Energy Efficiency in Edge Computing: Approaches, Challenges & Solutions

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Abstract

Edge computing has revolutionized the way we capture, process, and store sensor data in cloud-based hybrid environments. This emerging technology has helped the industry in meeting the ever-demanding computational and data transfer needs of the smart devices being used in domestic and industrial applications. Using Edge computing, the cloud data centres can offload the required data on the edge nodes to reduce the latency in data transfer and processing. These advances have helped the industry and product developers to enable solutions that can provide data, decisions, and control in real-time while making use of local as well as cloud-based data storage and processing. The concept of energy efficiency has been studied, researched, and implemented in various domains, technologies, and applications of computing platforms, but it has not received much attention in the area of edge computing. The edge computing frameworks make use of energy efficiency-focused smart design and implementation solutions at various levels in the form of resource management, workload scheduling, cluster management, VM migration, etc. In this article, we have conducted an extensive literature review of energy-efficient approaches, technologies, challenges, and opportunities that can be used to come up with new innovative approaches and solutions that are leaning towards sustainable energy-based computing and data storage solutions.

Keywords: Edge Computing, Energy Efficiency, Resource Management, Workload Scheduling, Cloud Computing, Edge Devices, Real Time Data Processing, Hybrid Approaches

INTRODUCTION

e in the form of sensors, the Internet of things, or any other device/sensor or application that produces data in the form of a continuous stream or at frequent or infrequent time intervals. This generated data is processed by an application that may be hosted on a server close to the data source or on a cloud platform. In a traditional cloud computing-based architecture, the data produced by these sensors or data sources is transferred to the cloud via a network. The business applications hosted on the cloud environment will receive, process, and sandbag this data as per the application requirements. This architecture is most suitable for applications that do not generate or require a large amount of data. The new software solutions that make use of smart sensors, high-definition cameras, and other similar data sources may generate terabytes of data within one hour. It will be near impossible to transfer, process, analyze and store this amount of data on a cloud server in real-time. This shall lead to higher latency and more network congestion in the form of excessive bandwidth usage. But the localized processing also has its own disadvantages in terms of security, reliability, and cost-related factors. Considering some critical system-based real-time applications, even a delay of microseconds could be devastating to the system's performance and safety. Such environments require that the data should be processed and analyzed in near real-time so that the corrective and protective actions could be initiated based on the data trends. Hence the question arises of which technology to opt for to address all these concerns?

To overcome the above-stated challenges, the researchers developed the edge computing-based architecture that make the best use of both the cloud and localized data processing and storage approaches. Edge computing is a distributed computing-based architecture that brings the computation and data as close to the data source as much possible. As computing is not to be confused with IoT as this is not simply a median collection of sensors and data producers connected to the Internet. I shall be considered as a topology-sensitive and geo-location-oriented paradigm that makes use of distributed computing.

The edge computing approaches and implementations have been widely used in the latest service-oriented applications for industrial as well as domestic usage. A lot of research work has been done in other areas of edge computing except energy efficiency in the management, operation, and optimization of edge computing-based architectures. Through this article, the authors shall discuss the need of new energy efficiency-based approaches that are tailored to the specific requirements of edge computing environments. Along with the various resource contributions of the research community in the area of energy efficiency and add computing, researchers shall also discuss the various initiatives, approaches, and challenges related to various energy efficiency-oriented solutions in an edge computing-based environment. The energy efficiency-based solutions are implemented at the network level, the data storage level, or at the computational level while processing the workload. This can be in the form of resource management and workload scheduling strategies to make the best use of the available resources while keeping the energy consumption to a minimum. It becomes ever more crucial to map data generation rate with the data processing capability of the localized that server in order to avoid any congestion or underutilization of edge server capabilities. This is required for meeting the quality of service (QOS) conditions while optimally utilizing the available computational resources. To achieve this, the edge server and the cloud management services they need to continuously communicate and coordinate with each other for facilitating the required cooperation for delivering the required outcome while also focusing on the green computing implementations.

For optimal resource utilization and energy efficiency maintenance it is very crucial that the cloud services are able to balance or allocate the presently ongoing workload on all the edge servers equally are were selected at the devices based on their computational load. If the overall computational requests are not equal to the processing capability of the cloud edge architecture. The energy consumption of edge devices can be reduced by reallocating their workload to the other active edge devices to effectively utilize their computational capabilities. There are several other such strategies at various levels of cloud edge architecture that makes it possible to save some energy while still delivering the required outcome as per the quality-of-service standards. The following sections shall discuss such approaches, implementations and the corresponding challenges.

This paper has been organized in six sections in which Section 1 has discussed the introduction, Section 2 discusses some prominent applications of edge computing, Section 3 discusses the need of energy-efficiency-based designs. The Section 4 discusses the comparative aspects of the various approaches and finally the Section 6 provides conclusion and the future work of the work under consideration. Before starting with the energy efficiency-based architectural and management approaches, it is very crucial to understand the applications of edge computing in different environments and applications in our day-to-day life[1]. We have discussed few prominent applications of edge computing in the following section:

EDGE COMPUTING DELIVERABLES

edge computing is crucial because it is leading to the improvement of processes, businesses by improving their operational efficiency hence leading to significant improvements in outputs, automation of the underlying business processes. It also needs to the improved availability of data and services and can lead to a 360° transformation of enterprise. Edge computing can deliver the following[1]:

1. Provide optimal solutions for the challenges associated with the cloud computing base architecture by addressing the issues related to performance, bandwidth, responsiveness, data locality and over all security[2].
2. Edge computing can fulfill the exponentially growing computational and data storage requirements of the next Industrial Revolution for transforming the supply-chain, manufacturing and service deliveries.
3. Create a real time data analysis and business intelligence solutions that help businesses in making quick decisions through actionable intelligence[3].
4. Provide a more efficient, faster and cost-effective business ecosystem based on service-oriented architecture requirements of the dynamic environment.
5. Deliver a scalable, flexible, robust and secure environment for automated systems and technologies in education, healthcare[4], automobile [5] and industry sectors.
6. Provide a reliable and dependable automation solutions in order to free the manpower from lower-level management activities to focus on high-level operational activities for business transformation.
7. Reduce the business downtime due to the compromise of reliability and availability insulating to direct and indirect costs that may be industry or application dependent. Edge computing-based solution can save businesses from recovery cost, customer loss and reputation damage.

EDGE COMPUTING APPLICATIONS

Due to its application and quality of service-oriented design, it has started and progressed with its integration in the existing solution-based IT infrastructure. As evident from its design and operation it has led to increased responsiveness and efficient service delivery for industry, healthcare and lifestyle-based applications. The following are a few examples of edge computing applications:

1. *Healthcare Industry:* The modern healthcare solutions require capturing and processing a tremendous amount of data monitoring the patients through real-time data processing and analytical solutions [6]. The healthcare industry makes use of edge computing architecture to process data through video analytics, body mounted sensors along with various analytical and prediction solutions. Imagine an ambulance that is equipped with edge-based data processing capabilities and can process the portal patient data while on route to the hospital while avoiding the latency caused by a long-distance cloud-based data access
2. *Automobile Industry:* Edge computing is providing solution to numerous challenges faced by the automobile industry in the form of driver assisted and predictive maintenance related technologies[7]. Through these functions a car can capture large amount of data through video cameras and sensors and process it in real time to decide the future controlling events for better driving expedience as well as the human safety. Also using the predictive analytics-based relations the car can monitor its health by capturing and processing data in real-time and generating modifications and alerts through self-diagnosis [8]
3. *Manufacturing Sector:* With industry 4.0-based solutions, it is the need of the hour to capture, process and analyze the data and status of various manufacturing operations and sub processes [9]. The localized data storage and processing solution provided by edge computing helps the manufacturing industries in developing the customized solutions that can deliver as per their expectations with the certainty of

reliability and efficiency. This is where edge computing comes in handy as this is related to the core design principle of cloud-edge based hybrid solutions [10]

4. *Financial Sector:* Edge computing technologies are providing very sophisticated and usable solutions to the financial sector [11]. For example, using edge computing-based solution a bank can monitor the security of an ATM in real time by using video analytics and face recognition applications to monitor the events happening inside an ATM cabin on room [12], [13]. In order to reduce the amount of data transferred between a local bank branch and its cloud-based server, Edge computing-based localized server can be placed at the local branch building that will process the user data locally and only share the required data with the cloud server. This hybrid approach shall preserve the data privacy and maintain the security [14].
5. *Smart Agriculture:* Many startups are developing smart agriculture based customized solutions for farmers [15] . These applications are designed to cover all the aspects of modern smart farming which involves monitoring the soil quality, monitoring the livestock health along with the crop health analysis by making use of drones, cameras and sensors while processing their data in real time through our localized Edge based service [16], [17]. Based on the frequency and scale of monitoring, the various sensors and data input devices require a large amount of computational capacity which cannot be accessed remotely from cloud to network-based data transfer. Hence due to the bandwidth induced latencies it is always optimal to make use of localized data processing service and hardware if available [18].

The above-mentioned applications are among the most prominent ones, but other than these, the Edge computing is being used in space exploration, satellite design [19], [20], education, mining, banking, cyber security[12], [21], [22] and other related applications.

EDGE COMPUTING: NEED FOR ENERGY EFFICIENCY

The first wave of the Internet of things-based applications started with an integration to the cloud platform and services to provide real-time, responsive and reliable service to the users [23]. But as the number of devices connected to the Internet grew so did the network congestion and processing load on the cloud layer. It became the need of hour to come up with new innovative solutions that can come up with a hybrid architecture that can make use of the best features of both the worlds in terms of localized processing and cloud storage [24]. In order to address the need of mobile devices in terms of data processing and storage capability, researchers develop a customized solution in the form of mobile edge computing (MEC)[25]

The MEC also known as Multi-access Edge Computing extend the community of a cloud computing environment by bringing the computational processes right at the edge of the network [25] . In a traditional architecture of cloud computing the processing takes place at the remote servers that may be within the mobile user's country, or in a foreign country. But with the help of MEC, the data processing takes place at the base station, a centralized office or add an aggregation point close to the network edge [24]. This architecture has several applications in the area of at her normal self-driving Michael that can process the data locally in order to gather the situational awareness for safe and efficient driving. This approach has also various applications in the area of mixed reality, virtual reality and augmented reality where applications can be built on top of these underlying platforms to provide localized processing and view of the data to worker/operator working in an index clear environment for production, operation, maintenance and repairs [9], [10]. Considering the ever-expanding requirements of Edge computing-based applications, various energy efficiency-oriented approaches have been implemented at different levels. These include energy efficiency and architecture, hardware, computational offloading, operating system, applications and at middleware level implementations as given in Fig 1. In the following sections we shall discuss these approaches one by one.

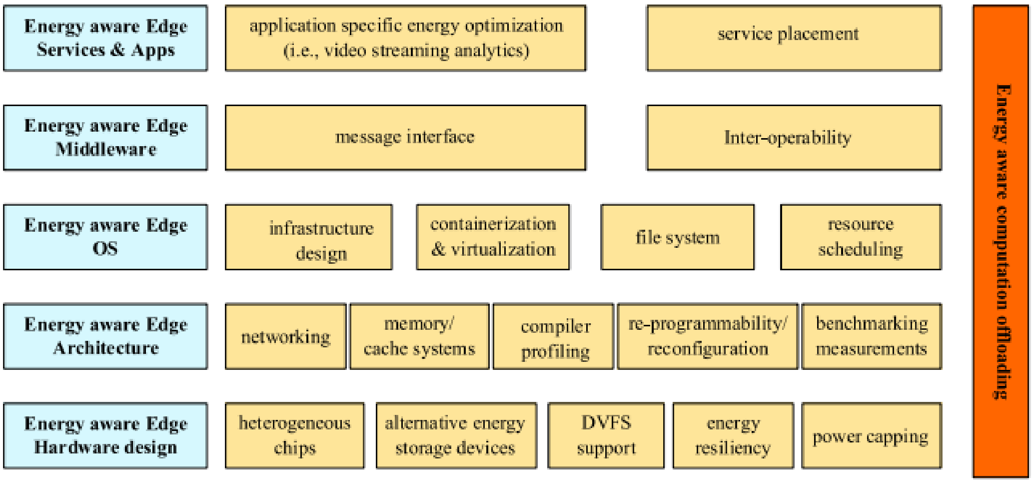

Figure 1: Energy Aware Approaches in Edge Computing

Hardware Level Energy Efficiency

Considering the fact that at the computing-based approaches are being used in smart buildings, cities and other large-scale application domains, it becomes crucial to have low cost and lightweight devices to act as sensors, routers and switches. This is due to the fact that sitting the scale these devices need to be cost-effective considering the large number of devices. Hence it becomes crucial to utilize their available battery capacity in an efficient way to serve the purpose while keeping the cost to a minimum. As a result, for edge devices such as CPUs, sensors, and edge servers, energy efficiency should be the primary design priority. When edge devices are used, this procedure can save a lot of energy. The energy efficient architecture should also be able to consider the heterogeneous nature of edge sensors, processes and data storage devices. Considering the traditional CPU based data processing it requires thousands of instructions to execute one simplified mathematical operation. But considering the evolution of GPUs that are exceeding the traditional CPUs in computing power and also the ECU DA programming framework simplifies development and programming of the modern GPU systems.

It also allows the code running on a CPU to be migrated for processing on a GPU which makes it even more useful in terms of various computational tasks in the form of 30 renting, crypto mining and caching encryption along with high-energy physics and other related applications. In this way and edge computing device can serve several purposes based on the application requirements while consuming considerably less energy in comparison to the number of computations performed [26], [27]. Field programmable gate areas (FPGAs) are indicated circuit that posts a combination of programmable logical blocks that can be configured with hardware-based description language in combination with memory modules. Although it is more flexible than CPU and GPU but it requires low level hardware interactions for programming. On the other hand, a GPU programming does not require such low-level hardware interactions but the FPGA is more compatible considering the heterogeneous nature of input output devices, signal levels speed and number of input output devices/operations for a broader range of applications. Also, the energy efficiency of FPGA is better in comparison to CPU and GPU hence it becomes more suitable for ads computing applications where energy efficiency is off high-priority due to low power availability[28], [29] .

At the hardware level, edge computing devices are provided with alternate power supply that are of lightweight and have better power capacity and duration. Every year we are witnessing new battery designs based on sleep Lithium-ion batteries that can increase the storage capacity up to 10%. The other type of batteries that are evolving are based on zinc-based alkaline batteries along with nickel hydrogen batteries. The Edge devices are also tilting towards making use of solar-based green and renewable energy by coming up with intelligent designs and algorithms that can switch between battery power and solar power supply mechanisms to offer a less expensive and more scalable options that are easy to deploy in the sunny regions of the world.

Another approach of farmer conservation for energy efficiency can be implemented in the form of Dynamic Voltage and Frequency Scaling (DVFS) which involves controlling the CPU frequencies and other DVS capital components to decrease the power consumption. For example, our modern smart phones can optimize its operations in order to perform a trade-off between energy consumption and user experience. The user can set the preferences to receive a certain degree of performance from the device and the DVS as mechanism makes intelligent decisions to deliver that required service while keeping the power consumption to a minimum. A process of power consumption can be calculated using Equation 1 given below[30].

$$P = CV^2F \tag{1}$$

in this situation P the processor's power, C denotes switchable Capacitor, the V represents voltage supplied and F stands for processer's running frequency. The DVFS governor applications keeps an off-line record and analysis of the various applications and their corresponding requirements in order to deliver an optimal performance for user experience. In case the user is actively switching between applications with dynamic behavior, DVFS is not that effective in this case but can still switch to a dynamic governing behavior based on real-time application requirement and performance analysis[31].

Resiliency to Power Cuts

Like any other data storage and processing device, edge computing devices also need to be resilient to words power blackouts, disruption and power supplies and any other unforeseen circumstances relating to discontinuation of continuous power supply. In order to avoid power disruption, and edge device has to be able to do the following: 1) to be able to avoid power supply disruptions/failures, 2) dealing with the outcomes/effects of power supply disruption and lastly,3) be able to recover processed data and computations post power failures. A power failure may lead to an application interruption where the user shall not receive the required quality of service. A frequent power disruption may lead to repeated computations of the same tasks hence leading to the stage of computational power, energy and time. In order to a wireless various fault-tolerant approaches have been developed that make use of redundancy, checkpointing or similar approaches. Redundancy is one of the most effective approaches in order to provide continuous power supply using redundant power supply sources and lines. Checkpointing also makes use of storing process/application state during execution in order to restart the process execution form the most recent checkpoint in case process execution is interrupted for any reason [32].

Energy efficient network communication

Edge computing makes it possible to bring closer computing and storage resources in comparison to the traditional cloud-based approach. Because computing and data transfer is used to and from the edge nodes and cloud data storage centers, hence it becomes necessary to make use of the existing infrastructure and develop the new topologies on top of that in order to realize edge computing architecture. Provide a dynamic quality of service, the data can be classified into groups based on its priority and necessity. The system can switch between different routing and data transmission algorithms based on what type of data is being transmitted[33]. The traditional domain name server approach for DNS discovery shall not be effective in case of edge computing as frequent DNS references are made for the changing service and process references. This can lead to too much time consumption all DNS resolution hence leading to network delay and jitter. In order to resolve this, a new approach called Naming Data Network (NDN) has been proposed for service discovery in an edge computing-based environment. It is a self-organizing data network which works in combination with a P2P based centralization, where it names and identifies the data and services uniquely for quick discovery[34].

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