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A Review on Big Data for Internet of Things

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Abstract- *With the rapid development of the Internet of Things (IoT), Big Data technologies have emerged as a critical data analytics tool to bring the knowledge within IoT infrastructures to better meet the purpose of the IoT systems and support critical decision making. Although Big Data and IoT are two distinct approaches that have evolved independently, they are becoming more and more interconnected over time. The convergence of IoT and Big Data provides new opportunities and results in development of new applications in many fields, including business, healthcare, sciences and engineering. At the same time, various challenges are faced during processing and management of massive amounts of data, as well as during their storage in different environments. In this paper, we present a review of many approaches related to Big Data and IOT and discuss the encountered problems and open issues. Furthermore, we give a brief discussion on Big Data technologies in different IoT domains to facilitate and stimulate knowledge sharing across the IoT domains.*

***Keywords*:-** IoT, Big data, Big data analytics, Industrial IoT, RFID, Data Sets.

Introduction

Nowadays the development of network and information leads to the explosive growth of data. With the exponential growth of data that obtained through various approaches, Big data plays an essential role in large quantities of domains, including business, search engines, education, and so on [1].

Generally, big data refers to large data sets, collected by firms and governments, that are so large and complex that traditional data processing methods are inadequate to deal with the calculations needed to make sense of the data. These data sets are extremely valuable because of the vast information hidden within the data structures. When analyzed computationally, big data can provide more precise insights into hidden patterns, trends, and associations, especially in the context of human decision making. The term "Big data" is believed to be originated from the Internet search companies who had to query loosely structured very large distributed data.

More than 50 billion devices including smart phones, laptops, sensors, and game consoles are forecasted to be connected to the internet via several disparate access networks, such as Radio Frequency Identification (RFID) and Wireless Sensor Networks. If we do not have any solution to this increasing volume of data over the time, gradually, this amount of data will stop us. Therefore, we must think about the processes of transferring, processing, and storing data. In the table 1, we are showing the comparison between a traditional database (i.e. RDBMS) and big data in terms of some parameters.

Table1: Comparison between relational database system (RDBMS) and Big Data.

Parameter	RDBMS	Big data Solutions
Data Size	Gigabytes	Petabyte
Data type	Structured	Semi-structured or unstructured
Access	Interactive and batch	Batch
Update pattern	Read/Write many times	Write once, read many
Structure	Static schema	Dynamic Schema
Integrity	High (ACID)	Low
Scaling	Nonlinear	Linear

From above table, it is clear that the big data area is used for the large volume of data that has no specific structure. Therefore, we can use big data on IoT, which has numerous and various device connections that lead to the creation of a large volume of data in different variations and high generation velocity. By studying IoT and big data articles, we concluded that we could use big data in storage, transmission, processing, and analysis.

With regard to the definition of Big data, IBM used volume, velocity, variety, value and veracity as 5Vs to summarize the concept of Big data. More commonly, a dataset can be called Big data if it is large enough and contains valuable information at the available analysis technologies. The term big data was coined by Doug Laney in the early 2000 and his definition includes three concepts [1] that is shown in Figure.

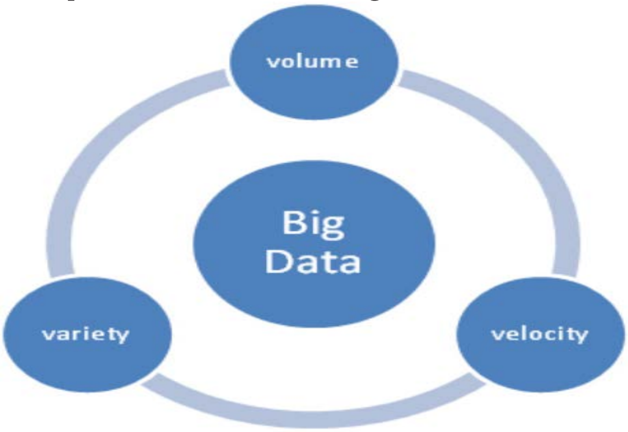

Fig.1: 3V's in Big-Data.

Volume: It is the type and detail of data being collected. Today, the volume of data collected from consumers and by agencies continues to grow but because of computing capacity, storage is no longer an issue.

Velocity: It is the speed at which data are collected. Data are no longer lagged. Instead, data are being collected in real time at incredibly fast rates.

Variety: It is the types of data being collected. Whereas basic demographic data, attitudes and opinions, and possibly geographic information might have been collected in the past, today nearly anything and everything a consumer does online is being captured.

Apart from above, Big Data has been also classified according to five fundamental elements, which are volume (size of data), variety (different types of data from several sources), velocity (data collected in real time), veracity (uncertainty of data) and value (benefits to various industrial and academic fields). Moreover, other researcher has also introduced additional characteristics beyond the 5Vs model such as: validity (correct processing of the data), variability (context of data), viscosity (latency data transmission between the source and destination), virality (speed of the data sent and received from various sources) and visualization (interpretation of data and identification of the most relevant information for the users). Despite the existence of additional characteristics of Big Data, the 5V model lays the foundational description of the Big Data concept. Recently, Big Data research has been undergoing substantial transformation from its research harvest towards its high impact and applications in different areas [7].

Since IoT connects the sensors and other devices to the Internet, it plays an important role to support the development of smart services. In other words, the dynamic things collect different kinds of data from the real-world environment. Afterwards, the extraction of relevant information from IoT data can be used to improve and enrich our daily life with context-aware applications, which can for example display contents related to the current situation of the user. Further, context can be defined as the information that is used to characterize the situation of entities (i.e. whether a person, place or object) and the situation is considered to be relevant to the real-time interaction between a user and an application, including the user and the application themselves.

As context is typically featured by location, time, state of people, and environmental settings, IoT becomes an important source of contextual data with an enormous volume, variety and velocity, which makes it an interesting and challenging domain for Big Data research. The fusion of Big Data and IoT technologies has created opportunities for the development of services for many complex systems like Smart Cities. Several Big Data technologies have emerged to support the processing of large volumes of IoT data, which are collected from different sources in the smart environment. However, the advancement of IoT and its applications in many different domains are causing a significant increase of vast amount and different types of data. At the same time, Big Data and its technologies have opened new application opportunities for industries and academia to develop new IoT solutions. Therefore, the fusion of Big Data and IoT, as well as the highly dynamic evolution of the two domains, create new research challenges, which however have so far not been recognized and addressed by the research community [7].

Another significant technology trend that nowadays is gaining increasing attention is Internet of Things (IoT). In IoT, intelligent and self-configuring embedded devices and sensors are interconnected in a dynamic and global network infrastructure, enabling scalability, flexibility, agility and ubiquity in fields of massive scale multimedia data processing, storage, access and communications. IoT is driving new interest in Big Data, by generation of enormous amount of new types of data being generated by sensors and other input devices, which have to be stored, processed and accessed. The need to monitor, analyze and act upon these data brings many issues like data confidentiality, data verification, authorization, data mining, secure communication and computation [4].

The terms of big data and big data analytics have been utilized to describe analytical techniques for data- sets that are so large and complex, needing advanced data storage, management, analysis and visualization technologies. In that rapidly growing environment, the velocity of data makes the conversion of data into valuable knowledge quickly a necessity. The differences between conventional analytics and fast analytics with Big data is explained in many parameters like analytics characteristics (i.e. type, objective and method), and data characteristics (i.e. type, age/flow, volume), and it is illustrated in Table 2.

Table 2: Comparison between Conventional and Big Data Analytics.

Parameters	**Conventional analytics**	**Big data analytics**
Analytics type	Descriptive, Predictive	Predictive, Prescriptive
Analysis methods	Hypothesis-based	Machine learning
Primary objective	Internal decision support and performance management	performance management
Data type	Structured and defined (rows & columns)	Unstructured and undefined
Data flow	> 24 h Static pool of data	< Min Constant flow of data
Data volume	Tens of terabytes or less	100 terabytes to petabytes

The rest of this paper is organized as follows : In the Section 2, we describe different domains of IoT, where Big data are generated and applied. Section 3 explains about how IoT and big data can be integrated for further processes. Benefits of IoT based Big Data are discussed in Section 4. Section 5 discusses about how BDA is used for providing intelligent information for industrial IoT. In section 6, we conclude our review paper.

II. Domains of IoT generated Big Data

IoT technologies have been incorporated into various important domains in our life. Over the past years, many traditional domains such as manufacture industry, healthcare or energy have become IoT-based and gained the capability of communicating among machines and human, as well as production of enriched data. IoT domains refer to the IoT techniques that are applied in certain context such as healthcare IoT or transportation IoT. Furthermore, different IoT domains share a set of common features. For example, most of the IoT domains emphasize the data collection, monitoring, sharing, automation, control and collaboration. Also, their datasets usually consist of relatively homogeneous data records e.g. from sensors and other IoT devices, which are often in a time series. In the following, we are describing the IoT domains where Big Data approaches are applied.

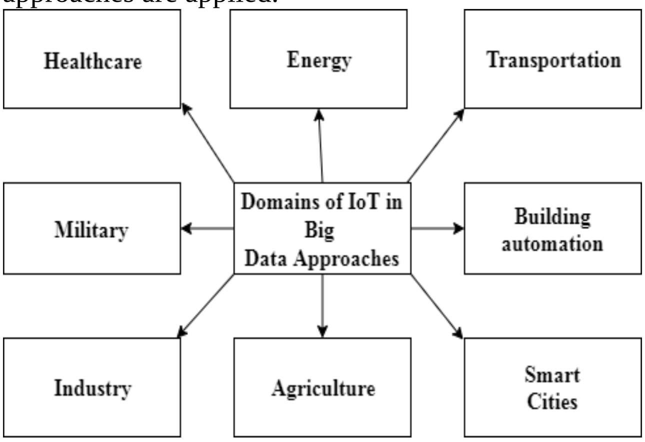

Fig. 2: Application areas of IoT generated Big Data.

Healthcare- The main purpose of applying IoT in healthcare is to gather and analyze real-time medical information in order to minimize the limitations of traditional medical treatment. Moreover, cloud platforms are used to store and analyze the collected medical data stream. Consequently, the gathered information about the patient's health status allows the healthcare organizations to develop ubiquitous healthcare applications and optimize the existing services and solutions, i.e. applications for remote monitoring, nutrition, medicinal products, medical devices, medical facility, or health insurance. Hence, the application of IoT in healthcare domain aids to find the best health condition and healing plan for patients.

Energy- Energy is mostly featured by smart grid IoT, which is an emerging intelligent electricity distribution system that aims at integration of renewable resources in power systems, greater control of the grid for its operators and consumer engagement in optimal power consumption. Besides, smart grid offers many valuable services such as distribution and consumption management, transmission, advanced metering infrastructure, renewable energy integration, self-healing systems and energy storage. For these reasons, the smart grid has been considered as one of the smart technologies that will contribute in the development of Smart Cities by guaranteeing the efficiency, reliability, sustainability and safety of the electric grid. To achieve these goals, smart grid cooperates with IoT technologies to create various intelligent services, and it uses Big Data technologies to achieve the insightful intelligence and efficient power management quality.

Transportation- Due to IoT technologies, the intelligent transportation systems have become more ubiquitous. Since transportation is one of the key activities for each citizen, the IoT sensors produce each day a significant amount of data that can be used to guide route planning and develop the applications for surveillance, emergency management, traffic control, anomaly detection, situation recognition and traffic prediction. In addition, the shared transportation data can minimize the risk of pollution and traffic accidents that might damage the health of citizens. Therefore, the information sharing through IoT devices also contributes to a sustainable smart environment.

Building automation- The integration of a large number of heterogeneous IoT devices installed in smart buildings, i.e. homes, faculties and offices, is enabling monitoring of everyday activities of the citizens as well as predicting their future actions. As a result, IoT devices in smart buildings gather sensitive information that is timely and describes very detailed interactions between humans and machines. Hence, understanding how general and personal information can advance the smart building research and is critical to optimize the smart services offered in smart buildings, such as security, access control, digital video, intrusion detection, fire detection and alarm, indoor air quality services or lighting control.

Smart Cities- The vision of Smart Cities is to improve the lifestyle of citizens by providing smart applications in various fields. To achieve this goal, the city employs IoT technologies to optimize different public systems and services, such as car parking, city cleaning, waste management, street lightning and emergency control. The big picture for Smart Cities can be illustrated with existing projects, such as SmartSantander, which is being considered as a practical system for a large-scale Smart City test bed. Collection of data is a key initiative in case of smart cities to get experience and knowledge necessary to support the rapid development of the Smart City.

Agriculture- Agriculture is a vital domain of our society that also takes advantage of the benefits from IoT technologies to assure the quality of the products and the satisfaction of end-customers. For example, monitoring from IoT devices plays an important role to protect the agricultural products from attacks by rodents or insects. To effectively manage all the agricultural activities and find the optimal environmental conditions, cloud platforms are used to store and analyze the sensed information and in turn improve the agricultural productivity as well as save energy.

Industry- The development of IoT applications for future industrial automation is a highly promising topic in the industry and manufacture domain. Modern industrial companies adopt the IoT research to boost the growth of the global economy and to keep competitive advantages. There are many IoT applications in industry such as the development of industrial IoT competences by integrating IoT technology and its usage for the training in digital learning factories, product supply chain management, machine-to-machine (M2M) communications or energy saving. It is often focused on the deployment and exploitation of company's own or shared data to provide suitable goods that the customer favours as well as the improvement of the functionality of the industrial IoT systems, i.e. performance evaluation, intelligent M2M communications, simulation, modeling and industrial wireless networks.

Military- The application of IoT is also extended to the military domain and brings a significant and valuable source of information that could improve the intelligence of various military applications such as military logistics, surveillance and military robots. Furthermore, the integration of IoT in military domain is expected to save lives of citizens by detecting harmful chemicals or biological weapons. For these reasons, the management and analysis of the shared information is necessary to make the right protective decisions, provide guidelines to perform the tasks as well as understand, in real time, the implications of these decisions.

III. Integration of IoT and Big Data

The Internet of Things means the production of tremendous amount of data and a collection of substantial different data bulk that has not seen so far. Big data management and generating smart data are the research interests of the companies which produces these data. Without the application of big data analytics, the vast volume of data generated by the Internet of Things adds to the overhead of any organization and considered to be one of the most significant obstacles towards the deployment of this technology. In other hand, organizations must know what to do with the massive amount of data that collected. The explosive growth of Internet use, along with Smartphone and social programs and machine-to-machine (M2M) communication, has revolutionized big data [3]. With the help of the Internet of Things technology, the ability to connect each object to the network is provided.

The Internet of Things offers a chain of connected people, objects, applications, and data over the Internet for remote control, interactive, services integration and management. Hence this network is overgrowing; we need a platform that can collect and store the data generated by IoT devices. Some of the advanced Internet of Things services require a mechanism to collect, analyze and process raw data from sensors to be used as operational control information. Some types of sensor data may have very high volumes because of the significant number of sensors in the Internet of Things ecosystems. Possibly, we would see a data flood coming from these devices. Accordingly, we need new technologies or architectural patterns in the area of data collection, storage, processing, and data retrieval. As we have already understood that IoT affects people, processes, data, and things.

People- More objects can be monitored and controlled, and subsequently in-creased individual's abilities.

Processes- Users and more machines will be able to interact with each other in real time. Therefore, very complex tasks can finish in less time as the percentage of engagement and participation in doing a job is far more significant.

Data- The ability to collect data at a higher frequency and reliability provided which can lead to a correct decision making.

Things- the ability to control things more accurately. Therefore, the value of objects such as mobile devices will be more and can help with much more than the current situation.

A collection, preparation, and analysis of large volume of data will not be an easy task. Firstly, the amount of data can be doubled in several months and secondly, the gendered nature of this kind of data has its particular complexities. The variety in the template or the format of this type of data is extensive and often includes hundreds of pseudo-structured forms or unstructured formations. Most importantly, to achieve a broad view of the sensor data, it should be possible to analyze and manage every structured and unstructured data. An analysis based on a specific data format can significantly limit the created potential insight.

Organizational data ware-houses are not able to focus on unstructured data. Accordingly, we need to look for solutions that enable unstructured data storage and analysis [14]. If we want to convert the unstructured data into a specific structure by defining a particular structure and using relational database tables, we will lose time. Consequently, that will surely be possible with the condition of not having the technical limitations. The use of any technology to create an analytical infrastructure that has some limitations can reduce the ability to analyze and, in practice, minimizes the potential for possible value creation.

Analysis of big data with the help of related technologies can be one of the leading actors in this field. Analyzing big data in some cases can help anyone in combining, integrating and analyzing all structured, semi-structured and unstructured data regardless of source, type, size, and format. It is also possible to create an appropriate insight into a decision making process by a quick and cost effective analysis of the high volume data.

IV. Benefits of IoT based Big Data

Various structures for big data analysis and IoT proposed, which can manage the challenges of storage and analysis of high volume data from intelligent buildings. The first presented structure consists of three main components which are big data management, IoT sensor, and data analysis. These analyzes use are in the real-time management of oxygen level, dangerous gases/soot and the amount of ambient light in smart buildings. In addition to smart building management, IoT devices and sensors for receiving traffic information can be used in real time traffic management with low cost and examine the strengths and weaknesses of existing traffic systems.

Sometimes it is essential to pay attention to the concepts of web technology in particular proposed framework to investigate the analytical results obtained from the big data in the Internet of Things. We have created a conceptual framework consisting of 5 layers and they are shown in figure 3 and also discussed below :

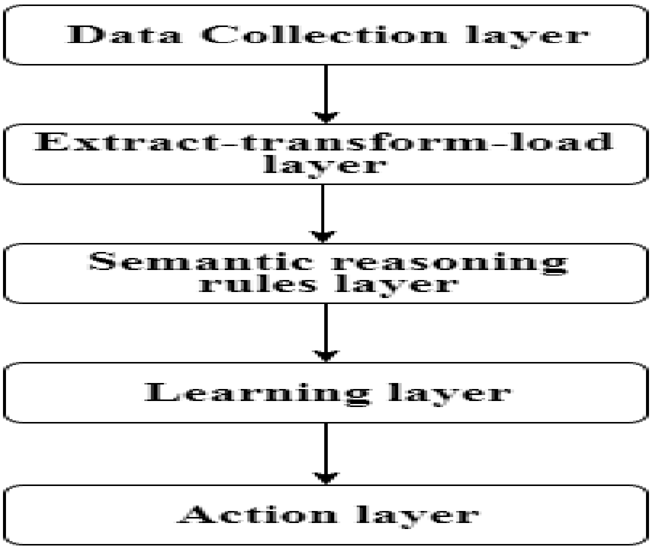

Fig. 3: Framework of analyzing big data in IoT.

Data Collection layer- This layer collects data from various sources, and it is the input layer of our framework.

Extract-transform-load (ETL) layer- This layer provides the ability to change the format of information received from different types of sensors into a defined format.

Semantic reasoning rules layer- It is an inference engine that acts on the information received from the ETL layer

Learning layer- From the data tailored to the existing extraction data, this layer extracts the various specifications and attributes, and finally, machine learning-based models provided.

Action layer- This layer executes a set of predefined actions by the outputs of the learning layer.

V. BDA for Delivering Intelligence in IIOT

IIoT (also known as Industry 4.0) is currently attributed as the fourth industrial revolution. The technology ecosystem underpinning IIoT is mainly the integration of cyber physical systems (CPS), Internet of Things, cloud computing, automation, Internet of service, wireless technologies, and augmented reality, amongst others. Big data analysis (BDA) is a related area that enables IIoT systems to deliver value for data captured from cross platform integration. BDA refers to the process of collecting, managing, processing, analyzing and visualizing continuously evolving data in terms of volume, velocity, value, variety and veracity. Big data in IIoT systems arise due to unbounded internal and external activities relevant to customers, business operations, production and machines. BDA processes in IIoT systems manage the collected data using multiple transient and persistent storage systems that provide on-board, in-memory, in-network and large-scale distributed storage facilities across IIoT systems.

The granularity of data processing facilities for BDA processes in IIoT systems vary from resource-constrained IoT devices to resourceful large-scale distributed cloud computing systems. BDA processes are executed as a result of multistage highly interdependent application components and these components are categorized as follows :

Data Engineering- Data engineers build computing and storage infrastructure to ingest, clean, conform, shape and transform data. IIoT systems produce and ingest big data from inbound enterprise operations and outbound customer activities. The raw data at the earliest stage need further processing to improve the quality and establish the relevance with IIoT applications. Therefore, data cleaning methodologies help to select relevant datasets in case of historical data or data streams in case of streaming data. Data conformity procedures are applied to ensure relevant, correctly collected big data. Data shaping and transformation methodologies help to improve data quality by reducing the number of attributes and converting data formats for uniform data processing.

Data Preparation- Big data emerge in raw form with large volume and enormous speed, and data scientists spend 70% - 80% of their time in data preparation activities. Big data are refined using statistical methods to handle unstructured, unbalanced and non standardized data points efficiently. Data refinement helps to summarize voluminous data to reduce overall complexity. Accordingly, further involvement by data scientists is required to perform data cleaning and noise removal. Detection methods for outliers and anomalies are also needed to prepare big data for further analysis.

Data Analytics- The analytic processes in IIoT systems are executed in multiple phases. Data scientists generate learning models from high-quality well-prepared data. After the model is developed, model scoring operations are performed by giving sample datasets and finding and ranking the attributes in datasets/data streams. The correctly tuned models are deployed in production environments to find the knowledge patterns from future data.

Managing and Automating the Data Pipeline- Although existing literature still lacks the concept of automated data pipelines in IIoT systems, BDA processes are executed as a sequence of operations during data engineering, preparation and analytics. Life cycle management is needed for full process execution from raw data acquisition to knowledge visualization and actuation. The continuous evolution in data streams results in knowledge shift that enforces data pipelines to adaptively reconfigure analytic processes. The data pipelines need to be continuously monitored for change detection, and the entire BDA process needs to be re-executed to produce high-quality results.

VI. Conclusions

Big Data refers to large and disparate volumes of data generated by people, applications and machines. It is gaining increasing attention from a variety of domains, including education. The development of IoT devices, smart phones, and social media provides decision makers with opportunities to extract valuable data about users, anticipate future trends and fraud detection. With the creation of transparent and usable data, big data can create the organizations' values, make the changes clear and expand their performance. The use of data generated from the IoT and the analytical tools creates many opportunities for organizations. In this paper, we present the frameworks and case studies of the various enterprises that have benefited from BDA. This paper discusses the rise of big data in IIoT systems and presents a detailed discussion of related technologies, and domains. Here we have also reviewed on Big Data technologies in different IoT domains to facilitate and stimulate knowledge sharing across the IoT domains. This paper discusses the similarities and differences among Big Data technologies used in different IoT domains.

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