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EDGE COMPUTING VS. CLOUD COMPUTING: CHALLENGES AND OPPORTUNITIES IN INDUSTRY 4.0

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Abstract

With the technological development of advanced technologies and the use of the Internet of Things (IoT), the number of connected devices is increasing in manufacturing processes. As devices become more and more incorporated using more processing power, the big data is generated. However, increasing the generation of big data leads to problems related to processing and analysis. The current tendency of solving the problems of processing and analysis is via Cloud Computing technologies. However, more attention is dedicated of performing computations as close to the device as possible, relying on Edge Computing technologies. Motivated by these facts, this paper provides a comparative analysis of the roles of edge computing and cloud computing, summarizing challenges and opportunities of these technologies and providing their application in Industry 4.0.

Keywords: Industry 4.0; Internet of Things (IoT); Cloud Computing; Edge Computing; Data Analytics.

1. Introduction

Industry 4.0 or intelligent industry, is the major component of fourth industrial revolution [1]. Industry 4.0 is transforming many sectors, especially manufacturing, offering higher efficiency across many dimensions as well as innovative solutions that previously were not possible. All this due to available data and, based on it, better decision-making. The amount of acquired data is constantly increasing year by year, with technologies, broadly termed, Internet of Things (IoT) being main contributor to this trend [2], [3]. Enormous amounts of raw data generated in this way, named Big Data [4], [5] gradually started creating new generation of challenges in manufacturing. These extremely large and complex datasets need to be stored, processed and analysed using powerful software applications, which provide information, based on data analysis, valuable for manufacturing companies and its production.

Big Data cannot be processed and analysed with existing software applications and using personal computers due to insufficient processing power [4]. Manufacturing companies need to use Cloud Computing services [6] or to invest in more recent approaches such as Edge Computing technologies [3]. Cloud Computing offers the possibility of storing, processing and analysing Big Data generated via IoT, where data are located at one or more locations (external servers) provided by third-party [7]. The IoT connection adds the availability, scalability and accessibility of data using advanced statistical and machine learning tools via Big Data service [8]. Subsequently, Big Data and Cloud solutions are used together to bring valuable information for manufacturing companies, increasing agility, elasticity, accessibility and ease of processing [6]. However, security issues can be obstacle in implementation of Cloud Computing for many manufacturing companies [7].

Opposite to Cloud Computing, Edge Computing accepts data generated by various kinds of IoT devices and sensors, being located at the edge of the production process, inside manufacturing company. This make possible for Edge solutions to store, process, and analyse acquired data as close to physical source of data as possible [9]. The application of Edge Computing will make use of the computing capability of intelligent devices to achieve self-making decisions based on information and provide a real-time response in manufacturing processes [10]. However, the implementation of Edge Computing technologies

Motivated by similarities and differences between Cloud and Edge Computing, this paper provides a comparative analysis of the roles. Also, this paper summarizes challenges and opportunities of these technologies and providing their application in Industry 4.0.

The paper is organised as follows: Section 2 provides the background for the IoT, Big Data, Cloud Computing, and Edge Computing from the Data Analytics perspective; Section 3 outlines the current opportunities and challenges of both, Cloud and Edge Computing in Industry 4.0; while Section 4 presents conclusions and provides directions for the future research.

2. Background

The implementation of Data Analytics technologies combined with IoT can provide intelligent, flexible systems capable of self-configuration which represents the final goal of Industry 4.0 [11]. In order to achieve intelligent and flexible systems, the Big Data is required [12]. To discover knowledge in large databases, various advanced statistical tools, along with machine learning techniques, play an important role in the implementation of new technologies, namely Cloud Computing and Edge Computing [12], [13], [14].

Cloud Computing and Edge Computing, as parts of intelligent system in Industry 4.0, enable implementation in different areas of production processes. The analytical capabilities of these technologies are designed to extract knowledge from existing data and provide new valuable information. New information supports the process of self decision-making or prediction-making inside manufacturing system [11]. This section presents an overview of the related studies of IoT, Big Data, Cloud Computing, and Edge Computing technologies from Data Analytics perspective in Industry 4.0.

2.1. Internet of Things

Today, the growing number of devices are connected to the Internet, creating the Internet of Things (IoT) [15]. The IoT connects these devices, namely embedded devices, communication technologies, sensor networks, Internet protocols, Radio-Frequency Identification (RFID) tags and so on, via unique addressing schemes enabling the interaction and cooperation with each other to reach common goals [15], [16].

However, the multiple definitions of Internet of Things testify to the strong interest in the IoT issue. Atzori, Iera, and Morabito have proposed the first definitions of IoT is based on three perspectives, namely *"things", "Internet"* and *"semantic"*. In *"things"* oriented perspective of the IoT, the things are considered as a simple items, i.e. RFID tags, connected via network representing the *"Internet"* perspective. Besides these two perspectives, the *"semantic"* perspective is focused on appropriate modelling and language support for describing IoT objects, reasoning over data generated by IoT, semantic execution environments and architectures that accommodate IoT requirements, and scalable storing and communication infrastructure [16], [17]. Chen et al. [18] described IoT as *"a network, in which a massive number of objects, sensors or devices are connected through the information and communications technology (ICT) infrastructure"*. Kamble, Gunasekaran and Gawankar [19] definition of the IoT is oriented to communication speed and data collection that provides *"the real-time sensing and actuating abilities and fast transmission capability of data and information, so that the remote operation of manufacturing activities and efficient collaboration among stakeholders are greatly facilitated"*.

However, the collection of data via IoT in combination with Data Analytics technology is expected to shape the decision-making processes in various Industry 4.0 environments [14]. One of the proposed solutions for solving the challenging tasks of Data Analytics is oriented to Cloud Computing technologies presented in [20]. However, another solutions are proposed by [14] and [21] focusing on the Edge Computing technologies for analysing the data via IoT.

2.2. Big Data

Industry 4.0 unites various new advanced technologies to discover a more efficient way for improving manufacturing processes in every aspect of management. With the implementation of new advanced technologies in manufacturing processes, the amount of data approximately increasing at a rate of 10 times every five years, which results in a large quantity of raw data [5]. Using the appropriate methods, algorithms and software tools, different types of data can be collected and extracted from different layers in the production environment, named Big Data [22].

Although the term Big Data has become a buzz word, there is no general definition about what it really means. Thus, the term itself stayed quite vague and does not give any special meaning, since the notion of its size is too generic. Oussous et al. [23] defined Big Data as a *"large growing datasets that include heterogeneous formats: structured, unstructured and semi-structured data with complex nature that require powerful technologies and advanced algorithms for it's processing"*. Riahi and Riahi [24] described Big Data as a *"evolution and use of technologies that provide the right user at the right time with the right information from a mass of data that has been growing exponentially for a long time in our society, where challenge is not only dealing with rapidly increasing volumes of data but also the difficulty of managing increasingly heterogeneous formats as well as increasingly complex and interconnected data"*. Similar definitions are provided by Wu, Buyya, and Ramamohanarao[12], Taylor-Sakyi [22], and Maheshwari, Verma, and Chandra [25], who describe Big Data based on data attributes, namely volume, velocity, variety, veracity and value, where:

- *volume* – represents the large volumes of data generated continuously from millions of machines, devices and applications in manufacturing system;
- *velocity* – represents the speed of data acquisition, referring to the rate at which data is captured and the rate of data flow in real time;
- *variety* – represents the multiple formats of acquired data (e.g. videos, documents, comments, logs, etc.), since data are generated from various distributed sources;
- *veracity* – represents the uncertainty of data, i.e. where obtained data may be incorrect or inconsistent;
- *value* – represents the data ability to extract useful and meaningful information from datasets.

However, most definitions are data-oriented definitions, while data analysis is not emphasized as a main step in data transformation to useful information. The Data Analytics is used for processing the collected data without which the data collection would have no purpose. Since Data Analytics requires a great computing power, it is usually performed on the Cloud, named Cloud Computing. Nevertheless, more and more attention is dedicated of performing computations as close to the device as possible, relying on Edge Computing technologies due to security advantages over Cloud Computing [26].

2.3. Cloud Computing

Cloud Computing, as a mixture of centralized, distributed and parallel system, includes virtualized and organized computers that are dynamically supplied and set or a large number of existing computing resources creates a service at the level of the connected device [27]. Cloud Computing represents a computing technology providing services of storage, sharing and processing of data through visualized and scalable resources over the networks [28], [29]. With the advantage of flexibility, storage, sharing and easy accessibility, Cloud Computing has a big role in Data Analytics process with the accent on Big Data, namely Big Data Analytics (BDA), as it offers access-based computing infrastructure oriented to subscription, data, and application services [12], [29].

The goal of Cloud Computing is an emphasis on BDA that must use commodity hardware to build computing clusters and scale out the computing capacity for web crawling and indexing system workloads. Due to the massive volume of dataset, searching for optimal solution with fault tolerance computational capacity is an important factor for implementing Cloud Computing for BDA [12], [30].

Cloud Computing shares the majority of the Internet work computer resources instead of software or storage on local computers. To distribute their work, computer resources are placed in many locations where these computer parts are run simultaneously in a computer group. This method is used for creating an analytics that runs more rapidly and is capable of performing the time consuming and power-consuming data processing [27].

2.4. Edge Computing

The Edge Computing, unlike Cloud Computing, represents the decentralized computing service for storage, processing and applications. It takesplace on the network edge and acting as a middle layer between end user and cloud data centers. In that way itreducesthe distance that data must travel on the network while producing minimal delays [31], [32], [33], [34], [35]. The Edge Computing is perceived as a method of optimizing the Cloud Computing by performing Data Analytics as close to the data sources as possible [29].

Many researches find that Edge Computing is synonym for Fog Computing [14], [36], [37], [38]. As Shi et al. [32] and Mukherjee et al. [36] agree, Edge Computing can be interchangeable with Fog Computing, with the minor difference that Edge Computing is focused more toward the things side, while Fog Computing is focused more on the infrastructure side, while both of these technologies are the same regarding the Data Analytics perspective.

The multi-layer Edge and Fog Computing architecture is able to support quick response, providing high computing performance [37] used for processing the data along Data Analytics technology. The data processing is distributed between edge devices, while the data processing tasks, which can not be handled well by edge systems, are taken to the cloud. As a result, the scalability and efficiency is improved significantly due to fact that computing and routing burdens are decreased. This also benefits for lowers network traffic [38].

3. Edge Computing vs. Cloud Computing

Edge Computing and Cloud Computing technologies are similar regarding the methods of storing and processing data. However, the differences between these technologies are related to the physical locations of storing and processing, the amount of analysed data, processing speed and so on, presented on Figure 1. Because of those differences, the challenges of one computing technology represents the opportunities for the other one and vice versa. This section is providing the challenges and opportunities in both, Edge Computing and Cloud Computing technologies compared via several most important dimensions selected based on Data Analytics requirements, namely: amount of storage data; amount of processing data; computing power; processing and response time; security of network and data; costs of analysis transfer; expenses per year; and standardization focused on data analysis and connectivity presented in Table 1.

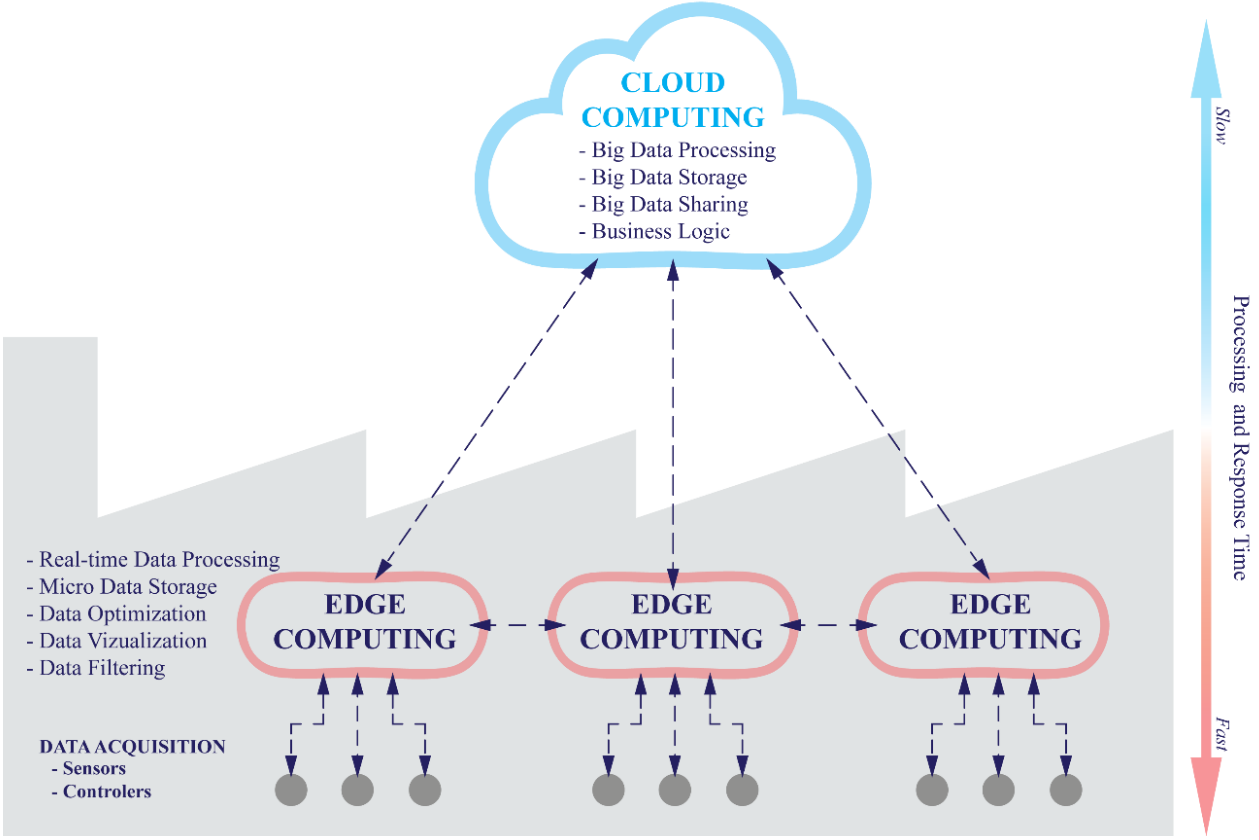

Fig. 1. The framework of differences between Edge Computing and Cloud Computing

3.1. Challenges of Edge Computing and Opportunities of Cloud Computing in Data Analytics Perspective

Edge Computing technologies are still in the early stages of it's the development. Proof of this are frameworks that are still in the infancy stages , unlike Cloud Computing frameworks, such as Microsoft Azure, Amazon Web Service, and Google App Engine and so on [39], [40]. According to Pan and McElhannon [9], most of the existing Edge Computing frameworks involve dedicated physical edge computing servers dedicated for computation and storage, or involve simple ports that provide limited virtualization supports.

The main barrier that Edge Computing is facing is related to limited amount of data [41]. Given that Edge Computing technologies have limitations regarding memory, the ability to store a very large amount of data is also limited [42]. Regarding this issue of Edge Computing devices, this technology is utilized for Micro Data storage. However, in Industry 4.0 environment, the amount of data is in constant growth [1].

As a result of data enlargement, the Edge Computing technology must support several types of storage, from ephemeral at the lowest level to semi-permanent at the highest, covering the wider range of local geographical area for longer period of time. However, Cloud Computing technologies provides global coverage used for monthly and yearly data storing [43]. Therefore, Cloud Computing solutions are modelled for Big Data storage where the data are stored in logical pools allowing users to have flexibility of accessing there data remotely [44].

Comparison dimensions	Edge Computing	Cloud Computing
The amount of storage data	Micro data storage	Big data storage
The amount of processing data	Small amount of data	Big data processing
Computing power	Less powerful	More powerful
Processing and response time	Fast	Slow
Security of network/data	Secure	Not secure
Costs of analysis transfer	No costs	Overhead of cost analysis to obtain offload decision
Expenses per year	Less expensive	More expensive
Standardization	No existing standards	No existing standards

Table 1. Comparison of Edge and Cloud Computing challenges and opportunities

Since the storage and data processing are preformed on the same place, the performances of Edge Computing computation power are constrained to process the limited amount of data [45]. Due to that fact, Edge Computing devices are fabricated to preform data analysis on small datasets. However, in Industry 4.0 environments, where the extremely large amount of data are generated every day, the data analytics require much higher computing power provided by Cloud Computing technologies [46], [47].

The amount of data processing is directly connected with computing power, where Edge Computing technology does not have sufficient power for data computing [48], due to hardware limitations of this technology. Notably, Cloud Computing has abilities of stronger computing power resulting the computing tasks on the cloud becomes a more efficient way of computing [32], [48].

Standardization represents the process of bringing an open environment for both, academia and industry to work in a single agreed platform [49]. However, Edge Computing, as a new technology, has not been implemented properly due to the lack of standardized IoT environment that will allow seamless and proficiently integration of all device via standardized protocols within Industry 4.0 environment [41], [50].

3.2. Challenges of Cloud Computing and Opportunities of Edge Computing in Data Analytics Perspective

The Cloud Computing is a technology that major industries adapt to facilitate the flexibility of their businesses regarding data storage, transform and exchange enabling to upgrade their profitability, interoperability, capability, scalability and so on [44]. However, many existing Cloud Computing challenges have not been fully addressed, while new challenges keep emerging in industry implementations of this technology. In this section, we summarize the challenges in Cloud Computing and argue that those challenges can be potentially solved by implementation of Edge Computing solutions.

When speaking of Cloud Computing challenges, the biggest issue represents the security of data due to the fact that data is stored in Cloud belong to different provides [44]. Since service providers do not usually have access to the physical data protection system in data centres, they need to rely on infrastructure providers for achieving complete data security. Even for a virtual private cloud, the service provider can determine security settings only remotely, not knowing if it is fully implemented [51]. Therefore, unauthorized user can take data or information and misuse them. Kadhim,Yusof and Mahd [44] explained original data must be kept in a password protected data management systems with security guard services in the cloud computing environments especially when it comes to sensitive and confidential data. However, Edge Computing technologies provide much higher security of the sensitive and confidential data due to the fact that these solutions are placed inside industrial environments and data are not transferred via Internet network, but Ethernet [50].

Another challenge regarding the Cloud Computing represents the processing and computing time. It is reflected in slower response time which disable the implementation of real-time analysis as data processing and computing is done far from data source [52]. Contrary to Cloud Computing, Edge enables processing and computing tasks at the network edge where data are generated reducing the distance that data must travel on the network with minimal delays [50]. As Hussain and Al-Karkhi [38] explained the results of using the Edge Computing over Cloud is seen in computing and routing burdens that are significantly decreased with improved efficiency and lower the network usage.

Even though, data storage, regarding the large amount of data, represents the advantage of Cloud Computing, the yearly expenses of data storage represent the obstacle for implementation of this solution. The expenses increase even more if the amount of data increased and if data analysis and processing is one of the paid requirements, besides data storage [6], [53], [54]. Noticeably, the Edge Computing solutions are not inexpensive itself. However, in comparison to Cloud solutions, Edge Computing is much more affordable using less-expensive IoT devices by shifting endpoint processor and memory capacity to edge gateways and not paying for additional services [32].

Regarding the expenses, Cloud Computing technologies require for additional payment for of analysis transfer in order to obtain the offload decision based on Data Analytics [55]. However, due to physical location of Edge Computing technologies, the analysis transfer in not required. For that reason, Edge Computing does not have cost regarding data analysis transfer [56].

Standardization, as presented in Table 1, represent the challenge in Cloud Computing as well as in Edge Computing, reflected in the lack of common standardized IoT protocols. The lack of common standards may cause different issues which leads to greater insecurity of data transfer to Cloud and vice versa [57].

4. Conclusion

The present article contributes to the existing literature in ways of explaining the background of Edge and Cloud Computing and their interconnection with IoT technologies and Big Data in Industry 4.0 environments. The relevant literature lack of overview of differences Edge Computing and Cloud Computing technologies regarding data analysis and connectivity. For that reason, the present research is focused on comparison between these two technologies based on Data Analytics requirements. It addresses and highlights the challenges and opportunities in both of these technologies, providing a better reasoning what to use in practise based on comparison dimension, namely: amount of storage data; amount of processing data; processing and response time; security of network and data; costs of analysis transfer; expenses per year; and standardization with the focus on data analysis and connectivity.

Edge and Cloud Computing, as an emerging technologies in Industry 4.0, have a lot of similarities regarding the methodology of storing and processing data. However, the main differences between these two technologies is reflected in the physical location where storing and processing are preformed, where location of Edge Computing devices is known and placed inside production system, while the location of Cloud Computing is unknown. However, that difference represents the main reason for the emergence of challenges in both technologies.

The biggest constraints Edge Computing technology is a limitation on the amount of data that can be stored and processed, where is not considered the Big Data, but small data sets, namely Micro Data generated by IoT devices or sensor networks. These constraints are closely related to the limitations in the processing power of the Edge computing device itself. However, Edge Computing challenges are seen as Cloud Computing opportunities, where Cloud Computing offers services of Big Data storage, processing as well as sharing.

Considering the Cloud Computing challenges, the security of network and data represent the biggest obstacle of implementing this technology, since the location of data is outside the industrial environment. In comparison to the Cloud, Edge Computing offers more secure network and data transfer since it is placed inside the industry.

Processing and response time is another challenges regarding Cloud Computing, since it can not be achieved due to the fact that data processing and computing is preformed far away from data source. Contrary to that, in Edge Computing, the data are generated at the network edge reducing the distance that data must travel on the network enabling real-time responce. Regarding the yearly expenses for data storage, Cloud solutions are more expensive. Besides the data storage, the expenses increase even more if the amount of data increased and if data analysis and processing is one of the paid requirements. Also, analysis transfer requires additional payments in Cloud Computing. However, Edge Computing is more affordable due to the fact that is uses less-expensive IoT devices and do not require additional payment for special services, such as analysis transfer. Standardization is the only comparison dimension that represents challenges for both, Edge and Cloud Computing, due to the reason that standardized IoT protocols which do not exist. The lack of common standards may cause different issues: in the environment that has implemented Edge Computing technology, it does not allow integration of all device; and in Cloud Computing implementation it leads to greater insecurity of data transfer.

Based on this research, it can be concluded that Cloud and Edge Computing do not rule out one another, but complement each other to form a mutually beneficial and interdependent service continuum. Edge Computing provides solutions for difficulties in Cloud Computing and vice versa. The combination of these two computing technologies have potential of solving many of the above addressed challenges: namely: can address Big Data acquisition, storage, and processing, reducing the data transfer and warehousing on Cloud by utilizing Edge Computing where local data can be collected and processed at the regional edge nodes to provide real-time feedback to end users, while the detailed and thorough analysis, and computational intensive tasks can be performed remotely on the Cloud.

A limitation of the present paper is that this research is only based on existing literature that lacks of practical implementation process of both, Edge and Cloud Computing technologies. Therefore, the future research will be focused on comparison of the Edge and Cloud Computing with a practical implementation examples in production environments. Hopefully, the results of this paper will also help other researchers to take a step forward in the directions of research in the existing Edge and Cloud Computing issues.

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