Application and Development of Cloud-Edge Collaboration Technology in Low-Altitude Traffic Management at Airports

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ABSTRACT

Cloud-edge collaboration technology deeply integrates cloud computing and edge computing to provide low-latency, high-resilience solutions for low-altitude traffic management at airports . The edge enables real-time data processing, conflict detection, and emergency obstacle avoidance, while the cloud handles digital twin construction, global trajectory optimization, and multi-airport collaboration. Key technologies include edge AI inference, federated learning, low-latency communication, blockchain security, and dynamic airspace allocation. Successful applications have been implemented in Shenzhen, Chengdu, and other locations, significantly improving airspace capacity and flight safety. In the future, with the development of 6G and large-scale models, cloud-edge collaboration will become a core support for the large-scale development of the low-altitude economy , driving the transformation and upgrading of smart civil aviation.

Keywords: Cloud-Edge Collaboration, Low-Altitude Traffic Control, Edge Computing, Digital Twin, Low-Latency Communication

1. Overview of Cloud-Edge Collaboration Technology

1.1 Basic Concepts and Architecture

Cloud-edge collaboration technology is a computing paradigm that combines cloud computing and edge computing, and it has been widely used in the field of airport low-altitude traffic control . Its basic concept is to distribute computing, storage and network resources in the cloud and the edge to achieve efficient collaboration [1]. In the airport low-altitude environment, the cloud is mainly responsible for global tasks, including big data analysis, training of complex artificial intelligence models, long-term trajectory prediction and collaborative decision-making among multiple airports , providing powerful computing capabilities and a global perspective; the edge is deployed in locations such as control towers, UAV base stations, ADS-B ground stations and radars, focusing on real-time data acquisition, preprocessing and low-latency conflict detection and obstacle avoidance command issuance to ensure rapid response. The typical architecture adopts a three-layer structure: the perception layer consists of various sensors and edge nodes, responsible for acquiring raw data; the edge computing layer uses mobile edge computing (MEC) servers to achieve millisecond-level response; the cloud platform layer performs unified management and optimization. Through 5G or satellite communication links, the cloud and edge data are synchronized in both directions. When the network fluctuates, the edge nodes can operate autonomously, forming a resilient system of "cloud-edge collaboration in normal times and edge autonomy in extreme cases". This architecture significantly reduces the control latency of low-altitude aircraft (such as drones and eVTOLs) to less than 50ms, greatly improving airspace capacity and flight safety [2].

1.2 Key Technologies

The key technologies of cloud-edge collaboration in airport low-altitude traffic control mainly include edge AI inference, deploying lightweight conflict detection models (such as YOLO series or Transformer variants) to the edge to achieve real-time target recognition and 4D trajectory prediction; cloud-edge model collaborative training, using federated learning and model segmentation technology, training large-scale models in the cloud, and fine-tuning and uploading gradients locally at the edge, which protects data privacy and adapts to specific environments; low-latency communication technology, using 5G URLLC and satellite backup links to ensure that the cloud-edge synchronization latency is less than 20ms; digital twin technology, constructing a digital twin of the entire airport's low-altitude airspace in the cloud, and mapping the physical state at the edge in real time to achieve predictive control; blockchain combined with zero-trust security mechanism, authenticating edge nodes and uploading data to the chain to prevent tampering and denial-of-service attacks; intent perception and dynamic airspace allocation, integrating multi-source data such as meteorology and temporary restricted areas to achieve adaptive gridded airspace management. These technologies together promote the evolution of airport low-altitude traffic control from the traditional passive control mode to the proactive service and intelligent decision-making mode, improving the overall system efficiency, security and robustness [3].

2. Airport Low-Altitude Traffic Control Needs

2.1 Characteristics and Challenges of Control

Airport low-altitude traffic control is characterized by high aircraft density, complex and variable trajectories, extremely high real-time requirements (collision detection requires <1s), diverse participating entities (coexistence of UAVs, eVTOL, and traditional aircraft), and fragmented dynamic airspace [4]. The main challenges include: high latency (>300ms) of traditional centralized cloud control, which is difficult to meet the millisecond-level obstacle avoidance requirements of low-altitude areas; network interruption or congestion leading to system paralysis; difficulty in real-time fusion of massive heterogeneous data (radar, ADS-B, video, meteorology); high privacy and security risks, which are easily tampered with or attacked by denial of service; and weak computing power of low-altitude aircraft, which cannot independently complete complex decisions. These problems lead to low airspace utilization and insufficient security margin in the traditional mode, which urgently require distributed and highly resilient architecture support.

2.2 Necessity of Cloud-Edge Collaboration

Cloud-edge collaboration is an inevitable choice to solve the problem of low-altitude traffic control at airports. Pure cloud mode has high latency, high bandwidth pressure, and high risk of single point of failure; pure edge mode has weak computing power and is difficult to achieve global optimization and multi-airport collaboration [5]. Cloud-edge collaboration pushes real-time high-frequency tasks down to the edge (conflict detection, emergency obstacle avoidance) and global complex tasks up to the cloud (trajectory optimization, digital twin), and achieves efficient collaboration through 5G/satellite. The edge can run autonomously when the network is abnormal, ensuring system continuity. At the same time, it supports federated learning to protect privacy, blockchain to ensure data trustworthiness, and dynamic resource scheduling to improve efficiency, significantly reducing latency and improving airspace capacity and safety level, and has become the core technical support for the large-scale development of the low-altitude economy .

3. Analysis of Cloud-Edge Collaborative Applications

3.1 Edge Computing and Data Processing

The edge computing layer is deployed at airport control towers, drone base stations, ADS-B ground stations, and radar sites, equipped with high-performance MEC servers to achieve near-real-time processing of low-altitude traffic data. Its main tasks include multi-source heterogeneous data acquisition (radar, ADS-B, video, photoelectric, meteorological), preprocessing (filtering, fusion, compression), and lightweight AI inference. YOLOv8n and EfficientFormer models are used for target detection, tracking, and 4D trajectory prediction, with collision detection latency <30ms. Edge nodes support direct issuance of intent recognition and emergency obstacle avoidance commands, reducing reliance on the cloud. Through a data tiering strategy, only key features and alarm events are uploaded, while raw data is stored locally, reducing bandwidth usage by over 80%. Combined with 5G URLLC slicing and local caching mechanisms, the system ensures continuous operation even during network jitter, forming an "edge-first, cloud-edge complementary" data processing closed loop, significantly improving the real-time control capabilities and system resilience of low-altitude aircraft.

3.2 Cloud-based decision-making and case studies

The cloud-based system, relying on high-performance computing clusters and big data platforms, is responsible for complex global decision-making, including digital twin construction, full-airspace 4D trajectory optimization, multi-airport collaborative scheduling, long-term conflict prediction, and dynamic airspace allocation based on reinforcement learning. It integrates feature data uploaded from the edge with historical data to achieve minute-level traffic prediction and hourly pre-tactical adjustments. Typical examples include: Shenzhen Airport's low-altitude demonstration zone, which adopted an Alibaba Cloud + China Mobile MEC solution, achieving daily management of 5,000 drone flights in 2024, reducing conflict alarm response time from 1.2 seconds to 180 milliseconds; and Chengdu Tianfu Airport's eVTOL project, utilizing Huawei Cloud + edge collaboration, completing 3,000 hours of safe flight verification in the first half of 2025, increasing airspace capacity by 40%. These cases validate the model of global optimization in the cloud combined with real-time execution at the edge, which has become a standard paradigm for large-scale low-altitude traffic management.

Conclusion

Cloud-edge collaborative technology, with its core features of low latency, high resilience, and intelligence, has become an essential technological path for low-altitude traffic management at airports. By combining real-time edge perception with AI inference, and cloud-based digital twins with global optimization, it has successfully reduced conflict detection latency to milliseconds and increased airspace capacity by more than 40%, completely breaking through the bottlenecks of traditional centralized control in terms of real-time performance, bandwidth, and security. Real-world examples show that this technology has supported the safe operation of tens of thousands of aircraft in low-altitude demonstration zones in Shenzhen, Chengdu, and other locations, marking the completion of the transformation of low-altitude traffic from "passive control" to "proactive service and intelligent decision-making."

In the future, with the further development of 6G, space-ground integrated networks and large-scale models, cloud-edge collaboration will evolve towards full-domain perception, intent-driven, and autonomous decision-making, ultimately supporting the trillion-dollar scale and safe development of the urban low-altitude economy , and becoming the core pillar of new smart civil aviation infrastructure.

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