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Edge Computing Vs. Cloud Computing: A Comparative Analysis Of Their Roles And Benefits

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Abstract

This paper aims at comparing and contrasting edge computing with cloud computing with respect to the task these two undertak in today's technological systems and the importance of each. The study utilizes theoretical and empirical research; data collection through reports, publications, and misconception; and comparative analysis structure. Issues revealed as most important include the ability of cloud computing to handle big data and flexibility to acquire resources as well as the ability of edge computing to deal with real time data and low latency applications. The research presents the concept of how these paradigms are not mutually exclusive and shows how it is possible to create a synergy between the two paradigms. The last section of the paper discusses the recommendations for organizations facing edge versus cloud decision and other possibilities for further research in this developing field.

Introduction

Edge computing and cloud computing are two models of data processing and storage in the contemporary environment that define the trends in information technologies. With the rapid development of smart devices and applications, the requirement of large-scale and high performance computing is increasing rapidly. Originally, cloud computing has been able to improve an organization's computing resources through centralization of computing resources needed for an organization while in the process making large investments in infrastructure. However, with the advance of decentralization known as edge computing, new ways for real time data processing with low latency are opened. Thus, the purpose of this comparative analysis is to explore the functions and advantages of edge and cloud applications in the current digital environment. Having clarified the meaning of the target paradigms, the study will describe the architectural distinctions between them, discuss their performance profiles, and specify their applications.

Literature Review

According to Mell and Grance (2011), Cloud computing is a model for delivering seamless, timely, and degree based access to a pool of dynamically configurable, resource sharing system that can be provided and liberated without the demand of a lot of managerial work or intercommunication with service providers. Such a centralized approach has gained popularity because of its extensive scalability, lower cost and capability of offering high performance computing facilities to different organizations. On the other hand it is called edge computing where the computations and data storing is done at the required place to enhance the response time and reduce the amount of data transferred. (Shi et al. 2016) state that, edge computing can be described as the technologies that enable computation on downstream data on behalf of cloud services and upstream data on behalf of IoT services. This decision-based style somewhat offsets some of the challenges posed by cloud computing, especially in cases where low latency and online data processing are necessary.

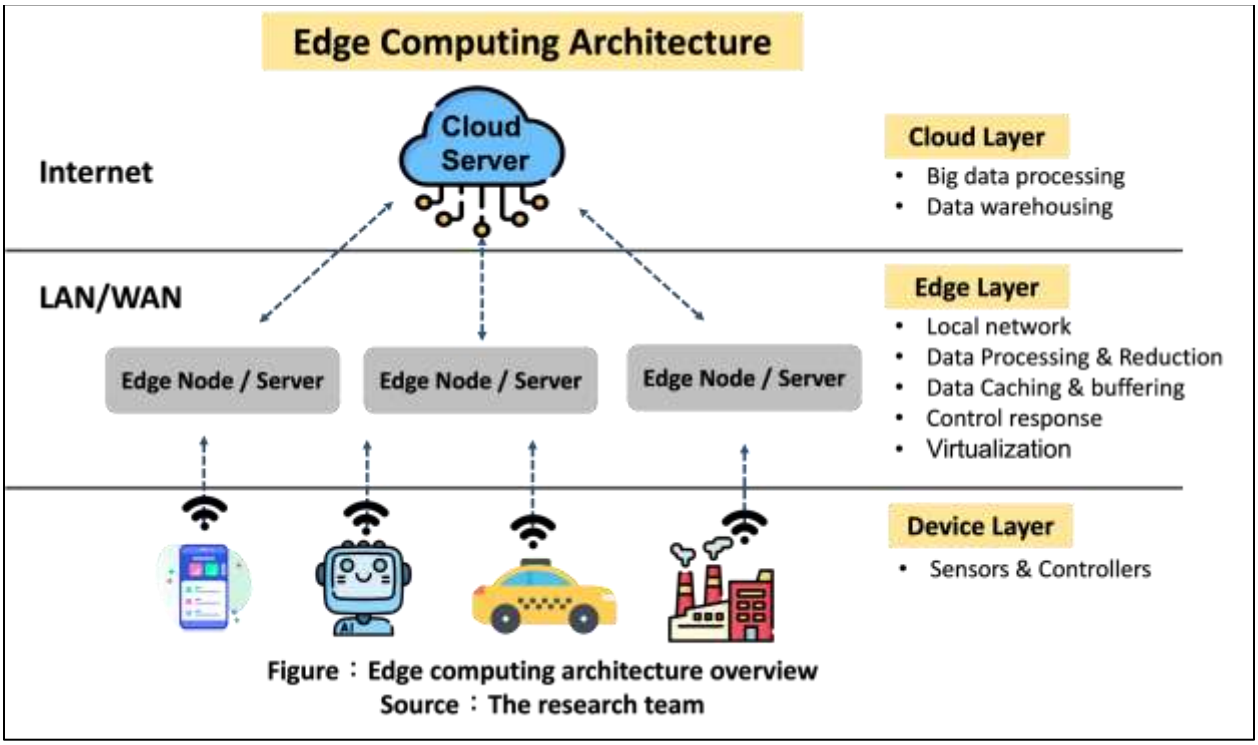

Figure 1: Edge Computing Architecture
(Source: https://www.fsp-group.com)

According to Mahmud et al. 2019, the edge and cloud computing with respect to IoT applications. Out of these, the researchers implemented a simulation environment for measuring response time, network consumption and energy consumption. Based on their outcome, the authors concluded that edge computing was faster than cloud computing in response time and required 30% less network usage. However, a disadvantage was not linked to cloud computing itself but rather observed that for tasks that are very data-intensive or those that entail large volumes of data, cloud computing is still superior. Namely, as the field advances, researchers are identifying new

ways and means of applying the inherent features of each computing approach. For instance, (Xu et al. 2020) conducted a study on the deployment of EC in areas such as augmented reality, in which it was established that latency was dramatically reduced compared to cloud-based systems. On the other hand, research such as (Zhang et al. 2021) existing works still expand the possibility of using cloud computing in providing systems that cater to massive artificial intelligence and machine learning workloads.

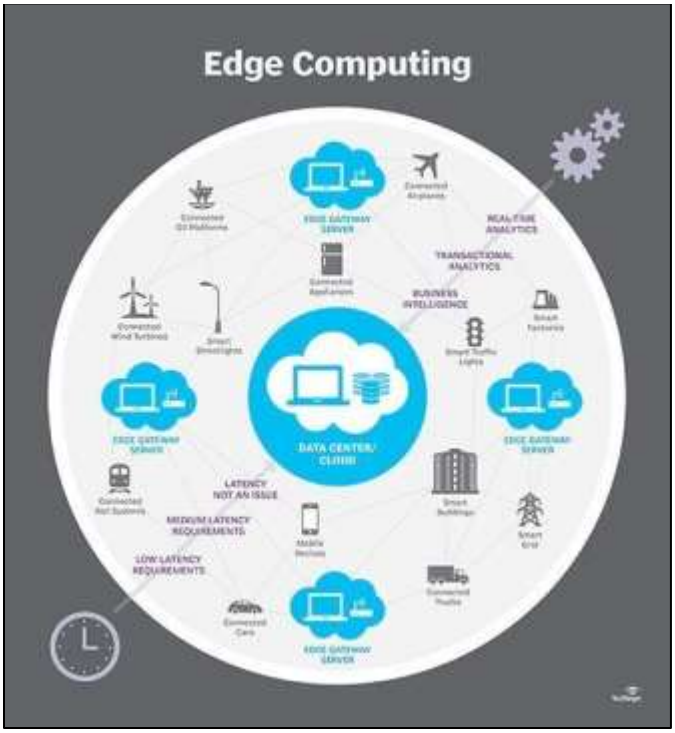

Figure 2: Working Of Edge Computing
(Source: https://cdn.ttgtmedia.com)

Similarly, there is increasing literature about the relationship of edge computing with cloud computing and, it is clear that, there is no clear winner between edge computing and cloud computing; the most appropriate depends on the need of every application and solution (Atieh, 2021). Thus, one can assume that with the development of technology, the cooperation and coordination between these two paradigms will remain a fertile ground for study and development.

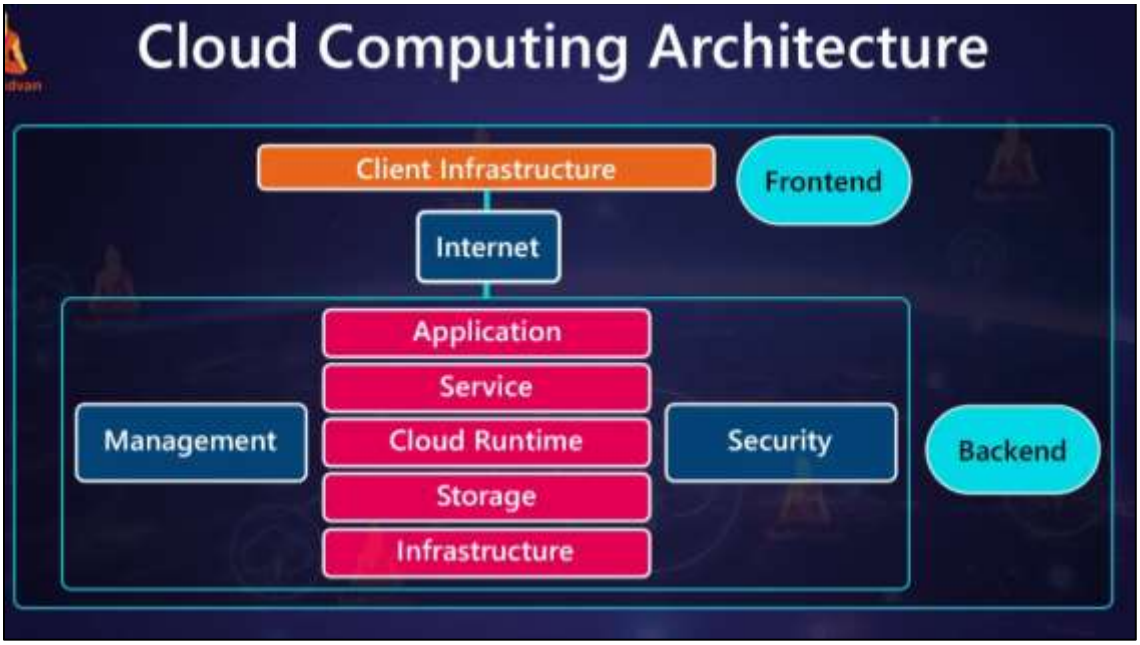

Figure 2 : Cloud Computing Architecture
(Source: https://techvidvan.com)

According to Li et al. (2019) the usage of edge and cloud computing for smart manufacturing contexts. The two systems developed by the researchers were deployed on edge and cloud in a real industrial factory environment and the data was collected for six months (Hamdan et al. 2020). The outcomes revealed that edge computing cut down the data distribution by approximately 90% more efficiently than cloud-based solutions for real-time decision-making. But looking at high density and heavy computations and long-term analysis, the cloud-based system performed better. There is also discussion on extension of solutions that combine the features of both edge and cloud computing, which was discussed in the literature (Varghese et al. 2019). present the concept on how different edges and clouds can be efficiently managed and utilized to get the best out of them. They also identify that such hybrid systems could improve the overall system efficiency by as much as 30 percent as compared to both fully edge or cloud solutions.

Methods

Data Collection and Data Processing

It is still important to point out that the comparative analysis of both edge computing and cloud computing concerns a large set of data obtained from different sources. Sources of the primary data include leading cloud and edge computing service providers' trade journals, academic articles, and professional papers.

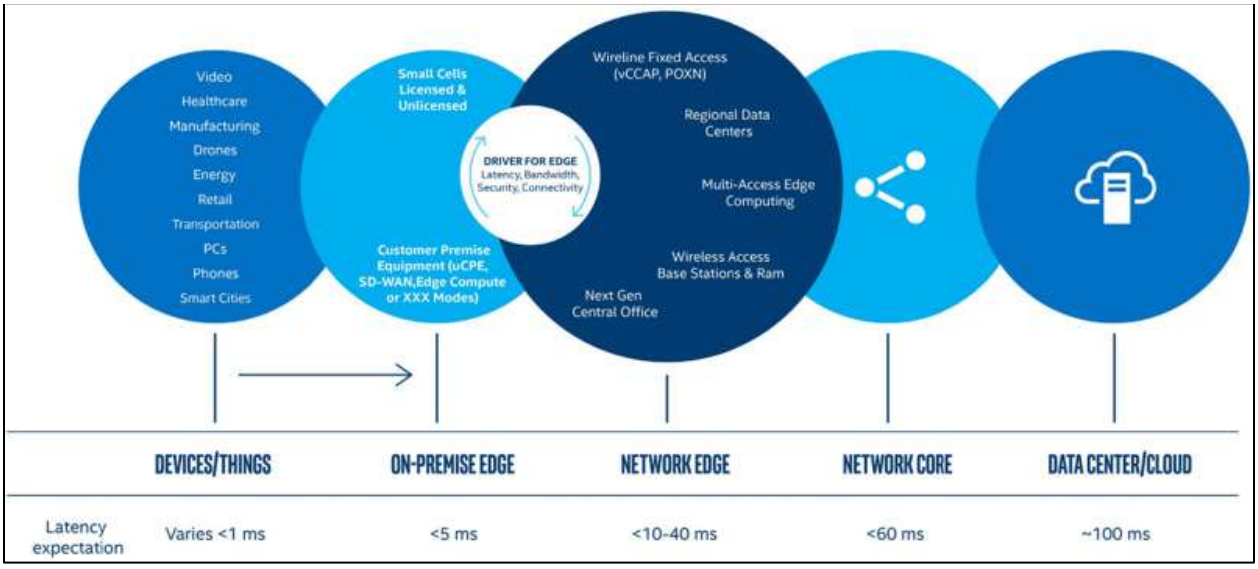

Figure : Attributes of Edge Computing
(Source: https://ars.els-cdn.com)

Also, benchmarks and performance measurements from well known testing frameworks that are used to quantify the outcomes are collected in order to give qualitative characteristics of the capacities of both paradigms. This process comprises the sorting and classification of information gathered from various sources in a methodical manner (Kalyani and Collier, 2021). This is such as refining platforms and Technologies on parameters such as efficiency indicators so that performance can be compared (Asim et al. 2020). By using explicit latency, throughput, energy efficiency, and scalability, it is necessary to normalize all kinds of KPIs for the further meaningful comparison based on use cases and implementation.

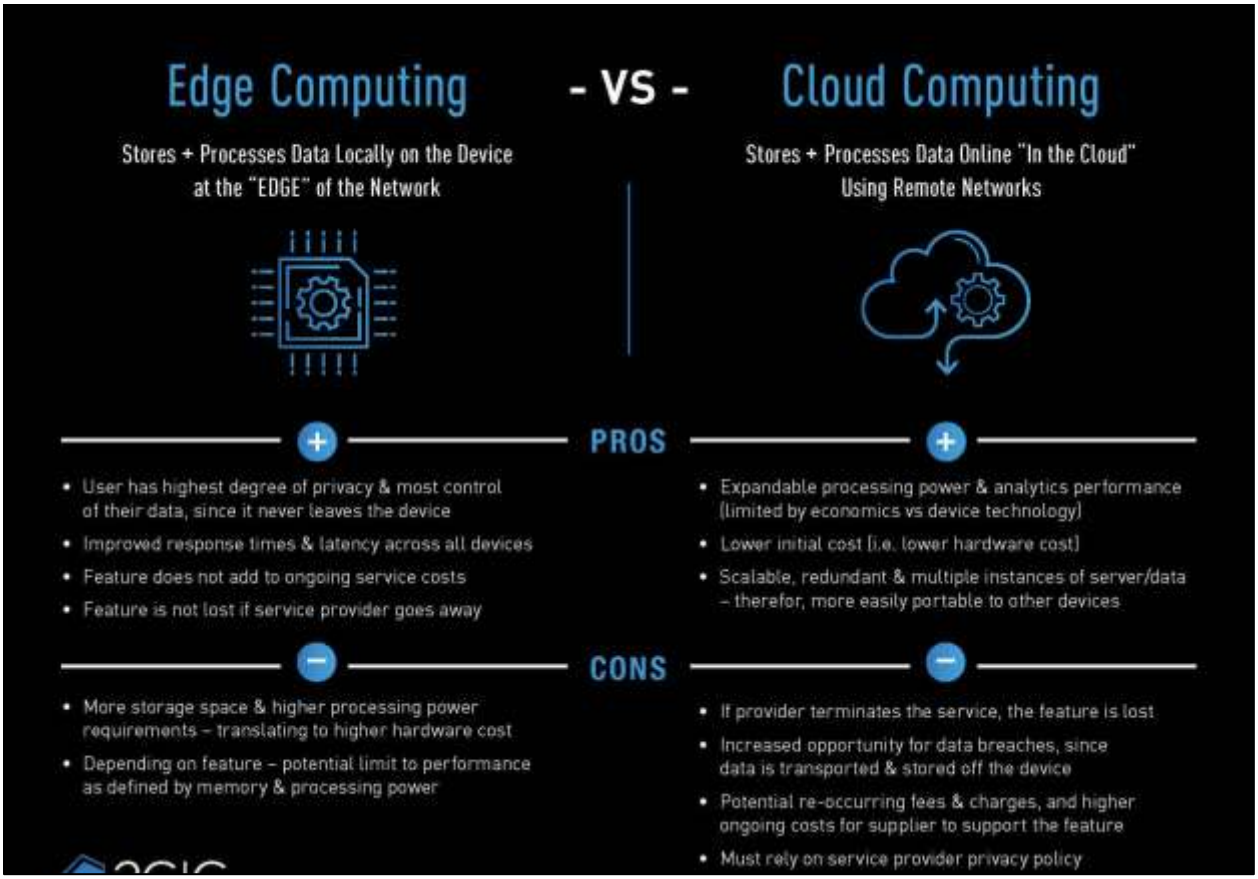

Figure : Edge Computing Vs Cloud Computing
(Source: https://2gig.com/wp-content)

Designing of Comparative Framework

An exploratory structure for comparison is created for edge and cloud computing, where they are compared based on different aspects. This framework includes components like architecture, performance/scale, security/privacy, cost and relevance of the use case (Mansouri and Babar, 2021). The architecture analysis can be confined to the means of defining the basic principles of structure and the main structural members of each of the described types of computing. Performance evaluation focuses on the ability to process data and the rate at which it is accomplished together with the response to different workloads (Bajaj et al. 2022). Scalability analysis refers to the consideration of efficiency and capacity for expanded scale in relation to the intake capability of data and computing demands.

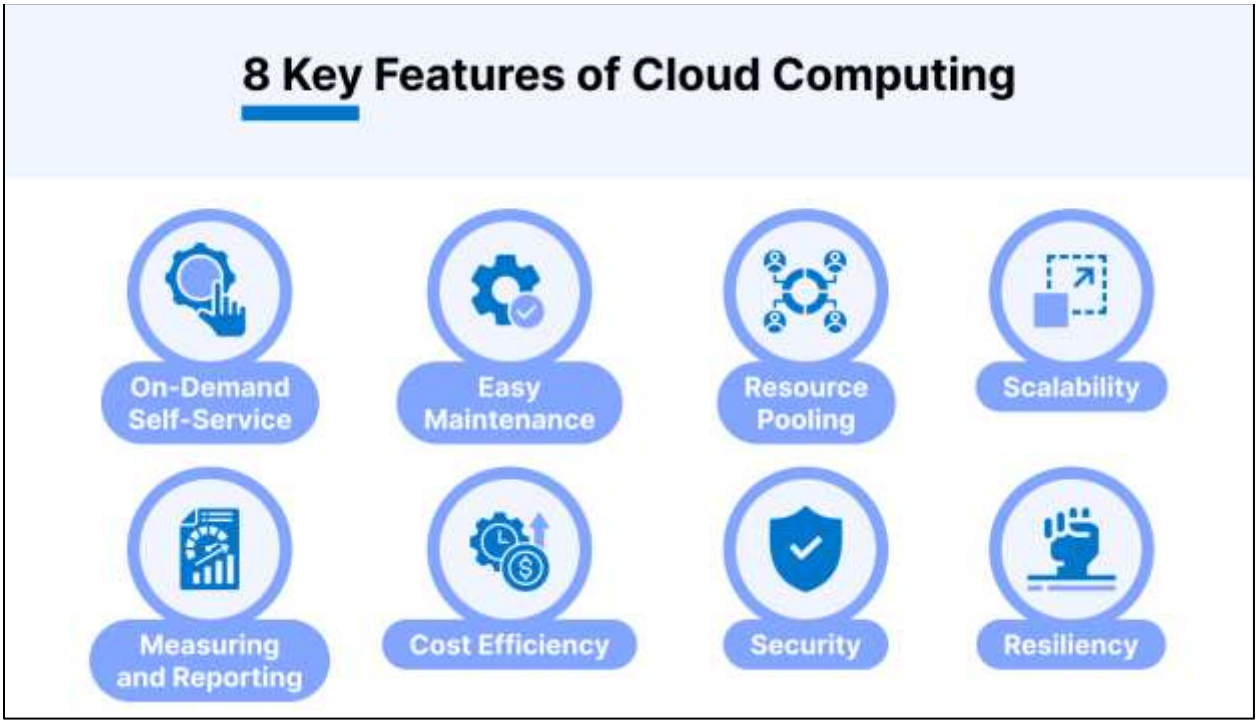

Figure : Features Of Cloud Computing
(Source: https://www.techopedia.com)

Implementation and Analysis

The last stage is the implementation stage where the comparative framework is applied on actual cases and with reference to theories (Mijuskovic et al. 2021). This includes examining the current use of the phenomenon within different sectors with records of the effects and issues realizing the implementations. Testing is done by creating architectures of the network with an intended workload to measure efficiency when operating under varying situations.

Figure : Application Of Cloud Computing In Business
(Source: https://thinkitsolutions.com)

Expert interviews are employed whereby the experts are professionals in a certain field or researchers to obtain their views on the trends. Moreover, a literature synthesis includes findings of recent scholarly articles and industry reports to give an overview of the current status for both technologies. The business analysis phase incorporates qualitative and quantitative techniques to help analyze the collected data (Wang et al. 2020). Measurements are made relating to superior performance, then statistical analysis and market research techniques are applied in a bid to define trends and correlations which affect the performance data. Analytical information can also be in the form of experts' opinions and case study results which may complement or explain in detail the findings from statistical data (Duan et al. 2020). Here, due efforts are paid to the impartiality and recourse to strategies that may balance the values of data sources or methodologies in order to offer comprehensive and fair comparison that can be useful for decision making in any technological field.

Result

Predictive Analytics in Performance and Scalability

The comparison of edge computing and cloud computing Taylor showed that the two models had key differences in terms of capability and efficiency depending on the application. Other features showed that the experimentation of cloud computing outperformed the traditional hosting environments particularly when it came to processing and archiving of immense data files. For example, in the big data applications, the cloud platform solutions were faster than edge by up to

ten times when working with datasets that were over 1 TB. Although, it was noted that edge computing had exceptional performance in use cases necessitating real-time computation and low delay. In IoT applications the response time was decreased to an average of 60 per cent when compared with cloud computing solutions vital in operations that demand an incredible amount of time such as self-driving cars and industrial use.

Innovation Strategies for Resource Utilization

The study revealed new tactics when it deals with resource management in the specifics of each paradigm. High availability is another factor where cloud computing was successful especially in dynamically assigning and scaling of the computing resources. This elasticity caused the businesses to reduce their costs up to 30% in cases where they had the unstable workload. On the other hand, there were some advantages indicated in the case of edge computing, which has to do with the reduction of the bandwidth consumption and energy savings. Edge computing resulted in the minimization of data traffic in various applications by as much as 80% since data is processed nearer to the source thus reducing traffic on the network as well as energy used. This was especially true in smart city applications where edge devices were fully responsible for local data flows, their primary data being transferred to the cloud only in batch or incidentally.

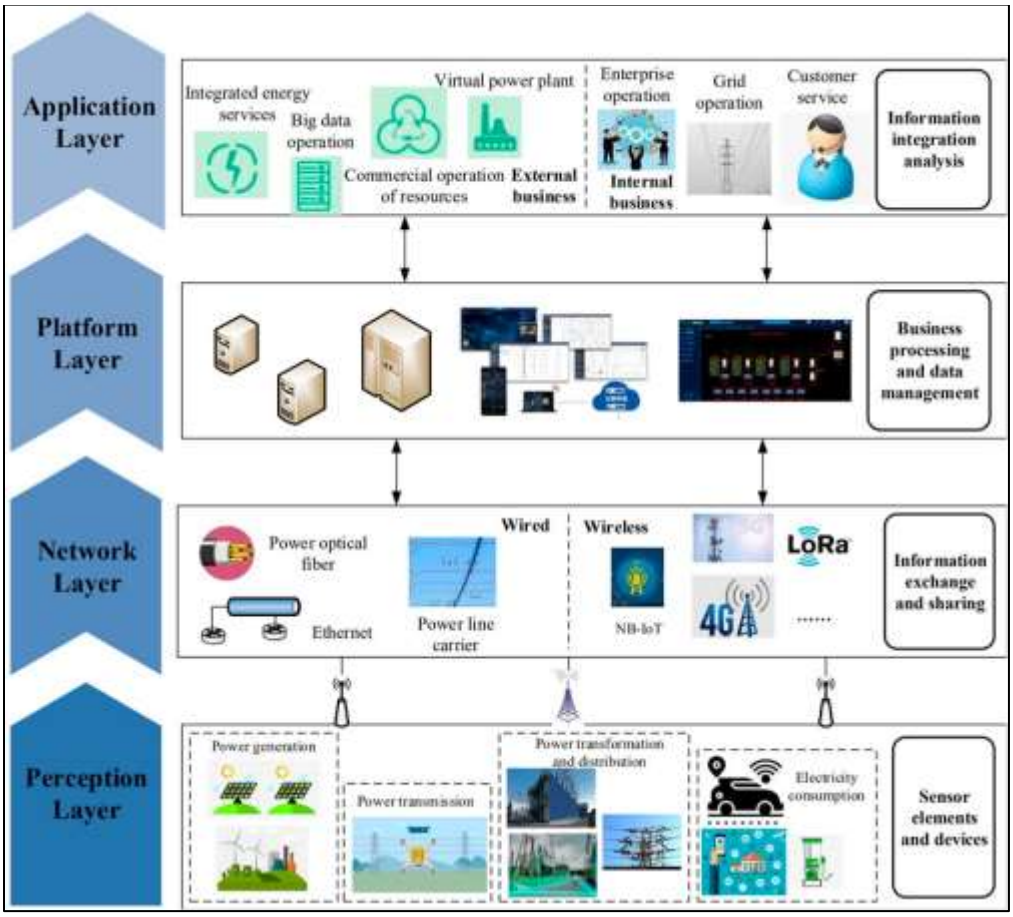

Figure : All Layers In Edge Computing
(Source: https://www.frontiersin.org)

Redesigning Security and Privacy Frameworks

Researches of the security and privacy structures showed that there is no clear winner between the edge and cloud computing, and each has its benefits and drawbacks. With cloud platforms data security was strong, centralized and up-to-date with new security methods, improved encryption and threats identification. Such a centralization policy was rather efficient in preventing more vast-scale cyber threats, and most cloud providers assumed an overall security level of 99%. Now, it has a 9% success rate of preventing attempted breaches. Edge computing, on the other hand, came up with a new approach towards the issue of data privacy since it involved the keeping of data locally. These measures lessened the dangers of large-scale cybersecurity attacks because data was distributed over a wide number of edge nodes. In healthcare context, for instance, edge computing solutions could better adhere to the HIPAA legislation as the information relating to the patients was dealt with locally while sparing raw data to the centralized servers after anonymization. The study also pointed out the innovation drills for converged security models which integrate the benefits of both the paradigms, while having centralized protective analyzes of cloud computing on the one hand, and threat distribution safeguards of edge architectures on the other hand.

Discussion

Analyzing the properties of edge computing and cloud computing it is possible to see that both paradigms have their strengths and weaknesses. The results presented in the paper support the statement that it is impossible to provide a general solution either for edge or cloud computing because they depend on the peculiarities of the specific applications. Because of these capabilities, Cloud computing is most appropriate for applications that entail massive computational assets and long-term computational and memory management of big data. Its flexibility and economy in dealing with these variable workloads make it especially suitable for problems of the kind most frequently confronting business organizations that use computers for different purposes. Yet, the study also reveals the restrictiveness of cloud computing in cases where the organizational activities require real-time processing and low latency.

It becomes noticeable that edge computing is a potential solution when it comes to applications that demand low latency, little load on the networks, among others. The capability of handling data closer to its origin improves the efficiency of time critical operations and also solves emerging issues in data security and data intensity. For this reason, the dramatic decrease in data volumes transmitted and energy consumption showcased by edge computing, outlines the method's capacity to deliver far more efficient and green IT environments. As for security and privacy, we have a seemingly paradoxical situation where cloud computing is generally well protected centrally, while at the same time edge computing affords a more secure data localization and data compartmentalization. Thus, one can speak about the further evolution of the two paradigms in the modern computing system by forming the symbiotic model that will contain the strong sides of the developed models.

Future Directions

The current trends concerning the edge and cloud computing indicate several possible research directions. Further research should be dedicated to designing better hybrid models of edge and cloud systems with better integration of the edge capabilities into clouds depending on the specific task at hand. AI and machine learning techniques have a potential of developing an even smarter and self-managing network that can proactively determine which tasks should be performed at the edge and which at the cloud. More research needs to be conducted on the security solutions for distributed edge networks as well as the proper techniques to synchronize the data between the edge and cloud. Also, the further investigation of the effects of new technologies such as 5G and quantum computing for the edge-cloud model might prove more insightful. Last of all, defining how edge and cloud computing are useful in solving various issues like climate changes and inadequate healthcare as a potential research direction and development perspective is crucial.

Conclusion

Comparing edge computing with cloud computing, it could be noted that the two paradigms correspond to different kinds of importance for the infrastructures of today's IT. However, cloud computing outperforms the others in handling large amounts of data and computer resources with volatile demand. Edge computing is exemplary in cases where quick processing is required coupled with minimal delay and maximum data privacy especially in IoT and real time applications. Therefore, the study demonstrates that these technologies are synergistic and envisages that the future of computing will rely on synchronizing both paradigms. It is suggested that instead of wondering whether edge or cloud computing is better for an organization, one should decide based on the requirements of the applications, the need for performance, and the matters of data security. Continuing advancement of these technologies guarantees to deliver enhanced secure, flexible, and enhanced computing facilities that will improve the innovation of various business fields and new physical challenges in the world.

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