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Research Article

A comparative study of latency in cloud, edge, and UAV-based intelligent edge computing

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ABSTRACT

Due to the recent increase in digital data, data processing and management have become more important. As a solution to this, UAV-based communication networks are emerging. Against this background, the UAV-based communication networks are emphasizing the fact that they are emerging as promising solutions in wireless communication systems. This study aims to compare the latency between cloud computing(CC), edge computing(EC), collaborative cloud and edge computing(CCEC), and UAV-based intelligent edge computing(UEC). This study analyzes the performance differences of these four methods as the number of nodes increases. By setting up a virtual environment, penalties due to lack of infrastructure resources were given to CC and EC and CCEC, and under these conditions, it was confirmed that UEC performs better than other methods. In addition, this study emphasizes the importance and efficiency of UEC, and as a result, this study presents the possibility and importance of building an advanced UAV communication network.

I. Introduction

Data processing and management have become more important due to the recent increase in digital data. As a solution to this, UAV-based communication networks are emerging. Against this background, it is emphasized that UAV-based communication networks are emerging as promising solutions in wireless communication systems.[1],[2]. Advances in new technologies are continuing, and CC, EC, and UEC have become essential elements in the current configuration of data processing systems.

CC is widely used in business processing and online service delivery, which require efficiency in large-capacity data processing and resource management. Recently, with the advent of "Cloud AI," which integrates artificial intelligence technology into CC, it enables faster and more accurate data processing and is being applied in various fields. The use of cloud AI has enabled companies to make more precise and faster decisions.

EC has the advantage of reducing network traffic to CC by processing data directly on-site rather than transferring it to the cloud. This enables rapid decisions, especially by processing and analyzing large amounts of data generated by IoT devices, and enables more robust systems through efficient linkage with CC.

CCEC enable real-time data processing, drastically reducing latency and saving network bandwidth. It also increases data security and improves overall system reliability and availability by providing flexible scalability and cost-effectiveness.

UEC enables instant on-site processing and analysis of data using drone-mounted sensors and cameras, enabling quick and effective responses in a variety of fields, including geographic analysis, urgent medical services, and safety management.

As such, the combination of CC, EC, CCEC, and UEC plays a central role in modern data processing systems. The interaction of these technologies is a key factor in maximizing the efficiency of large-scale data processing and expanding the applicability in various fields. In the introduction of this paper, we would like to explore the importance of these technologies and their complementary relationships.

This study sets up an experimental environment to compare the performance of these technologies by analyzing the differences in hardware usage with modeling algorithms of CC, EC, CCEC, and UEC. By comparing and analyzing the advantages and disadvantages of each technology, we present which technology is more efficient in a specific situation, and explore its appropriate applicability while increasing our understanding of these technologies. This will provide a comprehensive understanding of the technological achievements and limitations and provide guidance for the optimal technology selection in a specific situation. This analysis will contribute significantly to the search for optimization of data processing systems, including the cooperative use of CC and EC.

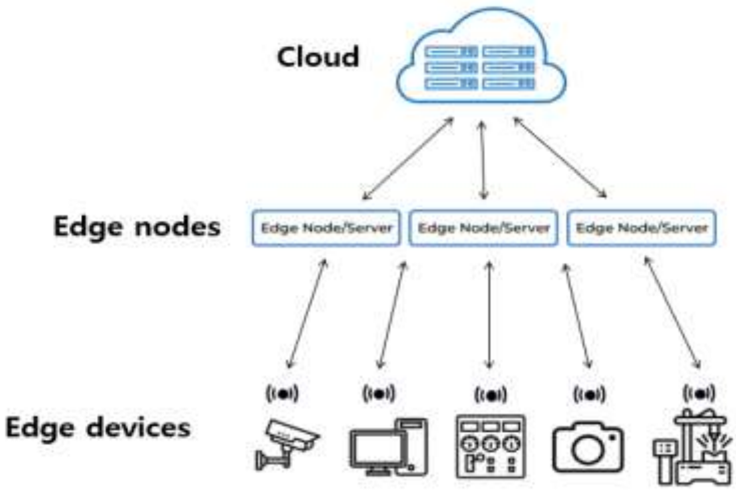
II. Cloud Computing

Cloud computing(CC) offers significantly more processing power than devices located at the edge of a network. This means that moving all computing tasks to the cloud has proven to be an efficient way to process data [3]. CC, which can be applied to a variety of domains, has the ability to process large amounts of data more quickly and efficiently and can significantly improve the management of IT resources for enterprises. In addition, CC, which is used in a variety of fields beyond data storage and processing, continues to enhance functionality and leads the demand of the market, emerging as a promising technology. Advances in CC have the potential to revolutionize enterprise and individual IT infrastructures, with superior processing power and scalability based on a centralized structure. However, these structures can struggle with real-time processing of data, and problems in the cloud can affect the overall service [4]. Additionally, the deployment of many IoT devices, such as UAVs, can constrain bandwidth, stability, and security.

III. Edge Computing

Edge computing(EC) is a technology that processes and utilizes the vast amount of data generated within IoT environments directly at the edge of the network, thereby improving data analytics speed and providing services to users more quickly. While CC has the problem of processing all data on a central server, EC takes an approach that allows each IoT device to analyze and process data directly on the ground.

Figure 1. Edge computing architecture



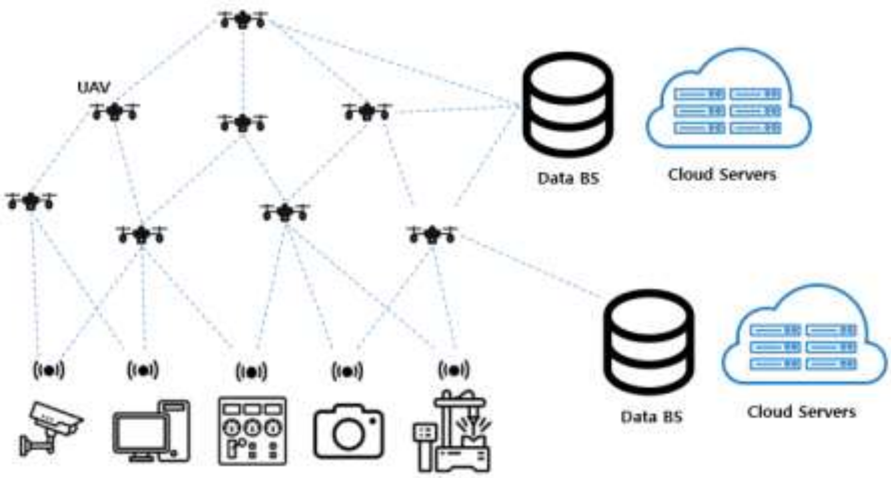
IV. Collaborative Cloud and Edge Computing

Through the Collaborative Cloud and Edge Computing(CCEC), an edge cloud located near a terminal access point can reduce the response time of IoT services and optimize the resource use in the central data center by initially collecting and analyzing IoT data and sending only the necessary information to the central cloud [5][6]. CCEC systems consist of edge nodes and cloud services, where edge nodes play a key role in collecting and processing data intensively with hardware such as IoT devices. Meanwhile, cloud services share data collected from edge nodes with other devices or servers, and utilize this data to provide various services. This study aims to verify the efficiency of CCEC compared to cloud computing in situations where large amounts of data processing and fast response speed are required. The results of the study confirm that CCEC performs well in terms of data processing speed, which is of great importance, especially when large amounts of data processing and real-time analysis are required in the IoT field. The architecture of CCEC is shown in Figure 1.

V. UAV-Based Intelligent Edge Computing

UAV-Based Intelligent Edge Computing(UEC) based on unmanned aerial vehicles is an advanced technology that processes, analyzes, and transmits data using drones, which are characterized by rapid response and vast data processing capabilities. The UEC system contains several components, which include drones, local servers, data centers, and cloud services. Drones move at high speeds and provide the ability to collect and process a wide variety of data. Local servers are responsible for regional data processing and analysis, and play data-driven analysis and management roles. Data centers provide tasks and storage space that are difficult to handle with local servers, and the cloud provides a variety of data processing and analysis services. Important technologies in UEC include virtualization, artificial intelligence, and real-time data powder, which increase the efficiency and convergence of servers through virtualization technologies, and use artificial intelligence to extract useful information from data collected by drones. In addition, real-time data analysis enables fast response times and real-time processing. This study showed that UEC is superior in terms of data processing speed, mobility, and regional suitability compared to conventional CC and EC. These advantages can be applied in various fields such as real-time large-scale data processing and analysis, rapid response and emergency handling in the event of a disaster. Thus, this study presents the potential for the development of smart drone systems beyond the limits of CC and EC for data processing and analysis, and the architecture of UEC is shown in FIg. 2 [8].

Figure 2. UAV-based Intelligent Edge Computing Architecture



VI. Algorithms

In a CC environment, let's assume that the amount of data is R, the communication bandwidth is B, the GPU's processing power is G, the CPU's processing power is C, and the RAM capacity is F. Under these conditions, the time required for data processing of a CC system (tc), the response latency of this system (lc), the time taken for data processing in an EC system (te), and the response latency of EC (le). In addition, the time taken for data processing in a CCEC system can be calculated in a specific way. Based on these calculations, performance in various computing environments can be compared and analyzed and expressed respectively as follows.

$$t_c = \frac{R}{B_c} + \frac{R}{G_c} + \frac{R}{C_c} + \frac{R}{F_c} \quad (1)$$

$$l_c = d_c + t_c \quad (2)$$

$$t_e = \frac{R}{B_e} + \frac{R}{G_e} + \frac{R}{C_e} + \frac{R}{F_e} \quad (3)$$

$$l_e = d_e + t_e \quad (4)$$

$$t_{ce} = \frac{R}{B_{ce}} + \frac{R}{G_{ce}} + \frac{R}{C_{ce}} + \frac{R}{F_{ce}} \quad (5)$$

$$l_{ce} = d_{ce} + t_{ce} \quad (6)$$

In smart CCEC using unmanned aerial vehicles (UAVs), the time (tu) required for data processing and the latency (lu) of the system can be expressed by a specific formula. Through these computational methods, it is possible to quantitatively understand the time it takes for a UEC system to process and respond to data. By analyzing the performance metrics that can be obtained through the combination of UAV technology and CCEC, the efficiency and response speed of these systems can be evaluated and expressed as follows.

$$t_u = t_q + t_a + t_x + t_l \quad (7)$$

$$l_u = d_u + t_u \quad (8)$$

In the above equation, tq represents the data transmission time in UEC, and ta represents the data processing time. It is assumed that the data collection time (tx) and the data load time (tl) are included here, and are expressed as follows, respectively.

$$t_q = \frac{R}{B_u} \quad (9)$$
$$t_a = \frac{R}{G_u} + \frac{R}{C_u} + \frac{R}{F_u} \quad (10)$$
$$t_x = 0.1 \quad (11)$$
$$t_l = 0.1 \quad (12)$$

VII. Experiment and Results Analysis

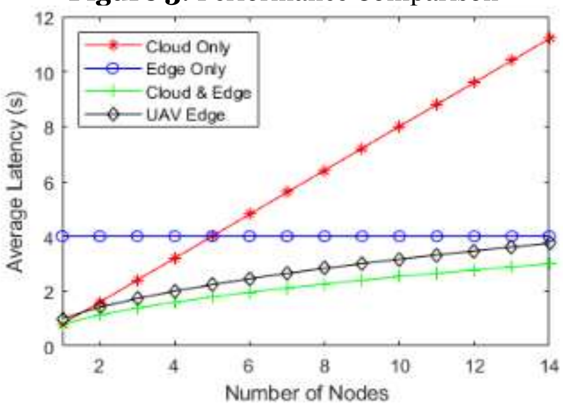
Table 1. Parameter

Parameters	Setting
Data Size, R	10000 MB
Bandwidth Cloud, B_c	1000 Mbps
Bandwidth Edge, B_e, B_{ce}	100 Mbps
Bandwidth UAV, B_u	50 Mbps
GPU Cloud, G_c	10000 GFLOPS
GPU Edge, UAV, G_e, G_{ce}, G_u	500 GFLOPS
CPU Cloude, C_c	1500 GFLOPS
CPU Edge, UAV, C_e, C_{ce}, C_u	100 GFLOPS
RAM Cloud, F_c	256 GB
RAM Edge, UAV, F_e, F_{ce} ,F_u	16 GB
Distance Factor Cloud, d_c	0.08
Distance Factor edce, d_e, d_{ce}	0.016
Distance Factor UAV, d_u	0.01
Infra penalty	0, 25, 50, 200

In this study, various environments were prepared, compared, and analyzed for the implementation of CC, EC, and UEC. The parameter values that enable fair comparisons between different computing methods are set up in Table 1. These comparisons allowed us to evaluate how each computing model works efficiently according to different environments and requirements.
Figure 3 compares the average system latency with the number of edge nodes in four different ways. As can be seen from this figure, the cloud-only method and the collaboration method that utilizes both the cloud and the edge have limited computational resources, which tends to lead to longer system latency as the number of edge nodes increases. On the other hand, the edge-only method does not use the cloud, which means that the system latency is constant regardless of the number of edge nodes. Furthermore, fewer edge nodes have shown better performance than the cloud-only method. This is because when there are fewer edge nodes, the CC power assigned to each mobile device is relatively greater than the EC power. Therefore, to reduce system latency, more data needs to be transferred to the cloud for processing.

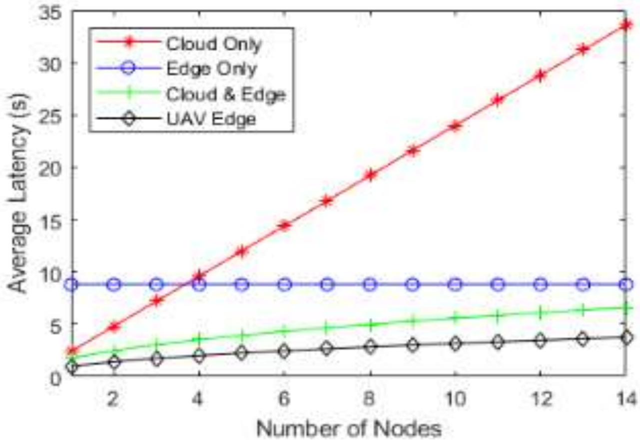
As the number of edge nodes increases, the edge-only approach starts to outperform the cloud-only approach due to limited cloud computing resources. In particular, when the number of edge nodes becomes so large, we see that edge-only methods perform better than fixed methods with both cloud and edge, meaning that more data needs to be assigned to EC. UEC performs similarly to CCEC, but some performance degradation occurs as UAVs perform slightly lower than typical CCEC methods. However, in all situations, CCEC provides the best performance by leveraging the computational power of edge nodes and cloud servers.

Figure 3. Performance Comparison



Next, mobility is often an important factor in situations such as natural disaster sites and military operations. In situations like this, exploiting unmanned aerial vehicle UEC computing can provide significant benefits. It can provide computing resources even in environments where network connectivity is difficult, giving it a significant advantage over CC or traditional EC. Therefore, in this work, we consider the infrastructure penalty values of CC, EC, and CCEC in setting up virtual environments.

Figure 4. Performance Comparison with Infrastructure Penalty



In Figure 4, an infrastructure penalty is assigned to each computing, and the simulation was conducted with the environmental setting as shown in Figure 3. As can be seen from this figure, the method of using only CC and EC, and CCEC tend to increase the overall system delay time through each infrastructure penalty assignment. UEC also shows relatively low latency due to similar principles to CCEC. Moreover, UEC can further reduce network latency by using UAV to perform data processing in mobility and closer locations.

VIII. Conclusion

Comprehensive analysis of the experimental results shows that CC, EC, CCEC, and UEC have different characteristics, advantages, and disadvantages, which can be used appropriately for different environments and needs. Cloud computing is an optimized choice for large-capacity data processing and batch processing, but it is expensive and has disadvantages that a stable network connection is essential. EC performs well in real-time data processing and IoT environments, and is advantageous in situations where network latency is critical. However, care should be taken when stable connectivity and high levels of security are required. The CCEC reduces response time for IoT services and optimizes resource usage in central data centers, as edge clouds located near terminal access points initially collect and analyze IoT data and send only the necessary information to the central cloud. However, in situations such as natural disasters or military operations, performance can be degraded due to lack of infrastructure. Meanwhile, UEC has great advantages in special cases such as emergency response due to its excellent mobility and real-time processing power. However, this method is susceptible to external factors such as communication failure, noise, and cost issues. In this experiment, UEC algorithms were executed under certain assumptions, and the results may vary depending on the change of assumptions. Therefore, these technologies should be selected and utilized according to the situation. By choosing the best computing method for the specific environment, the efficiency and best performance of data processing can be achieved. Such decisions should be made taking into account several factors such as user needs, technical constraints, and cost. Furthermore, continuous research and development are needed to increase the performance and efficiency of these technologies. It is important to maximize the advantages and overcome the limitations of these technologies through advances in hardware, the exploration of new algorithms, and the advancement of security technologies. The experimental results show that UEC can perform well under special circumstances. This is because its mobility and immediate processing power serve as great advantages, especially in emergencies. This allows us to implement more advanced data processing methods and develop the ability to respond flexibly to different situations.

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