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UAV-Based Intelligent Edge Computing

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Abstract: The growth of digital data has increased the importance of data processing and management. UAV-based communication networks leverage unmanned aerial vehicles to provide wireless services in remote areas. These systems have the potential to deliver high-speed data transfer, reliable connectivity, and improved network coverage, making them popular for various applications. The present study aimed to compare data processing time and latency between cloud computing (CC), edge computing (EC), and UAV-based intelligent edge computing (UEC). The performance differences of these three methods were analyzed as the number of nodes increased. The virtual environment was set up to give CC and EC penalties due to a lack of infrastructure resources, and under these conditions, UEC performed better than the other two methods. In addition, the study emphasizes on the importance and efficiency of UEC and presents the possibility and importance of building an advanced UAV communication network.

Keywords*: Cloud Computing, Edge Computing, Virtual Environment, Digital Data, Communication Network*

1. Introduction

Data processing and management are becoming more important as the amount of digital data has increased exponentially in recent years. Against this backdrop, UAV-based communication networks have emerged as a very promising solution in wireless communication systems [1],[2]. New technologies are constantly being developed, but data processing systems built on CC, EC, and UEC are now fundamental requirements and are considered leaders among them.

CC is widely used in environments that require large-scale data processing and efficient resource management, such as corporate business processing and online service provision [3]. Recently, 'cloud AI', which combines AI technology with CC to enable faster and more accurate data processing, has emerged and is being used in various fields. The use of such cloud AI has the advantage of enabling companies to make more accurate and faster decisions. EC has the advantage of reducing network traffic connected to CC by processing large-scale data locally without moving it to the cloud and allows fast decision-making by calculating and analyzing large-scale data generated from IoT devices [4]. UEC is widely used in environments that can process and analyze data immediately on the edge side and require adequate resource management using devices such as cameras mounted on drones and can be applied to geographic and urgent medical and safety processing in various fields with the recent emergence of "Cloud AI," which combines AI technology with CC to enable faster and more accurate data processing.

In this study, the difference between modeling algorithms and hardware use of these three technologies is analyzed to form an experimental environment for performance comparison, and the advantages and disadvantages of each technology are compared. This presents which technology is most efficient to use in which situations, enhances the understanding of each technology, and analyzes whether it is a technology that can be applied appropriately. The performance and limitations of these technologies will be comprehensively analyzed to identify their strengths and weaknesses and to suggest in what situations which technologies are most efficient to use.

2. Cloud Computing

Moving all computing activity to the cloud has proven to be an effective mechanism for processing data [5] because the cloud provides greater processing capacity than network edge devices. Cloud Computing (CC) can be applied in a wide variety of fields. Data processing covered in this paper can process large amounts of data faster and more effectively and can improve many aspects of IT resource management in enterprises. CC is used in various fields besides data processing and storage purposes and is a promising technology due to its continuous functional development and market demand leadership. The ever-growing role of CC with new technology discoveries demonstrates the potential for significant changes to the IT infrastructure of enterprises and individuals. CC is based on a centralized architecture, so it is superior in terms of data processing capacity and scalability. However, it is difficult to process data in real-time due to bottlenecks, and in the event of a cloud failure, the entire service may be delayed or interrupted [6]. In addition, deploying a large number of IoT devices, such as UAVs, limits bandwidth, stability, and security.

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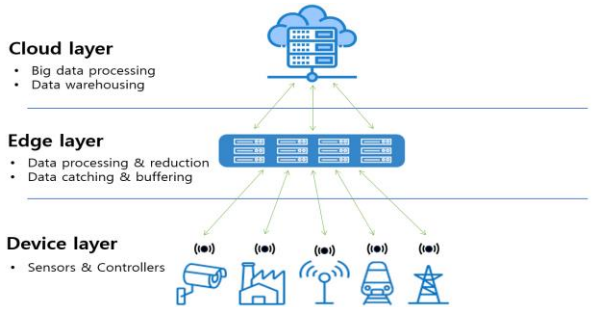
3. Edge Computing

Edge Computing (EC) is a technology that processes and utilizes vast amounts of data generated in IoT environments at network edges to improve overall data analysis speed and provide faster services to users. Unlike CC, where a central server processes all data and delays data processing time, data that can be analyzed by each IoT device is a concept that processes directly in the field. In addition, IoT data can be collected and analyzed primarily from edge clouds near terminal access, and only necessary data is transmitted to the central cloud, thereby minimizing latency for IoT services and saving central data center resources [7][8]. The components of EC include edge nodes and cloud services. Edge nodes are hardware, such as IoT devices, and are an important part of collecting and processing data. Cloud services share data collected from edge nodes with other devices or servers and process them to provide various services. In this paper, we perform efficiency comparisons with CC to demonstrate that EC is particularly useful for large-scale data processing or fast response speed requirements. Research has demonstrated that EC is superior in terms of data processing speed, and these results are particularly important when large-scale data processing and real-time data analysis are required in the IoT field, and the architecture of EC is shown in Figure. 1.

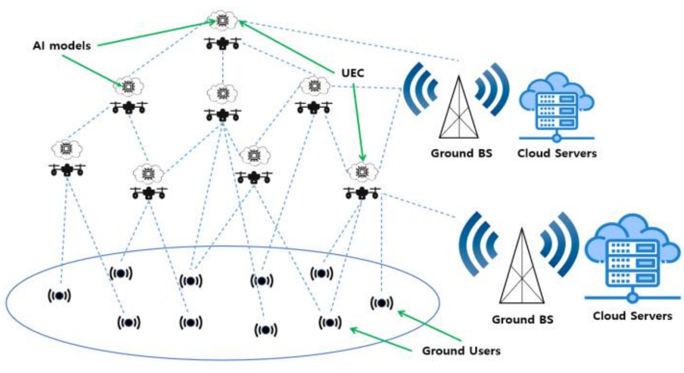
Fig 1. Edge computing architecture



4. UAV-Based Intelligent Edge Computing

UAV-based intelligent edge computing (UEC) is a technology that processes, analyzes, and transmits data using unmanned aircraft, and has fast responsiveness and large-scale data processing capabilities [9]. The components of UEC include drones, local servers, data centers, and clouds. Drones provide fast mobility and can collect and process large amounts of data and a variety of data. Local servers handle local processing and analysis tasks and perform data-driven analysis and management. The data center handles processing and storage tasks that cannot be handled by local servers, and the cloud provides a variety of data processing and analysis services. In UEC, virtualization technology, artificial intelligence, and real-time data analysis are used as core technologies. Virtualization technology increases efficiency and convergence by creating multiple servers or virtual machines on one server. Artificial intelligence technology extracts valuable information while analyzing data collected from drones, and real-time data analysis technology is effective for short response time and real-time data processing. In this paper, we demonstrated that UEC is superior to conventional CC and EC in terms of fast data processing, mobility, and locality. These advantages can be utilized in a variety of fields, such as real-time large-scale data processing and analysis using mobility and locality, dispatch in disaster situations and quick emergency treatment. Therefore, by analyzing the technology and performance of UEC, this study presents the possibility of the development of smart drone systems that can overcome the limitations of CC and EC for data processing and analysis provision and the UEC architecture is fig. 2 equal to [10].

Fig 2. UAV-based Intelligent Edge Computing Architecture



5. Algorithms

Suppose that the data size of CC is R, the bandwidth is Bc, and the GPU performance is Gc. Data processing time (t_c), delay time (l_c), data processing time (t_e), and delay time (l_e) of EC can be expressed as follows, respectively.

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

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

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

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

The data processing time t_u and the delay time l_u of the UEC may be expressed as follows.

$$t_u = t_q + t_a + t_c + t_l \quad (5)$$

$$l_u = d_u + t_u \quad (6)$$

In the above equation, t_q is the data transmission time of UEC, t_a is the data analysis time, and the data collection time (t_c) and data loading time (t_l) are assumed as follows and expressed as follows.

$$t_q = \frac{R}{B_u} \quad (7)$$

$$t_a = \frac{R}{G_u} + \frac{R}{C_u} + \frac{R}{F_u} \quad (8)$$

$$t_c = 0.1 \quad (9)$$

$$t_l = 0.1 \quad (10)$$

6. Experiment and Results Analysis

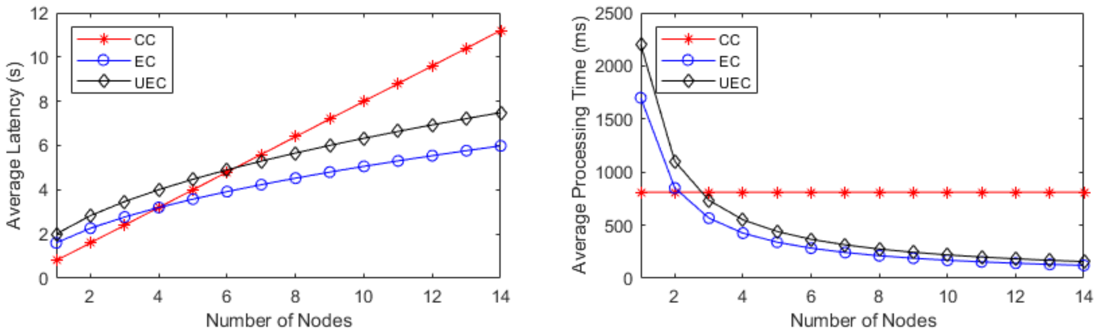
Table 1. Parameter

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

In this study, several environments were set up and compared for the implementation of cloud-putting, edge-putting, and UEC. In Table 1, parameter values are set to allow fair comparison between different computing models. In this way, you can see how effectively each computing model works in different environments and requirements.

The results for the average latency are shown in Figure 3(a), which clearly shows the performance differences between CC, EC, and UEC. In the case of CC, the average latency tends to increase linearly as the number of nodes increases. This can be interpreted as the centralized architecture of CC causing a network bottleneck, which increases latency as the number of nodes increases. On the other hand, EC and UEC show that the average latency increases as the number of nodes increases, but the increase gradually decreases. The distributed processing method of EC mitigates network bottlenecks and can be interpreted as reducing latency because data is processed at the nearest location where it was created. Since UAV optimizes data processing locations through mobility, UEC can interpret that even if the number of nodes increases, the resulting increase in latency is relatively lower than that of CC.

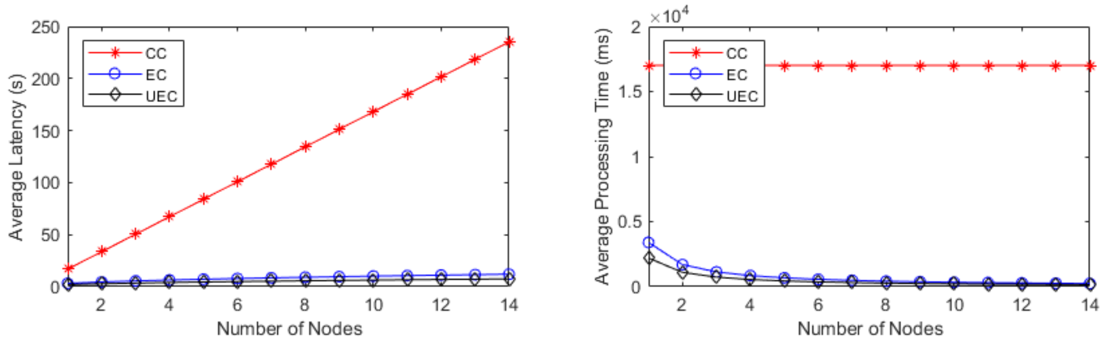
Fig 3. Performance Comparison with Infrastructure Penalty



(a) Average latency based on the number of nodes (b) Average processing time based on the number of nodes

Next, in situations such as corridor monitoring, work is often required in areas where network connectivity is not appropriate or limited. The advantages of UEC can be utilized to solve these problems. This is a great advantage over CCs and general ECs because UECs can provide computing resources even when network connectivity is limited. Therefore, this study considers the infrastructure penalty values of CC and EC in setting up the virtual environment for corridor monitoring.

Fig 4. Performance Comparison



(a) Average latency based on the number of nodes (b) Average processing time based on the number of nodes

Figure 4 (a) shows the average delay time results after reflecting the penalty due to lack of infrastructure. In the case of CC, the latency tends to increase depending on the number of nodes as shown in Figure 3.(a). However, the additional penalties due to infrastructure shortages have expanded further. This shows the limitations of CC that greatly affect overall performance when infrastructure resources are scarce at a certain point due to its centralized structure. On the other hand, EC has given relatively few infrastructure penalties compared to CC. Since EC processes data at the nearest edge node, each node handles tasks individually, resulting in relatively few penalties due to a lack of infrastructure. UEC also shows relatively low latency due to principles similar to EC. Moreover, UEC utilizes UAVs to perform data processing at a closer location Network latency can be further reduced.

Figure 5(a) shows the average processing time after reflecting the penalty due to a lack of infrastructure. In the case of CC, it can be seen that the average processing time has relatively increased as penalties are given due to a lack of infrastructure. This is a problem caused by the centralized structure of CC, and at a certain point, a lack of infrastructure resources can affect the performance of the entire system. On the other hand, EC uses a distributed processing method that independently processes data at each node, resulting in relatively few penalties due to a lack of infrastructure. Moreover, in the case of UIE computing, the average processing time was the lowest even if the number of nodes increased because it was processed at the closest location to perform data processing using UAV.

7. Conclusion

Putting the experimental results together, CC, EC, and UEC have their own characteristics and advantages and can be appropriately utilized according to various situations and requirements. CC is an ideal option for large-scale data processing and batch processing, but some limitations require high costs and reliable network connectivity. EC, on the other hand, shines in the real-time data processing and IoT fields, and is effective in situations where network latency is important. However, caution is required in situations where stable connectivity and strong security are required. Moreover, UEC is highly mobile and can process real-time data, showing great advantages in special situations such as emergency response. However, it can be vulnerable to a variety of external factors such as communication disruptions, noise, and security issues. In addition, in this experiment, a UIE computing algorithm was implemented using a specific assumption value, and the result value may vary depending on the change in this assumption value. Therefore, these technologies should be appropriately selected and utilized according to the situation. By selecting the most suitable computing method for a specific situation, efficient data processing and optimal performance can be achieved. These choices should be made by comprehensively considering various factors such as user requirements, technical limitations, and cost. In addition, continuous research and development are needed to further improve the performance and efficiency of these technologies. It is important to maximize the advantages of CC, EC, and UEC through advances in hardware, development of new algorithms, and reinforcement of security technologies, and overcome limitations. However, experimental results show that UIE computing can perform somewhat better in certain situations. This is because the mobility and real-time processing capabilities of UEC act as great advantages in responding to specific situations, especially emergencies. This will allow us to implement more advanced data processing methods and have the flexibility to respond to various situations.

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