; Fog's distributed architecture, which consists of heterogeneous resources, must be managed in a distributed manner (Bonomi, F. et al., 2014; Oppitz, M. et al., 2018). Fog architecture, like Cloud architecture, is concerned with the coexistence of applications belonging to diverse tenants (Khodadadi, F. et al., 2015; Atlam, H. F. 2018; Bonomi, F. et al., 2014). Each tenant considers their resources to be dedicated and establishes a topology Bonomi, F. et al., 2014 (). To enable scalable and autonomous resource management, Fog, like the cloud, adds a policy-based orchestration and provisioning layer to the resource virtualization layer (Diene, B. et al., 2020; Bonomi, F. et al., 2014). Finally, the Fog architecture provides APIs for the development and deployment of applications.

The Fog network infrastructure is also physically diverse, with high-speed connections connecting enterprise data centres and the core to a range of wireless access technologies at the edge (Bonomi, F. et al., 2014). Wireless access has a variety of technologies, like: 3G/4G, LTE, WiFi, and so on (Omar, H. A. et al., 2016; Kuran, M. S. et al., 2017). As depicted in figure 3, the components of Fog architecture explain thoroughly how the above objectives come true 9Bonomi, F. et al., 20140.

4.4. Fog geo-distribution: A new dimension of big data

Volume, Velocity, and Variety are the three dimensions that define BD today (Ullah, A. et al., 2020; Sharma, R. et al., 2020; Huo, Z. et al., 2016; Mahdavinejad, M. S. et al., 2018). Many IoT use cases, such as Smart Cities, Smart Grids, Connected Rail, and pipeline monitoring, are physically and geographically spread, as argued in many IoT use cases (Gharaibeh, A. et al. 2017; Bonomi, F. et al., 2014; Hashem, I. A. T. et al. 2016). This shows that the properties of BD should be expanded to include a fourth dimension, namely, geo-distribution (Sharma, R.et al., 2020; Bonomi, F. et al., 2012; Oppitz, M. et al., 2018).

The fundamental issue in the aforementioned use cases areas is not the volume or rate of data produced by any single device, but rather the large number of sensors/ actuators that must be controlled, managed, and orchestrated as a unified unit

(Kamruzzaman, M. M. et al., 2022; Bonomi, F. et al., 2014; Mineraud, J. et al., 2017). Moving data processing from a central Cloud to a distributed Cloud is becoming more difficult (Diene, B. et al., 2020; Bonomi, F. et al., 2014; Ning, H. et al., 2020; Chiang, M. et al., 2017). At the Fog, a distributed intelligent platform that handles dispersed computing, networking, and storage resources is required (Bonomi, F. et al., 2014; Tsai, C. W. et al., 2015). So, even FC adds a new dimension to BD, loT and surely complementing CC, it plays a crucial role to manage data heterogeneity by connecting loT devices locally, providing local computing and data storage which is faster and cheaper (Díaz, M. et al., 2017; Mahmud, R. et al., 2018; Alreshidi, E. J. et al., 2022; Chiang, M. et al., 2016; Ribeiro, F. M. et al., 2021; Jain, S. et al., 2021; Barik, R. et al., 2017).

4.5. Computation domain of cloud computing, fog computing, and edge computing

Several computing paradigms have already been given in computation technologies, taking into account the concepts of Edge Computing (EC) and Cloud Computing (CC) (Makiabadi, M. K. 2021). Mobile Edge Computing (MEC) and Mobile CC (MCC) are two of them that have emerged as potential extensions of CC and EC (Mahmud, R. et al., 2018; Makiabadi, M. K. 2021).

MEC has long been regarded as one of the most important enablers of cellular base station evolution (Mahmud, R. et al., 2018, Khalil, F. Y. 2018; Chen, M. et al., 2020). It allows EC servers and cellular base stations to work together (Mahmud, R. et al., 2018; Chen, M. et al., 2020). MEC can be connected to faraway Cloud data centers or it can be disconnected (Mahmud, R. et al., 2018). As a result, MEC can deploy 2-tier or 3-tier hierarchical applications into the network [47].

MEC also wants to improve network efficiency and adapt speedier cellular services for clients (Mahmud, R. et al., 2018). To accommodate 5G communications, MEC has been significantly improved (Mahmud, R. et al., 2018; Cau, E. et al. 2016). Furthermore, it seeks to provide content distribution and application development with flexible access to radio network information (Mahmud, R. et al., 2018; Cau, E. et al. 2016).

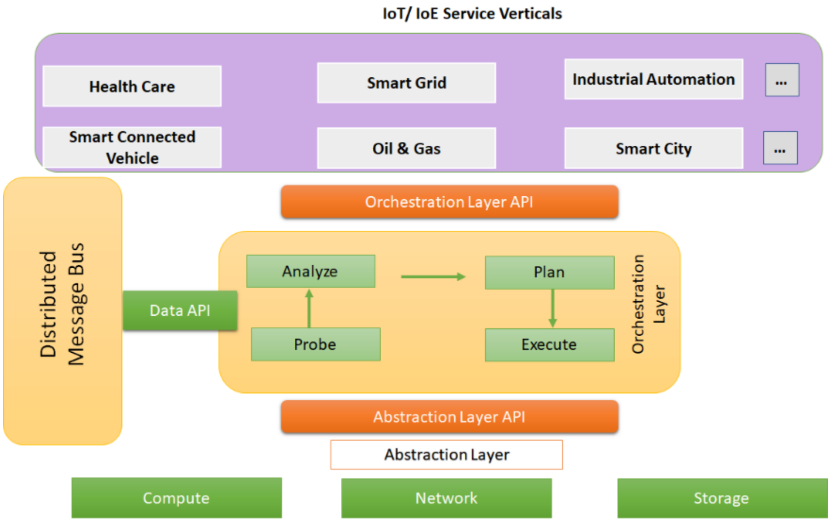
MCC provides vital computational resources to let offloaded mobile apps run faster and closer to end users (Sanaei, Z. et al., 2013). Cloudlets, which are light-weight cloud servers, are frequently installed at the edge network in MCC (Mahmud, R. et al., 2018; Sanaei, Z. et al., 2013). Cloud servers, in conjunction with end-user mobile devices and cloud data centres, create a 3-tier hierarchical framework for rich mobile application deployment (Mahmud, R. et al., 2018). For both network operators and cloud service providers, MCC combines cloud computing, mobile computing, and wireless communication to increase end-user quality of experience (QoE) and extend corporate market potential (Mahmud, R. et al., 2018; Sanaei, Z. et al., 2013).

Both edge and core networking components can be used as computational infrastructure in FC, as depicted in fig 4 (Mahmud, R. et al., 2018). Like MEC and MCC, FC can also allow edge computation (Mahmud, R. et al., 2018). However, FC can be extended to the core network besides the edge network (Ahad, M. A. et al., 2020; Tsai, C. W. et al., 2015). Moreover, FC components at the edge network can be positioned closer to the loT devices compared to cloud servers and cellular edge servers (Mahmud, R. et al., 2018; Gill, S. S. 2022). As a result, multi-tier application deployment and service demand mitigation of many loT devices can easily be monitored through FC Mahmud, R. et al., 2018.

This solution allows loT data to be stored and processed within the vicinity of loT devices, which is advantageous because loT devices are widely scattered and require real-time response to any service requests (Mahmud, R. et al., 2018). As a result, service delivery latency for real-time loT applications will be minimized to a great extent. Unlike EC, FC can extend cloud-based services like laaS, PaaS, SaaS, etc., to the edge of the network (Mahmud, R. et al., 2018; Alreshidi, E. J. et al., 2022). FC is thought to have greater potential and structure for loT than other similar computing paradigms because of the aforementioned characteristics (Mahmud, R. et al., 2018; Gill, S. S. 2022).

5. Complementary aspects between fog computing and cloud computing 103 ground floor

The LTE core's Packet Data Network Gateways (PDN-GW) and Service Gateways (S-GW), massive servers in a data center, and routers and core gateways in a WAN backbone are all examples of expensive, centralized, big, and difficult-to-innovate "boxes" that supply services and applications (Chiang, M. et al., 2016; Cruz, B. de O. 2013; Cao, J. et al., 2019; Dawood, M. 2020). The traditional view of the edge is that it relies on core networks and data centers, whereas the fog view sees the edge as a



component of both the core network and data center (Chiang, M. et al., 2016). Table 4 highlights the main features of Fog compared to Cloud .

Fig. 3: FC architecture (Bonomi, F. et al., 2014)

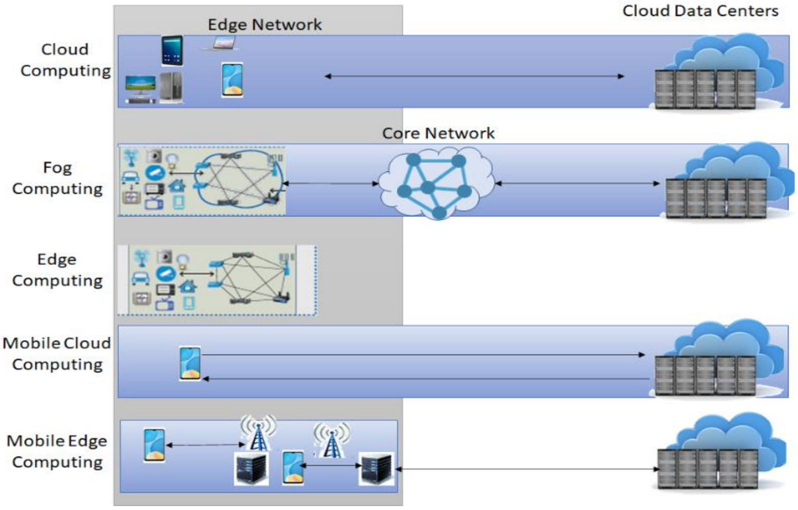


Fig. 4: Computation domain of CC, FC, and EC (Mahmud, R. et al., 2018)

Table 4: Main characteristics of FC and CC (Chiang, M. et al., 2016)

Aspect	Cloud	Fog
Location Model of Computing	Centralized computing in few data-centers	Distributed computing in many locations, and many areas, centralized or distributed control
Size	very big number of data centers, each has thousands of servers	One fog per location or as big as required Big fog system consists of a large number of fog nodes
Deployment	advanced deployment	ad-hoc deployment with little or no planning
Operation	For Facilities & environments selected and fully controlled by Cloud operators. Require technical expert teams. Large companies for operation.	Customers or their requirements determine the environment. Need no or little human involvement. Large & small companies for operation is accepted, fog size is the measure
Applications	Support cyber- domain applications. Accept delay of few seconds or longer	Supports cyber- domain and cyber- physical applications. Time-critical applications with latency requirements below tens of milliseconds or maybe lower.

Internet connectivity & Bandwidth requirements	Internet connectivity is required Bandwidth requirements increase with volume of data generated by all clients	Internet connectivity is not required After Fog filtration, the Bandwidth requirements increase with volume of data to be sent to the Cloud

6. Fog Computing platform for FoT (Fog of Things)

6.1. FoT platform overview

The rapid adoption of smart-homes - as a sample environment - is gaining traction around the world, and it's becoming a lucrative commercial potential for a variety of industrial applications. Smart-homes that use IoT create a lot of important data. To fully realize the potential of this data, modern BD analytics tools and platforms capable of processing, analyzing, and managing it in a cost-effective manner are required. The value of this data increases day by day. Moreover, the environments utilizing IoT and urgently needs to get the maximum value of this data, other than smart-homes are increasing. For instance, predictive maintenance, intelligent farm management, ... etc. This section discusses the system requirements for developing loT BD with Fog and CC, as well as the components of the proposed Fog of Things (FoT) platform. In the FoT platform, all data collection, management, processing, and even data heterogeneity management are done between loT sensors, EC (if required), and FC. CC is involved in this platform only for centralized computing.

6.2. FoT platform PROS and CONS

FoT platform resolves almost all Cloud-IoT challenges with one solution. It depends mainly on FC in data saving and processing. Data collection from IoT sensors, and historically saving this data on fog server for local processing and decision making releasing a big load from CC. Localizing data storing, processing and even management on fog server directly increases data privacy performance and surely decrease CC cost. FoT platform will lose CC huge hardware capabilities, central data storing, central data processing and central data streaming like broadcasting. Meanwhile, this CC advantage may cost a lot of money with no significant needs, which can be managed with a cost-effective way to utilize CC with minimum cost best.

6.3. FoT platform best fit

FoT platform can be best utilized when it acts as a focal point for loT processing engine as he directs processing to fog server when it comes to local processing. If there is any central processing, it will run on a cloud server. Moreover, any analytics results or artificial intelligence programs can run on Cloud and spread its results to all fog servers to act as a local server for this Intelligent decision based on the training of data feeding on cloud server to fog server.

6.4. FoT platform architecture

As described in figure 5, the FoT platform consists of loT sensors that act as data sources directly connected to loT middleware. loT middleware takes EC's (Edge Computing) role to get data from loT sensors and directly send it over the local network to the local fog server. Moreover, EC sends the same data over the Internet to cloud servers for backup and central continuous with interactive training for machine learning. Fog servers are main components in Fog platform as they receive data from EC and executes a lot of local FC like: storing data, analyzing data, processing data, producing real time decisions. These decisions maybe intelligent decisions and depend on central deep learning algorithm running on cloud server, for example. This is why FC is still having limited functionality and has a lot of challenges to be resolved. FoT cannot neglect the existence of cloud servers even it seeks to rarely use it. Cloud server in FoT has all central functions like: analysis, searching, monitoring and surely intelligent prediction. The artificial intelligence systems running on Cloud serves only.

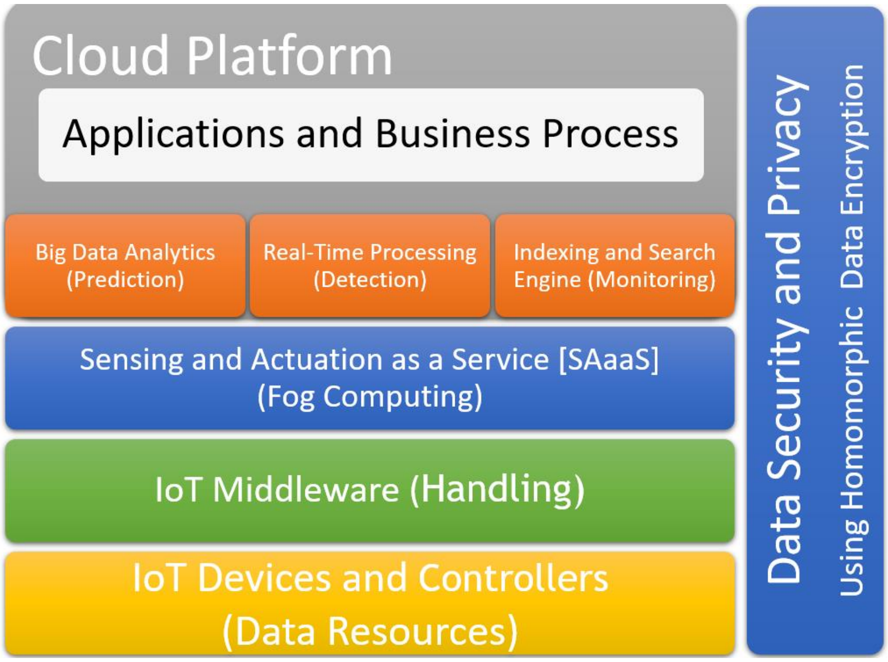


Fig. 5: FoT platform architecture

7. Discussion

The main added value for the FoT platform is that it can rarely use the cloud server and replace it with a local fog server. This can make real-time systems and real-time data processing acts better than depending on CC, which takes significantly much more time for data transmission over the Internet. Moreover, fog servers may be locally connected to loT sensors away from any internet connectivity, minimizing internet dependency risk. Reducing cloud server utilization directly affects data privacy as FoT manages data processing locally over a local network, greatly enhancing data privacy. CC cost, which is already expensive can be minimized by increasing data processing and management on FoT, which maximize its value-added. So, the FoT platform helps increase performance, reduce response time, minimize infrastructure and internet connectivity dependency, and reduce CC cost by minimizing its utilization.

To the best of our knowledge, the FOT platform can be considered the most overall platform that targets orchestrating the IoT data management operations locally and globally. FOT platform will play a crucial role in handling data heterogeneity and increasing data privacy for IoT. Downgrading global data processing on a cloud server to the minimum greatly affects increasing IoT data privacy. Processing data locally on the fog server and sending only selective data fiends to the cloud server is a smart way to handle IoT data heterogeneity and expand IoT data privacy limits. FC can take a large amount of central processing traditionally managed by CC. The best utilization of the FC layer in the FOT platform is to manage a big portion of data processing locally or regionally and replace central Processing on CC.

8. Conclusion and future work

IoT data heterogeneity and privacy are big challenges that have to be handled to utilize IoT sensors' data best and extract fruitful information and valuable knowledge. Several research have proposed data heterogeneity solutions, frameworks, and platforms based on EC, FC, and CC architectures. We primarily looked at research that were cutting-edge and relevant to our work. Detailed requirements for IoT data heterogeneity management platform via fog and cloud computing were addressed. FOT platform implementation and recommended tools for building this platform will be the focus on future work. This platform implementation will cover all modules highlighted in platform architecture. Real-time data streaming and historical data management will be big challenges to tackle in platform implementation.

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