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Towards an Internet of Things (IoT) based Big Data Analytics

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Abstract. Introduction: Internet of Things (IoT) is an emerging area in a computing environment. A large number of devices connected to Internet results to generate an explosive amount of data day by day. Actually, the generated data through these devices can be named as big data. In connected networks, the management of generated data involves data collection, analysis, processing, storing and security etc. To deal with the management of big data researchers shows great interest and face several challenges related to the deployment of IoT devices. There has been published a large number of studies on big data analytics and IoT, so the convergence of these areas provide several opportunities for researchers to explore further in big data and IoT. **Methodology:** In this paper, we pinpoint the recent advances in the management of big data analytics in IoT environment. We critically review the latest literature on the emergence of IoT with big data analytics. **Results and Conclusion:** This paper discusses the processing and analytics platforms for big data with key requirements in IoT environment. We highlight some important parameters for big data analytics. Further, we identify some opportunities for effective big data analytics

Keywords: Internet of Things, Big Data Analytics, Smart Environments, IEEE, ACM

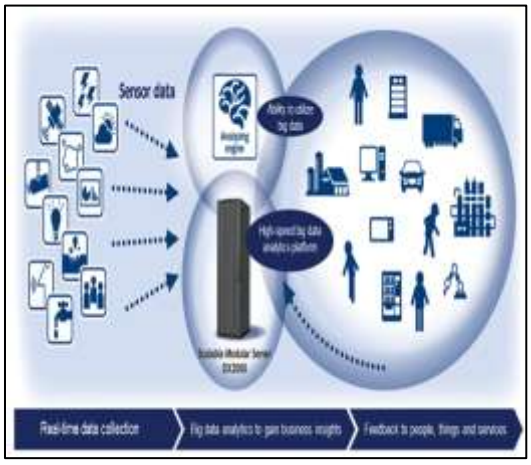
1. Introduction

The emergence of the Internet of Things (IoT) rapidly goes to increase day by day by the convergence of wireless networks and microsystem technologies. According to the report generated by Cisco, the emergence of internet connected devices has exceeded the total number of humans that are existing in the world. These devices may include different sensors, wearable devices, smartphones, personal systems etc. and are shown in Fig, 1. In the coming four to five years there will be a rapid increase in the internet connected devices and human beings will control different objects through these devices. IoT devices monitor different events by the use of different Wi-Fi enabled sensors and these sensors require custom protocols like "Message Queue Telemetry Transport" (MQTT) to establish communication between different internets connected objects. Different industries use sensors for the collection of information, so the data generated through these IoT enabled sensors may be in massive volume. IoT enabled devices to help us to find the potential research trends. The generated data through these IoT enabled devices are

being processed by the use of different analytics tools [1]. The capturing of data, data processing and data analytics in IoT environment is represented in Fig, 2.

The efficiency of multiple works is being increased by the use of IoT that results in increasing the revenue of organizations by reducing the costs. Collection of massive volumes of data through IoT devices is difficult to handle.

Fig, 1. Sources of Big data in IoT



Fig, 2. Data flow in IoT

Companies and organizations create platforms on which they can easily collect, manage and analyze the data in an effective manner through IoT devices [2]. The big data platforms are being considered vital because these platforms handle the diverse type of data. Organizations can improve their business processes and give their customers appropriate information and feedback on the spot by correctly

analyzing the huge volumes of data. Different analytics tools are being used for mining of information generated by sensors. By identifying the latest research trends in IoT and Big Data Analytics the paper focuses on the emerging trends in IoT with emphasis on big data analytics. In section 2 we discuss the recent advancements and emerging trends in IoT by considering big data analytics an important element. In section 3 we discuss the processing and analytics platforms for big data with key requirements in IoT environment. In section 4 we highlight some important parameters for big data and analytics. In section 5 we identify some opportunities for effective big data analytics. Section 6 concludes the whole paper.

2. Recent advancements and emerging trends in IoT

IoT is a fast-growing area of research due to rapid convergence of wireless sensors that are being used for the collection of massive volumes of data. Smart buildings are being created by the use of IoT. Smart buildings originate large and massive volumes of data. To handle these massive volumes of data is a challenging and worthy task. In [3] authors propose a framework based on IoT and Big Data for managing

The challenges related to the storing and analyzing of data that is being generated through smart buildings. As sensors are being deployed in smart buildings for the collection of massive volumes of data so the framework is actually integrated IoT Big Data Analytics (IBDA) is proposed in this research work. The said framework is developed by using the Python language and "Cloudera Hadoop" distribution. Data analytics is performed by using Pyspark in this study. The proposed framework manages the oxygen level, air temperature and luminosity in different parts of the smart buildings. Their proposed framework can be used in other IoT applications like smart cities, smart hospitals and in smart environments.

In [4] authors propose a cyber-physical system based on IoT to improve the production standards in various industries by analyzing the information. To meet the business needs the proposed CPS have the capabilities to interchange the modules with each other? The authors of this paper also proposed a new contextual framework of intelligent nature to manage industrial big data generated through sensors and have the capabilities to mining the unstructured data into meaningful insights. Further, they present a case study to explain the working of CPS.

In [5] propose a cost-effective traffic management system by comparing their work with other traffic management systems. They highlight the strengths and weakness of other traffic management systems to prove their work a great work. To capture the real-time information related to the traffic they propose a cost-effective and real-time traffic management system by deploying IoT sensors and devices. Traffic sensors having low costs are embedded in the middle of the roads for every 500 to 1000 m distance. They used predictive analytics methods and various data analytics tools to analyze the collected data from traffic sensors. For measuring the density of traffic they develop a mobile application that helps them to manage traffic in an alternative way.

In [6] authors propose a Firework, that allows processing of data in a distributed manner by using IoT based collaborative edge computing. Virtual data views of physically distributed data can be viewed by end users through this Firework. All participants who are involved in this Firework can access these virtual data views. Detailed data analytics can be performed by merging these data views into a single job.

The authors of this paper attempt multiple case studies as "connected health and find the lost" to illustrate this concept.

In [7] authors propose an efficient smart city management system (SCMS) based on IoT and big data analytics. To establish a smart city the authors of this paper use multiple sensors for the collection of city data. The sensors used for developing SCMS includes smart home sensors, water and weather sensors, smart parking sensors, surveillance objects, vehicular networking, etc. They proposed a model for this purpose by using Hadoop ecosystem in a real environment. All types of data management including data generation, data capturing, processing and decision making is done in the implementation process of their proposed system. Spark over Hadoop has been used there for the effective big data processing. However, the accuracy of their proposed system is yet under observation.

In [8] authors highlights the significance of using IoT for the improvements of living standards of citizens including health services and energy efficiency. The authors suggest that the systems that are being developed by using IoT must be based on open data and there must be involvements of third-party innovation. A GreenIoT platform is developed by the authors of this paper in Sweden to evaluate the advantages of open data platforms for the development of smart cities.

In [9] authors introduced the advanced framework based on IoT, big data, and semantic web-based technologies. The authors performed the analysis of their proposed framework of IoT based system by analyzing the key requirements. Their proposed framework consists of five layers that include data acquisition, extract transform load (ETL), semantic rule reasoning, learning, and action. These layers perform different functionalities that range from data collection to data analyzed by extracting different features of data and then provide an output of the learning layer.

In [10] authors work for designing a system, that has the capability of extracting real-time data streaming from the deployed sensors to make fast decisions and the authors give the name to this edge analytics platform as Geelytics. This platform performs low latency analytics of geo-distributed data from IoT sensors. Dynamic stream processing is supported by this framework.

In [11] the authors try to develop a framework by merging the big data analytics and IoT technologies for the maritime cluster to revolutionize the industrial outcomes and productivity. In [12] this paper the authors aim to develop such a system that can handle the workload of IoT generated data on a cloud platform by using advanced centric technologies and multiple software solutions. The authors give this platform the name of ServIoTicy API. In [13] authors proposed a solution for the big data processing and analytics by developing a system "AllJoyn Lambda". This software solution has the capability of storing a large number of sensors collected data and can analyze the data in an effective manner. In [14] authors conduct a study to pinpoint the existing challenges and solutions for the data generated by cyber-physical systems. Their study focuses on the integration of data coming from different sources and they highlight the need to develop such a system that can perform real-time data processing and analytics.

In [15] authors propose a mechanism called IoT-Statistic DB for the analysis of big data by using statistical operations. Multiple servers have been used there for the analysis of big data in distributed and parallel fashion. In [16] authors reviews the role of data analytics in healthcare and identify that the body sensors generate a massive volume of data related to health. As identified by the authors of this study

generation of electronic health record and presenting this record to health service provides is a challenging task. The authors of this study suggest the scalable cloud architecture by proposing a sensor integration framework. Spark and Apache Kafka are used for processing of a large amount of sensor data in real-time. But their proposed framework lacks the security.

In [17] authors attempts to predict the human behavior in social IoT environment by using IoT and big data analytics. Their proposed architecture comprises three operational domains. They also analyze the use of collaborative filtering techniques to analyze and determine the human behavior. In [18] authors classify network-enabled devices by utilizing the techniques of big data and analytics in an IoT environment. KNN, SVM, NB, and RF algorithms have been used by them for analysis and classification. The authors of this study explain the results of experiments by comparing all the results of all these four machine learning algorithms and highlight that the accuracy of SVM is best among all of them.

In [19] authors arrange an exploratory study to preserve the privacy of location in the modern era of IoT with big data and analytics. The authors of this study try to describe the privacy issues in a wide manner in the context of IoT and big data. They have a plan to develop a framework for future to control location privacy. In [20] authors claim that smart devices of IoT as like mobile phone and home gateways can perform the data parallel analytical jobs. They proposed a suitable algorithm that can perform processing and analysis of massive volumes of data. Their results are highly appreciated because of the use of parallel analytics algorithm in an IoT environment. In [21] authors proposed a framework for data parallel processing and analytics in an IoT environment. Their designed framework "Condor" has a great performance of data parallel execution if we compare it with another traditional database model.

For IoT crowd sensing application, a framework "MIST" is proposed based on fog computing [22] and is used for data analytics. The latency of service can be reduced and real-time data processing can be improved by using their proposed "MIST" framework based on fog computing. In [23] authors investigates several problems arises due to the implementation of smart devices in smart city environments and try to minimize the cost of collecting data in real time environment by proposing a system. Their proposed system has a four-tier architecture. Their proposed system has the capability to establish communication among different sensors. Data is collected and then processed by using Hadoop framework and then different analytics techniques have been used for analysis of data. Their proposed system has good processing time in the real-time environment.

Data mining algorithms including SVM, NB, LDA, ANN, KNN have been applied in a work [24] to determine the execution time and accuracy of data processing in real time environment for data generated through IoT devices. The authors of this specific study have the plan to implement these algorithms for diverse IoT systems in future. In [25] authors propose a framework to monitor and analyze the massive volumes of data collected from the internet of Underwater Things (IoUT). For data processing they use MapReduce and after using MapReduce for data processing they analyze that MapReduce has less query execution time as if they compare it with SQL. Modern systems can take the place of old traditional systems by implementing IoT in manufacturing industries [26]. Hence industrial big data can be generated through the use of IoT. The authors of this specific study demonstrate their work by providing a case study of integrating almost hundred machines with IoT.

3. BD processing and analytics platforms

Fog computing [27], mobile edge computing [28, 29] and cloudlets services [30] have been used for big data processing and analytics in an IoT environment. This section provides the BD processing and analytics platforms with key requirements and these platforms will be used for managing and analyzing massive volumes of IoT generated data.

3.1. Apache Hadoop

Apache Hadoop [31] provides an open source platform where a massive volume of data can be stored and analyzed in well effective and efficient manner. This platform was first used by Facebook and Yahoo! MapReduce and Hadoop Distributed File System (HDFS) are the most familiar and important components of Hadoop architecture. In Hadoop data is stored by using HDFS and processed by using MapReduce [32]. In small data sets, Hadoop is not considered a suitable platform because it lacks encryption at network and storage levels.

3.2. MapR

MapR is a framework that can process and analyze massive volumes of data. To deal with security and privacy some components of Hadoop has been used in the MapR framework by replacing HDFS with network file system (NFS) [33]. Predictive analysis and fast processing of data can be done by using MapR. Only the one challenging task in MapR is its complexity as compared to Hadoop.

3.3. Cloudera

To process and analyze massive volumes of enterprise data generated through IoT devices a framework known as Cloudera has been introduced. Cloudera is based on Hadoop framework. Cloudera combines multiple components to achieve reliability and security. This tool normally depends on third parties due to not having its own hardware and software. Cloudera data hub [34] can be used for collaborative data analytics.

3.4. Infobright

Analysis and data management of large-scale data is a challenging task. A tool known as Infobright [35] is designed to solve these challenges. Data up to 50 terabytes can be analyzed by using Infobright. Machine generated data (IoT data) can be easily analyzed by Infobright due to its high compression. The Infobright tool is also based on Hadoop framework. Due to its columnar design, only related data will be processed by Infobright during query processing.

3.5. 1010data

1010data is a tool used for large infrastructure [36]. This tool has columnar database design and can easily handle IoT data. This tool has advanced capabilities of performing statistical analysis and data optimization to satisfy customer demands. In terms of Extract Transform Load (ETL) this tool is not considered an effective tool.

3.6. SAP-Hana

To address the transactional needs a framework called SAP-Hana [37] was introduced to perform IoT based big data analytics. A large amount of transactional data that may be in unstructured format can be analyzed by the use of SAP-Hana. In SAP-Hana data unstructured data from any row and column can be accessed but the capabilities of SAP-Hana are limited as compared to other analytics platforms.

The requirements of adopting IoT based big data analytics have been revolutionary increased due to the advance decision making abilities of devices over the past few years. The way for collecting and analyzing of data has been changed due to the convergence of IoT based big data and analytics. Data generated through sensors could be analyzed through the tools and techniques of big data and analytics to extract meaningful information. Some functional and nonfunctional requirements to improve the productivity of big data in IoT environment are presented here.

- *Connectivity*

Machine sensors generate massive volumes of data in IoT environment and one of the most important requirement is reliable and strong connectivity between different components of the system for effective big data analytics. IoT services can be enhanced by improving the connectivity between devices. However, due to the rapid growth in WI-FI and 4G-LTE wireless network access[38], the communication between different devices is already effective. Although in smart city environment [39] to embed intelligence there should be strong connectivity between IoT, Big Data Analytics, and cloud computing.

- *QoS*

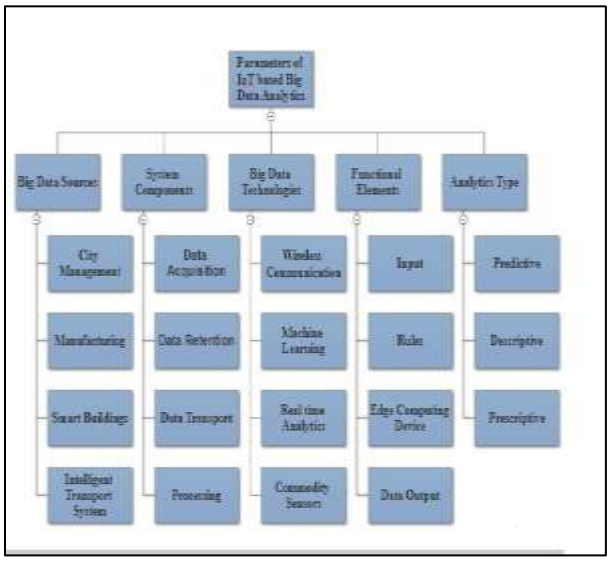
To analyze the massive volumes of data generated through IoT devices and mobile devices the QoS is considered an important requirement for effective resource sharing. However, there have been published a large number of studies to deal with the QoS in IoT environment [40] to effectively analyze big data. QoS should guarantee the real-time data transfer generated through IoT devices. There is a need of implementing advanced technologies in IoT environments to improve the capabilities of big data processing.

- *Storage*

The requirements of storing massive volumes of IoT generated data is the main concern, to handle and manage the unstructured data by providing low latency for analytics. Big data tools, techniques, and applications have been used for data processing and analytics to enhance the services of smart cities. Sensor data, social media data, smart applications data of smartphones are the big sources of data generated through IoT devices. To establish reliable communication, machine to machine (M2M) communication protocols have been embedded in IoT services as the storage capacity of Cloud computing infrastructure [41]. Real-time data analytics is the key requirement of IoT generated data to make on the spot decisions [42], so the analytics must be performed in real-time more quickly to help organizations to make decisions by obtaining insights.

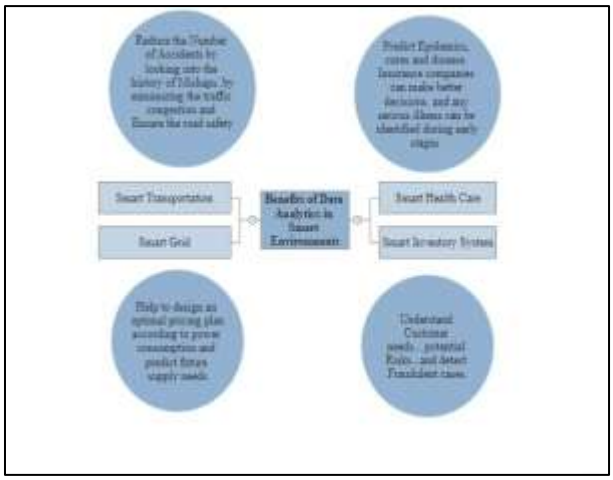
4. Parameters of IoT based big data analytics

This section provides an overview of the parameters related to the IoT based big data and analytics. The categorization of these parameters is given, as like Big Data Sources, System Components, Big Data Enabling Technologies, Functional Elements, and Analytics Type. IoT applications play an important role in generating big data. These IoT applications may include smart city management, Intelligent Transport System (ITS) and sensors. As in smart city management system, a massive amount of data is generated through sensors, cameras, to provide security to the citizens. So definitely this data needs to be analyzed and processed to collect useful information. Similarly, smart industries use IoT sensors to maximize the productivity of their products. In smart industries for the designing of new and advanced material products IoT based big data and analytics solutions have been used. The overall goal in all smart environments is to extract the valuable insights from massive volumes of data. After this extraction of valuable insights, decision makers improve the service management. Fig, 3. Represents some Big Data Sources, System Components, Big Data Enabling Technologies, Functional Elements, and Analytics



Fig, 3. Parameters of IoT based Big Data Analytics

Type. Furthermore, their classification could be understood by the same Fig, 3. Both IoT and Big Data analytics are beneficial for each other. IoT applications such as Smart Transportation, Smart Healthcare, and Smart Grids [43, 44] have been increasingly adopted applications in smart environments due to the Big Data and Analytics. These applications are taking advantage of big data and analytics as shown in Fig, 4.



Fig, 4. Benefits of Data Analytics in Smart Environments.

5. Opportunities

This section provides opportunities for big data and analytics in the context of IoT.

5.1. Effective Decision Making

The expanding trend of IoT devices, smartphones, and social computing provides an opportunity for decision makers to predict the future trends by extracting the most important information about their users. Transparent information can be only retrieved by the effective use of big data analytics. The data generated through sensors and the analytical tools provide several opportunities for organizations to improve the productivity after viewing the adopting trends of their customers. Classification and clustering techniques can be applied for attaining data mining solutions. Hence by the use of big data and analytics, the decision-making abilities of individuals can be improved.

5.2. Efficiency

Efficiency could be only achieved by the use of cost-effective tools and techniques. Big Data technologies such as Cloudera and Hadoop have the ability to store and process massive volumes of data in effective and efficient manner. These technologies of big data have the ability to handle the diverse data of different types whereas traditional analytics techniques require the data into a specific format before processing and storing big data.

5.3. Value Added Applications

Some advanced technologies (Machine Learning [45], Artificial Intelligence [46], and Deep Learning [47]) use IoT and Big Data Analytics provide value-added applications to different industries and vendors. Before IoT and Big Data Analytics the computation power for such applications was very low. Different analytical platforms [48] and business intelligence platforms [49] have merged by the use of IoT and Big Data Analytics to improve productivity.

6. Conclusion

As there are different sources of big data and IoT is one of them. Without analytics power these sources are useless. There are a strong connection and interaction between IoT and Big Data Analytics. The presented work in this paper mainly focuses on IoT based Big Data Analytics. This paper provides a detailed insight of current literature related to IoT based Big Data. We have discussed the Processing and Analytics platforms for big data by considering key requirements in IoT environment. We highlighted the important parameters of BDA and in the same section, we highlighted the benefits of data analytics for IoT applications. And in the last section, we highlighted the opportunities for effective big data analytics in the context of IoT. Further work needs to be carried out in many areas such as data organization, domain-specific tools, and platform tools in order to create next-generation Big Data infrastructures based on IoT. We will further work on these emerging areas to overcome different challenges in future.

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Competing interests

The author declares no competing interests.

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